EFFECT OF DIFFERENT SHEAR WALL CONFIGURATIONS OF A 5-STOREY RC BUILDING DUE TO EARTHQUAKE

(AS PER IS 456:2000, IS 1893:2002)

Submitted in partial fulfilment of the Degree of
Bachelor of Technology

विद्या तत्व ज्योतिसम:

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

May - 2014

ANSHUL SUD (101682)

RAGHAV SINGH SHEKHAWAT (101653)

under the Supervision of

Mrs. POONAM DHIMAN

DEPARTMENT OF CIVIL ENGINEERING
JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY,
WAKNAGHAT

CERTIFICATE

This is to certify that project report entitled "Effect of Different Shear Wall Configurations of a 5-Storey RC Building due to Earthquake *(As Per IS 456:2000, IS 1893:2002)*", submitted by ANSHUL SUD , RAGHAV SINGH SHEKHAWAT in partial fulfilment for the award of degree of Bachelor of Technology in Civil Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Date:

Mrs. Poonam Dhiman

Associate Professor, Civil Deptt.

JUIT Waknaghat, Solan-173234

ACKNOWLEDGEMENT

Knowledge, energy, and time are the resources in the completion of this project but the most requisite is the proper guidance of our respected mentor, **Mrs. Poonam Dhiman** (Associate Professor, Department of Civil Engineering) to whom we extend the sincere word of thanks, for her invaluable cooperation and help throughout the project. She acted as constant source of motivation throughout the development stage of the project.

We would like to thank our H.O.D. **Dr. Ashok Kumar Gupta** and other faculty members, for their valuable suggestion and guidance in all the seminars and viva-voce during evaluation.

We also express our obligation to all people who helped us directly or indirectly in the completion of this project. No thanks can counter our indebtedness to our parents and families who have been with us through every thick and thin, we thank them from core of our hearts.

Anshul Sud (101682)
B. Tech Final Year Student,
Civil Engg.

Raghav Singh Shekhawat (101653)
B. Tech Final Year Student,
Civil Engg.

ABSTRACT

The ground shaking during earthquakes can cause the collapse of structures. In order to save loss of lives and property; the structures need to be designed against the forces coming from ground shaking.

In this project, an RCC framed 5-storeyed building has been analyzed for earthquake loads on 5 different configurations of shear walls established in 5 different patterns viz. bare frame, shear wall symmetrically placed at exterior bays (centrally) , at core and adjacently placed in exterior of the building, lying in Indian seismic zone-V. The tool used for computations is STAAD.Pro V8i.

The analysis has been carried out for earthquake loads as per Indian Standard codes IS-1893:2002 (part-1). The analysis is done with limit state method conforming to IS-456:2000 inbuilt in the STAAD.Pro V8i. The two best configurations chosen, are curtailed up to the top two floors in order to make the building economic.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

"Earthquake don't kill people, unsafe buildings do."

GENERAL

The chapter deals with an introduction to the main attributes of the earthquake resistant design of structures with a special emphasis on related additional features in comparison to civil engineering design. Designing Earthquake Resistant Structures is indispensable. Every year, earthquakes take the lives of thousands of people, and destroy property worth billions. It is imperative that structures are designed to resist earthquake forces, in order to reduce the loss of life. Structural design plays an important role. Here, different tips and techniques used in designing Earthquake Resistant structures are discussed.

1.1 What is an Earthquake?

An earthquake is a sudden, rapid shaking of the Earth caused by the breaking and shifting of rock beneath the Earth's surface. For hundreds of millions of years, the forces of plate tectonics have shaped the Earth as the huge plates that form the Earth's surface move slowly over, under, and past each other. Sometimes the movement is gradual. At other times, the plates are locked together, unable to release the accumulating energy. When the accumulated energy grows strong enough, the plates break free causing the ground to shake. Most earthquakes occur at the boundaries where the plates meet; however, some earthquakes occur in the middle of plates.

Ground shaking from earthquakes can collapse buildings and bridges; disrupt gas, electric, and phone services; and sometimes trigger landslides, avalanches, flash floods, fires, and huge, destructive ocean waves (tsunamis). Buildings with foundations resting on unconsolidated landfill and other unstable soil, and trailers and homes not tied to their foundations are at risk because they can be shaken off their mountings during an earthquake. When an earthquake occurs in a populated area, it may cause deaths and injuries and extensive property damage.

The dynamic response of building to earthquake ground motion is the most important cause of earthquake-induced damage to buildings. The damage that a building suffers primarily depends not upon its displacement, but upon acceleration. Whereas displacement is the actual distance the ground and building may move during an earthquake, acceleration is a measure of how quickly they change speed as they move. The conventional approach to earthquake resistant design of buildings depends upon providing the building with strength, stiffness and inelastic deformation capacity which are great to withstand a given level of earthquake-generated force. This is generally accomplished through the selection of an appropriate structural configuration and the carefully detailing of structural members, such as beams and columns, and the connections between them.

1.2 How do Earthquakes affect Reinforced Concrete Buildings?

A typical RC building is made of horizontal members (beams and slabs) and vertical members (columns and walls), and supported by foundations that rest on ground. The RC frame participates in resisting the earthquake forces. Earthquake shaking generates inertia forces in the building, which are proportional to the building mass. Since most of the building mass is present at floor levels, earthquake induced inertia forces primarily develop at the floor levels. These forces travel downwards - through slabs and beams to columns and walls, and then to foundations from where they are dispersed to ground. As inertia forces accumulate downwards from the top of the building, the columns and walls at lower storey experience higher earthquake- induced forces and are therefore designed to be stronger than those in storey above.

1.2.1 *Horizontal Earthquake Effects*

Under gravity loads, tension in the beams is at the bottom surface of the beam in the central location and is at the top surface at the ends, while during the earthquakes, significant forces act horizontally on the building members. The level of bending moment due to earthquake loading depends on severity of shaking and can exceed that due to gravity loading. Thus, under strong earthquake shaking, the beam ends can develop tension on either of the top and bottom faces. Since concrete cannot carry this tension, steel bars are required on both faces of beams to resist reversals of bending moment.

1.2.2 *Role of Floor Slabs and Masonry*

Floor slabs are horizontal plate like elements, which facilitate functional use of buildings. Usually, beams and slabs at one storey level are cast together. In residential multi-story buildings, thickness of slabs is only about 110-150 mm. When beams bend in the vertical direction during earthquakes, these thin slabs bend along with them and, when beams move with columns in the horizontal direction, the slab usually forces the beams to move together with it. In most buildings, the geometric distortion of slab is negligible in the horizontal plane; this behavior is known as the rigid diaphragm action.

After columns and floors in a RC building are cast and the concrete hardens, vertical spaces between columns and floors are usually filled-in with masonry walls to demarcate a floor into functional spaces (rooms). Normally, these masonry walls, also called infill walls, are not connected to surrounding RC columns and beams. When columns receive horizontal forces at floor levels, they try to move in horizontal direction, but masonry walls tend to resist this movement. Due to their heavy weight and thickness, these walls attract rather large horizontal forces. However, since masonry is a brittle material, these walls develop cracks once their ability to carry horizontal load is exceeded. Thus masonry walls are enhanced by mortars of good strength, making proper masonry courses, and proper packing of gaps between RC frame and masonry infill walls.

1.3 Protection from Earthquakes

For a building to remain safe during earthquake shaking, columns should be stronger than beams, and foundations should be stronger than columns. If columns are made weaker, they suffer severe local damage, at the top and bottom of a particular storey.

1.3.1. *Earthquake Resistant Building Design Philosophy*

a) Under minor but frequent shaking, the main members of the buildings that carry vertical and horizontal forces should not be damaged; however buildings parts that do not carry load may sustain repairable damage.

b) Under moderate but occasional shaking, the main members may sustain repairable damage, while the other parts that do not carry load may sustain repairable damage.

c) Under strong but rare shaking, the main members may sustain severe damage, but the building should not collapse.

There are various new techniques which help in reducing the impact of earthquake forces on buildings. Most of these techniques are expensive to implement. The concept of base isolation is explained through an example building resting on frictionless rollers. When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to the shaking of the ground; simply, the building does not experience the earthquake. Now, if the same building is rested on the flexible pads that offer resistance against lateral movements, then some effect of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a fixed base building. The flexible pads are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings.

1.3.2 *Energy Dissipation Devices for Earthquake Resistance*

Another approach for controlling seismic damage in buildings and improving their seismic performance is by installing Seismic Dampers in place of structural elements, such as diagonal braces. These dampers act like the hydraulic shock absorbers in cars where, much of the sudden jerks are absorbed in the hydraulic fluids and only little is transmitted above to the chassis of the car. When seismic energy is transmitted through them, dampers absorb part of it, and thus damp the motion of the building.

1.3.3 *Active Control Devices for Earthquake Resistance*

a. Sensors to measure external excitation and/or structural response.

b. Computer hardware and software to compute control forces on the basis of observed excitation and/or structural response.

c. Actuators to provide the necessary control forces.

1.3.4 Shear Wall

Reinforced concrete (RC) buildings often have vertical plate-like RC walls this is called Shear wall.

Shear walls are like vertically-oriented wide beams that carry Earthquake/Wind loads downwards to the foundation.

These walls generally start at foundation level and are continuous throughout the building height.

Advantages of Shear Walls in RC Buildings

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 location in RC Buildings

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. Shear walls are more effective when located along exterior perimeter of the building – such a layout increases resistance of the building to twisting.

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.

Thin-walled hollow RC shafts around the elevator core of buildings also act as shear walls, and should be taken advantage of to resist earthquake forces.

1.4 Objective of the Project

- Objective is to analyze a 5-storeyed building lying in seismic zone-V.
- The building will be divided into portal frames and these frames have to be analyzed using the STAAD.Pro V8i software.
- The 5-storeyed portal will be analyzed for dead load, live load and earthquake load combinations.
- The analysis will give the forces arising in the members, namely – transverse beams and columns, due to the above loads and these members were designed for the several forces obtained due to the load combinations.
    - Slabs
    - Beams
    - Columns

- The members will be designed by the Limit State method, according to the guidelines prescribed by IS: 456-2000.

- IS-Codes which are to be used are as follows:-

- IS-875:1987 PART-1 for dead load
- IS-875:1987 PART-2 for live load
- IS-1893:2002 PART-2 for earthquake loads
- IS-456-2000 for limit state design

1.4.1 *Stages of Analysis*

The approach for analysis for the proposed building consisted of the following stages.

Estimation of Loads:

For the five-storey building, the analysis was performed and the design will be done for the following loads:

- Dead load
- Live load
- Earthquake load

The dead load was worked out by assuming a certain thickness for the slab and then the actual thickness was accordingly provided after calculating the required value. The load due to the flooring – screed, finishes, tiles etc. was given due consideration and an allowance was made for future erection of partitions.

Due to increased emphasis being laid on the design of earthquake resistant structures nowadays, the earthquake forces were estimated with the help of the provisions of the revised Seismic Code (IS:1893). The proposed building would lie in Zone IV. The value of the importance factor assigned to the entire structure was 1. The load was initially applied to the slabs and through trapezoidal distribution it was transmitted to the columns via beams (longitudinal and transverse), and consequently to the foundations.

The analysis of the structure was done for the above-mentioned loads – individually and for different load combinations recommended in the code.

The analysis gave the forces arising in the members, namely – transverse beams and columns, due to the above loads and these members will be designed for the severest of forces obtained due to the load combinations.

CHAPTER 2

SEISMIC LOAD CALCULATIONS

GENERAL

In this chapter, various loads acting on different beams and columns of the building and coming from slabs are calculated. The intensities of loads have been picked up from IS: 875 part-1, 2 and 3. The distribution of loads from slab to beams has been done as per IS-456: 2000, i.e. trapezoidal method of distribution has been adopted.

The calculation of loads coming from floors and roof and analysis is done by output of STAAD-pro.

2.1 Seismic Design Philosophy

The philosophy of seismic design can be summarized as:

a) The design philosophy adopted in the code is to ensure that structures possess at least a minimum strength to

i) Resist minor earthquake (<DBE) which may occur frequently, without damage

ii) Resist moderate earthquake (DBE) without significant structural damage through some non-structural damage

iii) Resist major earthquake (MCE) without collapse.

"DESIGN BASIS EARTHQUAKE (DBE) is defined as the maximum earthquake that reasonably can be expected to experience at the site once during lifetime of the structure. The earthquake corresponding to the ultimate safety requirement is often called as the MAXIMUM CONSIDERED EARTHQUAKE (MCE) .Generally DBE is half the MCE"

b) The actual forces that appear on the structures during earthquakes are much higher than the design forces specified in the code .the basic criteria for earthquake resistant design should be based on lateral strength as well as deformability and ductility capacity of the structure with limited damage but no collapse .ductility in the structures will arise from inelastic material, behavior and detailing of reinforcement in such a manner that brittle failure is avoided and ductile behavior is induced by allowing steel to yield in controlled manner.

c) The design lateral forces specified in the code shall be considered in each of the two orthogonal directions of structures. for structures which have lateral force resisting element in two orthogonal directions only the design lateral force shall be considered along one direction at time and or in both direction simultaneously.

d) Earthquake generating vertical inertia forces are to be considered in design unless it is not significant. Vertical acceleration should be considered in structures with large spans, those in which stability is the criterion for design or for overall stability of the structures.

e) The response of a structure to the ground vibrations is a function of the nature of foundation of the soil ; materials; form; size and mode of construction of structures; ad the duration and characteristics of ground motion.

Seismic design method

Conventional civil engineering structures are designed on the basis of two main criteria that are strength and rigidity. The strength is related to damageability or ultimate limit state, assuming that the force level developed in structures remains in the elastic range, or some limited plastic deformation. The rigidity is related to the serviceability limit state, for which the structural displacement must remain in some limits. This assures that no damage occur in the non structural elements.

2.2 Seismic Coefficient Method

Following is the procedure for calculating the equivalent lateral loads on buildings using seismic coefficient method as per IS-1893-2002.

- India has been divided into four zones with regard to horizontal seismic coefficients. For important structures these coefficient can be increased by 50%. The horizontal earthquake force should be calculated for full dead load and some percentage of live loads as given below
- The fundamental time period is given by:

  $T=0.075h^{0.75}$ for moment resisting frame without bracing or shear walls,

  $T=0.09h/d$ (for all others)

  Where, n = number of storeys including basement

  H= total height of buildings in m,

d = maximum base dimension of building in m, in direction parallel to applied seismic force.

The base shear is calculated by the following formula:

$$V_B = K.C_h$$

Where

C_h =design seismic coefficient =I_0

W=total dead load and appropriate percentage of live load

C= a coefficient that depends on the fundamental time period

T= fundamental time period in seconds

K= performance factor depending on the structural framing system and brittleness and ductility of construction

I= Importance factor, depending upon the life and function of the structure

$_0$ =basic horizontal seismic coefficient

Distribution of forces along the height of building is given by

$$Q_i = V_B (W_i h_i^2 / w_i h_i^2)$$

Where

Q_i= lateral forces at the floor i

V_B= base shear

W_i= load of the floor i

h_i = height measured from the base of the building to the floor i

n= number of storeys including the basement.

2.3 Values form IS codes

- Dead Load [Ref. Table 1 of IS 875(Part 1):1987]
  - Unit weight of RCC (assuming 5% steel) = 24 kN/m^3
  - Unit weight of brick masonry (common burnt clay bricks = 18.85 kN/m^3

[Ref table 1 of IS 875 (part1): 1987]

- Imposed load [Ref. Table1 of IS 875(Part 2):1987]

Office rooms = 4 kN/m^2

Roof = 1.5 kN/m^2

- For Earthquake Load Calculations

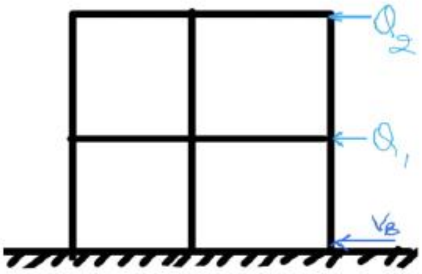


Fig. 1 Distribution of base shear at nodes of building

Total design lateral force or Design seismic base shear (V_B) along any principle direction

$V_B = A_h W$ (Refer IS 1893-2002 , §7.5.3)

where, A_h = Design horizontal seismic value

W = Seismic weight of all buildings

Now, $A_h = ZISa/2Rg$ (Refer IS 1893.2002 §6.4.2 Pg14)

where, Z is zone factor (Refer IS 1893.2002 table 2 Pg14)

Table 1 : Different values of zone factor (Z)

Seismic Zone	II	III	IV	V
Seismic Intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36

- I is Importance Factor (Refer IS 1893.2002 table 6 Pg18)
- I = 1.5 (Office Buildings)

- R is response reduction factor (Refer IS 1893.2002 table 7 Pg23)

- R= 3 (Ordinary RC moment resisting frame)
- Sa/g is avg. response acceleration coeff. (Refer IS 1893.2002 §6.4.5 Pg16)
- Fundamental natural period of vibration is given by :

$T=0.09h/\sqrt{d}$

where, h is the height of building in m and d is the base dimension in m

Hence, $T=0.09\times7/\sqrt{8} = 0.223s$

2.4 Analysis Methodology

- For the 2-storey building, the analysis will be performed and the design will be done for the following loads:

  - Dead load
  - Live load
  - Earthquake load

- The dead load will be worked out by assuming a certain thickness for the slab and then the actual thickness will be accordingly provided after calculating the required value. The load due to the flooring – screed, finishes, tiles etc. will be given due consideration and an allowance will be made for future erection of partitions.

- Due to increased emphasis being laid on the design of earthquake resistant structures nowadays, the earthquake forces will be estimated with the help of the provisions of the revised Seismic Code (IS:1893).

- The proposed building will lie in Zone V. The value of the importance factor assigned to the entire structure was 1.

- The load will initially applied to the slabs and through trapezoidal distribution it will be transmitted to the columns via beams (longitudinal and transverse), and consequently to the foundations.

- The members will be designed by the Limit State method, according to the guidelines prescribed by IS: 456-2000.

2.5 Example

A two-storey RC office building, shown in figure, is located in seismic zone V on medium soil, ordinary moment-resisting frames. Perform the static analysis for the following data:

Column sections:
300mm × 300mm

Beam Sections:
200mm × 300mm

Slab:
125 mm thick RCC slab on all floors

Unit weight of M25 concrete = 24 kN/m^3

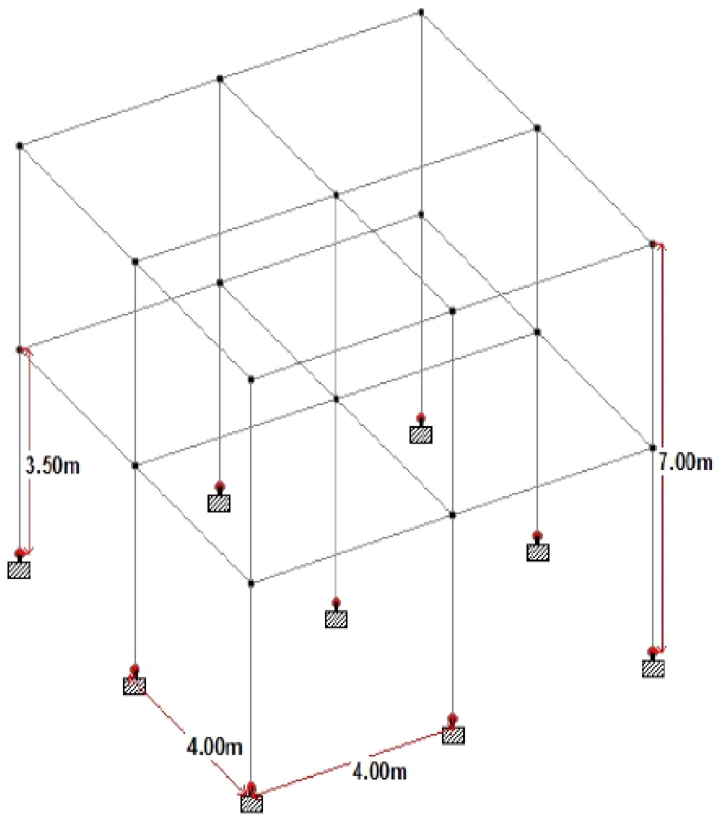


Fig. 2: Isometric View of a two-storey RC Building

Dead & Live Load Calculations

Dead Load :-

- Unit wt of M25 concrete = 24 kN/m^3

(Refer IS 875-1)

- Dead Load of beam = 0.2×0.3×4×24= 5.76 kN =5.76/4 =1.44 kN/m
- Dead Load of slab = .125×24 = 3 kN/m^2
- Dead Load of column (first floor) = 0.3×0.3×3.5×24
  = 7.56 kN
- Dead Load of column (ground floor)

= (0.3×0.3×3.5×24)+7.56 =15.12 kN

<u>Live Loads</u> :-

Floor of office building=4kN/m^3 (Ref IS 875-2,table 1 Pg.10)
Roof of office building=1.5kN/m^3(Ref IS 875-2,table 2 Pg.14)

Floor Load :-
Size of slab = 4×4m
Live Load = 4kN/m^2×4×4 = 64 kN
Live Load on one beam = 64/4 = 16 kN
Live Load on one beam per meter = 16/4=4 kN

Roof Load :-
Live Load = 1.5×4×4 = 24 kN
Live Load on one beam = 24/4 = 6 kN
Live Load on one beam per meter = 6/4 = 1.5 kN
Hence, Total load on floor beam = DL+LL
= 1.4+4
= 5.44kN/m
Total Load on roof beam = DL + LL
=1.44+1.5 = 2.94kN/m

<u>End Frame</u> :

W = Wt. of Floor + Wt. of Roof

=[(3×3.5×.3×.3×24)+(2×4×.2×.3×24)+(2×5×1/2×4×2)]

+

[(3×1.75×.3×.3×24)+(2×4×.2×.3×24)+(2×3.375×1/2×4×2)]

=74.2+49.86 =124.06 kN

Hence, V_B = 124.06 × [0.36×1.5×2.5/(2×3)] = 27.9kN

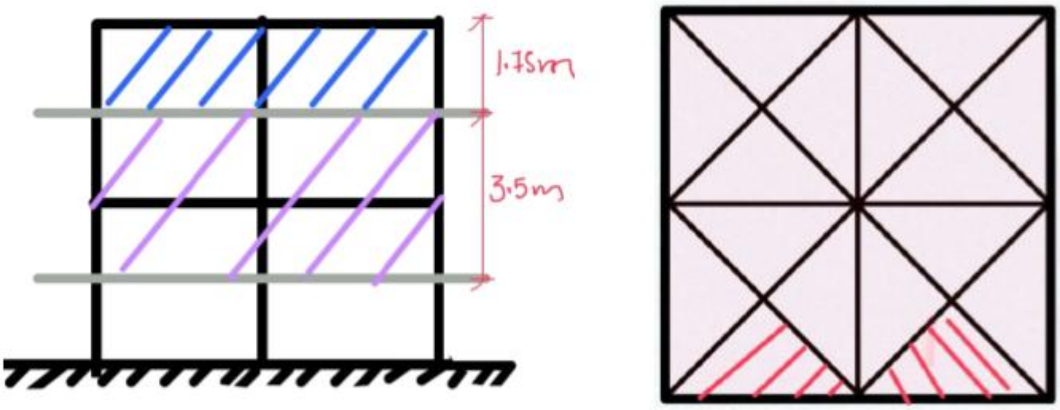


Fig. 3: Distribution of earthquake loads across the floors (front and top view)

And, Distribution of shear force, V_B shall be distributed along the height of building as per following expression:

$Q_i = V_B \, (W_i h_i^2 / \Sigma W_i h_i^2)$

Table 2: BASE SHEAR DISTRIBUTION (V_B) TABLE FOR END FRAME

(Refer IS 1893.2002 §7.7.1 Pg24)

Storey	W_i (kN)	h_i	$W_i \times h_i^2$	$W_i h_i^2/\sum W_i h_i^2$	Q_i (kN)	V_B
2	49.86	7	2443.14	0.73	20.30	27.9
1	72.4	3.5	887	0.27	8.53	27.9

$\Sigma W_i h_i^2 = 3330.14$

Table 3: BASE SHEAR DISTRIBUTION (V_B) TABLE FOR MIDDLE FRAME

Storey	W_i (kN)	h_i	$W_i \times h_i^2$	$W_i h_i^2/\sum W_i h_i^2$	Q_i (kN)	V_B
2	76.86	7	3766.14	0.73	31.39	43
1	14.2	3.5	1398.95	0.27	11.61	43

$\Sigma W_i h_i^2 = 5165.1$

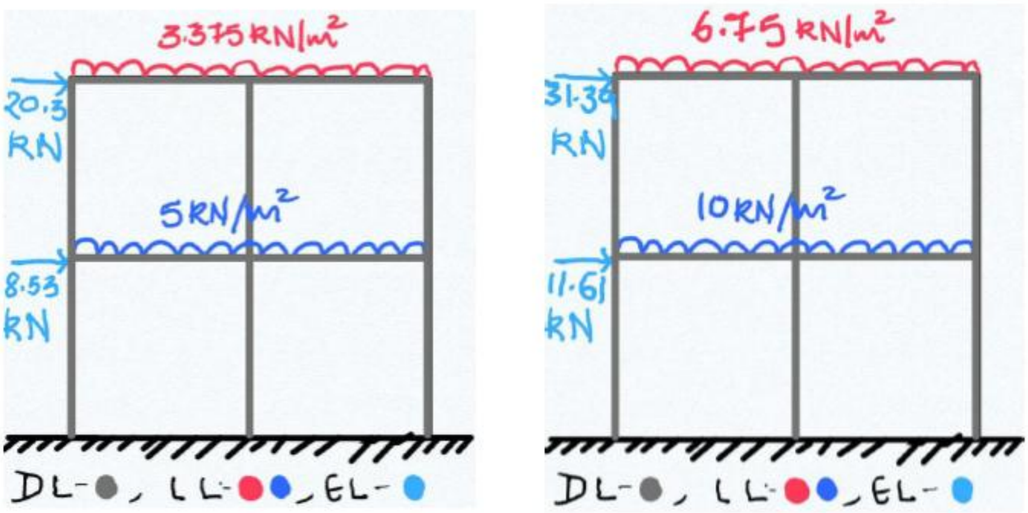


Fig. 4 : End Frame and Middle Frame with Dead Load, Imposed Load and Earthquake Load

CHAPTER 3

PROBLEM FORMULATION

3.1 BUILDING PARAMETERS

A 5-storey RC office building, shown in figure, is located in seismic zone V on medium soil, ordinary moment-resisting frames. Perform the static analysis for the following data:

Column sections:

350mm×500mm

Beam Sections:

500mm×500mm

Slab:

125 mm thick RCC slab on all floors

Shear Wall:

300 mm thick

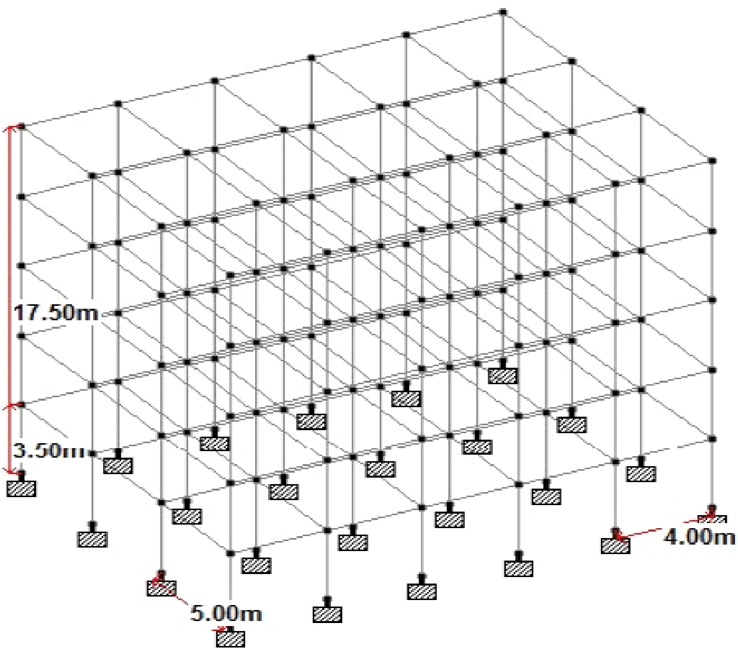


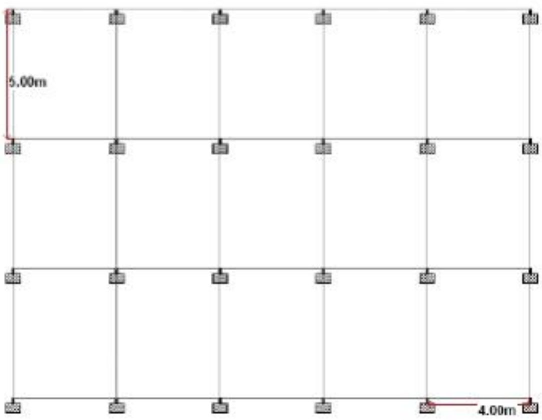
Fig. 5: Isometric View of a five-storey RC Building

3.2 FIVE CASES

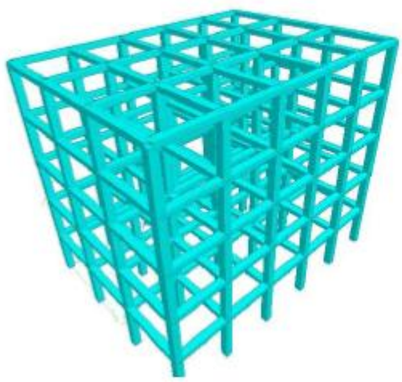
Five frames with different shear wall configurations viz. bare frame (frame 1), at core (frame 2) and shear wall symmetrically placed at exterior bays centrally (frame 3) and adjacently placed in exterior of the building (frame 4 and 5) as shown in Fig.6 are taken for the study.

Loads Acting on Structure :

- Self weight of Structure
- Imposed load of 4 kN/m^2 on Floors
- Imposed load of 1.5 kN/m^2 on Roof
- Earthquake load

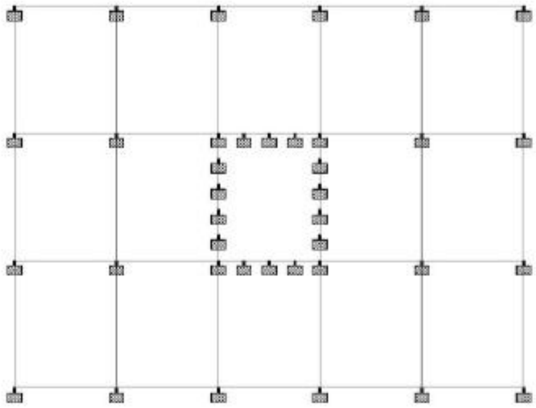


PLAN



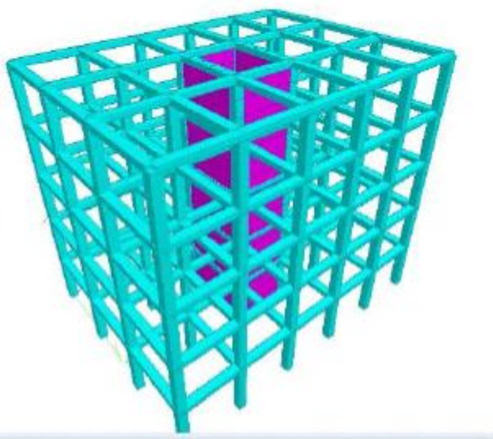
Isometric View

CASE 1

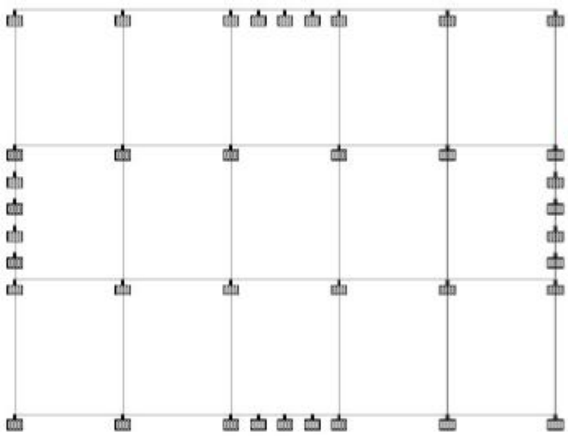


PLAN

Isometric View

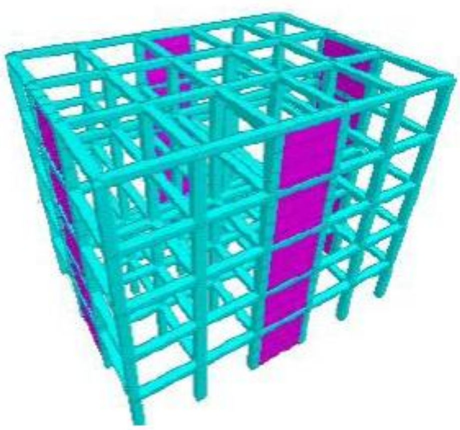


CASE 2



PLAN

Isometric View



CASE 3

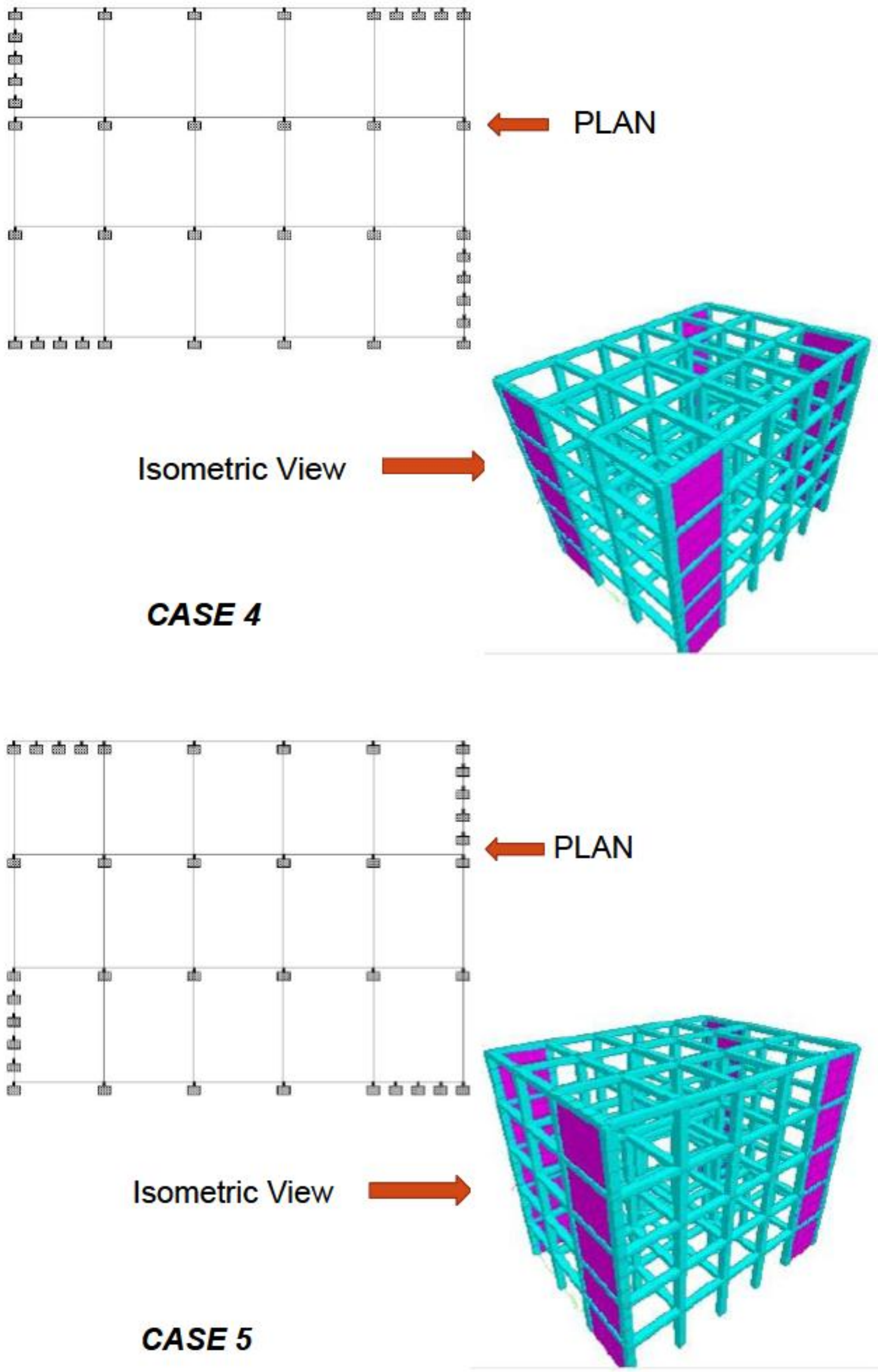


Fig.6 : Five frames showing different shear wall configurations of the building

Load Combinations:

- Partial safety factors for design of RC Structures :

1) $1.5\,(DL + IL)$
2) $1.2\,(DL + IL \pm EL)$
3) $1.5\,(DL \pm EL)$
4) $0.9\,DL \pm 1.5\,EL$

Frames are analysed for :

- Joint Displacement
- Bending Moment
- Shear Force
- Axial Force

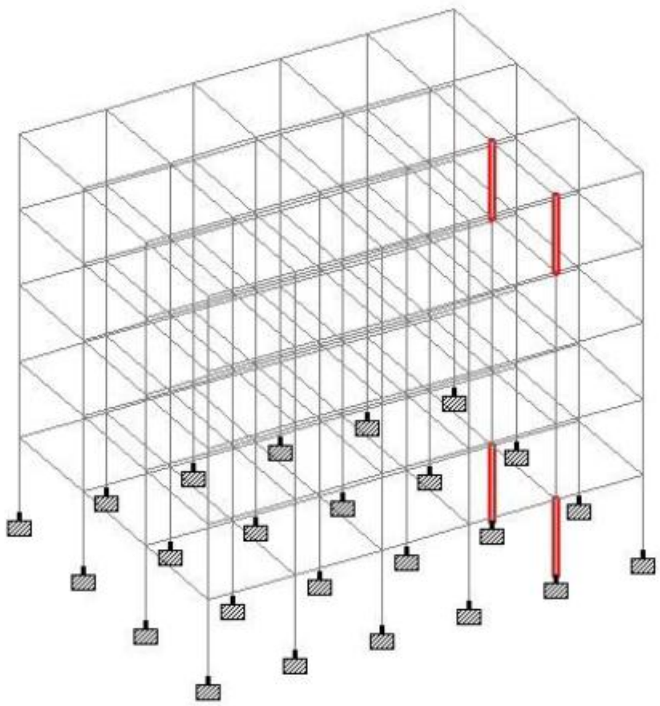


Fig. 7: Perimeter and interior columns for which frames are analyzed

3.3 ANALYSIS OF RESULTS

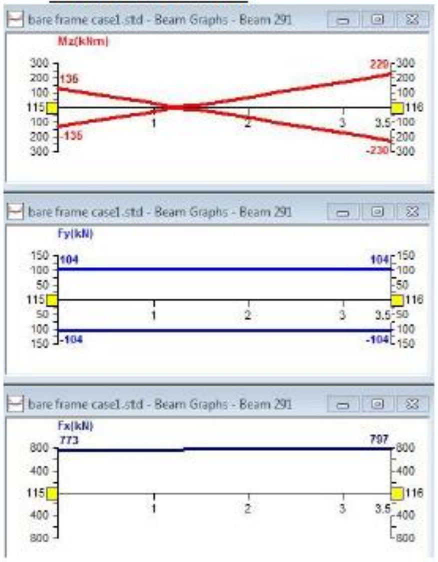
Here, we have shown bending moment, axial force and shear forces for the different shear wall configurations for perimeter and interior columns.

3.3.1 Frames

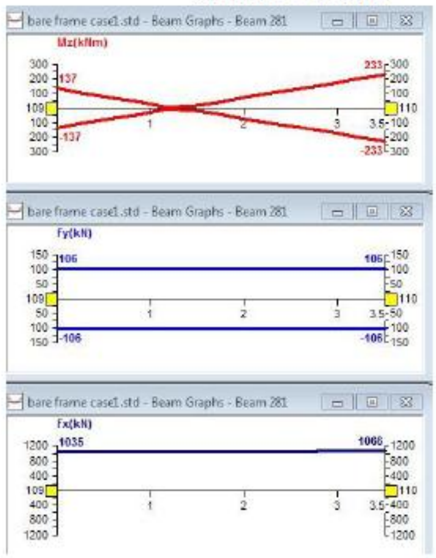
(A) FRAME 1

Ground Floor

Perimeter Column

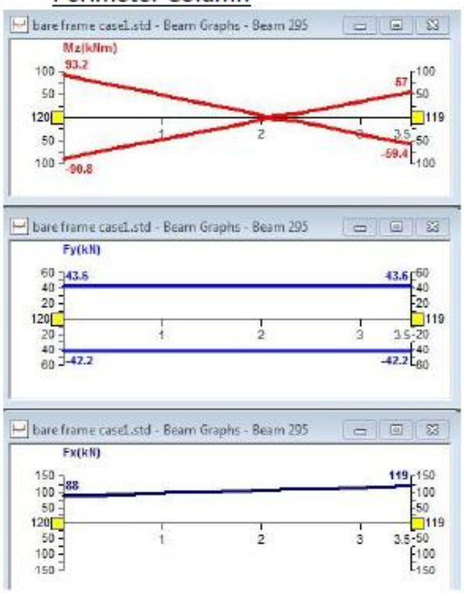


Interior Column

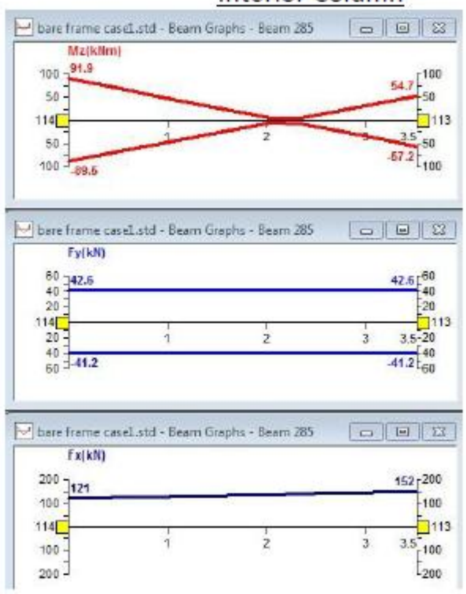


Top Storey

Perimeter Column



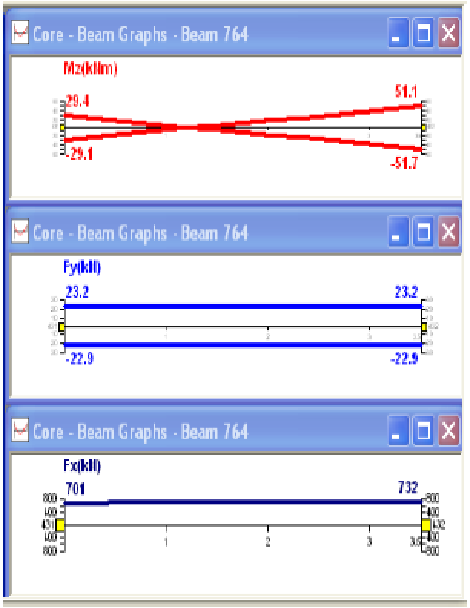
Interior Column



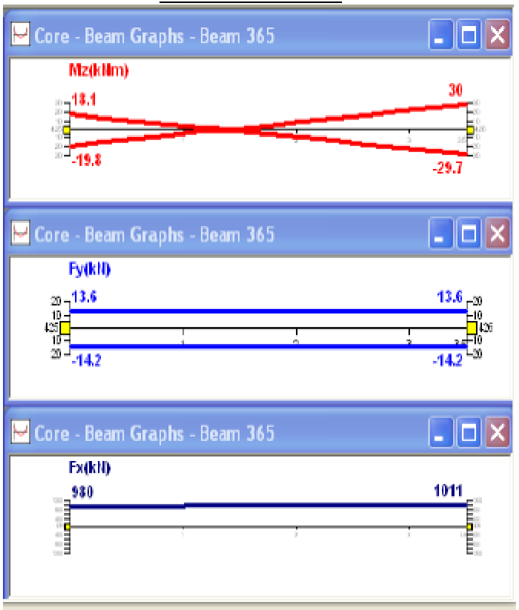
(B) FRAME 2

Ground Floor

Perimeter Column

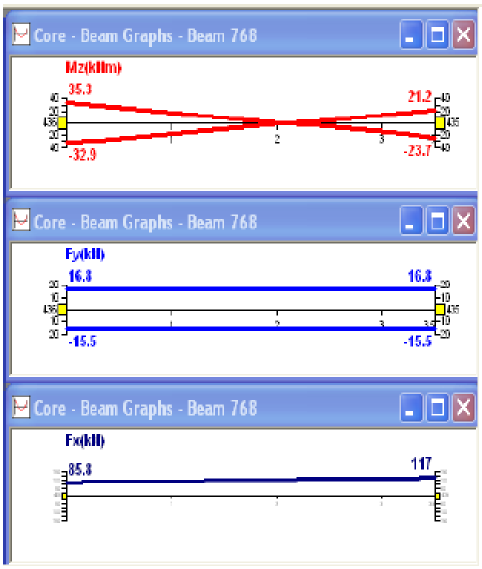


Interior Column

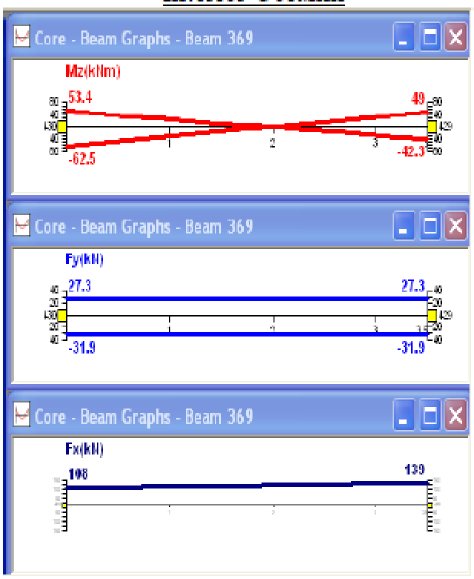


Top Storey

Perimeter Column



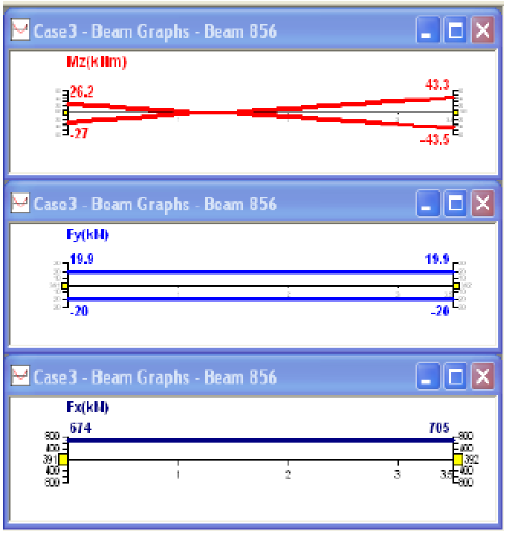
Interior Column



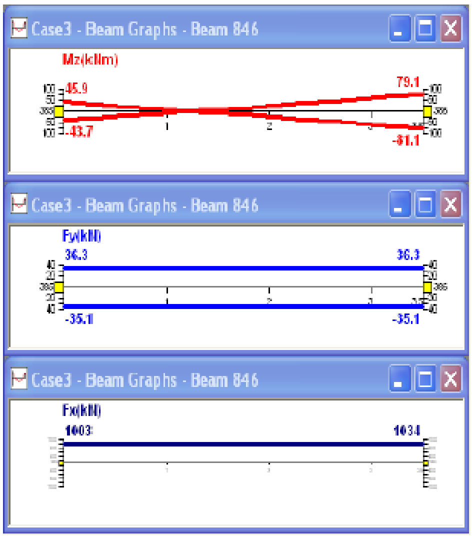
(C) FRAME 3

Ground Floor

Perimeter Column

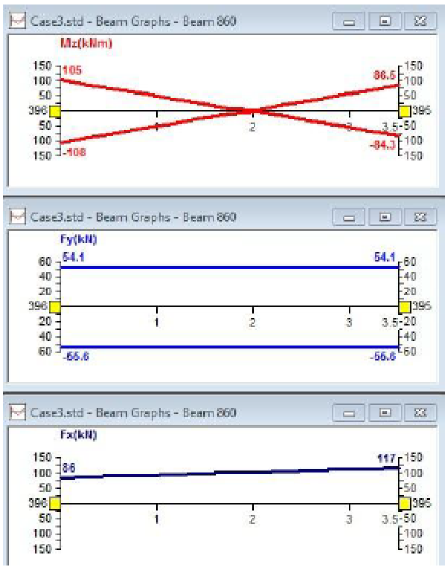


Interior Column

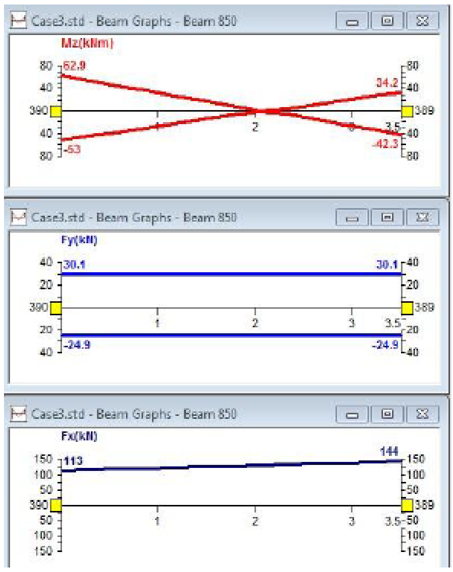


Top Storey

Perimeter Column



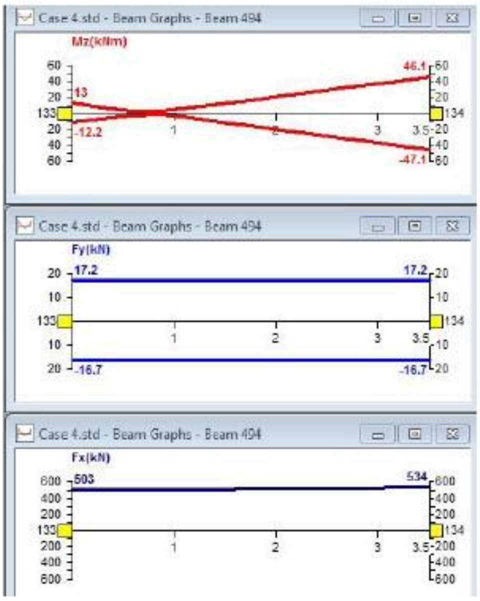
Interior Column



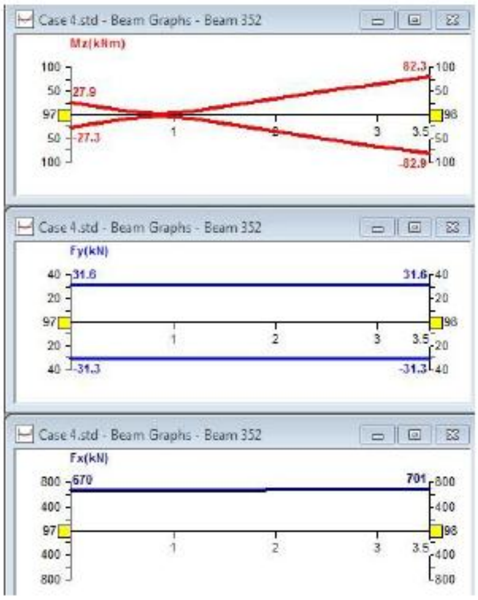
(D) FRAME 4

Ground Floor

Perimeter Column

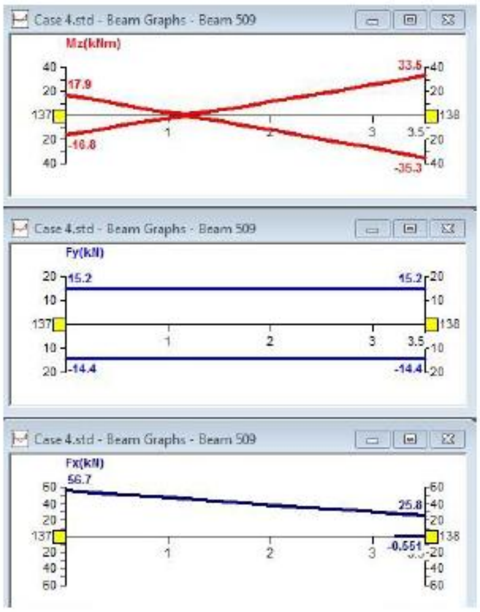


Interior Column

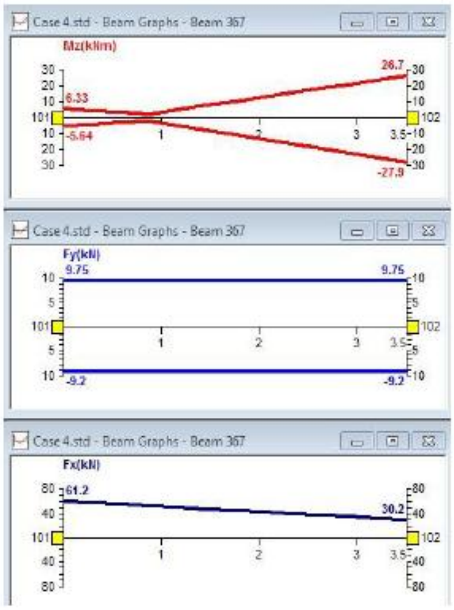


Top Storey

Perimeter Column



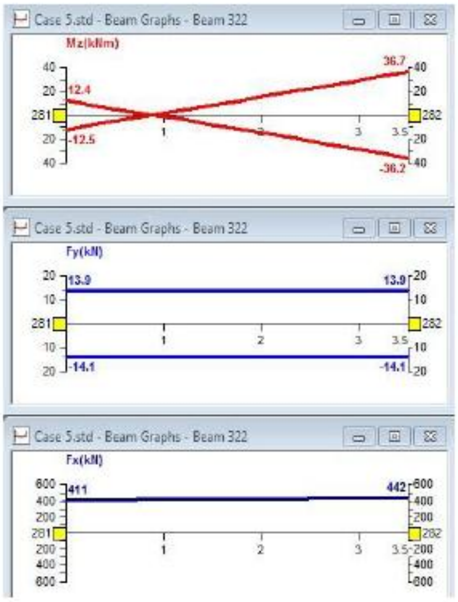
Interior Column



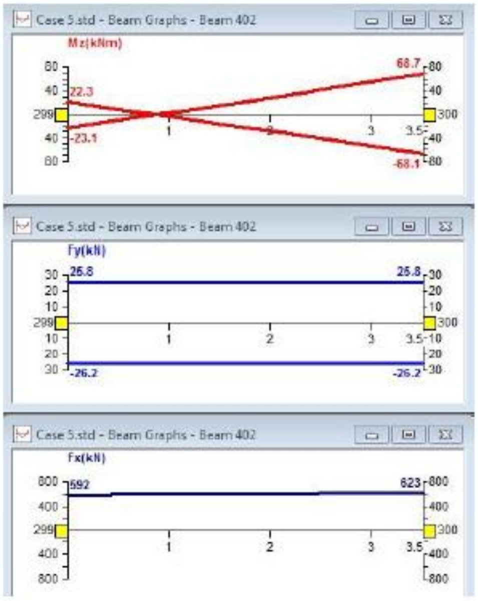
(E) FRAME 5

Ground Floor

Perimeter Column

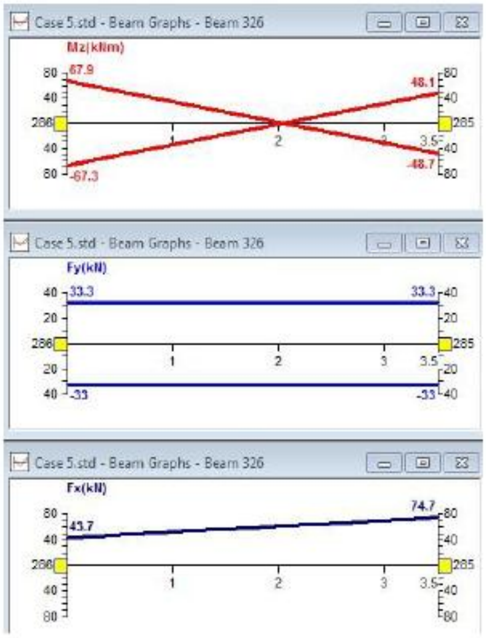


Interior Column



Top Storey

Perimeter Column



Interior Column

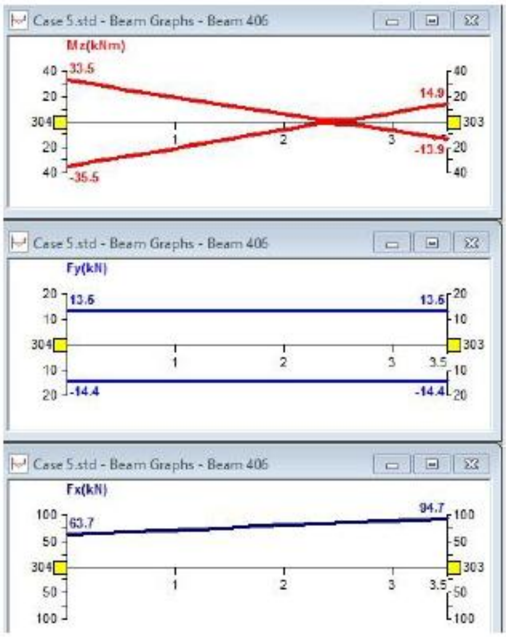


Fig.8 : Bending moment, axial force and shear forces for the different shear wall configurations.

3.3.2 Bar Graphs showing Results

i)

Ground Floor	Max Bending Moment(kN-m)	
	Perimeter Column	Interior Column
Frame-1	230	233
Frame-2	51.7	30
Frame-3	43.3	81.1
Frame-4	47.1	82.9
Frame-5	36.7	68.7

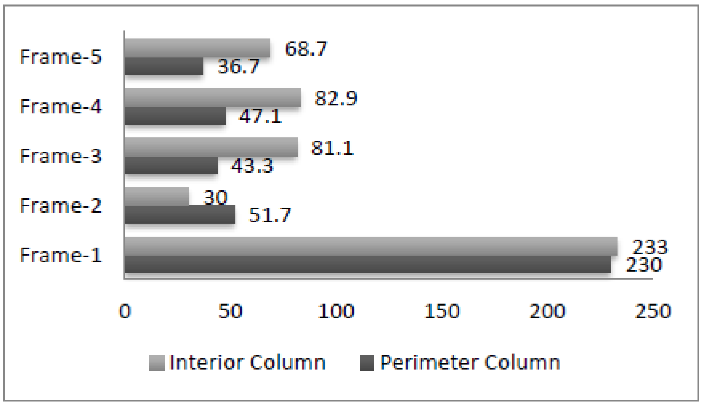


Table 4 & Fig. 9: Performance of Ground Storey Columns in Bending for all frames

ii)

Top Storey	Max Bending Moment(kN-m)	
	Perimeter Column	Interior Column
Frame-1	93.2	91.9
Frame-2	35.3	62.5
Frame-3	108	62.9
Frame-4	35.3	27.9
Frame-5	67.9	35.5

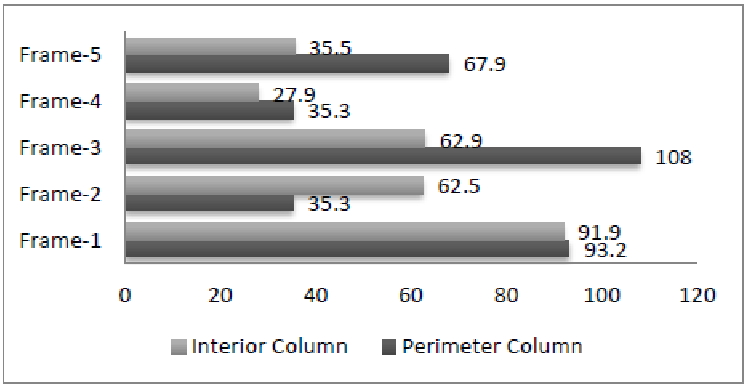


Table 5 & Fig. 10: Performance of Top Storey Columns in Bending for all frames

iii)

Ground Floor	Shear Force (kN)	
	Perimeter Column	Interior Column
Frame-1	104	106
Frame-2	23.2	14.2
Frame-3	20	36.3
Frame-4	17.2	31.6
Frame-5	14.1	26.2

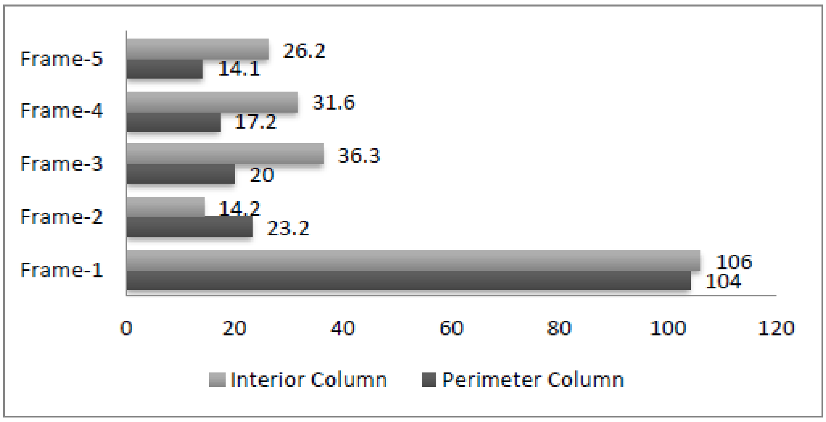


Table 6 & Fig. 11: Performance of Ground Storey Columns in Shear for all frames

iv)

Top Storey	Shear Force (kN)	
	Perimeter Column	Interior Column
Frame-1	43.6	42.6
Frame-2	16.8	31.9
Frame-3	55.6	30.8
Frame-4	15.2	9.75
Frame-5	33.3	14.4

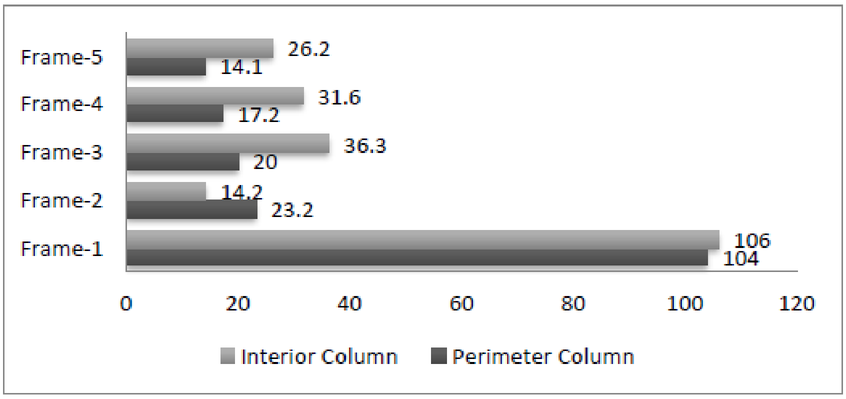


Table 7 & Fig. 12: Performance of Top Storey Columns in Shear for all frames

v)

Ground Floor	Axial Force (kN)	
	Perimeter Column	Interior Column
Frame-1	797	1066
Frame-2	732	1011
Frame-3	705	1034
Frame-4	534	701
Frame-5	442	623

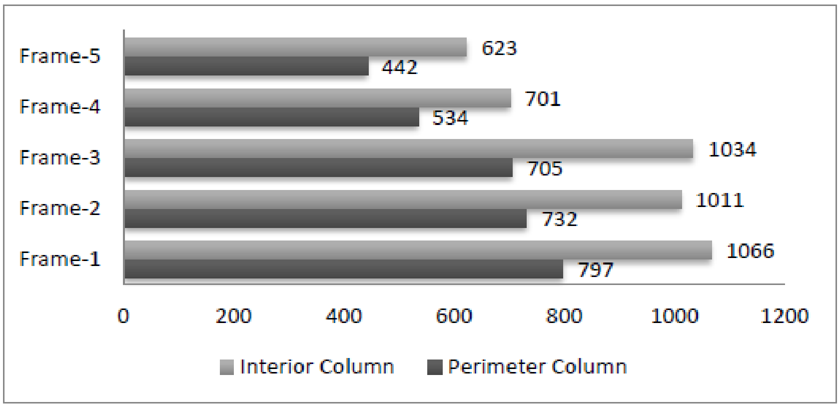


Table 8 & Fig. 13: Performance of Ground Storey Columns in Axial for all frames

vi)

Top Storey	Axial Force (kN)	
	Perimeter Column	Interior Column
Frame-1	119	152
Frame-2	117	139
Frame-3	117	144
Frame-4	56.7	61.2
Frame-5	74.7	94.7

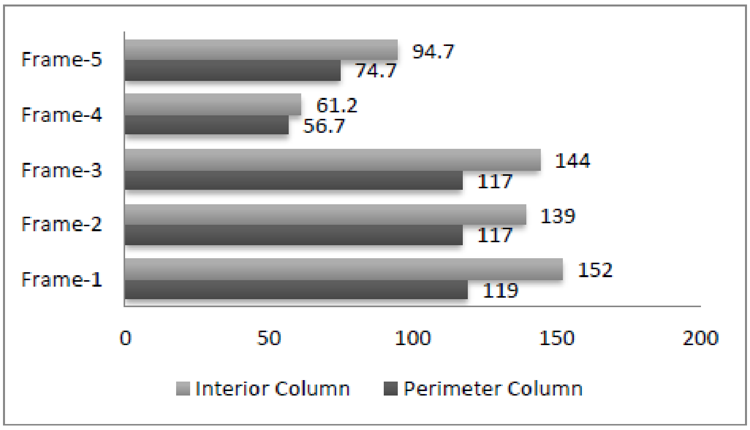


Table 9 & Fig. 14: Performance of Top Storey Columns in Axial for all frames

vii)

	Displacement(mm) in X direction					
Storey	**Frame-1**	**Frame-2**	**Frame-3**	**Frame-4**	**Frame-5**	
Fifth	34.813	9.964	12.403	14.998	12.248	0.713785
Fourth	30.940	8.586	9.494	11.95	9.301	
Third	24.122	6.290	6.343	8.192	6.297	
Second	15.317	3.728	3.455	4.594	3.558	
First	6.040	1.406	1.182	1.507	1.344	
Base	0.000	0.000	0.000	0.000	0.000	

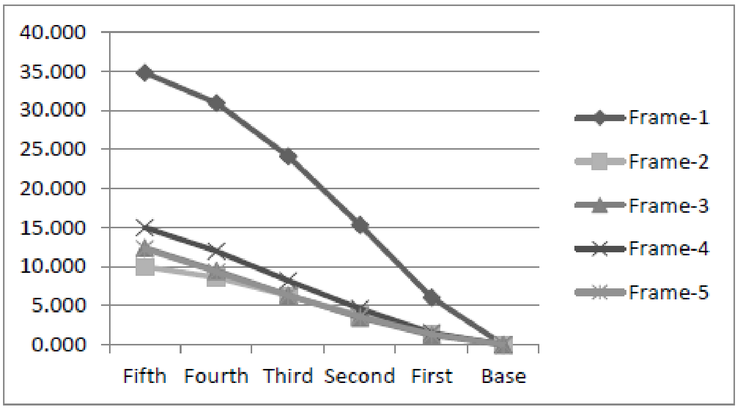


Table 10 & Fig. 15: Performance of All Story Columns in Joint Displacement (X direction) for all frames

viii)

	Displacement(mm) in Z direction					
Storey	**Frame-1**	**Frame-2**	**Frame-3**	**Frame-4**	**Frame-5**	
Fifth	60.911	13.444	10.135	12.917	11.691	0.83361
Fourth	53.123	11.569	7.689	9.84	8.982	
Third	40.622	8.477	5.107	6.729	5.942	
Second	24.849	4.922	2.773	3.832	3.183	
First	8.944	1.129	0.961	1.621	1.039	
Base	0.000	0.000	0.000	0.000	0.000	

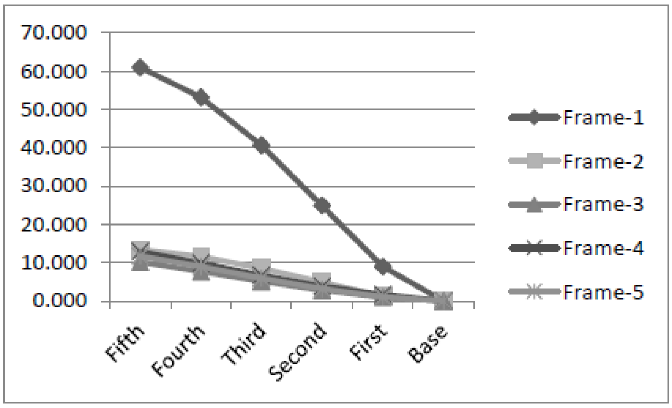


Table 11 & Fig. 16: Performance of All Story Columns in Joint Displacement (Z direction)

3.3.3 Points to be noted:

- Lateral load resisting capacity of the frame increases significantly in case of shear wall introduction, as is clear from the story displacements in X and Z directions.
- For case-2 (shear walls at core), lateral displacements are minimum in X-direction and merely 29% of the displacement of simple frame (from 34.83 mm to 9.96 mm)
- The frame with shear walls (Case-3) at mid-sides performs best for earthquake in Z-direction. The reduction in response is as high as 83% (60.9 mm to 10.14 mm).
- Inter storey drift which is crucial for columns is also reduced appreciably with the introduction of shear wall, minimum being for Cases 2 and 3.
- As far as bending moments in ground floor columns are concerned, Frame-2 and Frame-3 shows significant reduction in the same as compared to those in simple frame (Case-1). The reduction in B.M. is approximately 70 to 85% for interior and perimeter columns respectively.
- Shear force in ground storey columns is also reduced by as high as 86% for Frame-2 and Frame-5. This can be attributed to contribution of shear walls in taking base shear.
- Axial force in the columns during earthquake is reduced as much as 45% due to introduction of shear walls. Major reduction is seen for Frame-5.
- Similar trend in reduction of bending moments, shear forces and axial forces is seen in for top story columns. Frame-2 and Frame-4 are seen to perform better in this case.
- In the present case, the Frame-3 (shear walls at mid-sides) is seen to perform better in major number of cases.

In order to make our building economic, we carried forward the task of curtailment of the stable frames(Frame-2 and Frame-3) in chapter 4.

CHAPTER 4

CURTAILMENT OF THE MOST STABLE FRAMES

GENERAL

This chapter deals with curtailment of top two storey of shear walls in order to reduce the cost of construction. The two frames were analysed for earthquake loads and their performances were compared in terms of bending moment, shear forces, storey drift and inter storey drift, etc. The frame cases taken for curtailment are :

i) Frame with Shear walls placed at the core

ii) Frame with shear walls placed at centre of exterior bays

Based on the previous conclusions, we came to know that the Frame having shear walls at core and centrally placed at exterior bays were the configurations that showed maximum resistance to lateral loads.

4.1 FOUR FRAMES

- Frame 6 - Curtailment of top story with shear walls at core
- Frame 7 - Curtailment of top story with shear walls symmetrically placed at middle of exterior bays
- Frame 8 - Curtailment of top two storeys with shear walls at core
- Frame 9 - Curtailment of top two storeys with shear walls symmetrically placed at middle of exterior bays

The frames shown in Fig.12 are analysed for Joint displacement, Bending moment, shear force and axial forces.

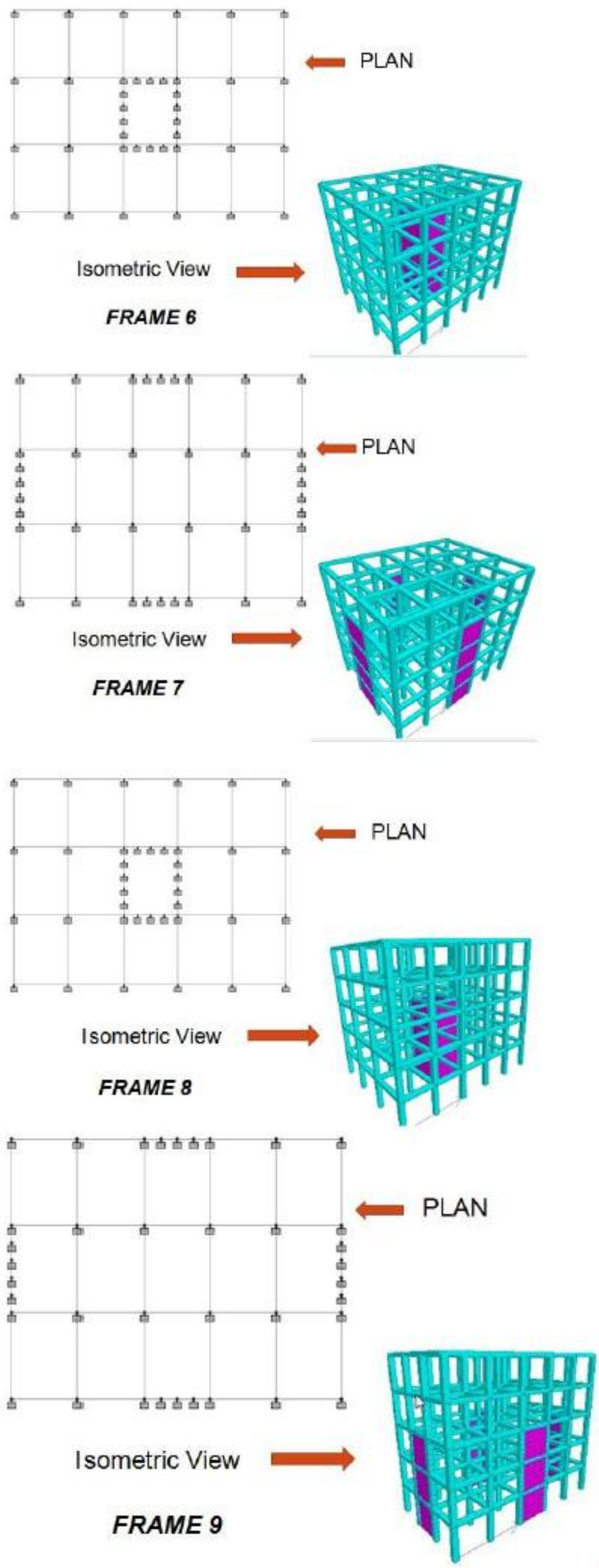


Fig.17 : Curtailed Frames

4.2 ANALYSIS OF RESULTS OF CURTAILED FRAMES

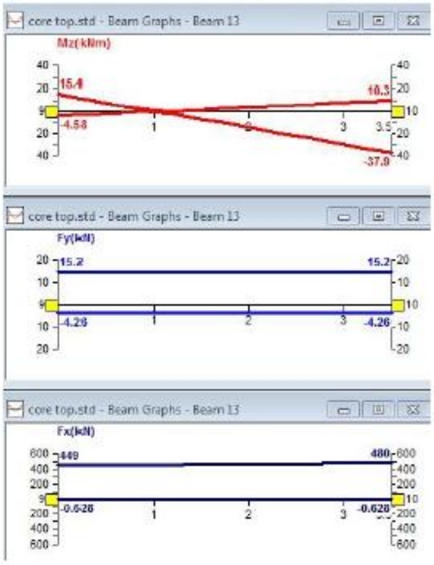
Here, we have shown bending moment, axial force and shear forces for the different curtailed frames for perimeter and interior columns.

4.2.1 Frames

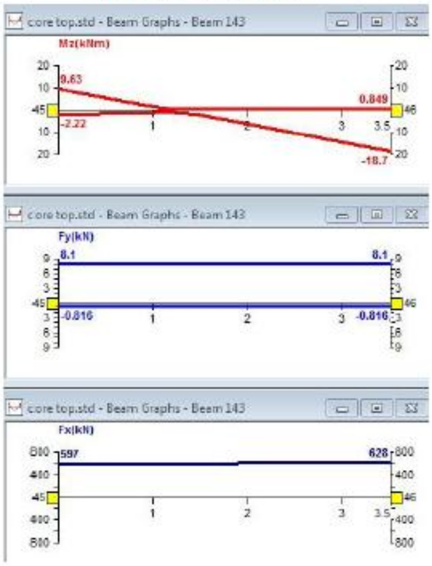
(A) FRAME 6

Ground Floor

Perimeter Column

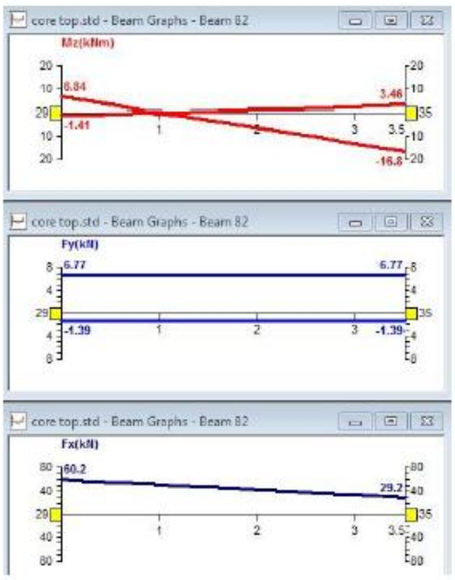


Interior Column

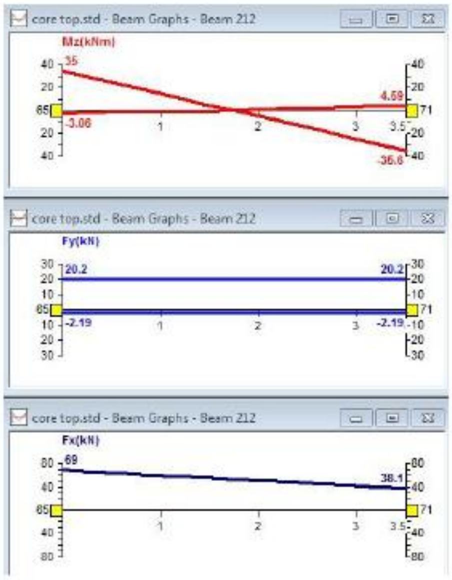


Top Storey

Perimeter Column



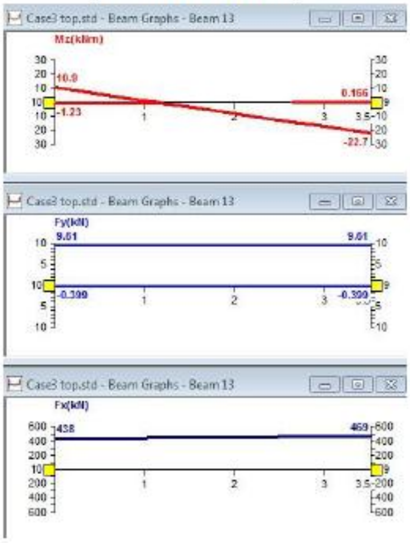
Interior Column



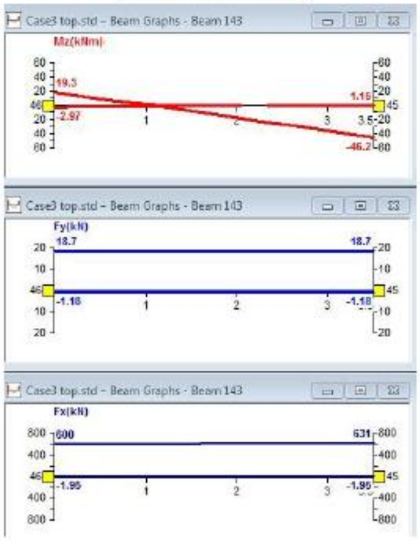
(B) FRAME 7

Ground Floor

Perimeter Column

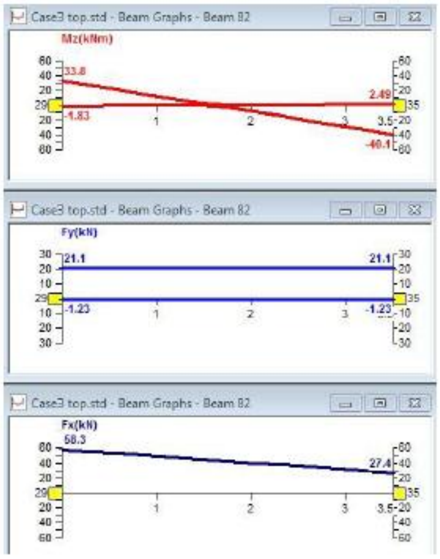


Interior Column

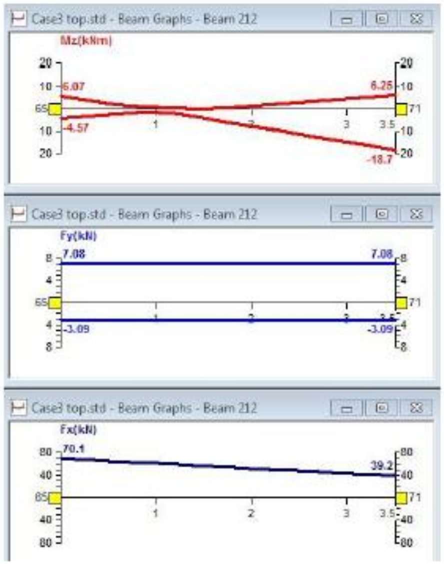


Top Storey

Perimeter Column



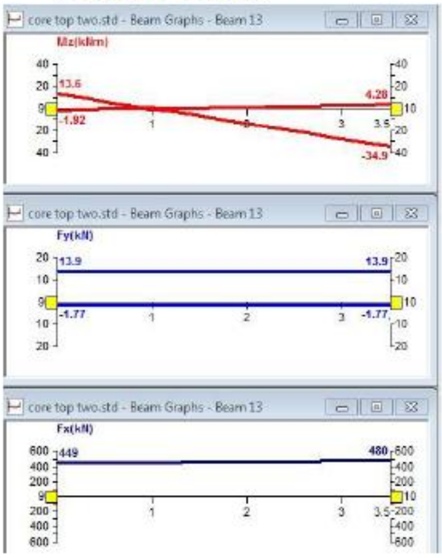
Interior Column



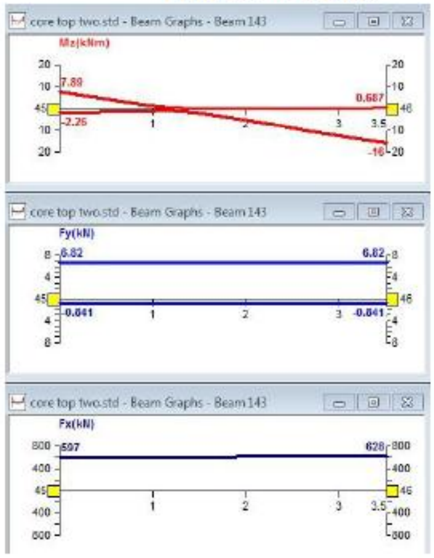
(C) FRAME 8

Ground Floor

Perimeter Column

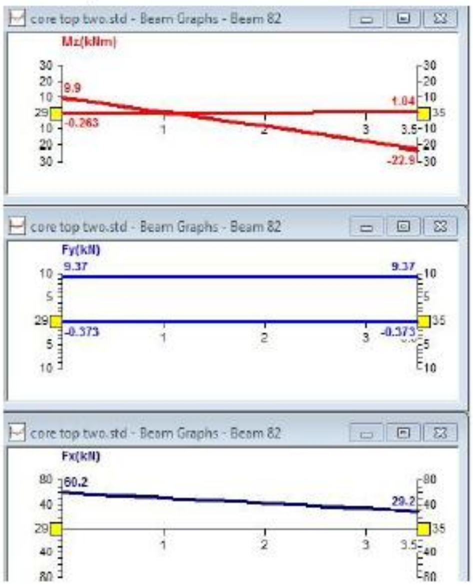


Interior Column

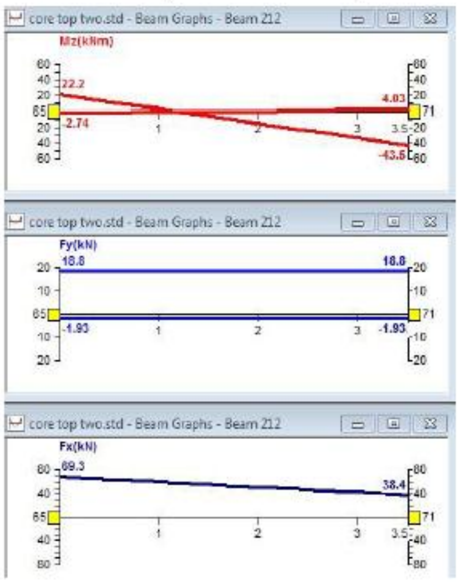


Top Storey

Perimeter Column



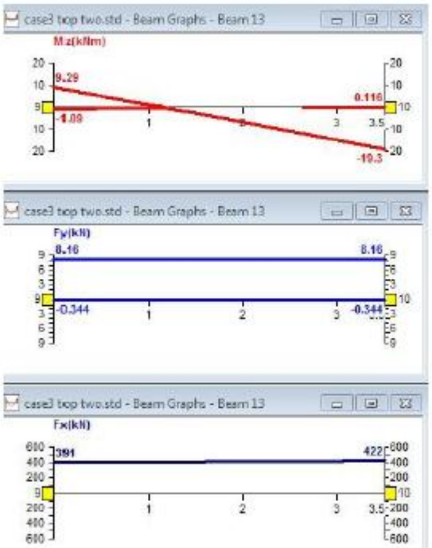
Interior Column



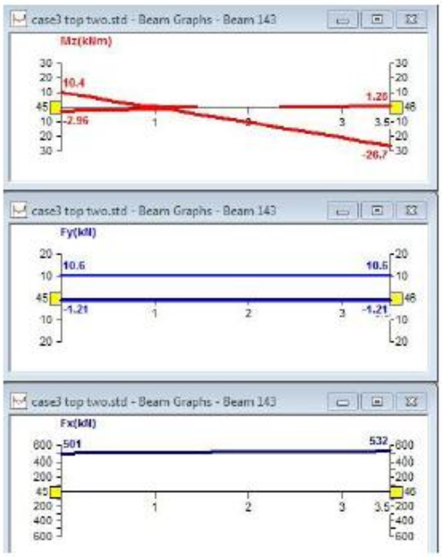
(C) FRAME 9

Ground Floor

Perimeter Column

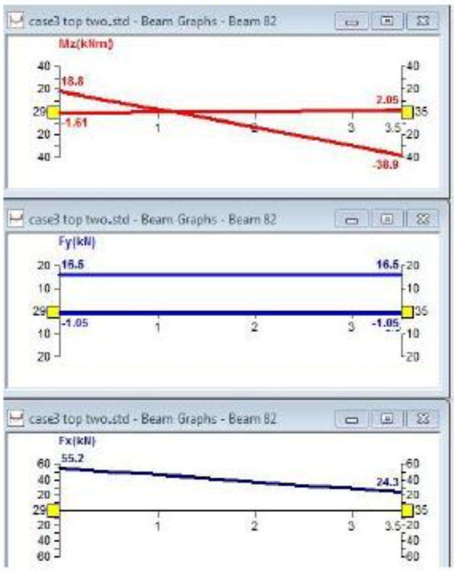


Interior Column



Top Storey

Perimeter Column



Interior Column

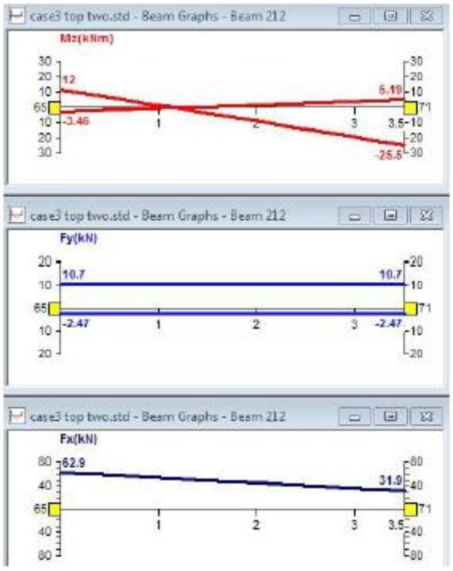


Fig.18 : Bending moment, axial force and shear forces for curtailed frames

4.2.2 Bar Graphs showing Results

i)

Ground Floor	Max Bending Moment(kN-m)	
	Perimeter Column	Interior Column
Frame-6	37.9	18.7
Frame-7	22.7	46.2
Frame-8	34.9	16
Frame-9	19.3	26.7

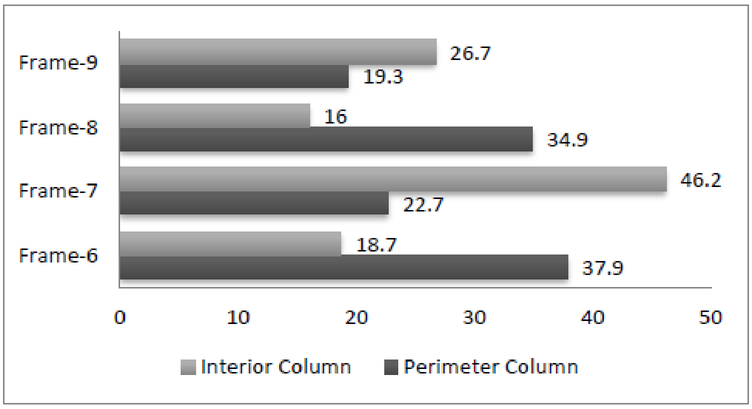


Table 12 & Fig.1 9: Performance of Ground Storey Columns in Bending for all curtailed frames

ii)

Top Storey	Max Bending Moment(kN-m)	
	Perimeter Column	Interior Column
Frame-6	16.8	35.6
Frame-7	40.1	18.7
Frame-8	22.9	43.5
Frame-9	38.9	25.5

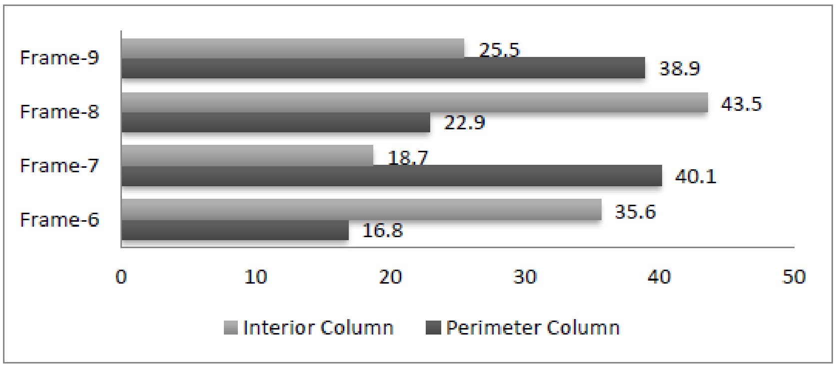


Table 13 & Fig. 20: Performance of Top Storey Columns in Bending for all curtailed frames

iii)

Ground Floor	Shear Force (kN)	
	Perimeter Column	Interior Column
Frame-6	15.2	8.1
Frame-7	9.61	18.7
Frame-8	13.9	6.82
Frame-9	8.16	10.6

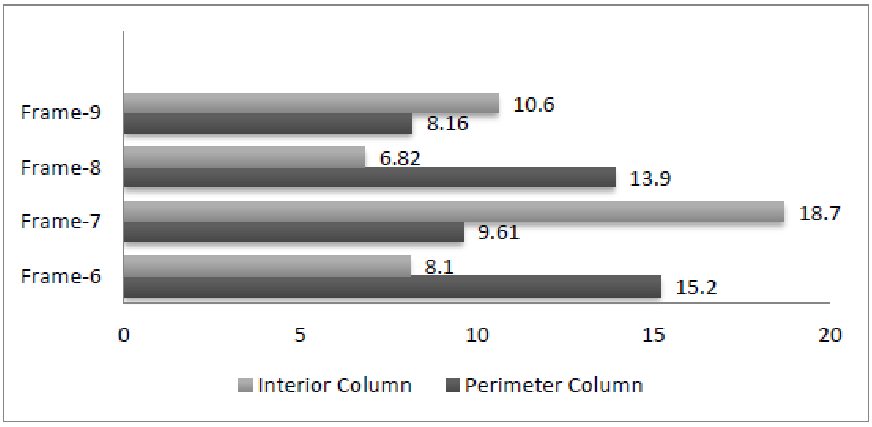


Table 14 & Fig. 21: Performance of Ground Storey Columns in Shear for all curtailed frames

iv)

Top Storey	Shear Force (kN)	
	Perimeter Column	Interior Column
Frame-6	6.77	20.2
Frame-7	21.1	7.08
Frame-8	9.37	18.8
Frame-9	16.5	10.7

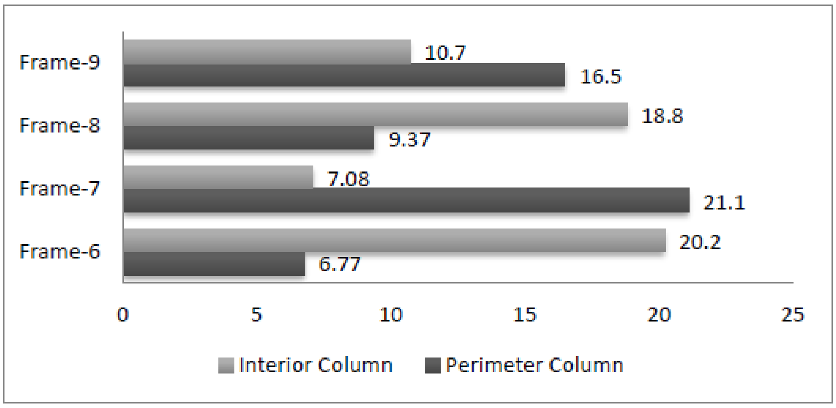


Table 15 & Fig. 22: Performance of Top Storey Columns in Shear for all curtailed frames

v)

Ground Floor	Axial Force (kN)	
	Perimeter Column	Interior Column
Frame-6	480	628
Frame-7	469	631
Frame-8	480	628
Frame-9	422	532

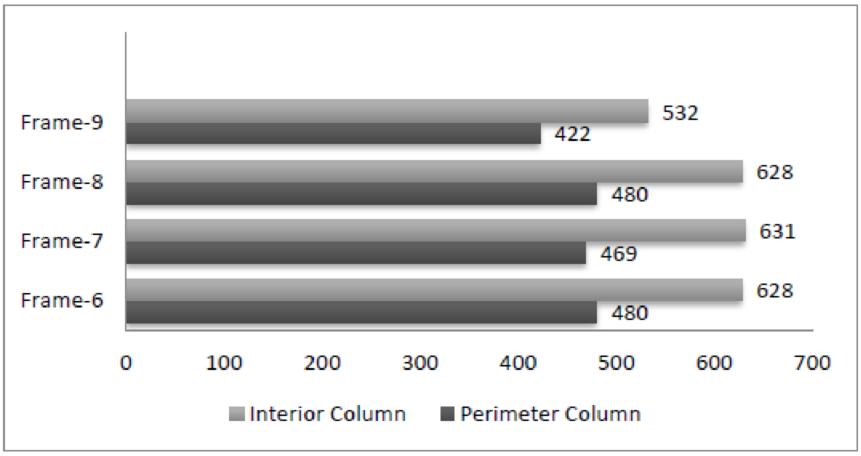


Table 16 & Fig. 23: Performance of Ground Storey Columns in Axial for all curtailed frames

vi)

Top Storey	Axial Force (kN)	
	Perimeter Column	Interior Column
Frame-6	60.2	69
Frame-7	58.3	70.1
Frame-8	60.2	69.3
Frame-9	55.2	62.9

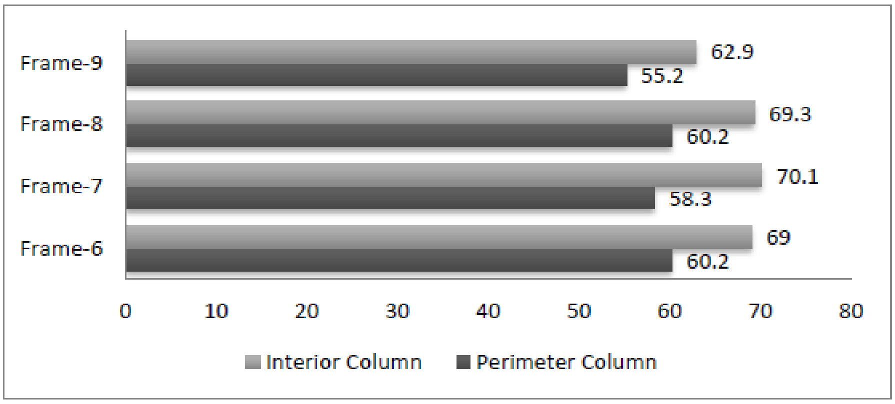


Table 17 & Fig. 24: Performance of Top Storey Columns in Axial for all curtailed frames

vii)

	Displacement (mm) in X direction				
Storey	Frame-6	Frame-7	Frame-8	Frame-9	
Fifth	14.329	7.857	9.977	8.966	.45150
Fourth	7.617	5.622	8.171	6.367	
Third	5.671	3.769	5.722	3.17	
Second	3.52	2.051	3.348	1.655	
First	1.152	0.646	1.046	0.55	
Base	0.000	0.000	0.000	0.000	

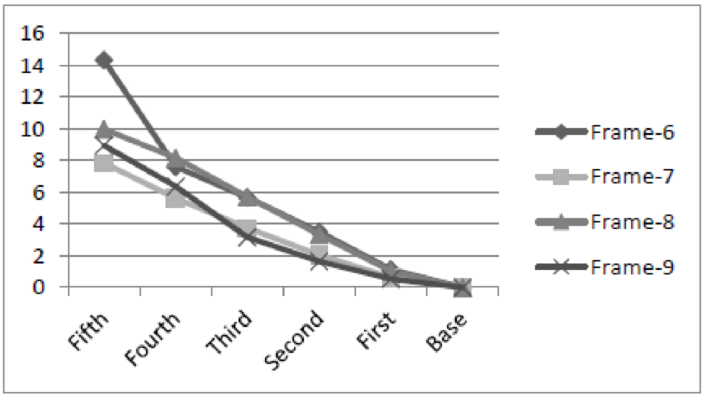


Table 18 & Fig. 25: Performance of All Story Columns in Joint Displacement (X direction) for all curtailed frames

viii)

	Displacement (mm) in Z direction				
Storey	Frame-6	Frame-7	Frame-8	Frame-9	
Fifth	14.329	9.468	16.989	14.821	.44269
Fourth	11.981	5.508	13.595	10.184	
Third	8.761	3.613	9.407	4.811	
Second	5.222	2.004	5.229	2.572	
First	1.755	0.666	1.644	0.871	
Base	0.000	0.000	0.000	0.000	

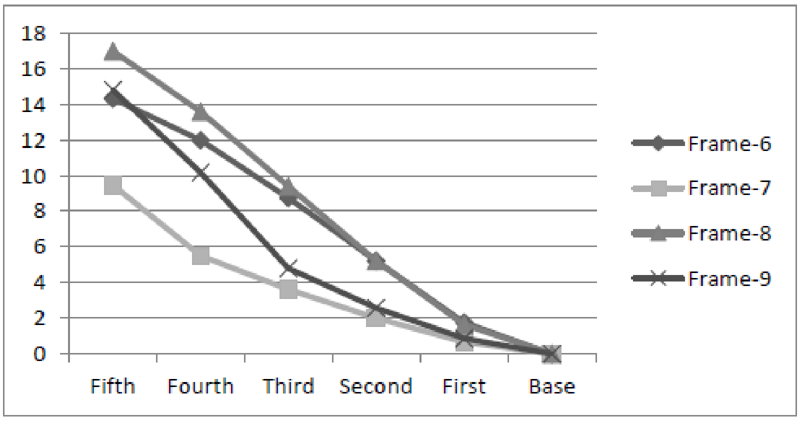


Table 19 & Fig. 26: Performance of All Story Columns in Joint Displacement (Z direction)

CONCLUSIONS

(1) Lateral load resisting capacity of the frame increases significantly in case of curtailment of shear wall , as is clear from the story displacements in X and Z directions.

(2) For Frame-7 (Curtailment of top story with shear walls at middle of exterior bays), lateral displacements are minimum in X-direction and merely 55% of the displacement of frame-6 (from 14.33 mm to 7.86 mm)

(3) The frame with shear walls at middle of exterior bays (Frame-7) performs best for earthquake in Z-direction. The reduction in response is as high as 44% (16.99 mm to 9.47 mm).

(4) Interstorey drift which is crucial for columns is also reduced appreciably with the curtailment of shear wall, minimum being for Frames-6 and Frame-7.

(5) As far as bending moments in ground floor columns are concerned, Frame-9 and Frame-8 shows significant reduction in the same as compared to those in Frame-7 and Frame-6. The reduction in B.M. is approximately 50 to 65% for perimeter and interior columns respectively.

(6) Shear force in ground storey columns is also reduced by as high as 54% for Frame-8 and Frame-9. Hence, Shear force has reduced significantly with the curtailment of top two storeys.

(7) Axial force in the columns during earthquake is reduced as much as 16% due to introduction of shear walls. Major reduction is seen for Frame-9.

(8) Similar trend in reduction of bending moments, shear forces and axial forces is seen in for top story columns. Frame-8 and Frame-9 are seen to perform better in this case.

(9) Shear walls are definitely good mechanism for lateral loads mitigation, but the placement of shear walls should be made judiciously. In order to make the building economically feasible ,curtailment should be done up to a certain height from the top. In the present case, the Frame-9 (curtailment of top two storeys with shear walls symmetrically placed at middle of exterior bays) is seen to perform better in major number of cases.

CHAPTER 5
SOURCE CODE OF STAAD.Pro V8i

5.1 Source Code of Frame -3 (Shear Walls middle of sides)

```
STAAD SPACE
START JOB INFORMATION
ENGINEER DATE 10-Nov-13
END JOB INFORMATION
INPUT WIDTH 79
UNIT METER KN
JOINT COORDINATES
1 0 0 0; 2 0 3.5 0; 3 0 7 0; 4 0 10.5 0; 5 0 14 0; 6 0 17.5 0; 7 0 0 5;
8 0 3.5 5; 9 0 7 5; 10 0 10.5 5; 11 0 14 5; 12 0 17.5 5; 13 0 0 10;
14 0 3.5 10; 15 0 7 10; 16 0 10.5 10; 17 0 14 10; 18 0 17.5 10; 19 0 0 15;
20 0 3.5 15; 21 0 7 15; 22 0 10.5 15; 23 0 14 15; 24 0 17.5 15;
25 0 1.02941 10; 26 0 1.02941 9; 27 0 0 9; 28 0 2.05882 10; 29 0 2.05882 9;
30 0 3.08824 10; 31 0 3.08824 9; 32 0 4.11765 10; 33 0 4.11765 9;
34 0 5.14706 10; 35 0 5.14706 9; 36 0 6.17647 10; 37 0 6.17647 9;
38 0 7.20588 10; 39 0 7.20588 9; 40 0 8.23529 10; 41 0 8.23529 9;
42 0 9.26471 10; 43 0 9.26471 9; 44 0 10.2941 10; 45 0 10.2941 9;
46 0 11.3235 10; 47 0 11.3235 9; 48 0 12.3529 10; 49 0 12.3529 9;
50 0 13.3824 10; 51 0 13.3824 9; 52 0 14.4118 10; 53 0 14.4118 9;
54 0 15.4412 10; 55 0 15.4412 9; 56 0 16.4706 10; 57 0 16.4706 9; 58 0 17.5 9;
59 0 1.02941 8; 60 0 0 8; 61 0 2.05882 8; 62 0 3.08824 8; 63 0 4.11765 8;
64 0 5.14706 8; 65 0 6.17647 8; 66 0 7.20588 8; 67 0 8.23529 8; 68 0 9.26471 8;
69 0 10.2941 8; 70 0 11.3235 8; 71 0 12.3529 8; 72 0 13.3824 8; 73 0 14.4118 8;
74 0 15.4412 8; 75 0 16.4706 8; 76 0 17.5 8; 77 0 1.02941 7; 78 0 0 7;
79 0 2.05882 7; 80 0 3.08824 7; 81 0 4.11765 7; 82 0 5.14706 7; 83 0 6.17647 7;
84 0 7.20588 7; 85 0 8.23529 7; 86 0 9.26471 7; 87 0 10.2941 7; 88 0 11.3235 7;
89 0 12.3529 7; 90 0 13.3824 7; 91 0 14.4118 7; 92 0 15.4412 7; 93 0 16.4706 7;
94 0 17.5 7; 95 0 1.02941 6; 96 0 0 6; 97 0 2.05882 6; 98 0 3.08824 6;
99 0 4.11765 6; 100 0 5.14706 6; 101 0 6.17647 6; 102 0 7.20588 6;
103 0 8.23529 6; 104 0 9.26471 6; 105 0 10.2941 6; 106 0 11.3235 6;
107 0 12.3529 6; 108 0 13.3824 6; 109 0 14.4118 6; 110 0 15.4412 6;
111 0 16.4706 6; 112 0 17.5 6; 113 0 1.02941 5; 114 0 2.05882 5;
115 0 3.08824 5; 116 0 4.11765 5; 117 0 5.14706 5; 118 0 6.17647 5;
119 0 7.20588 5; 120 0 8.23529 5; 121 0 9.26471 5; 122 0 10.2941 5;
123 0 11.3235 5; 124 0 12.3529 5; 125 0 13.3824 5; 126 0 14.4118 5;
127 0 15.4412 5; 128 0 16.4706 5; 129 4 3.5 0; 130 4 0 0; 131 4 7 0;
132 4 10.5 0; 133 4 14 0; 134 4 17.5 0; 135 4 3.5 5; 136 4 0 5; 137 4 7 5;
138 4 10.5 5; 139 4 14 5; 140 4 17.5 5; 141 4 3.5 10; 142 4 0 10; 143 4 7 10;
144 4 10.5 10; 145 4 14 10; 146 4 17.5 10; 147 4 3.5 15; 148 4 0 15;
149 4 7 15; 150 4 10.5 15; 151 4 14 15; 152 4 17.5 15; 153 8 3.5 0; 154 8 0 0;
155 8 7 0; 156 8 10.5 0; 157 8 14 0; 158 8 17.5 0; 159 8 3.5 5; 160 8 0 5;
161 8 7 5; 162 8 10.5 5; 163 8 14 5; 164 8 17.5 5; 165 8 3.5 10; 166 8 0 10;
167 8 7 10; 168 8 10.5 10; 169 8 14 10; 170 8 17.5 10; 171 8 3.5 15;
172 8 0 15; 173 8 7 15; 174 8 10.5 15; 175 8 14 15; 176 8 17.5 15;
177 8 1.02941 0; 178 8 2.05882 0; 179 8 3.08824 0; 180 8 4.11765 0;
181 8 5.14706 0; 182 8 6.17647 0; 183 8 7.20588 0; 184 8 8.23529 0;
185 8 9.26471 0; 186 8 10.2941 0; 187 8 11.3235 0; 188 8 12.3529 0;
189 8 13.3824 0; 190 8 14.4118 0; 191 8 15.4412 0; 192 8 16.4706 0;
193 8 1.02941 15; 194 8 2.05882 15; 195 8 3.08824 15; 196 8 4.11765 15;
197 8 5.14706 15; 198 8 6.17647 15; 199 8 7.20588 15; 200 8 8.23529 15;
201 8 9.26471 15; 202 8 10.2941 15; 203 8 11.3235 15; 204 8 12.3529 15;
205 8 13.3824 15; 206 8 14.4118 15; 207 8 15.4412 15; 208 8 16.4706 15;
209 9 1.02941 0; 210 9 0 0; 211 9 2.05882 0; 212 9 3.08824 0; 213 9 4.11765 0;
214 9 5.14706 0; 215 9 6.17647 0; 216 9 7.20588 0; 217 9 8.23529 0;
218 9 9.26471 0; 219 9 10.2941 0; 220 9 11.3235 0; 221 9 12.3529 0;
222 9 13.3824 0; 223 9 14.4118 0; 224 9 15.4412 0; 225 9 16.4706 0;
226 9 17.5 0; 227 9 1.02941 15; 228 9 0 15; 229 9 2.05882 15; 230 9 3.08824 15;
231 9 4.11765 15; 232 9 5.14706 15; 233 9 6.17647 15; 234 9 7.20588 15;
235 9 8.23529 15; 236 9 9.26471 15; 237 9 10.2941 15; 238 9 11.3235 15;
```

239 9 12.3529 15; 240 9 13.3824 15; 241 9 14.4118 15; 242 9 15.4412 15;
243 9 16.4706 15; 244 9 17.5 15; 245 10 1.02941 0; 246 10 0 0;
247 10 2.05882 0; 248 10 3.08824 0; 249 10 4.11765 0; 250 10 5.14706 0;
251 10 6.17647 0; 252 10 7.20588 0; 253 10 8.23529 0; 254 10 9.26471 0;
255 10 10.2941 0; 256 10 11.3235 0; 257 10 12.3529 0; 258 10 13.3824 0;
259 10 14.4118 0; 260 10 15.4412 0; 261 10 16.4706 0; 262 10 17.5 0;
263 10 1.02941 15; 264 10 0 15; 265 10 2.05882 15; 266 10 3.08824 15;
267 10 4.11765 15; 268 10 5.14706 15; 269 10 6.17647 15; 270 10 7.20588 15;
271 10 8.23529 15; 272 10 9.26471 15; 273 10 10.2941 15; 274 10 11.3235 15;
275 10 12.3529 15; 276 10 13.3824 15; 277 10 14.4118 15; 278 10 15.4412 15;
279 10 16.4706 15; 280 10 17.5 15; 281 11 1.02941 0; 282 11 0 0;
283 11 2.05882 0; 284 11 3.08824 0; 285 11 4.11765 0; 286 11 5.14706 0;
287 11 6.17647 0; 288 11 7.20588 0; 289 11 8.23529 0; 290 11 9.26471 0;
291 11 10.2941 0; 292 11 11.3235 0; 293 11 12.3529 0; 294 11 13.3824 0;
295 11 14.4118 0; 296 11 15.4412 0; 297 11 16.4706 0; 298 11 17.5 0;
299 11 1.02941 15; 300 11 0 15; 301 11 2.05882 15; 302 11 3.08824 15;
303 11 4.11765 15; 304 11 5.14706 15; 305 11 6.17647 15; 306 11 7.20588 15;
307 11 8.23529 15; 308 11 9.26471 15; 309 11 10.2941 15; 310 11 11.3235 15;
311 11 12.3529 15; 312 11 13.3824 15; 313 11 14.4118 15; 314 11 15.4412 15;
315 11 16.4706 15; 316 11 17.5 15; 317 12 3.5 0; 318 12 0 0; 319 12 7 0;
320 12 10.5 0; 321 12 14 0; 322 12 17.5 0; 323 12 3.5 5; 324 12 0 5;
325 12 7 5; 326 12 10.5 5; 327 12 14 5; 328 12 17.5 5; 329 12 3.5 10;
330 12 0 10; 331 12 7 10; 332 12 10.5 10; 333 12 14 10; 334 12 17.5 10;
335 12 3.5 15; 336 12 0 15; 337 12 7 15; 338 12 10.5 15; 339 12 14 15;
340 12 17.5 15; 341 12 1.02941 0; 342 12 2.05882 0; 343 12 3.08824 0;
344 12 4.11765 0; 345 12 5.14706 0; 346 12 6.17647 0; 347 12 7.20588 0;
348 12 8.23529 0; 349 12 9.26471 0; 350 12 10.2941 0; 351 12 11.3235 0;
352 12 12.3529 0; 353 12 13.3824 0; 354 12 14.4118 0; 355 12 15.4412 0;
356 12 16.4706 0; 357 12 1.02941 15; 358 12 2.05882 15; 359 12 3.08824 15;
360 12 4.11765 15; 361 12 5.14706 15; 362 12 6.17647 15; 363 12 7.20588 15;
364 12 8.23529 15; 365 12 9.26471 15; 366 12 10.2941 15; 367 12 11.3235 15;
368 12 12.3529 15; 369 12 13.3824 15; 370 12 14.4118 15; 371 12 15.4412 15;
372 12 16.4706 15; 373 16 3.5 0; 374 16 0 0; 375 16 7 0; 376 16 10.5 0;
377 16 14 0; 378 16 17.5 0; 379 16 3.5 5; 380 16 0 5; 381 16 7 5;
382 16 10.5 5; 383 16 14 5; 384 16 17.5 5; 385 16 3.5 10; 386 16 0 10;
387 16 7 10; 388 16 10.5 10; 389 16 14 10; 390 16 17.5 10; 391 16 3.5 15;
392 16 0 15; 393 16 7 15; 394 16 10.5 15; 395 16 14 15; 396 16 17.5 15;
397 20 3.5 0; 398 20 0 0; 399 20 7 0; 400 20 10.5 0; 401 20 14 0;
402 20 17.5 0; 403 20 3.5 5; 404 20 0 5; 405 20 7 5; 406 20 10.5 5;
407 20 14 5; 408 20 17.5 5; 409 20 3.5 10; 410 20 0 10; 411 20 7 10;
412 20 10.5 10; 413 20 14 10; 414 20 17.5 10; 415 20 3.5 15; 416 20 0 15;
417 20 7 15; 418 20 10.5 15; 419 20 14 15; 420 20 17.5 15; 421 20 1.02941 10;
422 20 1.02941 9; 423 20 0 9; 424 20 2.05882 10; 425 20 2.05882 9;
426 20 3.08824 10; 427 20 3.08824 9; 428 20 4.11765 10; 429 20 4.11765 9;
430 20 5.14706 10; 431 20 5.14706 9; 432 20 6.17647 10; 433 20 6.17647 9;
434 20 7.20588 10; 435 20 7.20588 9; 436 20 8.23529 10; 437 20 8.23529 9;
438 20 9.26471 10; 439 20 9.26471 9; 440 20 10.2941 10; 441 20 10.2941 9;
442 20 11.3235 10; 443 20 11.3235 9; 444 20 12.3529 10; 445 20 12.3529 9;
446 20 13.3824 10; 447 20 13.3824 9; 448 20 14.4118 10; 449 20 14.4118 9;
450 20 15.4412 10; 451 20 15.4412 9; 452 20 16.4706 10; 453 20 16.4706 9;
454 20 17.5 9; 455 20 1.02941 8; 456 20 0 8; 457 20 2.05882 8;
458 20 3.08824 8; 459 20 4.11765 8; 460 20 5.14706 8; 461 20 6.17647 8;
462 20 7.20588 8; 463 20 8.23529 8; 464 20 9.26471 8; 465 20 10.2941 8;
466 20 11.3235 8; 467 20 12.3529 8; 468 20 13.3824 8; 469 20 14.4118 8;
470 20 15.4412 8; 471 20 16.4706 8; 472 20 17.5 8; 473 20 1.02941 7;
474 20 0 7; 475 20 2.05882 7; 476 20 3.08824 7; 477 20 4.11765 7;
478 20 5.14706 7; 479 20 6.17647 7; 480 20 7.20588 7; 481 20 8.23529 7;
482 20 9.26471 7; 483 20 10.2941 7; 484 20 11.3235 7; 485 20 12.3529 7;
486 20 13.3824 7; 487 20 14.4118 7; 488 20 15.4412 7; 489 20 16.4706 7;
490 20 17.5 7; 491 20 1.02941 6; 492 20 0 6; 493 20 2.05882 6;
494 20 3.08824 6; 495 20 4.11765 6; 496 20 5.14706 6; 497 20 6.17647 6;
498 20 7.20588 6; 499 20 8.23529 6; 500 20 9.26471 6; 501 20 10.2941 6;
502 20 11.3235 6; 503 20 12.3529 6; 504 20 13.3824 6; 505 20 14.4118 6;
506 20 15.4412 6; 507 20 16.4706 6; 508 20 17.5 6; 509 20 1.02941 5;
510 20 2.05882 5; 511 20 3.08824 5; 512 20 4.11765 5; 513 20 5.14706 5;
514 20 6.17647 5; 515 20 7.20588 5; 516 20 8.23529 5; 517 20 9.26471 5;
518 20 10.2941 5; 519 20 11.3235 5; 520 20 12.3529 5; 521 20 13.3824 5;

522 20 14.4118 5; 523 20 15.4412 5; 524 20 16.4706 5;
MEMBER INCIDENCES
1 1 2; 2 2 3; 3 3 4; 4 4 5; 5 5 6; 6 2 8; 7 3 9; 8 4 10; 9 5 11; 10 6 12;
11 7 113; 12 8 116; 13 9 119; 14 10 123; 15 11 126; 16 8 14; 17 9 15; 18 10 16;
19 11 17; 20 12 112; 21 13 25; 22 14 32; 23 15 38; 24 16 46; 25 17 52;
26 14 20; 27 15 21; 28 16 22; 29 17 23; 30 18 24; 31 19 20; 32 20 21; 33 21 22;
34 22 23; 35 23 24; 36 25 28; 37 28 30; 38 30 14; 39 32 34; 40 34 36; 41 36 15;
42 38 40; 43 40 42; 44 42 44; 45 44 16; 46 46 48; 47 48 50; 48 50 17; 49 52 54;
50 54 56; 51 56 18; 52 58 18; 53 76 58; 54 94 76; 55 112 94; 56 113 114;
57 114 115; 58 115 8; 59 116 117; 60 117 118; 61 118 9; 62 119 120; 63 120 121;
64 121 122; 65 122 10; 66 123 124; 67 124 125; 68 125 11; 69 126 127;
70 127 128; 71 128 12; 72 2 129; 73 3 131; 74 4 132; 75 5 133; 76 6 134;
77 8 135; 78 9 137; 79 10 138; 80 11 139; 81 12 140; 82 14 141; 83 15 143;
84 16 144; 85 17 145; 86 18 146; 87 20 147; 88 21 149; 89 22 150; 90 23 151;
91 24 152; 92 129 130; 93 131 129; 94 132 131; 95 133 132; 96 134 133;
97 129 135; 98 131 137; 99 132 138; 100 133 139; 101 134 140; 102 135 136;
103 137 135; 104 138 137; 105 139 138; 106 140 139; 107 135 141; 108 137 143;
109 138 144; 110 139 145; 111 140 146; 112 141 142; 113 143 141; 114 144 143;
115 145 144; 116 146 145; 117 141 147; 118 143 149; 119 144 150; 120 145 151;
121 146 152; 122 147 148; 123 149 147; 124 150 149; 125 151 150; 126 152 151;
127 129 153; 128 131 155; 129 132 156; 130 133 157; 131 134 158; 132 135 159;
133 137 161; 134 138 162; 135 139 163; 136 140 164; 137 141 165; 138 143 167;
139 144 168; 140 145 169; 141 146 170; 142 147 171; 143 149 173; 144 150 174;
145 151 175; 146 152 176; 147 153 179; 148 155 182; 149 156 186; 150 157 189;
151 158 192; 152 153 159; 153 155 161; 154 156 162; 155 157 163; 156 158 164;
157 159 160; 158 161 159; 159 162 161; 160 163 162; 161 164 163; 162 159 165;
163 161 167; 164 162 168; 165 163 169; 166 164 170; 167 165 166; 168 167 165;
169 168 167; 170 169 168; 171 170 169; 172 165 171; 173 167 173; 174 168 174;
175 169 175; 176 170 176; 177 171 195; 178 173 198; 179 174 202; 180 175 205;
181 176 208; 182 177 154; 183 178 177; 184 179 178; 185 180 153; 186 181 180;
187 182 181; 188 183 155; 189 184 183; 190 185 184; 191 186 185; 192 187 156;
193 188 187; 194 189 188; 195 190 157; 196 191 190; 197 192 191; 198 193 172;
199 194 193; 200 195 194; 201 196 171; 202 197 196; 203 198 197; 204 199 173;
205 200 199; 206 201 200; 207 202 201; 208 203 174; 209 204 203; 210 205 204;
211 206 175; 212 207 206; 213 208 207; 214 158 226; 215 158 226; 216 176 244;
217 176 244; 218 226 262; 219 226 262; 220 244 280; 221 244 280; 222 153 317;
223 155 319; 224 156 320; 225 157 321; 226 153 317; 227 155 319; 228 156 320;
229 157 321; 230 159 323; 231 161 325; 232 162 326; 233 163 327; 234 164 328;
235 159 323; 236 161 325; 237 162 326; 238 163 327; 239 164 328; 240 165 329;
241 167 331; 242 168 332; 243 169 333; 244 170 334; 245 165 329; 246 167 331;
247 168 332; 248 169 333; 249 170 334; 250 171 335; 251 173 337; 252 174 338;
253 175 339; 254 171 335; 255 173 337; 256 174 338; 257 175 339; 258 262 298;
259 262 298; 260 280 316; 261 280 316; 262 298 322; 263 298 322; 264 316 340;
265 316 340; 266 317 343; 267 319 346; 268 320 350; 269 321 353; 270 322 356;
271 317 323; 272 319 325; 273 320 326; 274 321 327; 275 322 328; 276 323 324;
277 325 323; 278 326 325; 279 327 326; 280 328 327; 281 323 329; 282 325 331;
283 326 332; 284 327 333; 285 328 334; 286 329 330; 287 331 329; 288 332 331;
289 333 332; 290 334 333; 291 329 335; 292 331 337; 293 332 338; 294 333 339;
295 334 340; 296 335 359; 297 337 362; 298 338 366; 299 339 369; 300 340 372;
301 341 318; 302 342 341; 303 343 342; 304 344 317; 305 345 344; 306 346 345;
307 347 319; 308 348 347; 309 349 348; 310 350 349; 311 351 320; 312 352 351;
313 353 352; 314 354 321; 315 355 354; 316 356 355; 317 357 336; 318 358 357;
319 359 358; 320 360 335; 321 361 360; 322 362 361; 323 363 337; 324 364 363;
325 365 364; 326 366 365; 327 367 338; 328 368 367; 329 369 368; 330 370 339;
331 371 370; 332 372 371; 333 317 373; 334 319 375; 335 320 376; 336 321 377;
337 322 378; 338 317 373; 339 319 375; 340 320 376; 341 321 377; 342 322 378;
343 323 379; 344 325 381; 345 326 382; 346 327 383; 347 328 384; 348 323 379;
349 325 381; 350 326 382; 351 327 383; 352 328 384; 353 329 385; 354 331 387;
355 332 388; 356 333 389; 357 334 390; 358 329 385; 359 331 387; 360 332 388;
361 333 389; 362 334 390; 363 335 391; 364 337 393; 365 338 394; 366 339 395;
367 340 396; 368 335 391; 369 337 393; 370 338 394; 371 339 395; 825 340 396;
826 373 374; 827 375 373; 828 376 375; 829 377 376; 830 378 377; 831 373 379;
832 375 381; 833 376 382; 834 377 383; 835 378 384; 836 379 380; 837 381 379;
838 382 381; 839 383 382; 840 384 383; 841 379 385; 842 381 387; 843 382 388;
844 383 389; 845 384 390; 846 385 386; 847 387 385; 848 388 387; 849 389 388;
850 390 389; 851 385 391; 852 387 393; 853 388 394; 854 389 395; 855 390 396;
856 391 392; 857 393 391; 858 394 393; 859 395 394; 860 396 395; 861 373 397;

862 375 399; 863 376 400; 864 377 401; 865 378 402; 866 373 397; 867 375 399;
868 376 400; 869 377 401; 870 378 402; 871 379 403; 872 381 405; 873 382 406;
874 383 407; 875 384 408; 876 379 403; 877 381 405; 878 382 406; 879 383 407;
880 384 408; 881 385 409; 882 387 411; 883 388 412; 884 389 413; 885 390 414;
886 385 409; 887 387 411; 888 388 412; 889 389 413; 890 390 414; 891 391 415;
892 393 417; 893 394 418; 894 395 419; 895 396 420; 896 391 415; 897 393 417;
898 394 418; 899 395 419; 900 396 420; 901 397 398; 902 399 397; 903 400 399;
904 401 400; 905 402 401; 906 397 403; 907 399 405; 908 400 406; 909 401 407;
910 402 408; 911 403 511; 912 405 514; 913 406 518; 914 407 521; 915 408 524;
916 403 409; 917 405 411; 918 406 412; 919 407 413; 920 408 508; 921 409 426;
922 411 432; 923 412 440; 924 413 446; 925 414 452; 926 409 415; 927 411 417;
928 412 418; 929 413 419; 930 414 420; 931 415 416; 932 417 415; 933 418 417;
934 419 418; 935 420 419; 936 421 410; 937 424 421; 938 426 424; 939 428 409;
940 430 428; 941 432 430; 942 434 411; 943 436 434; 944 438 436; 945 440 438;
946 442 412; 947 444 442; 948 446 444; 949 448 413; 950 450 448; 951 452 450;
952 454 414; 953 472 454; 954 490 472; 955 508 490; 956 509 404; 957 510 509;
958 511 510; 959 512 403; 960 513 512; 961 514 513; 962 515 405; 963 516 515;
964 517 516; 965 518 517; 966 519 406; 967 520 519; 968 521 520; 969 522 407;
970 523 522; 971 524 523;
ELEMENT INCIDENCES SHELL
372 154 177 209 210; 374 177 178 211 209; 376 178 179 212 211;
378 179 180 213 212; 380 180 181 214 213; 382 181 182 215 214;
384 182 183 216 215; 386 183 184 217 216; 388 184 185 218 217;
390 185 186 219 218; 392 186 187 220 219; 394 187 188 221 220;
396 188 189 222 221; 398 189 190 223 222; 400 190 191 224 223;
402 191 192 225 224; 405 192 158 226 225; 406 210 209 245 246;
407 209 211 247 245; 408 211 212 248 247; 409 212 213 249 248;
410 213 214 250 249; 411 214 215 251 250; 412 215 216 252 251;
413 216 217 253 252; 414 217 218 254 253; 415 218 219 255 254;
416 219 220 256 255; 417 220 221 257 256; 418 221 222 258 257;
419 222 223 259 258; 420 223 224 260 259; 421 224 225 261 260;
424 225 226 262 261; 425 246 245 281 282; 426 245 247 283 281;
427 247 248 284 283; 428 248 249 285 284; 429 249 250 286 285;
430 250 251 287 286; 431 251 252 288 287; 432 252 253 289 288;
433 253 254 290 289; 434 254 255 291 290; 435 255 256 292 291;
436 256 257 293 292; 437 257 258 294 293; 438 258 259 295 294;
439 259 260 296 295; 440 260 261 297 296; 443 261 262 298 297;
445 282 281 341 318; 447 281 283 342 341; 449 283 284 343 342;
451 284 285 344 343; 453 285 286 345 344; 455 286 287 346 345;
457 287 288 347 346; 459 288 289 348 347; 461 289 290 349 348;
463 290 291 350 349; 465 291 292 351 350; 467 292 293 352 351;
469 293 294 353 352; 471 294 295 354 353; 473 295 296 355 354;
475 296 297 356 355; 476 297 298 322 356; 478 13 25 26 27; 480 25 28 29 26;
482 28 30 31 29; 484 30 32 33 31; 486 32 34 35 33; 488 34 36 37 35;
490 36 38 39 37; 492 38 40 41 39; 494 40 42 43 41; 496 42 44 45 43;
498 44 46 47 45; 500 46 48 49 47; 502 48 50 51 49; 504 50 52 53 51;
506 52 54 55 53; 508 54 56 57 55; 510 56 18 58 57; 511 27 26 59 60;
512 26 29 61 59; 513 29 31 62 61; 514 31 33 63 62; 515 33 35 64 63;
516 35 37 65 64; 517 37 39 66 65; 518 39 41 67 66; 519 41 43 68 67;
520 43 45 69 68; 521 45 47 70 69; 522 47 49 71 70; 523 49 51 72 71;
524 51 53 73 72; 525 53 55 74 73; 526 55 57 75 74; 528 57 58 76 75;
529 60 59 77 78; 530 59 61 79 77; 531 61 62 80 79; 532 62 63 81 80;
533 63 64 82 81; 534 64 65 83 82; 535 65 66 84 83; 536 66 67 85 84;
537 67 68 86 85; 538 68 69 87 86; 539 69 70 88 87; 540 70 71 89 88;
541 71 72 90 89; 542 72 73 91 90; 543 73 74 92 91; 544 74 75 93 92;
546 75 76 94 93; 547 78 77 95 96; 548 77 79 97 95; 549 79 80 98 97;
550 80 81 99 98; 551 81 82 100 99; 552 82 83 101 100; 553 83 84 102 101;
554 84 85 103 102; 555 85 86 104 103; 556 86 87 105 104; 557 87 88 106 105;
558 88 89 107 106; 559 89 90 108 107; 560 90 91 109 108; 561 91 92 110 109;
562 92 93 111 110; 564 93 94 112 111; 566 96 95 113 7; 568 95 97 114 113;
570 97 98 115 114; 572 98 99 116 115; 574 99 100 117 116; 576 100 101 118 117;
578 101 102 119 118; 580 102 103 120 119; 582 103 104 121 120;
584 104 105 122 121; 586 105 106 123 122; 588 106 107 124 123;
590 107 108 125 124; 592 108 109 126 125; 594 109 110 127 126;
596 110 111 128 127; 597 111 112 12 128; 599 172 193 227 228;
601 193 194 229 227; 603 194 195 230 229; 605 195 196 231 230;
607 196 197 232 231; 609 197 198 233 232; 611 198 199 234 233;

613 199 200 235 234; 615 200 201 236 235; 617 201 202 237 236;
619 202 203 238 237; 621 203 204 239 238; 623 204 205 240 239;
625 205 206 241 240; 627 206 207 242 241; 629 207 208 243 242;
632 208 176 244 243; 633 228 227 263 264; 634 227 229 265 263;
635 229 230 266 265; 636 230 231 267 266; 637 231 232 268 267;
638 232 233 269 268; 639 233 234 270 269; 640 234 235 271 270;
641 235 236 272 271; 642 236 237 273 272; 643 237 238 274 273;
644 238 239 275 274; 645 239 240 276 275; 646 240 241 277 276;
647 241 242 278 277; 648 242 243 279 278; 651 243 244 280 279;
652 264 263 299 300; 653 263 265 301 299; 654 265 266 302 301;
655 266 267 303 302; 656 267 268 304 303; 657 268 269 305 304;
658 269 270 306 305; 659 270 271 307 306; 660 271 272 308 307;
661 272 273 309 308; 662 273 274 310 309; 663 274 275 311 310;
664 275 276 312 311; 665 276 277 313 312; 666 277 278 314 313;
667 278 279 315 314; 670 279 280 316 315; 672 300 299 357 336;
674 299 301 358 357; 676 301 302 359 358; 678 302 303 360 359;
680 303 304 361 360; 682 304 305 362 361; 684 305 306 363 362;
686 306 307 364 363; 688 307 308 365 364; 690 308 309 366 365;
692 309 310 367 366; 694 310 311 368 367; 696 311 312 369 368;
698 312 313 370 369; 700 313 314 371 370; 702 314 315 372 371;
703 315 316 340 372; 705 410 421 422 423; 707 421 424 425 422;
709 424 426 427 425; 711 426 428 429 427; 713 428 430 431 429;
715 430 432 433 431; 717 432 434 435 433; 719 434 436 437 435;
721 436 438 439 437; 723 438 440 441 439; 725 440 442 443 441;
727 442 444 445 443; 729 444 446 447 445; 731 446 448 449 447;
733 448 450 451 449; 735 450 452 453 451; 737 452 414 454 453;
738 423 422 455 456; 739 422 425 457 455; 740 425 427 458 457;
741 427 429 459 458; 742 429 431 460 459; 743 431 433 461 460;
744 433 435 462 461; 745 435 437 463 462; 746 437 439 464 463;
747 439 441 465 464; 748 441 443 466 465; 749 443 445 467 466;
750 445 447 468 467; 751 447 449 469 468; 752 449 451 470 469;
753 451 453 471 470; 755 453 454 472 471; 756 456 455 473 474;
757 455 457 475 473; 758 457 458 476 475; 759 458 459 477 476;
760 459 460 478 477; 761 460 461 479 478; 762 461 462 480 479;
763 462 463 481 480; 764 463 464 482 481; 765 464 465 483 482;
766 465 466 484 483; 767 466 467 485 484; 768 467 468 486 485;
769 468 469 487 486; 770 469 470 488 487; 771 470 471 489 488;
773 471 472 490 489; 774 474 473 491 492; 775 473 475 493 491;
776 475 476 494 493; 777 476 477 495 494; 778 477 478 496 495;
779 478 479 497 496; 780 479 480 498 497; 781 480 481 499 498;
782 481 482 500 499; 783 482 483 501 500; 784 483 484 502 501;
785 484 485 503 502; 786 485 486 504 503; 787 486 487 505 504;
788 487 488 506 505; 789 488 489 507 506; 791 489 490 508 507;
793 492 491 509 404; 795 491 493 510 509; 797 493 494 511 510;
799 494 495 512 511; 801 495 496 513 512; 803 496 497 514 513;
805 497 498 515 514; 807 498 499 516 515; 809 499 500 517 516;
811 500 501 518 517; 813 501 502 519 518; 815 502 503 520 519;
817 503 504 521 520; 819 504 505 522 521; 821 505 506 523 522;
823 506 507 524 523; 824 507 508 408 524;
ELEMENT PROPERTY
372 374 376 378 380 382 384 386 388 390 392 394 396 398 400 402 405 TO 421 -
424 TO 440 443 445 447 449 451 453 455 457 459 461 463 465 467 469 471 473 -
475 476 478 480 482 484 486 488 490 492 494 496 498 500 502 504 506 508 510 -
511 TO 526 528 TO 544 546 TO 562 564 566 568 570 572 574 576 578 580 582 584 -
586 588 590 592 594 596 597 599 601 603 605 607 609 611 613 615 617 619 621 -
623 625 627 629 632 TO 648 651 TO 667 670 672 674 676 678 680 682 684 686 -
688 690 692 694 696 698 700 702 703 705 707 709 711 713 715 717 719 721 723 -
725 727 729 731 733 735 737 TO 753 755 TO 771 773 TO 789 791 793 795 797 -
799 801 803 805 807 809 811 813 815 817 819 821 823 824 THICKNESS 0.3
DEFINE MATERIAL START
ISOTROPIC CONCRETE
E 2.17185e+007
POISSON 0.17
DENSITY 23.5616
ALPHA 1e-005
DAMP 0.05
END DEFINE MATERIAL

```
MEMBER PROPERTY
6 TO 10 16 TO 20 26 TO 30 52 TO 55 72 TO 91 97 TO 101 107 TO 111 117 TO 121 -
127 TO 146 152 TO 156 162 TO 166 172 TO 176 214 TO 265 271 TO 275 -
281 TO 285 291 TO 295 333 TO 371 825 831 TO 835 841 TO 845 851 TO 855 861 -
862 TO 900 906 TO 910 916 TO 920 926 TO 930 952 TO 955 PRIS YD 0.35 ZD 0.5
1 TO 5 11 TO 15 21 TO 25 31 TO 51 56 TO 71 92 TO 96 102 TO 106 112 TO 116 -
122 TO 126 147 TO 151 157 TO 161 167 TO 171 177 TO 213 266 TO 270 -
276 TO 280 286 TO 290 296 TO 332 826 TO 830 836 TO 840 846 TO 850 -
856 TO 860 901 TO 905 911 TO 915 921 TO 925 931 TO 951 956 TO 970 -
971 PRIS YD 0.5 ZD 0.5
CONSTANTS
MATERIAL CONCRETE ALL
SUPPORTS
1 7 13 19 27 60 78 96 130 136 142 148 154 160 166 172 210 228 246 264 282 -
300 318 324 330 336 374 380 386 392 398 404 410 416 423 456 474 492 FIXED
DEFINE 1893 LOAD
ZONE 0.36 RF 3 I 1 SS 2 ST 1 DM 0.05 PX 0.352 PZ 0.406
SELFWEIGHT 1
FLOOR WEIGHT
YRANGE 0 15 FLOAD 2
LOAD 1 LOADTYPE Seismic  TITLE LOAD CASE 1 +X
1893 LOAD X 1
PERFORM ANALYSIS PRINT LOAD DATA
CHANGE
LOAD 2 LOADTYPE Seismic  TITLE LOAD CASE 2 +Z
1893 LOAD Z 1
PERFORM ANALYSIS PRINT LOAD DATA
LOAD 3 LOADTYPE Dead  TITLE LOAD CASE 3 DEAD
SELFWEIGHT Y -1 LIST 1 TO 372 374 376 378 380 382 384 386 388 390 392 394 -
396 398 400 402 405 TO 421 424 TO 440 443 445 447 449 451 453 455 457 459 -
461 463 465 467 469 471 473 475 476 478 480 482 484 486 488 490 492 494 496 -
498 500 502 504 506 508 510 TO 526 528 TO 544 546 TO 562 564 566 568 570 -
572 574 576 578 580 582 584 586 588 590 592 594 596 597 599 601 603 605 607 -
609 611 613 615 617 619 621 623 625 627 629 632 TO 648 651 TO 667 670 672 -
674 676 678 680 682 684 686 688 690 692 694 696 698 700 702 703 705 707 709 -
711 713 715 717 719 721 723 725 727 729 731 733 735 737 TO 753 755 TO 771 -
773 TO 789 791 793 795 797 799 801 803 805 807 809 811 813 815 817 819 821 -
823 TO 971
LOAD 4 LOADTYPE Live REDUCIBLE TITLE LOAD CASE 4 LIVE
FLOOR LOAD
YRANGE 0 15 FLOAD -4 GY
YRANGE 15 18.5 FLOAD -1.5 GY
LOAD 5 GENERATED INDIAN CODE GENRAL_STRUCTURES 1
REPEAT LOAD
3 1.5 4 1.5
LOAD 6 GENERATED INDIAN CODE GENRAL_STRUCTURES 2
REPEAT LOAD
3 1.2 4 1.2
LOAD 7 GENERATED INDIAN CODE GENRAL_STRUCTURES 3
REPEAT LOAD
3 1.2 4 1.2 1 1.2
LOAD 8 GENERATED INDIAN CODE GENRAL_STRUCTURES 4
REPEAT LOAD
3 1.2 4 1.2 2 1.2
LOAD 9 GENERATED INDIAN CODE GENRAL_STRUCTURES 5
REPEAT LOAD
3 1.2 4 1.2 1 -1.2
LOAD 10 GENERATED INDIAN CODE GENRAL_STRUCTURES 6
REPEAT LOAD
3 1.2 4 1.2 2 -1.2
LOAD 11 GENERATED INDIAN CODE GENRAL_STRUCTURES 7
REPEAT LOAD
3 1.5
LOAD 12 GENERATED INDIAN CODE GENRAL_STRUCTURES 8
REPEAT LOAD
3 1.5 1 1.5
LOAD 13 GENERATED INDIAN CODE GENRAL_STRUCTURES 9
```

```
REPEAT LOAD
3 1.5 2 1.5
LOAD 14 GENERATED INDIAN CODE GENRAL_STRUCTURES 10
REPEAT LOAD
3 1.5 1 -1.5
LOAD 15 GENERATED INDIAN CODE GENRAL_STRUCTURES 11
REPEAT LOAD
3 1.5 2 -1.5
LOAD 16 GENERATED INDIAN CODE GENRAL_STRUCTURES 12
REPEAT LOAD
3 0.9 1 1.5
LOAD 17 GENERATED INDIAN CODE GENRAL_STRUCTURES 13
REPEAT LOAD
3 0.9 2 1.5
LOAD 18 GENERATED INDIAN CODE GENRAL_STRUCTURES 14
REPEAT LOAD
3 0.9 1 -1.5
LOAD 19 GENERATED INDIAN CODE GENRAL_STRUCTURES 15
REPEAT LOAD
3 0.9 2 -1.5
PERFORM ANALYSIS
LOAD LIST 5 TO 12
PRINT JOINT DISPLACEMENTS LIST 1 TO 524
PRINT MEMBER FORCES LIST 1 TO 371 825 TO 971
PRINT SUPPORT REACTION LIST 1 7 13 19 27 60 78 96 130 136 142 148 154 160 -
166 172 210 228 246 264 282 300 318 324 330 336 374 380 386 392 398 404 410 -
416 423 456 474 492
PRINT STORY DRIFT
FINISH
```

BIBLIOGRAPHY

- IS: 875(Part 1)– 1987 (Reaffirmed 2003), *Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures* (Second Revision).
- IS: 875(Part 2) – 1987 (Reaffirmed 2003), *Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures* (Second Revision).
- IS:456-2000(Reaffirmed 2005), *Indian Standard Code of Practice for Plain and Reinforced Concrete (Fourth Revision),* Bureau of Indian Standards, New Delhi.
- IS: 1893-2002, *Indian Standard Recommendations for Earthquake Resistant Design of Structures, Bureau of Indian Standards*, New Delhi.
- C K Wang, *Intermediate structures, McGraw Hills, 2004.*
- Aggarwal and Shrikhande, *Earthquake resistant design of structures, PHI Learning Limited, 2006.*

APPENDIX

International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622
National Conference on Advances in Engineering and Technology
(AET- 29th March 2014)

RESEARCH ARTICLE OPEN ACCESS

Best Placement of Shear Walls In an RCC Space Frame Based on Seismic Response

Anshul Sud*, Raghav Singh Shekhawat*, Poonam Dhiman**
*(Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat (India)
Email: raghavdhupalia@gmail.com)
** (Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat (India))

ABSTRACT
Shear walls are one of the most basic lateral load resisting elements in an earthquake resistant building. To avoid torsion in buildings, shear walls must be placed symmetrically in plan. In this paper, a five-storey RC building located in seismic zone-V is considered with four shear walls. Five different configurations of shear walls viz. bare frame, shear wall symmetrically placed at exterior bays (centrally), at core and adjacently placed in exterior of the building, are considered. These frames are analyzed for seismic forces to assess performance in terms of base shear, storey drift, member forces and joint displacements. The frame with shear walls at core and centrally placed at exterior bays showed significant reduction of order 29% to 83% in lateral displacement. The reduction in bending moments is approximately 70% to 85% for interior and perimeter columns respectively. Shear and axial forces in columns have reduced by 86% and 45% respectively. Based on such results, the best placement of shear walls in building plan is suggested.
Keywords - Seismic resistance, shear wall, base shear, storey drift

I. INTRODUCTION

Reinforced concrete buildings often have vertical plate-like RC walls, called shear walls. Shear walls are like vertically-oriented wide beams that carry earthquake or wind loads and transfer them downwards to the foundation. 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. Most RC buildings with shear walls also have columns. These columns primarily carry gravity loads and shear walls are designed to carry lateral loads. 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. In this paper, five frames with different placement of shear walls are analyzed for their performance in terms of base shear, storey drift, member forces and joint displacements.

II. PROBLEM FORMULATION

The A Five-storey RC office building is assumed to be located in seismic zone-V on medium soil (as per IS 1893:2002). It is designed as an ordinary moment-resisting frame. Column sections of size 350mm×500 mm, beam sections of size 500mm×500mm, 125 mm thick RCC slab on all floors and shear wall having 300 mm thickness are taken for proposed work. In x-direction (the longer direction in plan) there are 5 bays, each of 4 m width and in z-direction (the shorter direction in plan) there are 3 bays, each of 5 m width. The column height throughout the structure is 3.5 m. Five frames with different shear wall configurations viz. bare frame (Frame-1), shear wall symmetrically placed at exterior bays centrally (Frame-3), at core (Frame-2) and adjacently placed in exterior of the building (Frames-4 and 5) as shown in Fig1 are taken for the study. These frames are subjected to dead load, imposed load of 4 kN/m^2 on all floors, imposed load of 1.5 kN/m^2 on roof (as per IS 875-part-2) and earthquake loads as per IS 1893:2002.

These frames are analyzed for load combinations suggested by IS 1893, i.e,

1. 1.5(DL +IL),
2. 1.2 (DL + IL ± EL),
3. 1.5 (DL ± EL),
4. 0.9 DL ± 1.5 EL.

For the calculation of base shear, the zone factor 'Z' is taken as 0.36 for seismic zone V, Importance Factor 'I' equal to 1, Response reduction factor 'R' as 3 as it is an Ordinary RC moment resisting frame and fundamental natural period of vibration (T) is calculated as 0.352 seconds for x-direction and 0.406 seconds for z-direction (as per IS:1893-2002).

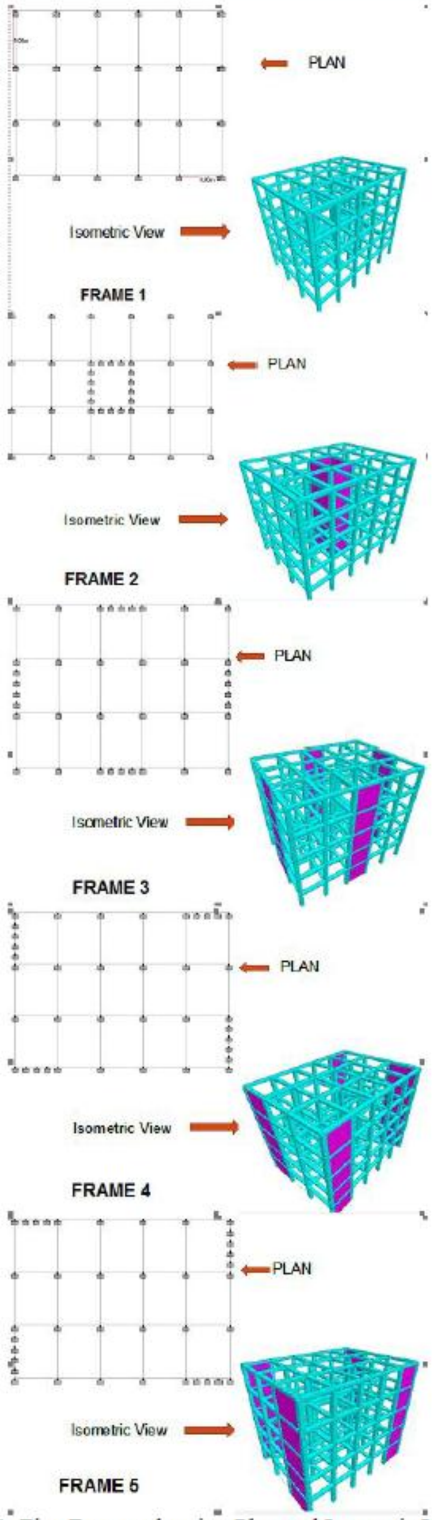


Fig 1: Five Frames showing Plan and Isometric View

III. ANALYSIS OF RESULTS

3.1 BENDING MOMENT IN COLUMNS

After carrying out analysis, bending moments (kNm) in bottom storey columns for all frames are taken from output file and are shown in Fig 2. The maximum value of bending moment both in the case of interior and perimeter columns for ground storey columns are seen in the case of Frame-1which is the frame with no shear wall which comes out to be 233 and 230 kNm respectively whereas the minimum value for both are seen in the case of Frame-2 where shear walls are placed at the inner core of the building symmetrically which comes out to be 30 and 51.7 kNm. From Fig 2, it can be concluded that Frame-2 have significant reduction in bending moment of ground storey columns.

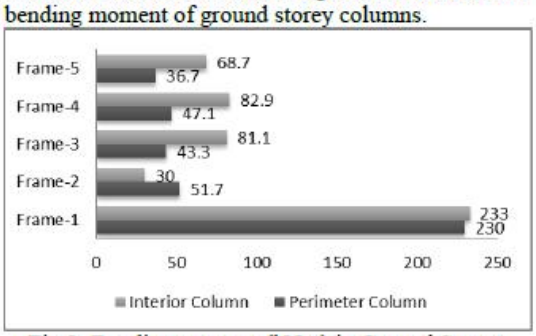


Fig 2: Bending moment (kNm) in Ground Storey Columns

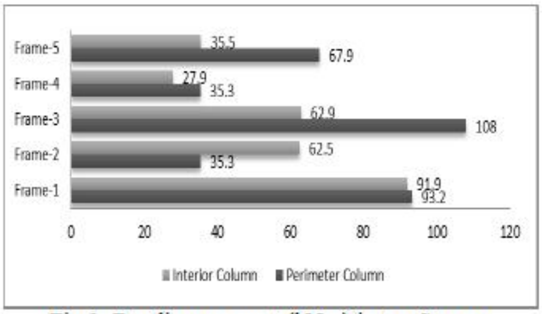


Fig 3: Bending moment (kNm) in top Storey Columns

Similarly, bending moments in top storey columns are shown in Fig 3. The maximum value of bending Moment both in the case of interior and perimeter columns for top storey columns are seen in the case of Frame-1which is the frame with no shear wall which comes out to be 91.9 and 93.2 kNm respectively whereas the minimum value for both are seen inthe cases of Frame-2 and Frame-4 where shear walls are placed at the inner core of the building symmetrically and shear wall symmetrically placed at exterior bays (centrally) which comes out to be 62.5,35.3 and 27.9, 35.3 kNm, respectively. It is evident from figure that frame-2 and frame-4 show predominant reduction in bending moment.

3.2 Shear Force

Shear force is a measure of lateral load borne by columns and shear walls. The maximum value of shear force both in the case of interior and perimeter columns for ground storey columns are seen in the case of Frame-1which is the frame with no shear wall comes out to be 106 and 104 kN respectively whereas the minimum value for both are seen in the cases of Frame-2 and Frame-5 where shear walls are placed at the inner core of the building symmetrically and adjacently placed in exterior of the building which comes out to be 14.2, 23.2kN and 26.2,14.1 kN respectively. Fig 4 shows shear force in ground storey columns for all the frames. It is evident from the figure that frame-2 and frame-5 show significant reduction in shear force on ground floor.

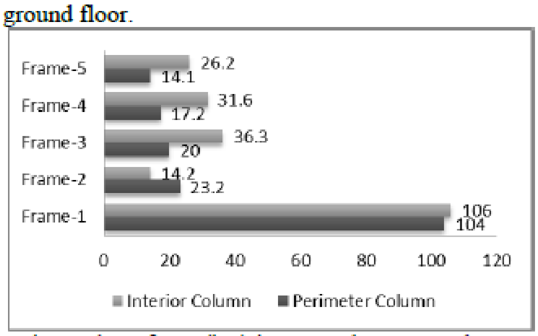


Fig 4: Shear force (kN) in Ground Storey Columns

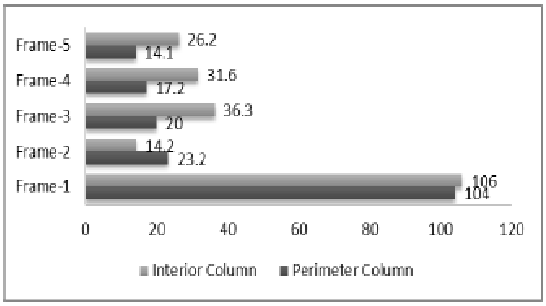


Fig 5: Shear force (kN) in Top Storey Columns

Similarly, shear force in top storey columns is shown in Fig 5.The maximum value of Shear Force both in the case of interior and perimeter columns for top storey columns are seen in the case of Frame-1which is the frame with no shear wall comes out to be 106 and 104 kN respectively whereas the minimum value for both are seen in the cases Frame-2 and Frame-5 where shear walls are placed at the inner core of the building symmetrically and adjacently placed in exterior of the building which comes out to be 14.2, 23.2 kN and 26.2,14.1 kN respectively.By looking at the results it can be inferred that frame-2 and frame-5 shows maximum reduction in shear forces in top storey.

3.3 Axial Force

The maximum value of axial force both in the case of interior and perimeter columns for ground storey columns are seen in the case of Frame-1which is the frame with no shear wall comes out to be 1066 and 797 kN respectively whereas the minimum value for both are seen in the case of Frame-5 where shear walls are placed at the adjacently placed in exterior of the building which comes out to be 623 and 442kN respectively. By looking at Fig 6, it is evident that the maximum reduction in axial force on ground floor is being experienced in case of frame-5.

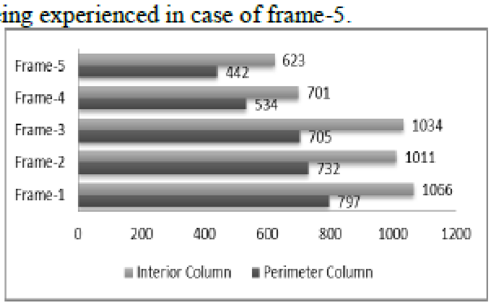


Fig 6: Axial force (kN) in Ground Storey Columns

The maximum value of shear force both in the case of interior and perimeter columns for top storey columns are seen in the case of Frame-1which is the frame with no shear wall comes out to be 152 and 119 kN respectively whereas the minimum value for both are seen in the case of Frame-4 where shear walls are placed at the adjacently placed in exterior of the building which comes out to be 61.2 and 56.7 respectively. By looking at Fig 7, it is evident that the maximum reduction in axial force on top floor is being experienced in case of frame-4.

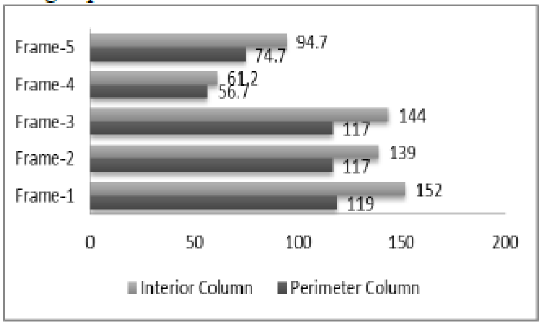


Fig 7: Axial force (kN) in Top Storey Columns.

3.4 Storey Drift

Vales of storey drift in x-direction for all the frames and for each storey are given in Table 1 and plotted in Fig 8. By analyzing these values, it can be concluded that frame-2 in x-direction and frame-3 in z-direction has maximum reduction in storey drift as shown in Fig 9.

Table 1: Storey Drift in *x*-direction

	Displacements (mm) in *x*-direction				
Storey	**Frame-1**	**Frame-2**	**Frame-3**	**Frame-4**	**Frame-5**
Fifth	34.813	9.964	12.403	14.998	12.248
Fourth	30.940	8.586	9.494	11.95	9.301
Third	24.122	6.290	6.343	8.192	6.297
Second	15.317	3.728	3.455	4.594	3.558
First	6.040	1.406	1.182	1.507	1.344

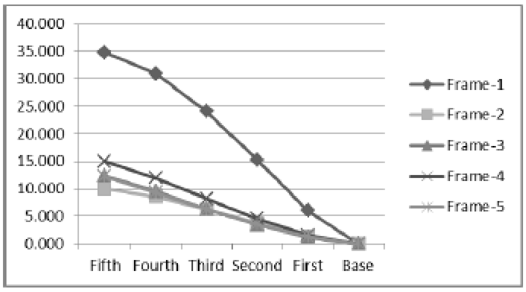


Fig 8: Storey drift (mm) in *x*-direction

Table 2: Storey drift in *z*-direction

	Displacement(mm) in *z*-direction				
Storey	**Frame-1**	**Frame-2**	**Frame-3**	**Frame-4**	**Frame-5**
Fifth	60.911	13.444	10.135	12.917	11.691
Fourth	53.123	11.569	7.689	9.84	8.982
Third	40.622	8.477	5.107	6.729	5.942
Second	24.849	4.922	2.773	3.832	3.183
First	8.944	1.129	0.961	1.621	1.039

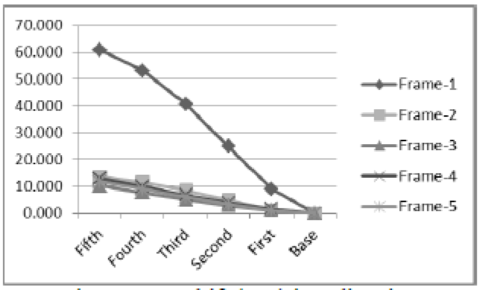


Fig 9: Storey drift (mm) in z-direction

IV. CONCLUSIONS

Based upon the studies carried as above, the following conclusions have been drawn.

- Lateral load resisting capacity of the frame increases significantly in case of shear wall introduction, as is clear from the story displacements in *x* and *z* directions.
- For frame-2 (shear walls at core), lateral displacements are minimum in x-direction and merely 29% of the displacement of simple frame (from 34.83 mm to 9.96 mm)
- The frame with shear walls (frame-3) at mid-sides performs best for earthquake in z-direction. The reduction in response is as high as 83% (60.9 mm to 10.14 mm).
- As far as bending moments in ground floor columns are concerned, Frame-2 and Frame-3 shows significant reduction in the same as compared to those in simple frame (frame-1). The reduction in B.M. is approximately 70 to 85% for interior and perimeter columns respectively.
- Shear force in ground storey columns is also reduced by as high as 86% for Frame-2 and Frame-5. This can be attributed to contribution of shear walls in taking base shear.
- Axial force in the columns during earthquake is reduced as much as 45% due to introduction of shear walls. Major reduction is seen for Frame-5.
- Similar trend in reduction of bending moments, shear forces and axial forces is seen in for top story columns. Frame-2 and Frame-4 are seen to perform better in this case.
- Shear walls are definitely good mechanism for lateral loads mitigation, but the placement of shear walls should be made judiciously. In the present case, the Frame-3 (shear walls at mid-sides) is seen to perform better in major number of cases.

REFERENCES

[1] C.K. Wang, *Intermediate structures* (McGraw Hills, 2004).

[2] Aggarwal and Shrikhande, *Earthquake resistant design of structures*,(PHI Learning Limited, 2006).

[3] IS:875(Part 1) – 1987 (Reaffirmed 2003), *Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures* (Second Revision).

[4] IS:875(Part 2) – 1987 (Reaffirmed 2003), *Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures* (Second Revision).

[5] IS:456-2000 (Reaffirmed 2005), *Indian Standard Code of Practice for Plain and Reinforced Concrete* (Fourth Revision), Bureau of Indian Standards, New Delhi.

[6] IS:1893-2002, *Indian Standard Recommendations for Earthquake Resistant Design of Structures, Bureau of Indian Standards*, New Delhi.