



**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULTY OF TECHNOLOGY
CIVIL ENGINEERING DEPARTMENT**

**EFFECTS OF TORSION ON LATERAL STABILITY OF
BUILDING STRUCTURES**

**A Thesis Submitted to
The School of Graduate Studies of Addis Ababa University in Partial
Fulfillment of the
Requirement for the Degree of Master of Science in Structural
Engineering**

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Declaration

I, the undersigned declare that this thesis is my original work and has not been presented in any University for a degree and that all sources of material used for this thesis have been duly acknowledged.

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List of Symbols

E = Eccentricity

X' = Centroid of typical structure in the x-direction

Y' = Centroid of typical structure in the y-direction

δ = Inter Story Drift Index

b = Width of Equivalent Frame

h = Height of Equivalent Frame

t = Thin Walled Thickness

DL = Dead Load

LL = Lateral Load

V = Sum of Lateral Loads at a Given Story

P_{cr} = Critical Load

λ = Normalized Axial Load

Δ = Lateral Displacement

SN = Storey Number

SH = Storey Height

D = Global Lateral Stiffness

D_c = Global Lateral Stiffness of Centric Model

D_e = Global Lateral Stiffness of Eccentric Model

D_L = Global Lateral Stiffness of Least Storey

D_n = Global Lateral Stiffness of Considered Storey

Rd (en) = Reduction in Global Lateral Stiffness of an Eccentric Model Relative to the Control Model

Rd (hn) = Reduction in Global Lateral Stiffness of nth Storey Relative to the Least Storey

Abstract

Key words: Torsion, Global Lateral Stability, Parametric Study, Eccentricity, Load Carrying Capacity, Axial Load, Storey Number, Lateral Loading, Gravity Loading.

This paper surveys the effects of torsion on the global lateral stability of a shear wall building with typical plan and elevation layouts.

In order to achieve the goal of study, a parametric investigation procedure is undertaken, on a series of sample structures with a condition which can cause torsion and their lateral stability under earthquake and gravity loading is investigated and discussed.

To study the effects of torsion on the lateral stability of building structures, three asymmetric models are constructed by moving the shear-wall couple in the centric model from grid lines “-X₁_X₁” to grid lines “X₁_X₂” in one model, and to grid lines “X₂_X₃” and grid lines “X₃_X₄” in another models.

In addition the effects of axial loading and increasing storey number on the lateral stability of building structures are parallelly studied on one of the series models.

To study the influence of storey number, three different stories are constructed on the same series model keeping their inter storey height constant.

Load-displacement diagrams are constructed for the above three conditions and are shown in Figure 6-1_Figure 6-10.

From the Load-displacement diagrams, global lateral stability “D” is computed. Reduction in global lateral stability due to the induced asymmetry proved to be (89%, 97% and 98%) respectively. Furthermore it is shown that the effect of axial loading is considerable in both the centric and eccentric wall configurations. And the lateral stability of a structure on the same configuration decreases while increasing storey number.

Thus depending on the analysis results conclusions and recommendations are made and some further studies are forecasted.

1. Introduction

1.1. Background of Study

Field inspections of earthquake performance of buildings demonstrate that the simpler the building the better the behavior, all other parameters being similar.

Here are two main reasons for this: first, it is easier to understand the overall earthquake behavior of a simple building than that of a complex one; second, it is easier to understand, formulate in drawings, and construct simple structural details than complicated ones. Symmetry and regularity in plan and elevation are desirable for much the same reasons. Symmetry is important in both directions of a plan. Lack of symmetry (in mass distribution and/or in stiffness, strength and ductility) leads to torsional effects which are difficult to assess properly and which can be very destructive. A plan layout with reentrant angles should be avoided (see Figure 1.1 below).

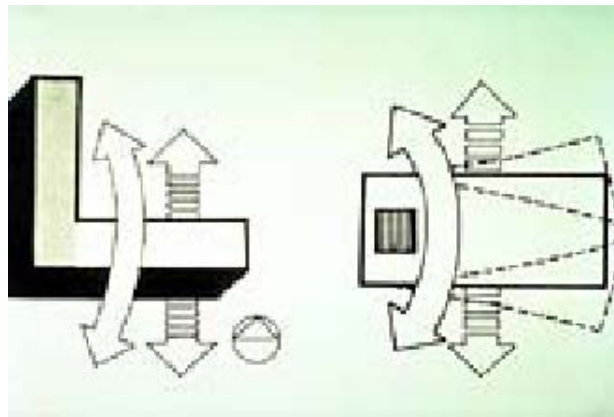


Figure 1-1: Shape of Building Plan (L Configuration) and By a Very Stiff Off-Center Core Area in a Rectangular (Regular) Plan Building.

Figure 1-1 shows torsional effects created by irregular shape of building plan (L-configuration) and by a very stiff off-center core area in a rectangular (regular) plan building. A structure with a complex configuration is subjected to torsion. When a building twist, its wall and frames displace at each floor about some center of

rotation creating inter storey drift. More over the building will be subjected to high acceleration with shorter period during earthquake hazards.

A well planned structural configuration or form, in conformance with code requirements, is expected to achieve objectives such as

- ❖ Predictable behavior
- ❖ Simplicity of design & construction
- ❖ Minimized structural cost for the required function

The objectives of the architectural and other design team members however, may not primarily have these goals as aesthetics and specialized function, to name a few, may have equal or greater priority. Moreover, they may be in direct conflict with the goals of structural design.

Early cooperation with other design team members, who have a stake in the structural form, can be very effective in realizing the desired objectives and achieving the cost/benefit tradeoffs that are acceptable to all. The structural engineer, being aware of the implications of building configuration on the stated objectives, is obliged to inform the team of any adverse impacts preferably at the earliest opportunity in the planning process.

This is because architects are responsible for the architectural configuration of buildings at first and architects may have greater priority to aesthetics, space and circulation than the structural stability of the building.

If you tour around construction sites in the city, it is not uncommon to see walls located arbitrary. For instance the following buildings are typical examples of buildings where structural walls and lift shafts are at an extreme edge.



Figure 1-2: An Office Building Where Lift Wall is at the Extreme Edge.



Figure 1-3: An Office Building Where Lift Wall is at the Extreme Edge.

1.2. Objective and Scope of Study

1.2.1. General Objectives

- ❖ Providing conceptual design to architects and clients. Conceptual design is defined as the avoidance or minimization of problems created by torsion by applying an understanding of the effect rather than using numerical computations.
- ❖ Creating control or decrease of demands: a decrease in demand can be achieved by a proper selection of the configuration of the building and its structural layout and by the proper proportioning and detailing of the structural and non-structural components, that is, by following the basic principles or guideline for achieving efficient lateral stability.
- ❖ Increase awareness to professional architects and graduate engineers.

1.2.2. Scope of Study

- ❖ Material linearity is considered throughout the analysis.
- ❖ The study is conducted on series samples regular in plan and elevation with stiff off wall location.
- ❖ Structural walls are considered to resist moments while contribution of frames is ignored.

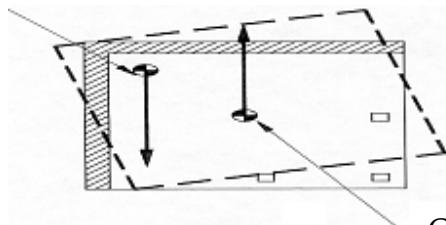
2. Literature Review

2.1. Torsion

An eccentric system is defined as a system with non-coincident center of mass and center of stiffness where center of mass is the point at which all the mass of a body may be considered to be concentrated in analyzing its motion.

Non uniform distributions of mass, stiffness and strength in an asymmetric building cause the building to experience torsional moments and rotational deformations around vertical axes. Rotational deformation cause non uniform distribution demand in lateral force resisting elements and increased damage in an asymmetric buildings[**Error! Reference source not found.**]. The vulnerability of asymmetric buildings has been addressed by building seismic design codes in the form of special torsion provisions. In these provisions the design eccentricity is defined as a combination of the stiffness eccentricity and accidental eccentricity. The plane in which any transverse force applied through causes no torsion is called Shear Center.

Center of Resistance



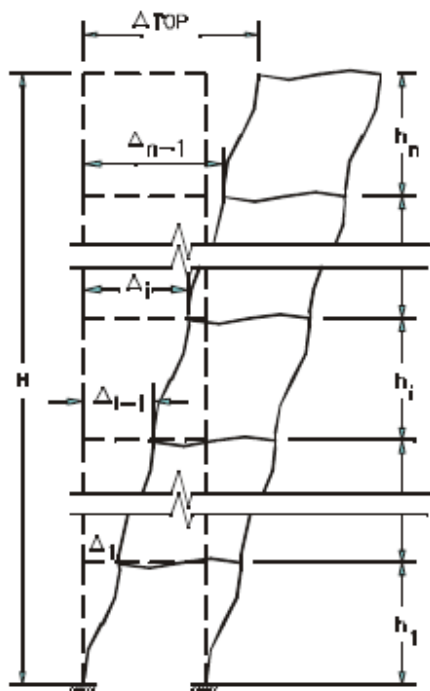
Center of Mass

Figure 2-1: Illustration of Torsion

2.2. Lateral Stability, Drift and P-Delta

Design for drift and lateral stability is an issue which should be addressed in the early stages of design development. In many cases, especially in tall buildings or in cases where torsion is a major contributor to structural response, the drift criteria can become a governing factor in selection of the proper structural system.

The relative lateral displacement of buildings is sometimes measured by an overall drift ratio or index, which is the ratio of maximum lateral displacement to the height of the building. More commonly, however, an inter story drift ratio, angle, or index is used, which is defined as the ratio of the relative displacement of a particular floor to the story height at that level. The term drift means the relative lateral displacement between two adjacent floors, and the term drift index, is defined as the drift divided by the story height.



Over all Drift = Δ_{Top}

Inter Storey Drift = $\Delta_i - \Delta_{i-1}$

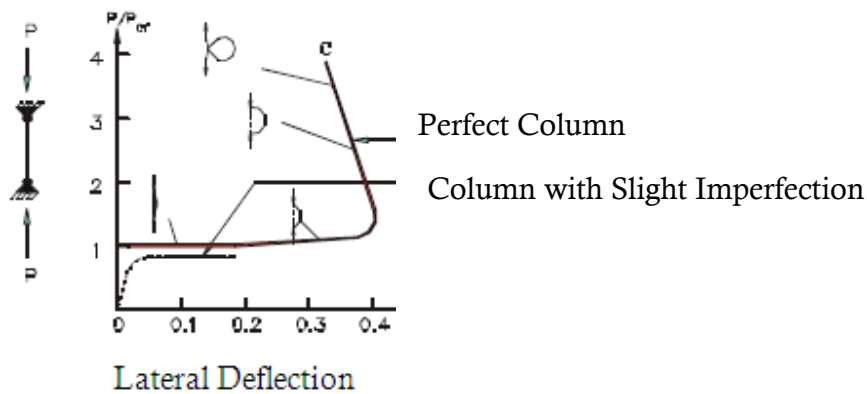
$$\text{Over all Drift Index} = \frac{\Delta_{Top}}{H}$$

$$\text{Inter Storey Drift Index} = \frac{\Delta_i - \Delta_{i-1}}{h_i}$$

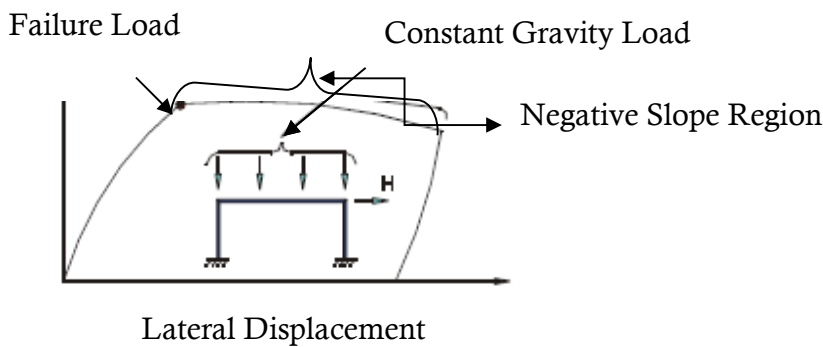
Figure 2-2: Definition of Drift

2.2.1. Concept of Lateral Stability

To illustrate the concept of lateral stability, consider an ideal column without geometrical or material imperfections. Furthermore, assume that there are no lateral loads, and that the column remains elastic regardless of the force magnitude. If the axial force is slowly increased, the column will undergo axial deformation, and no lateral displacements will occur. However, when the applied forces reach a certain magnitude called the critical load (P_{cr}), significant lateral displacements may be observed.



(a) Large Displacement Load-Deflection Behavior for an Ideal Elastic Column



(b) Load-Deflection Relationship for a Frame Subjected to Combined Gravity and Lateral Load

Figure 2-3: Structural Stability of an Idealized Column and a Real Frame.

Figure 2.3 (a) shows the load-deflection behavior of this ideal column. It is important to notice that when the magnitude of axial force exceeds P_{cr} , there are two possible paths of equilibrium: one along the original path, with no lateral displacements, and one with lateral displacements. However, equilibrium along the original path is not stable, and any slight disturbance can cause a change in the equilibrium position and significant lateral displacements. The force P_{cr} is called the bifurcation load or first critical load of the system. For this ideal column reaching the bifurcation point does not imply failure simply because it was assumed that it will remain elastic regardless of the deflection magnitude.

However, in a real column, such large deformations can cause yielding, stiffness reduction, and failure. In a structural system, buckling of critical members and the corresponding large lateral displacements can cause a major redistribution of forces and overall collapse of the system. It is important to note that the bifurcation point exists only for perfectly symmetric members under pure axial forces. If the same ideal column is simultaneously subjected to lateral loads, or if asymmetry of material or geometric imperfections are present, as they are in any real system, lateral displacements would be observed from very early stages of loading. When a frame under constant gravity load is subjected to slowly increasing lateral loads, the lateral displacement of the system slowly increases, until it reaches a stage that in order to maintain static equilibrium a reduction in the gravity or lateral loads is necessary (Figure 2.3 (b)). This corresponds to the region with negative slope on the force-displacement diagram. If the loads are not reduced, the system will fail. When the same frame is subjected to earthquake ground motion, reaching the negative slope region of the load-displacement diagram does not necessarily imply failure of the system (see Figure 2.3). In fact, it has been shown that in the case of repeated loads with direction reversals, such as those caused by earthquake ground motion, the load capacity of the system will be significantly larger than the stability load for the same system subjected to uni-directional monotonic loads. Perhaps this is one reason for scarcity of stability-caused building failures during earthquakes.

Exact computation of critical loads, for real buildings, is a formidable task. This is true even in a static environment, let alone the added complexities of dynamic

loading and inelastic response. Exact buckling analysis is beyond the capacity and resources of a typical design office, and beyond the usual budget and timeframe allocated for structural analysis of buildings.

In everyday structural analysis, the stability effects are accounted for either by addressing the problem at the element level (via effective length factors), or by application of one of the various P-Delta analysis methods.

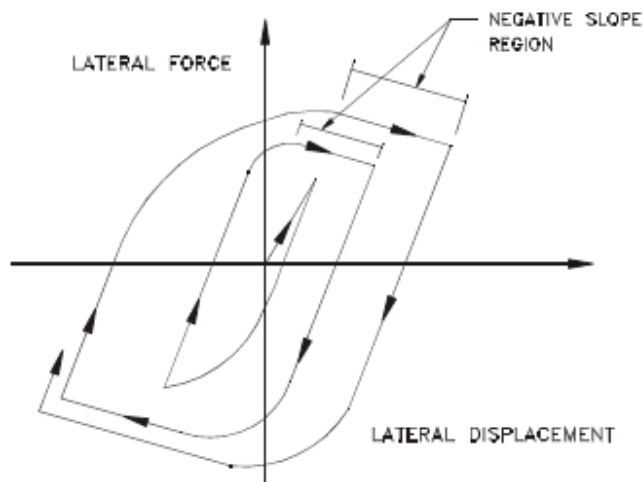


Figure 2-4: A Typical Load-Displacement Curve for a Frame under Constant Gravity Load & Reversing Lateral Load.

The simplest way to minimize lateral stability problems is to limit the expected lateral displacement or drift of the structure. In fact several studies ([4]) have shown that by increasing lateral stiffness, the critical load of the building will increase and the chances of stability problems are reduced. Drift limitations are imposed by seismic design codes primarily to serve this purpose.

2.2.2. The Need for Drift Design

The lateral displacement or drift of a structural system under wind or earthquake forces is important from three different perspectives: 1) structural stability; 2) architectural integrity and potential damage to various non-structural components; and 3) human comfort during, and after, the building experiences these motions. In this paper, the purpose of the first requirement is studied.

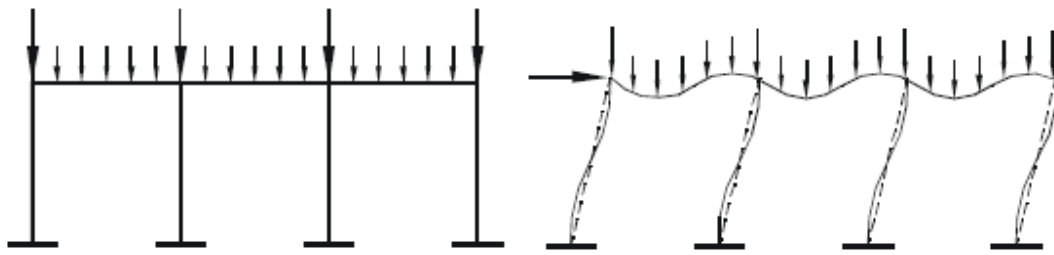
Excessive and uncontrolled lateral displacements can create severe structural problems. Empirical observations and theoretical dynamic response studies have indicated a strong correlation between the magnitudes of inter story drift and building damage potential. The fact that the potential for drift related damage is highly variable, and is dependent on the structural and nonstructural detailing provided by the designer, has proposed the following generalization of damage potential in relationship to the inter story drift index δ :

1. At $\delta = 0.001$; nonstructural damage is probable
2. At $\delta = 0.002$; nonstructural damage is likely
3. At $\delta = 0.007$; nonstructural damage is relatively certain and structural damage is likely
4. At $\delta = 0.015$; nonstructural damage is certain and structural damage is likely

Drift control requirements [1] are included in the design provisions of most building codes. However, in most cases, the codes are not specific about the analytical assumptions to be used in the computation of the drifts. Furthermore, most of the codes are not clear about how the magnifying effects of stability related displacements, such as P-delta deformations, are to be incorporated in evaluation of final displacements and corresponding member forces.

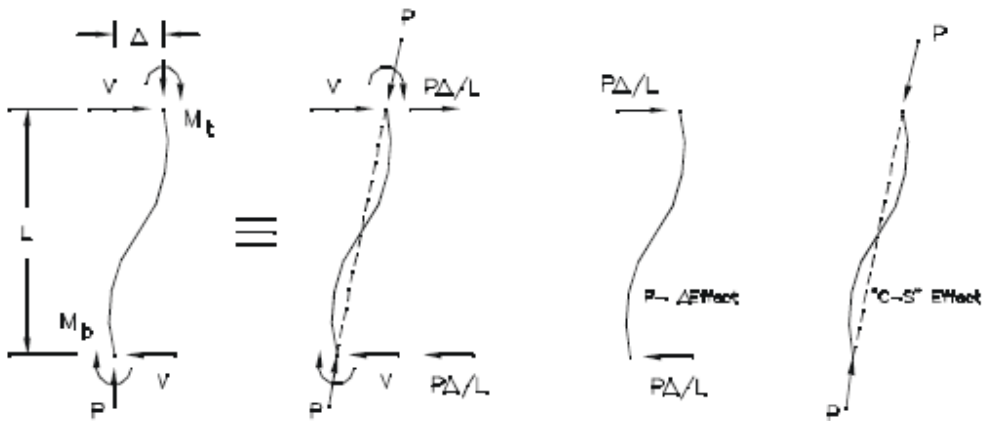
2.2.3. P-Delta Analysis

For most practical purposes, an accurate estimate of the stability effects may be obtained by what is commonly referred to as P-delta analysis. Overall stability failures of structures have not been common during past earthquakes. However, with the continuing trend towards lighter structural systems, and recent discoveries about the nature of near-field ground motion ([4]), the second-order effects are beginning to receive more attention. It is believed that, in most cases, observance of proper drift limitations will provide the necessary safeguard against the overall lateral stability failure of the structure.



(a) Un deformed State

(b) Deformed State



(c) Equivalent Column Forces in Deformed and undeformed States (d) Major 2nd order effect

Figure 2-5: (a) Equilibrium in under Formed State, (b) Immediate P-Delta Effect, (c) Accumulation of the P-Delta Effect, (d) Major 2nd Order Effect.

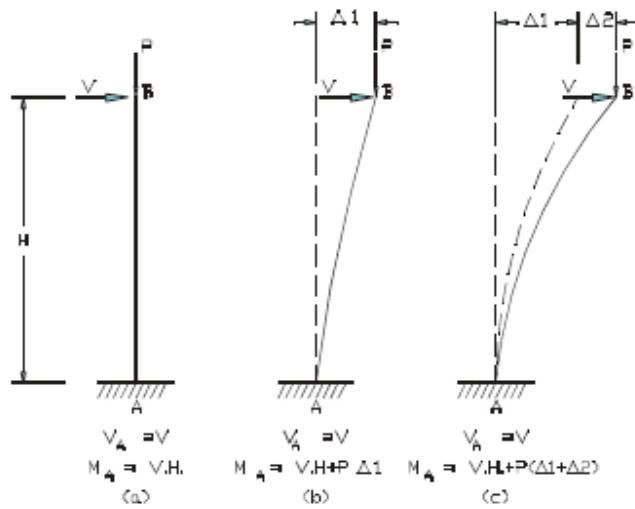


Figure 2-6: Applied Loads (A) In the un Deformed States And (B) Deformed States.

In conventional first-order structural analysis, the equilibrium equations are formulated for the un deformed shape of the structure. However, when a structure undergoes deformation, it carries the applied loads into a deformed state along with it (figure 2-5). The changes in position of the applied forces are cumulative in nature and cause additional second-order forces, moments, and displacements which are not accounted for in a first-order analysis. Studies [[4]] have shown that the single most important second-order effect is the P-delta effect. (Figure 2-6-b) illustrates the P- delta effect on a simple cantilever column. In some cases, stability or second-order effects are small and can be neglected. However, in many other cases such as tall buildings, systems under significant gravity loads, soft-story buildings, or systems with significant torsional response, the second-order effects may be quite significant and hence, should be considered in the structural analysis. Although it is true that ignoring second order effects is not likely to result in overall stability failure of typical buildings subjected to earthquake ground motion, these effects can frequently give rise to a series of premature material failures at the level of forces that would seem safe by a 1st-order analysis.

3. Preliminary Considerations

3.1. Typical Structures

The plans shown below are groups of “Typical Structures”, which are selected to carry out the parametric study, are chosen as one storey buildings with frames and walls where the walls are mainly resisting moments due to lateral and gravity loads. All structures are rectangular in plan and are composed of 3.0×5.0 m² modules. Schematic floor plans of typical structures with 8 axes in direction X, which are designated as types A, B, C and D, are shown in Figures 3-1:3-4. As can be seen in the figure, typical structure A is symmetrical about X and Y axes which is the control model. Structure types B, C and D are obtained by shifting the centers of gravity of walls by 5, 10 and 15 meters, respectively; in direction X. Story heights for all the typical structures are 3m. All the wall thicknesses are 20cm. All the beam cross sections are 30×50 cm². Column dimensions are 30×30 cm². Lateral loads are calculated for each arrangement and gravity loads are applied by fraction until the building attains its maximum load carrying capacity. Finally load deflection diagrams are constructed for each arrangement.

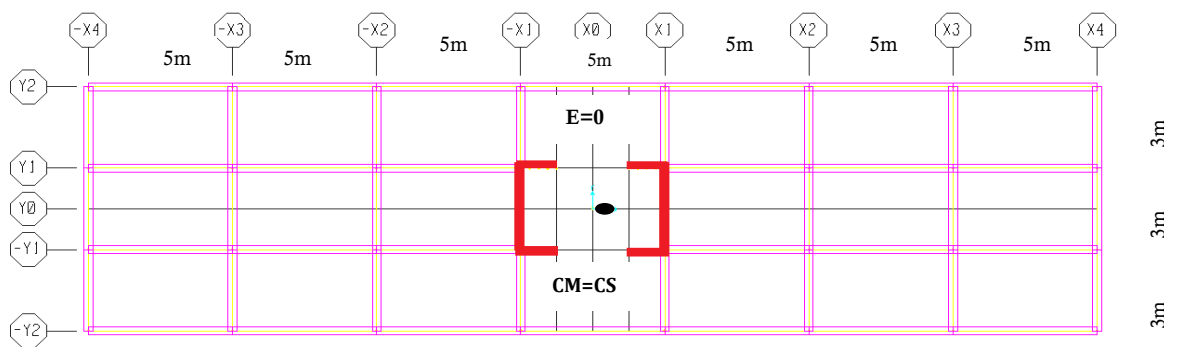


Figure 3- 1: Structural Wall at Axis $-X_1_X_1$, Type A (Control Model)

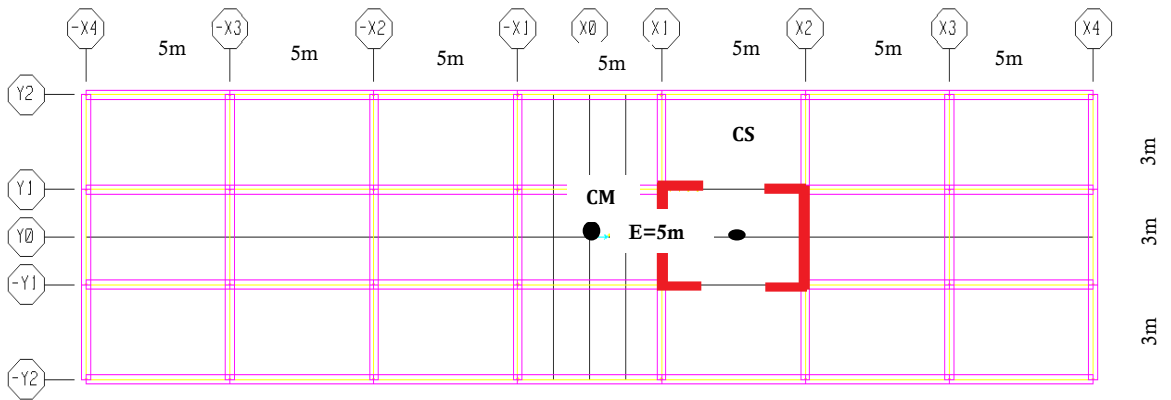


Figure 3- 2: Structural Wall at Axis $X_1_X_2$, Type B

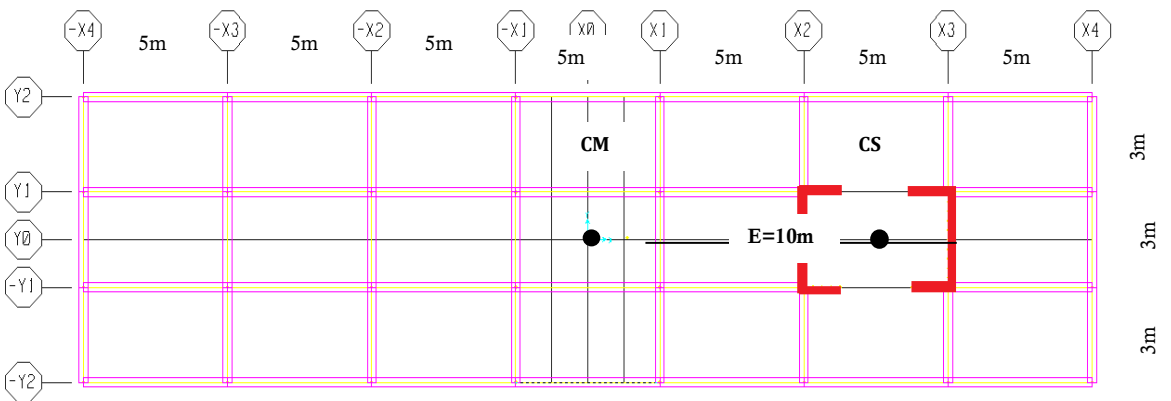


Figure 3- 3: Structural Wall at Axis $X_2_X_3$, Type C

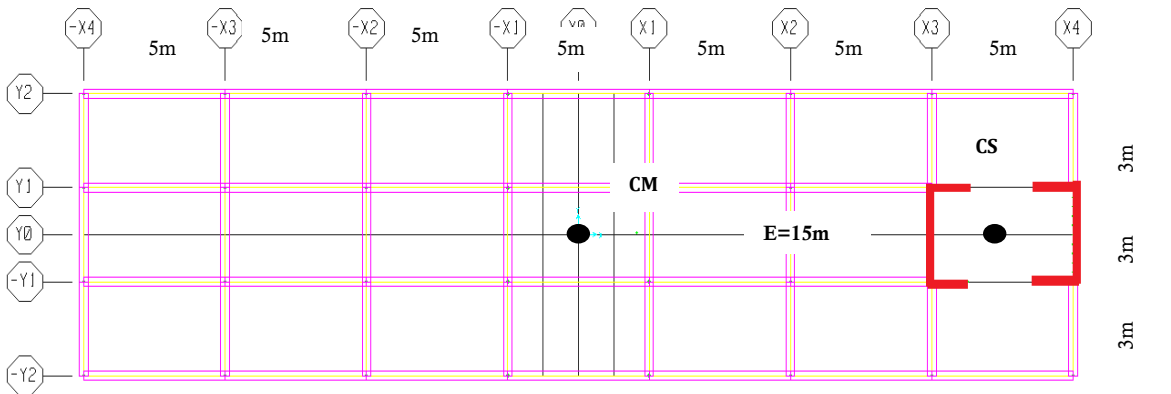


Figure 3- 4: Structural Wall at Axis $X_3_X_4$, Type D

3.2. Parametric Study Procedure

In order to achieve the goal of study, a parametric investigation procedure is undertaken, on the above series of sample structures with the condition which can cause torsion and their load carrying capacity behavior under earthquake and gravity loading is investigated and discussed. To study the effects of torsion on lateral stability of building structures, location of structural wall from the centroid (eccentricity) is considered as one parameter and the lateral stability of the buildings is computed under the same lateral and gravity loading.

3.3. Conditions Which Cause Torsion

On many occasions design by coinciding centroid and mass center of the building is the ideal for a structure. However, the design has to be based on off center position of the moment resisting walls with respect to the center of mass. The design in these cases results into an excessive stresses in most of the structural members, unwanted torsional moments and sways.

In this paper, the condition considered for the parametric study is

- ✓ Location of structural walls from the centroid.

The structural walls are arranged to satisfy the stability requirements. i.e The walls must be arranged and constructed in such a way that the system response is stable for any arbitrary lateral loading. To fulfill this [[2]]

- ✓ There must be a minimum of 3 structural walls.
- ✓ Lines of actions of the forces in the walls should not intersect at a point.
- ✓ At most 2 of the 3 walls shall be parallel to each other.

However, to study the effects of torsion on the lateral stability of building structures, structure types B, C and D are constructed by shifting the centers of gravity of walls by 5, 10 and 15 meters, respectively; in the X- direction.

3.4. Effects of Axial loading and Story Number on Lateral Stability of Building Structures

In addition to torsion, the effects of axial loading and number of stories on the lateral stability is parallely investigated. Thus the following parameters are considered for the study:

- ❖ To study the effects of axial loading on lateral stability of building structures:
 - ✓ Axial load is applied by fraction to structural walls until failure.
 - ✓ While the axial load in columns surrounding the walls is constant.
- ❖ To study the effects of storey number on lateral stability of building structures:
 - ✓ Various stories on the same wall configuration is considered for the study.

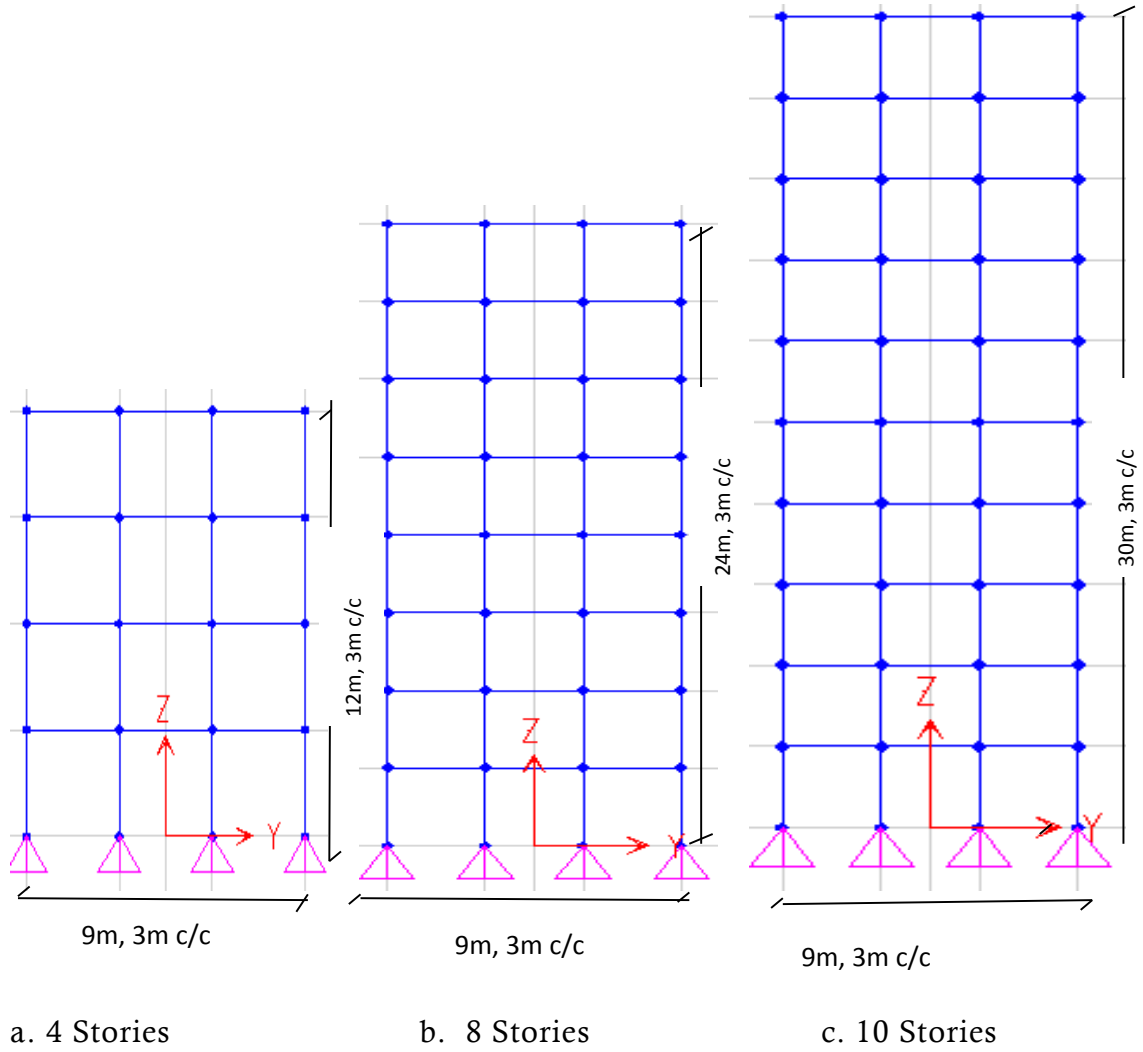


Figure 3- 5: Various Stories of Type A Considered for the Study.

3.5. Factors Affecting Lateral Stability

In general, the magnitude of the gravity loads and factors that increase lateral displacement, affect lateral stability of a structure.

3.5.1. Lateral Loads

Table 3- 1: Equivalent Static Load Determination

Lateral Load for One Storey				
<u>GROUND</u>		Concrete Grade	Concrete Section	
GBeam		25	0.15	3.75
Fcolumn		25	0.09	2.25
Wall1		25	0.9	22.5
Wall2		25	0.9	22.5
Geometric Center X		35		
Geometric Center Y		9		

Axes	Quantity	Length (m)	Weight (kn/m)	Weight (kn)	Distance X (m)	Distance Y (m)	W * X	W * Y
Beams								
<u>A</u>								
1_2	1	5.00	3.75	18.75	32.5	9.00	609.38	168.75
2_3	1	5.00	3.75	18.75	27.50	9.00	515.63	247.50
3_4	1	5.00	3.75	18.75	22.50	9.00	421.88	168.75
4_5	1	5.00	3.75	18.75	17.50	9.00	328.13	168.75
5_6	1	5.00	3.75	18.75	12.50	9.00	234.38	168.75
6_7	1	5.00	3.75	18.75	7.50	9.00	140.63	168.75
7_8	1	5.00	3.75	18.75	2.50	9.00	46.88	168.75
				131.25			2296.88	1260.00
<u>D</u>								
1_2	1	5.00	3.75	18.75	32.5	0.00	609.38	0.00
2_3	1	5.00	3.75	18.75	27.50	0.00	515.63	0.00
3_4	1	5.00	3.75	18.75	22.50	0.00	421.88	0.00
4_5	1	5.00	3.75	18.75	17.50	0.00	328.13	0.00
5_6	1	5.00	3.75	18.75	12.50	0.00	234.38	0.00
6_7	1	5.00	3.75	18.75	7.50	0.00	140.63	0.00
7_8	1	5.00	3.75	18.75	2.50	0.00	46.88	0.00
				131.25			2296.88	0.00
<u>B</u>								
1_2	1	5.00	3.75	18.75	32.5	6.00	609.38	112.50
2_3	1	5.00	3.75	18.75	27.50	6.00	515.63	112.50
3_4	1	5.00	3.75	18.75	22.50	6.00	421.88	112.50
4_5	0	5.00	3.75	0.00	17.50	6.00	0.00	0.00
5_6	1	5.00	3.75	18.75	12.50	6.00	234.38	112.50
6_7	1	5.00	3.75	18.75	7.50	6.00	140.63	112.50
7_8	1	5.00	3.75	18.75	2.50	6.00	46.88	112.50
				112.50			1968.75	675.00
<u>C</u>								
1_2	1	5.00	3.75	18.75	32.5	3.00	609.38	56.25
2_3	1	5.00	3.75	18.75	27.50	3.00	515.63	56.25
3_4	1	5.00	3.75	18.75	22.50	3.00	421.88	56.25
4_5	0	5.00	3.75	0.00	17.50	3.00	0.00	0.00
5_6	1	5.00	3.75	18.75	12.50	3.00	234.38	56.25
6_7	1	5.00	3.75	18.75	7.50	3.00	140.63	56.25
7_8	1	5.00	3.75	18.75	2.50	3.00	46.88	56.25
				112.50			1968.75	337.50

1									
	A_B	1	3.00	3.75	11.25	35	7.50	393.75	84.38
	B_C	1	3.00	3.75	11.25	35	4.50	393.75	50.63
	C_D	1	3.00	3.75	11.25	35	1.50	393.75	16.88
2			3.00		33.75			1181.25	151.88
	A_B	1	3.00	3.75	11.25	30	7.50	337.50	84.38
	B_C	1	3.00	3.75	11.25	30	4.50	337.50	50.63
	C_D	1	3.00	3.75	11.25	30	1.50	337.50	16.88
3			3.00		33.75			1012.50	151.88
	A_B	1	3.00	3.75	11.25	25	7.50	281.25	84.38
	B_C	1	3.00	3.75	11.25	25	4.50	281.25	50.63
	C_D	1	3.00	3.75	11.25	25	1.50	281.25	16.88
4			3.00		33.75			843.75	151.88
	A_B	1	3.00	3.75	11.25	20	7.50	225.00	84.38
	B_C	0	3.00	3.75	0.00	20	4.50	0.00	0.00
	C_D	1	3.00	3.75	11.25	20	1.50	225.00	16.88
5			3.00		22.50			450.00	101.25
	A_B	1	3.00	3.75	11.25	15	7.50	168.75	84.38
	B_C	0	3.00	3.75	0.00	15	4.50	0.00	0.00
	C_D	1	3.00	3.75	11.25	15	1.50	168.75	16.88
6			3.00		22.50			337.50	101.25
	A_B	1	3.00	3.75	11.25	10	7.50	112.50	84.38
	B_C	1	3.00	3.75	11.25	10	4.50	112.50	50.63
	C_D	1	3.00	3.75	11.25	10	1.50	112.50	16.88
7			3.00		33.75			337.50	151.88
	A_B	1	3.00	3.75	11.25	5	7.50	56.25	84.38
	B_C	1	3.00	3.75	11.25	5	4.50	56.25	50.63
	C_D	1	3.00	3.75	11.25	5	1.50	56.25	16.88
8					33.75			168.75	151.88
	A_B	1	3.00	3.75	11.25	0	7.50	0.00	84.38
	B_C	1	3.00	3.75	11.25	0	4.50	0.00	50.63
	C_D	1	3.00	3.75	11.25	0	1.50	0.00	16.88
					33.75			0.00	151.88
					735.00	0.00	0.00	12862.50	3386.25

Columns									
<u>A</u>									
1	1	3.00	2.25	6.75	35	9.00	236.25	60.75	
2	1	3.00	2.25	6.75	30	9.00	202.50	60.75	
3	1	3.00	2.25	6.75	25	9.00	168.75	60.75	
4	1	3.00	2.25	6.75	20	9.00	135.00	60.75	
5	1	3.00	2.25	6.75	15	9.00	101.25	60.75	
6	1	3.00	2.25	6.75	10	9.00	67.50	60.75	
7	1	3.00	2.25	6.75	5	9.00	33.75	60.75	
8	1	3.00	2.25	6.75	0	9.00	0.00	60.75	
				54.00			945.00	486.00	
<u>B</u>									
1	1	3.00	2.25	6.75	35	6.00	236.25	40.50	
2	1	3.00	2.25	6.75	30	6.00	202.50	40.50	
3	1	3.00	2.25	6.75	25	6.00	168.75	40.50	
4	0	3.00	2.25	0.00	20	6.00	0.00	0.00	
5	0	3.00	2.25	0.00	15	6.00	0.00	0.00	
6	1	3.00	2.25	6.75	10	6.00	67.50	40.50	
7	1	3.00	2.25	6.75	5	6.00	33.75	40.50	
8	1	3.00	2.25	6.75	0	6.00	0.00	40.50	
				40.50			708.75	243.00	
<u>C</u>									
1	1	3.00	2.25	6.75	35	3.00	236.25	20.25	
2	1	3.00	2.25	6.75	30	3.00	202.50	20.25	
3	1	3.00	2.25	6.75	25	3.00	168.75	20.25	
4	0	3.00	2.25	0.00	20	3.00	0.00	0.00	
5	0	3.00	2.25	0.00	15	3.00	0.00	0.00	
6	1	3.00	2.25	6.75	10	3.00	67.50	20.25	
7	1	3.00	2.25	6.75	5	3.00	33.75	20.25	
8	1	3.00	2.25	6.75	0	3.00	0.00	20.25	
				40.50			708.75	121.50	
<u>D</u>									
1	1	3.00	2.25	6.75	35	0.00	236.25	0.00	
2	1	3.00	2.25	6.75	30	0.00	202.50	0.00	
3	1	3.00	2.25	6.75	25	0.00	168.75	0.00	
4	1	3.00	2.25	6.75	20	0.00	135.00	0.00	
5	1	3.00	2.25	6.75	15	0.00	101.25	0.00	
6	1	3.00	2.25	6.75	10	0.00	67.50	0.00	
7	1	3.00	2.25	6.75	5	0.00	33.75	0.00	
8	1	3.00	2.25	6.75	0	0.00	0.00	0.00	
				54.00			945.00	0.00	
				189.00			3307.50	850.50	

Walls									
<u>B</u>									
X'1_X1	1	1.25	22.50	28.13	19.375	6.00	544.92	168.75	
_X'1_X1	1	1.25	22.50	28.13	15.625	6.00	439.45	168.75	
				56.25			984.38	337.50	
<u>C</u>									
X'1_X1	1	1.25	22.50	28.13	19.375	3.00	544.92	84.38	
_X'1_X1	1	1.25	22.50	28.13	15.625	3.00	439.45	84.38	
				56.25			984.38	168.75	
<u>4</u>									
B_C	1	3.00	22.50	67.50	20	4.50	1350.00	303.75	
				67.50			1350.00	303.75	
<u>5</u>									
B_C	1	3.00	22.50	67.50	15	4.50	1012.50	303.75	
				67.50			1012.50	303.75	
				247.50	0.00	0.00	4331.25	1113.75	

SUMMARY			
	Total Weight	Total W * X	Total W *Y
	(kn)		
Beams	735.00	12862.50	3386.25
Columns	189.00	3307.50	850.50
Walls	247.50	4331.25	1113.75
	<u>1171.50</u>	<u>20501.25</u>	<u>5350.50</u>
<u>x'</u>	<u>17.50</u>		
<u>y'</u>	<u>4.57</u>		

Table 3- 2: Equivalent Static Load for One Storey

Level	hi, m	hi, m	Geq.	Gi*hi	Fx (Kn)	x'	y'
Ground	3.00	1.50	1,407.75	2,111.63	175.97	17.50	4.57
				2,111.63	175.97		

Table 3- 3: Equivalent Static Load for Four Stories

Level	hi, m	hi, m	Geq.	Gi*hi	Fx (Kn)	x'	y'
1st storey	3	2	1,408	2,112	44	17.50	4.57
2nd storey	3	5	1,408	6,335	132	17.50	4.57
3rd storey	3	8	1,408	10,558	220	17.50	4.57
4th storey	3	11	1,408	14,781	308	17.50	4.57
				33,786	704		

Table 3- 4: Equivalent Static Load for Eight Stories

Level	hi, m	hi, m	Geq.	Gi*hi	Fx (Kn)	x'	y'
1st storey	3	2	1,408	2,112	17	17.50	4.57
2nd storey	3	5	1,408	6,335	52	17.50	4.57
3rd storey	3	8	1,408	10,558	87	17.50	4.57
4th storey	3	11	1,408	14,781	122	17.50	4.57
5th storey	3	14	1,408	19,005	157	17.50	4.57
6th storey	3	17	1,408	23,228	192	17.50	4.57
7th storey	3	20	1,408	27,451	227	17.50	4.57
8th storey	3	23	1,408	31,674	262	17.50	4.57
				135,144	1,118		

Table 3- 5: Equivalent Static Load for Ten Stories

Level	hi, m	hi, m	Geq.	Gi*hi	Fx (Kn)	x'	y'
1st storey	3	2	1,408	2,112	13	17.50	4.57
2nd storey	3	5	1,408	6,335	38	17.50	4.57
3rd storey	3	8	1,408	10,558	63	17.50	4.57
4th storey	3	11	1,408	14,781	88	17.50	4.57
5th storey	3	14	1,408	19,005	113	17.50	4.57
6th storey	3	17	1,408	23,228	138	17.50	4.57
7th storey	3	20	1,408	27,451	163	17.50	4.57
8th storey	3	23	1,408	31,674	188	17.50	4.57
9th storey	3	26	1,408	35,898	213	17.50	4.57
10th storey	3	29	1,408	40,121	238	17.50	4.57
				211,163	1,250		

I. Lateral Load Distribution

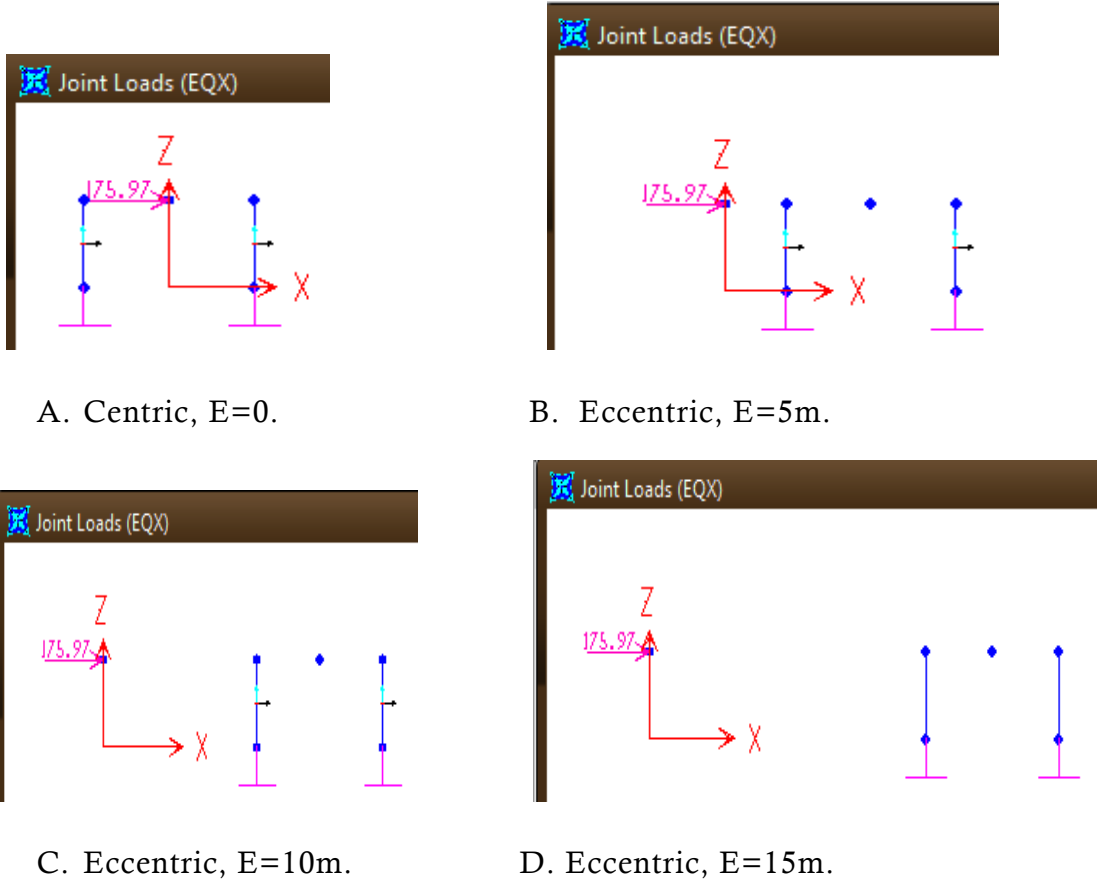
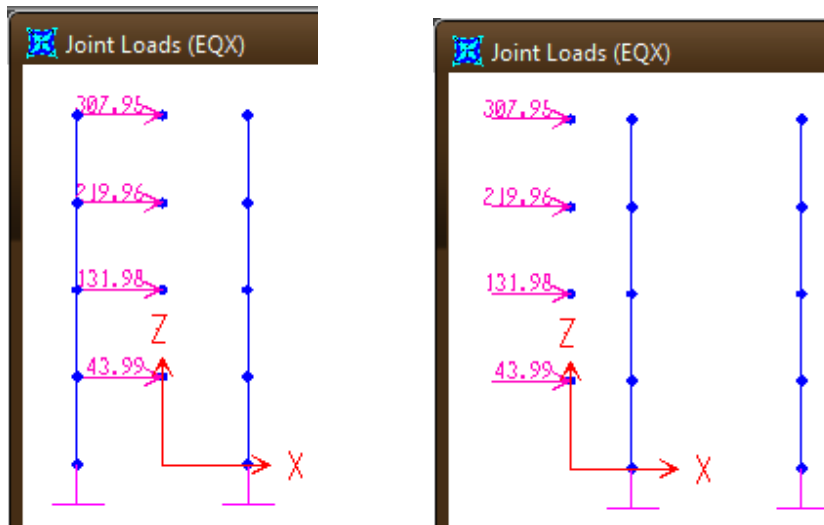


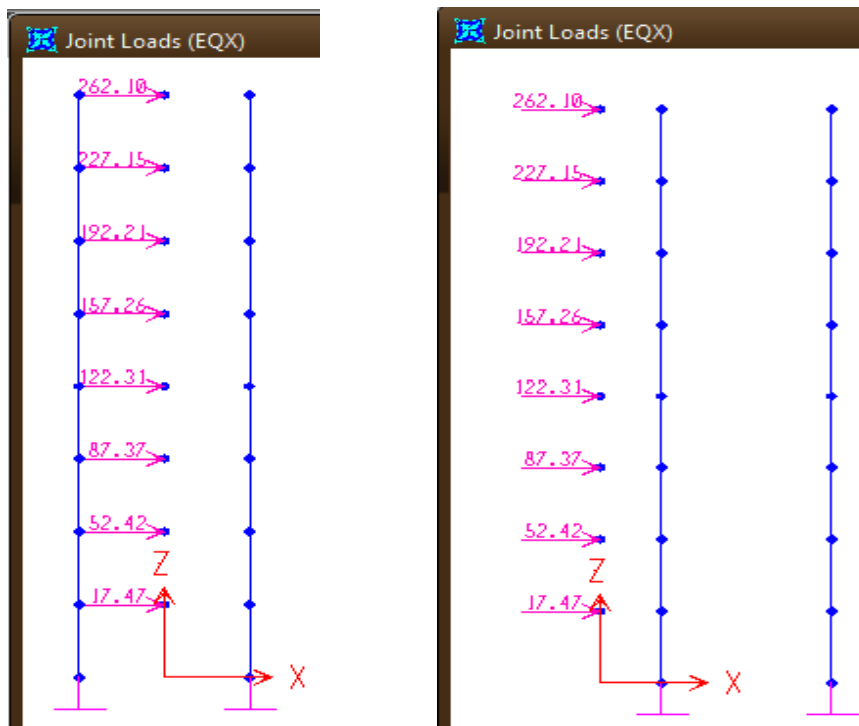
Figure 3- 6: Lateral Load Distribution for one Storey of Various Wall Location



A. Centric, E=0

B. Eccentric, E=5m

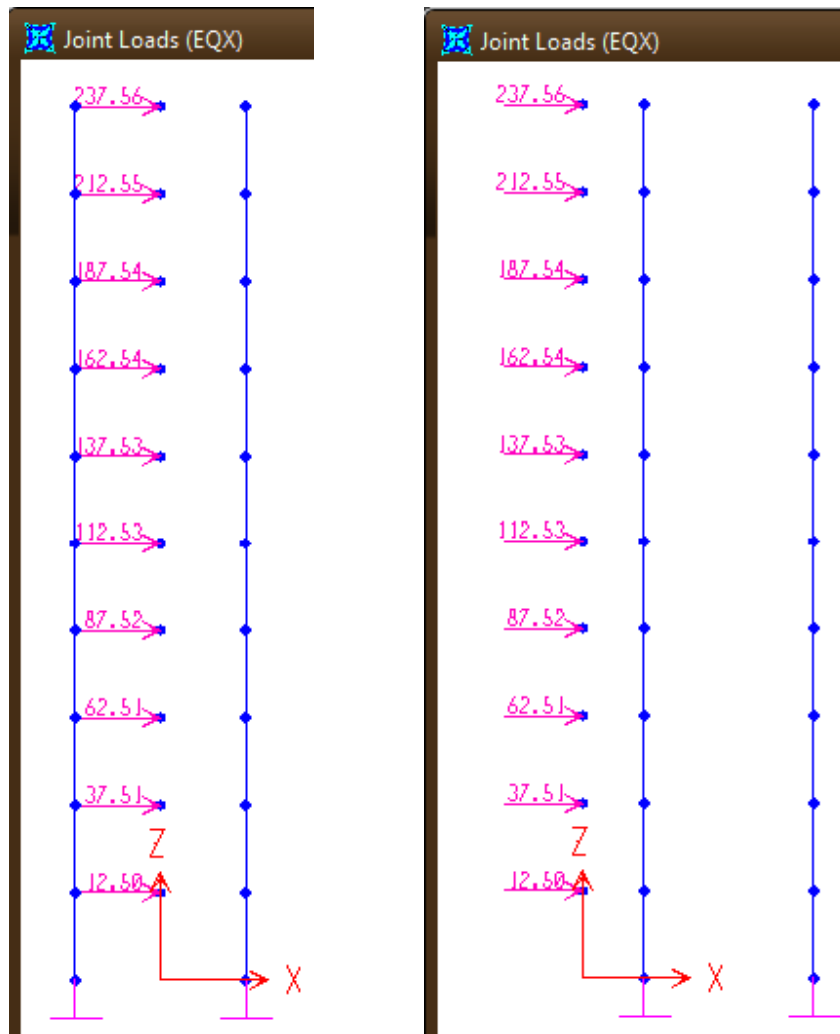
Figure 3-7: Lateral Load Distribution for Four Stories of Various Wall Locations



A. Centric, E=0

B. Eccentric, E=5m

Figure 3- 8: Lateral Load Distribution for Eight Stories of Various Wall Locations

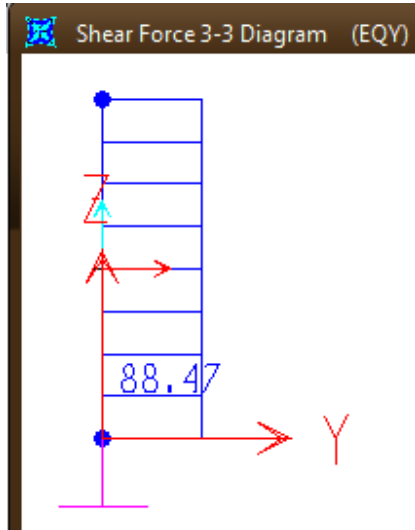


A. Centric, $E=0$

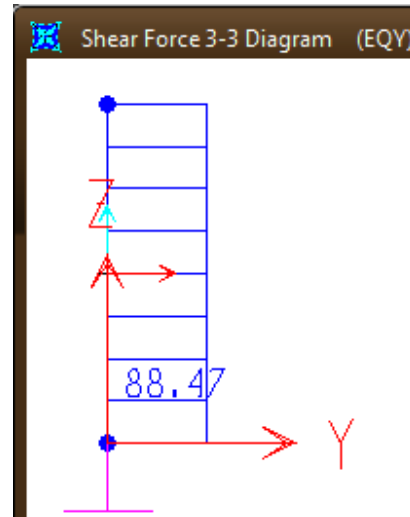
B. Eccentric, $E=5m$

Figure 3- 9: Lateral Load Distribution for Ten Stories of Various Wall Locations

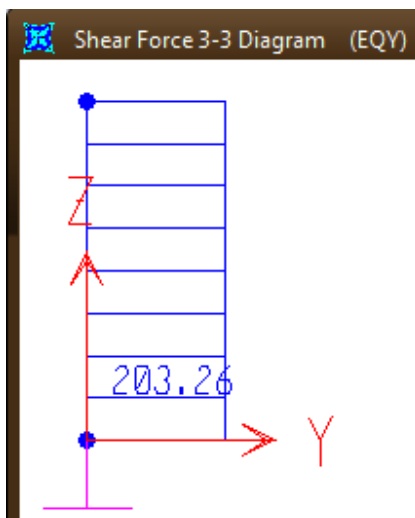
II. Shear Force Distribution



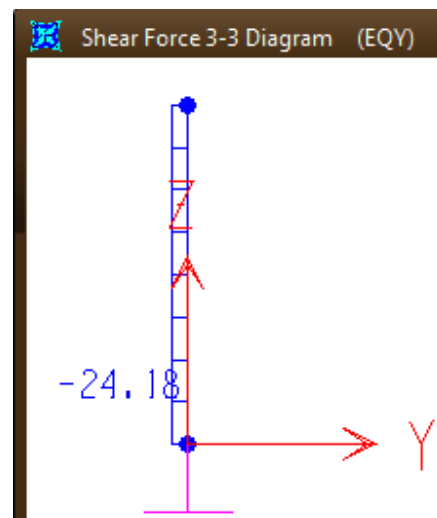
A. Wall 1, Centric, E=0



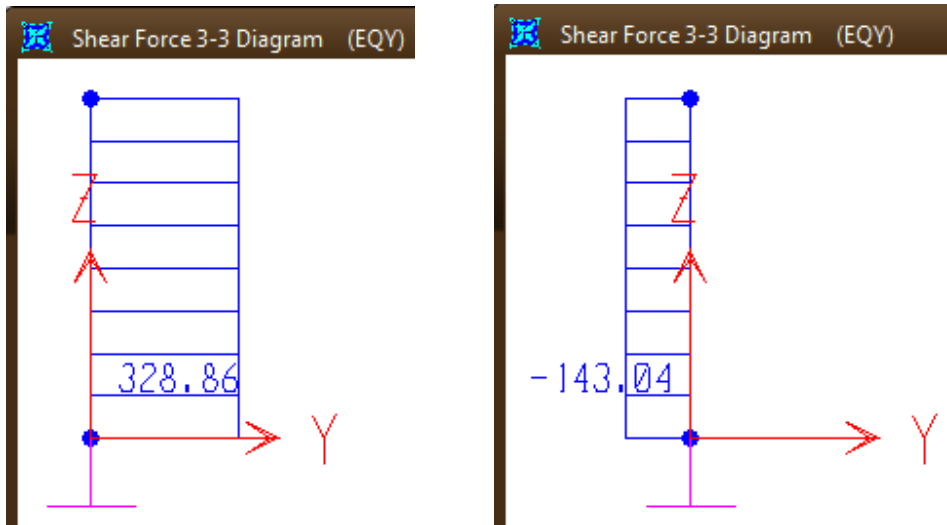
B. Wall 2, Centric, E=0



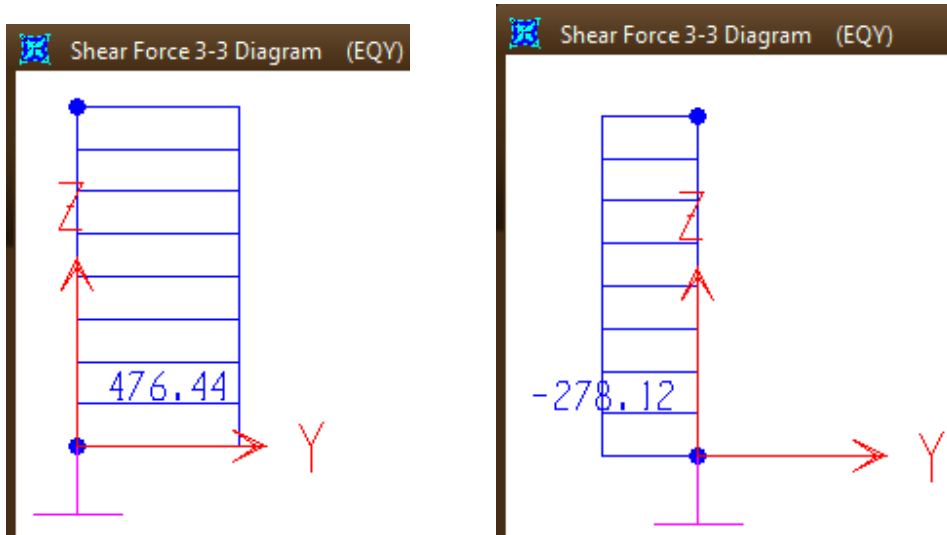
C. Wall 1, Eccentric, E=5m



D. Wall 2, Eccentric E=5m

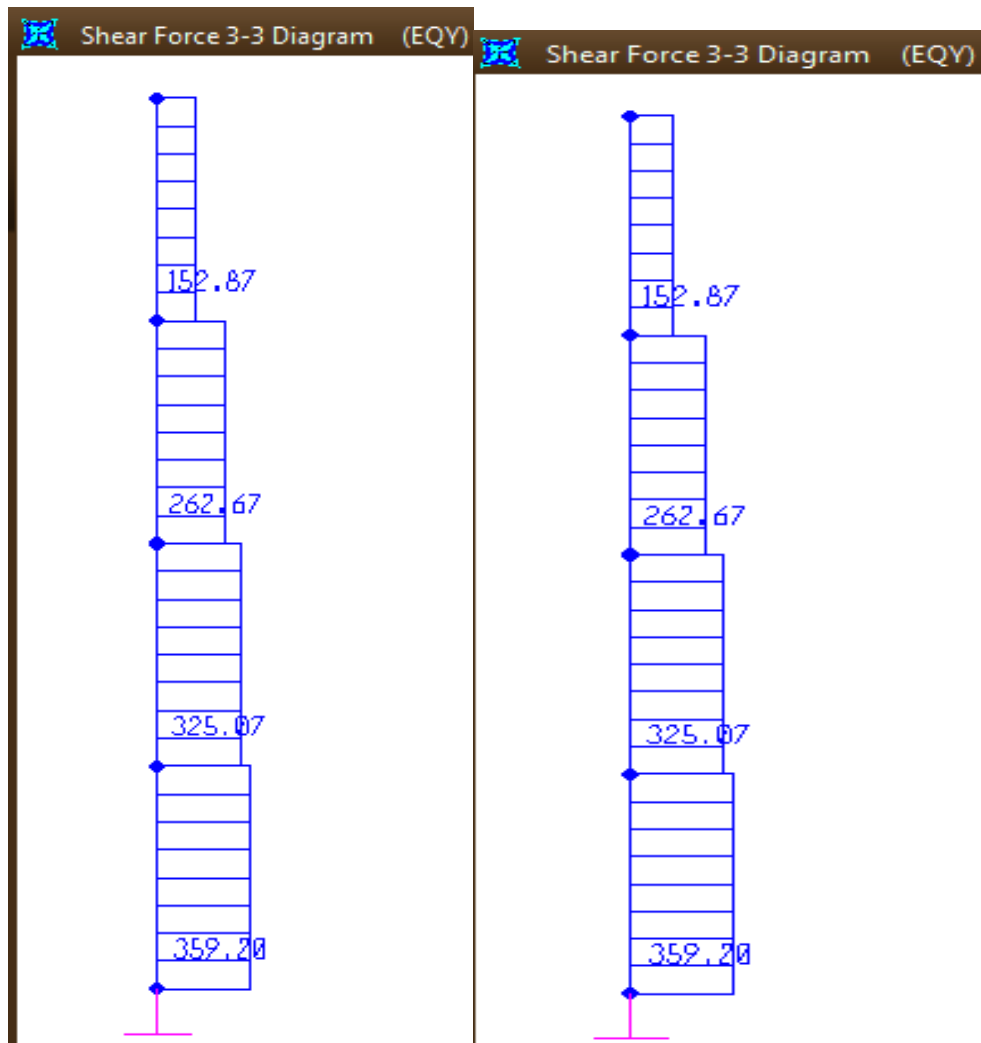


A. Wall 1, Eccentric, $E=10\text{m}$ B. Wall 2, Eccentric, $E=10\text{m}$

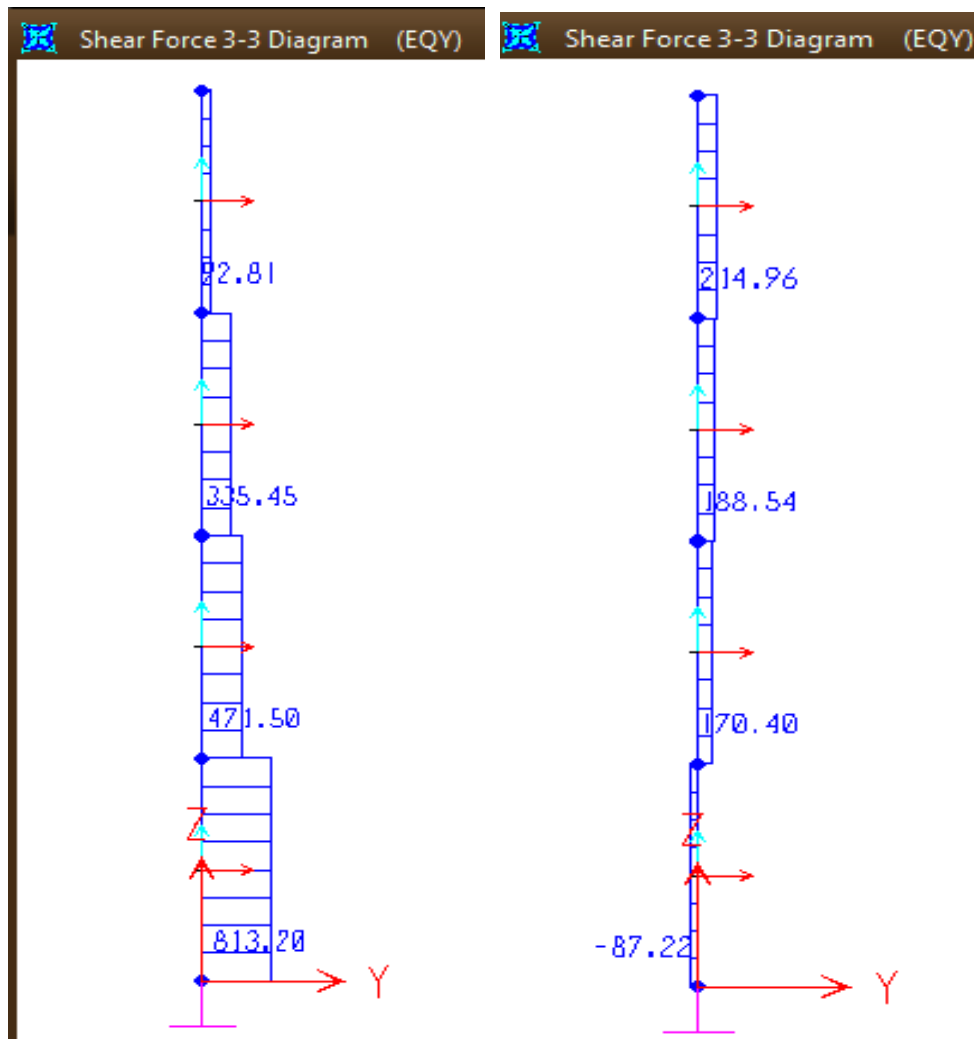


C. Wall 1, Eccentric, $E=15\text{m}$ D. Wall 2, Eccentric, $E=15\text{m}$

Figure 3- 10 (A-D): Shear Force on Structural Walls of One Storey Building on various Eccentricities

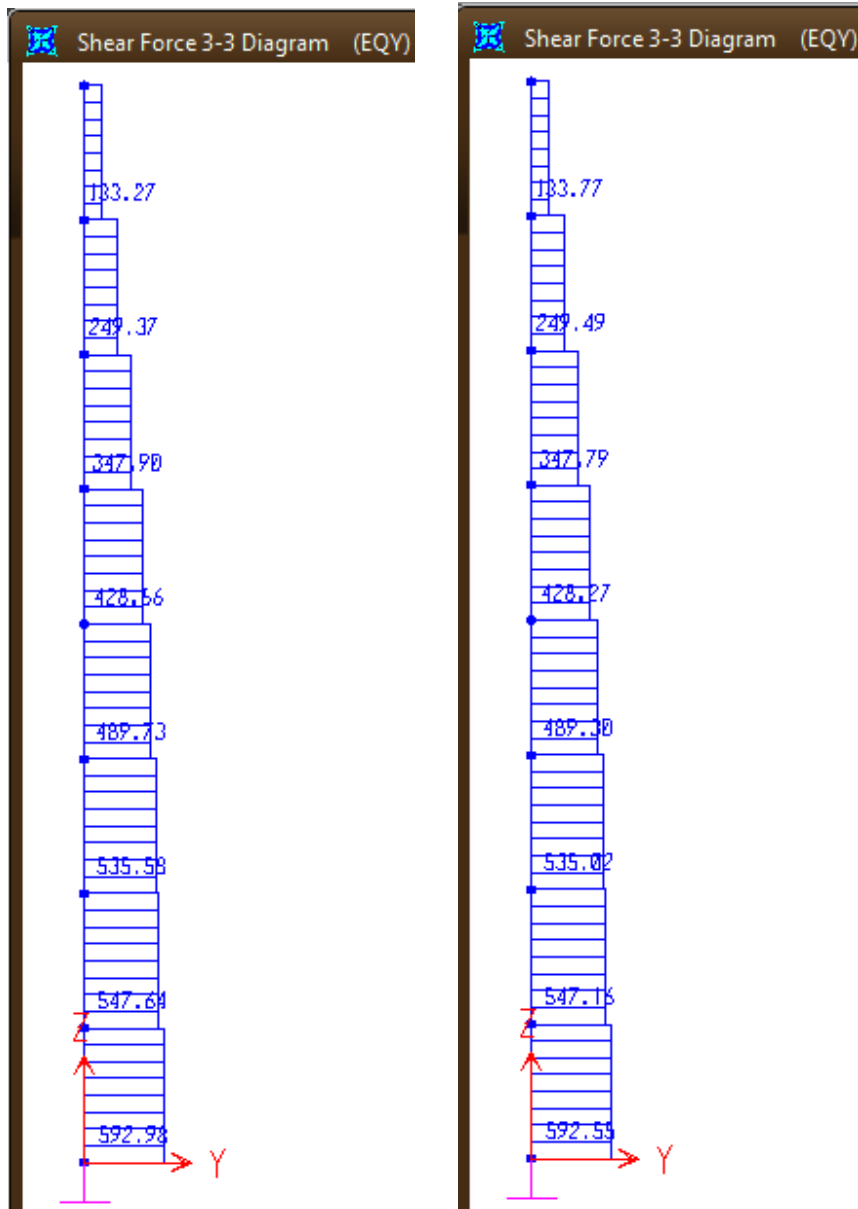


A. Wall 1, Centric, E=0 B. Wall 2, Centric, E=0

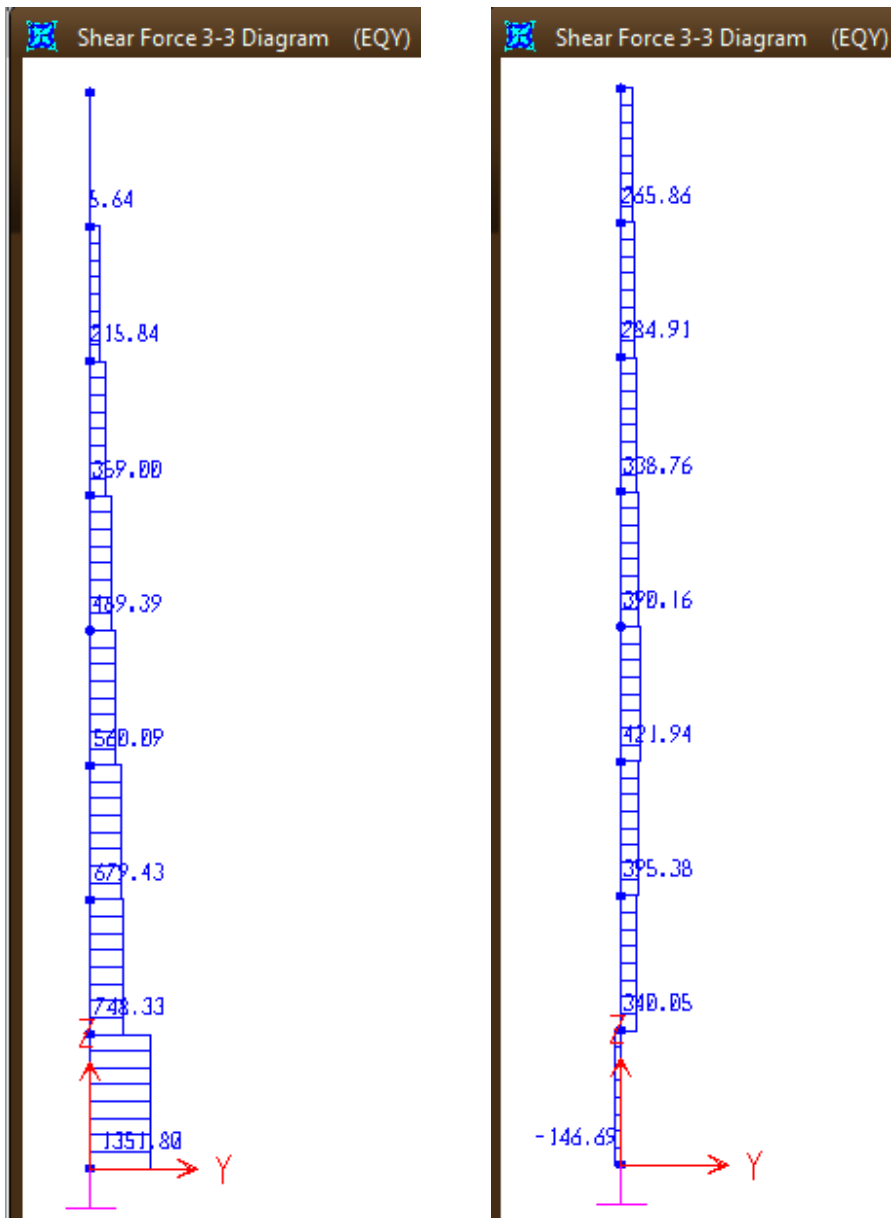


C. Wall 1, Eccentric, E=5m D. Wall 2, Eccentric, E=5m

Figure 3- 11 (A-D): Shear Force on Structural Walls of Four Story Building on various Eccentricities

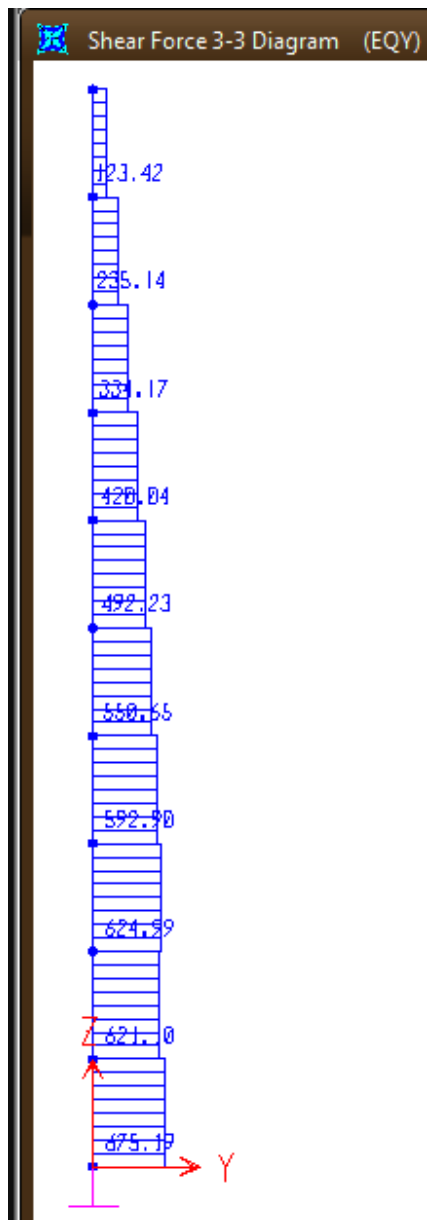


A. Wall 1, Centric, E=0 B. Wall 2, Centric, E=0

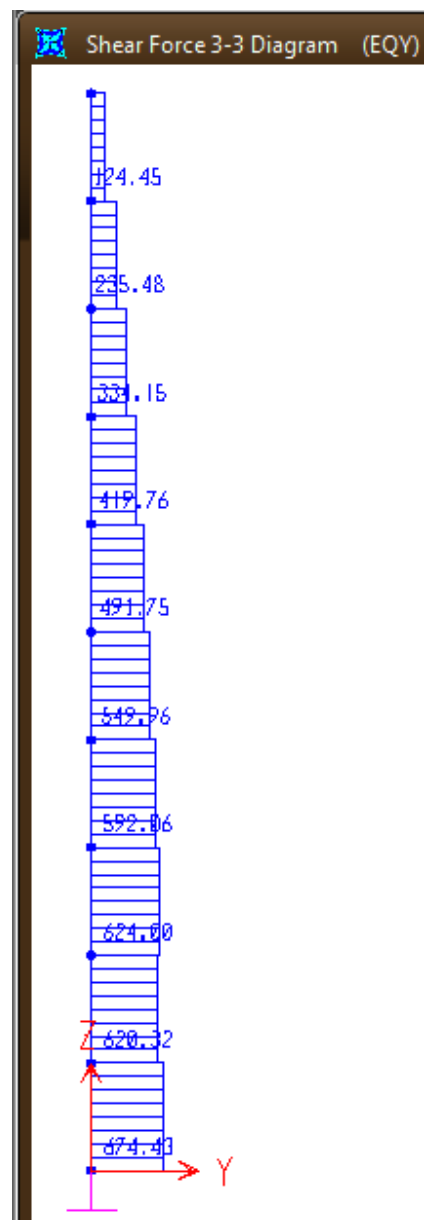


C. Wall 1, Eccentric, E=5m D. Wall 2, Eccentric, E=5m

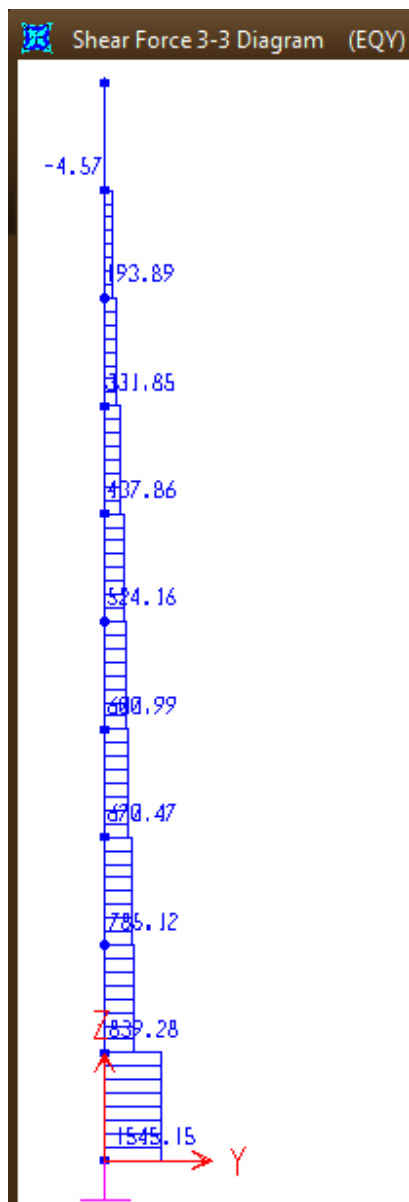
Figure 3- 12: Shear Force on Structural Walls of Eight Storey Building



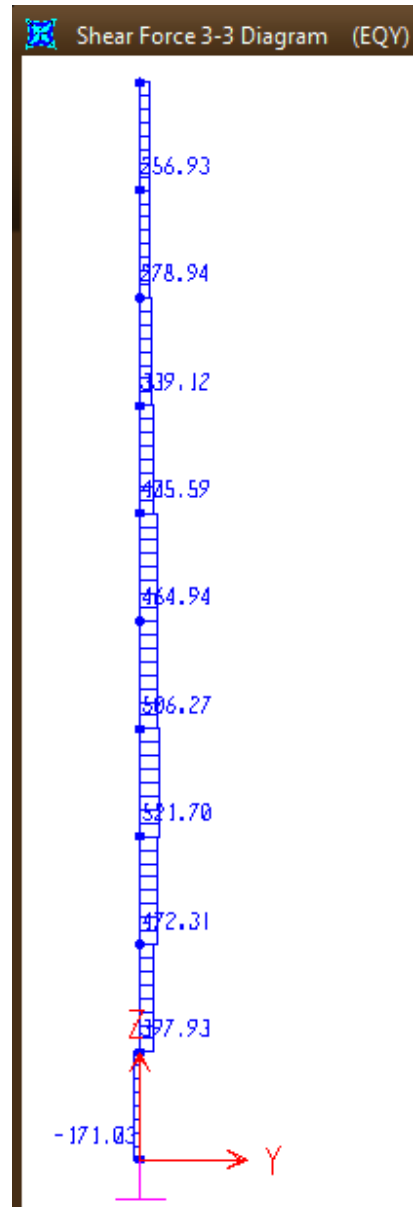
A. Wall 1, Centric, E=0



B. Wall 2, Centric, E=0



C. Wall 1, Eccentric, E=5m



D. Wall 2, Eccentric, E=5m

Figure 3- 13 (A-D): Shear Force on Structural Walls of Ten Storey Building

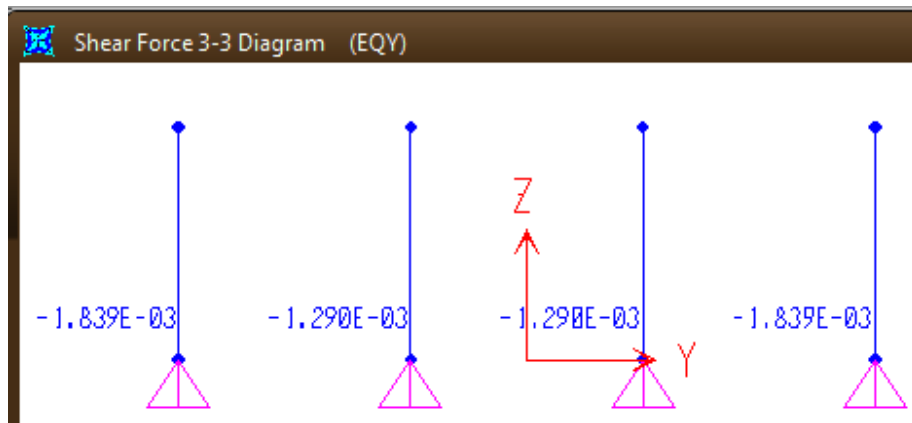


Figure 3- 14: One Storey Shear Force On Surrounding Columns of Axis Y_2-X_2

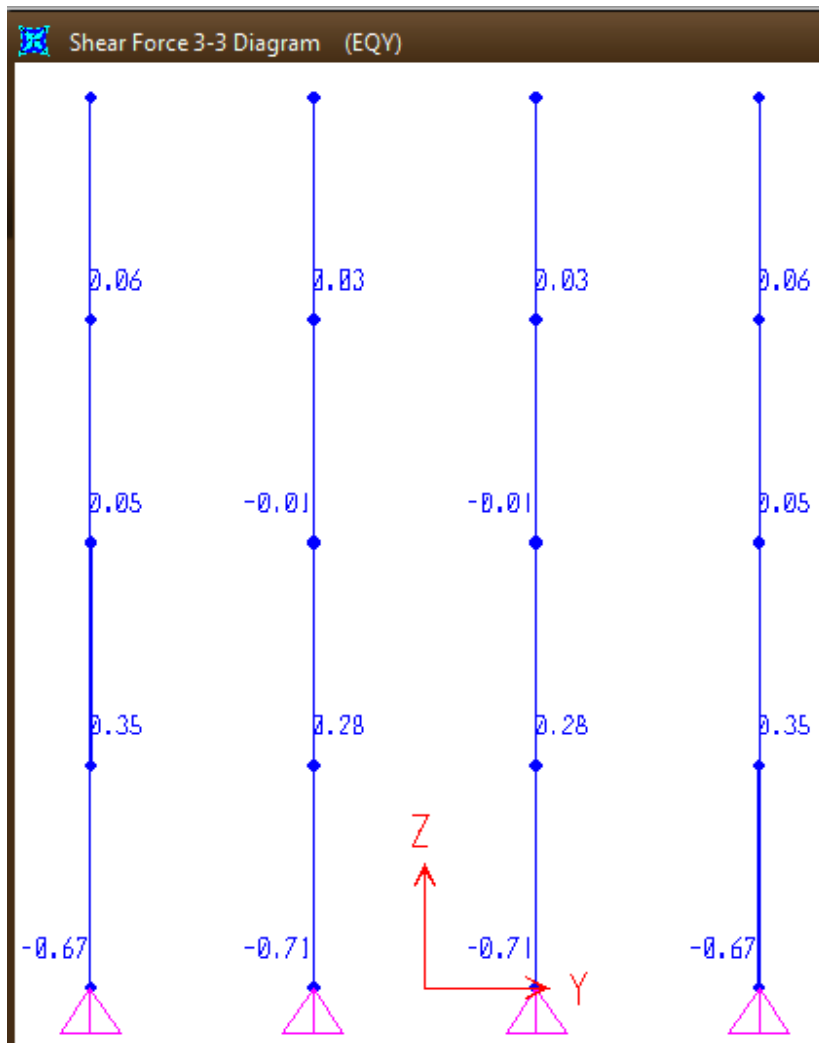


Figure 3- 15: Four Stories, Shear Force On Surrounding Columns of Axis Y_2-X_2

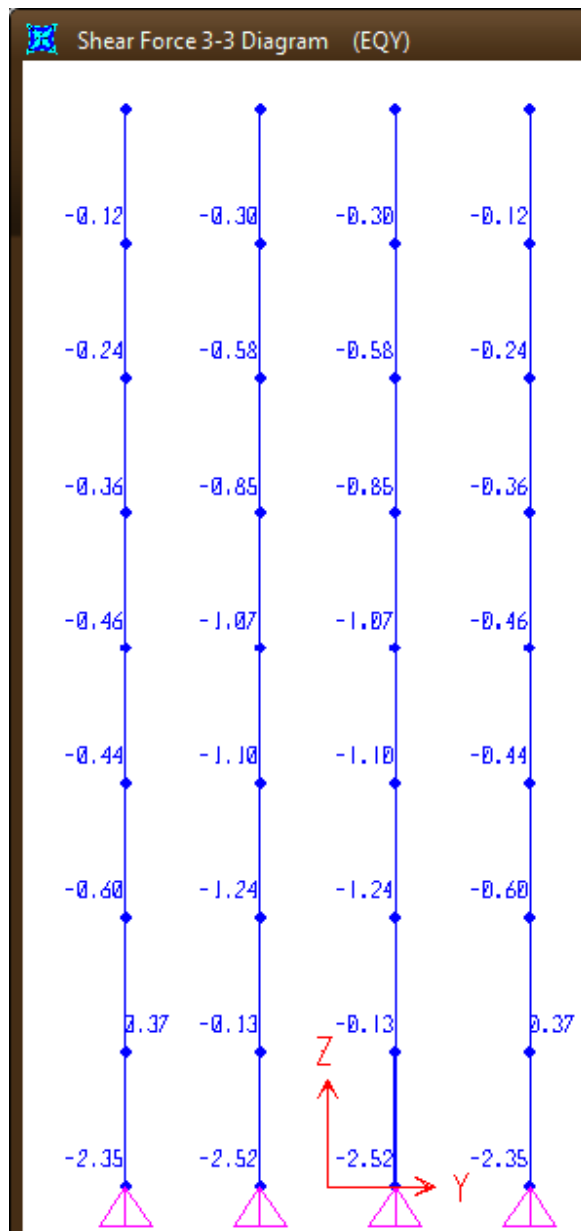


Figure 3- 16: Eight Stories, Shear Force On Surrounding Columns of Axis Y_2-X_2

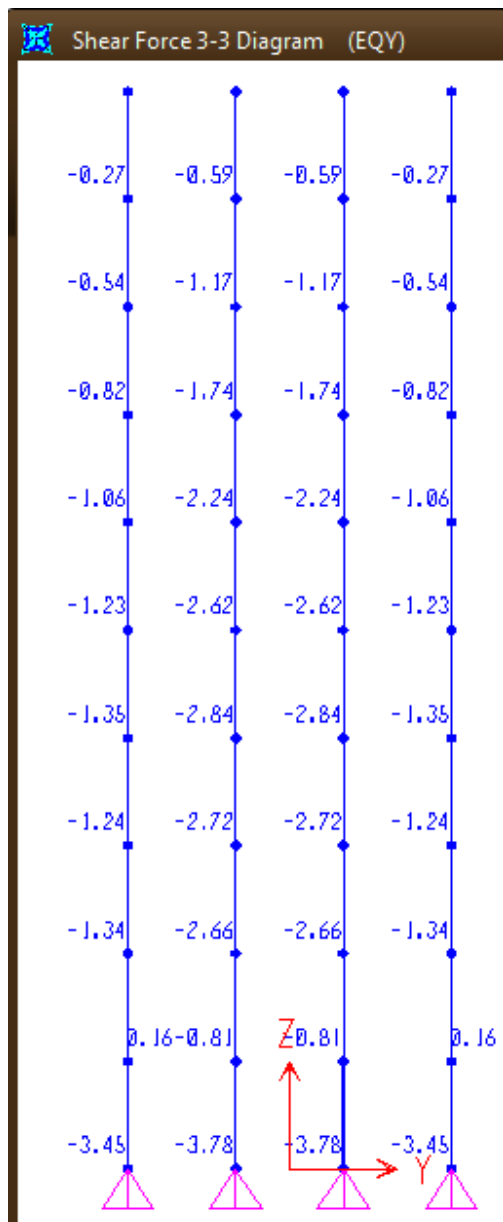


Figure 3- 17: Ten Stories, Shear Force On Surrounding Columns of Axis Y_2-X_2

3.5.2. Gravity Loads

Table 3- 6: Dead Load on Floors

Description	Depth(m)	Unit Weight, KN/m ³	Weight, KN/m ²
Weight of plastering (KPa)	0.005	23	0.12
Weight of partition (KPa)	1.000	1	1.00
Weight of floor finish and screed (KPa)	0.050	23	1.15
Weight of slab (KPa)	0.150	25	3.75

6.02KN/m²

- ❖ Dead Load=6.02KN/m²
- ❖ Live Load= 3KN/m²
- ❖ Design Load= DL+ LL=6.02+3=9.02KN/m²
- ❖ Load on a Central Column=9.02*2*(3*5) =270.6KN
- ❖ Load on an Edge Column=9.02* (3*5) =135.3KN

3.6. Buckling of Columns

Whether bending moment is induced by initial imperfection or by transverse load, or by any other cause such as eccentricity of compressive loading, the critical, or Euler buckling load cannot be exceeded in a real or imperfect column without producing a buckled shape of large deflections. It is natural to expect that this critical load for a linear elastic column may be obtained directly and easily from a simplified and idealized column rather than from a real column, or beam-column. The following assumptions and idealization are made for the idealized column:

- ❖ The column is perfectly straight;
- ❖ The load is applied along the center line;
- ❖ No transverse load is present;
- ❖ The material is homogeneous and free of initial stress.

The load carrying capacity of a column is not increased significantly beyond buckling. The load that causes the column to buckle is called the critical load. Thus, a study of buckling is important because this failure type reduces the load carrying capacity of a member in compression.

Approximate Buckling Load:

In approximate buckling analysis, the buckling load of a single story, or that of the structure as a whole, is estimated. This method takes advantage of the fact that most multi-story buildings have lateral load displacement characteristics that are similar to those of either a flexural cantilever or a shear cantilever. For a flexural cantilever of height H and constant stiffness EI , the uniformly distributed vertical load, per unit height (Figure below), p_{cr} , that will cause lateral buckling is given by the equation:

$$P_{cr} = 7.84 * \frac{EI}{H^3}$$

Table 3- 7: Approximate Critical Load Computation

Section properties			Approximate Buckling Load of a building Mod as flextural cantilever with Constant EI				
lx=ly	1.33	m4	Pcr=7.84EI/H3 (KN/m)				
E	29000000	KN/m2					
7.84*E*I	303146666.67	KNm2					
Approximate Buckling Load Deter							
SN		SH	Pcr (KN/m)	pcr(KN)	0.75Pcr	0.5Pcr	0.125Pcr
I	II	III	IV	V=IV*H	0.75*V	0.5*V	0.125*V
1	Storey1	3	11,227,654.32	16,841,481.48	12,631,111.11	8,420,740.74	2,105,185.19
4	Storey1	12	175,432.10	263,148.15	197,361.11	131,574.07	32,893.52
	Storey2			263,148.15	197,361.11	131,574.07	32,893.52
	Storey3			263,148.15	197,361.11	131,574.07	32,893.52
	Storey4			263,148.15	197,361.11	131,574.07	32,893.52
8	Storey1	24	21,929.01	32,893.52	24,670.14	16,446.76	4,111.69
	Storey2			32,893.52	24,670.14	16,446.76	4,111.69
	Storey3			32,893.52	24,670.14	16,446.76	4,111.69
	Storey4			32,893.52	24,670.14	16,446.76	4,111.69
	Storey5			32,893.52	24,670.14	16,446.76	4,111.69
	Storey6			32,893.52	24,670.14	16,446.76	4,111.69
	Storey7			32,893.52	24,670.14	16,446.76	4,111.69
	Storey8			32,893.52	24,670.14	16,446.76	4,111.69
10	Storey1	30	11,227.65	16,841.48	12,631.11	8,420.74	2,105.19
	Storey2			16,841.48	12,631.11	8,420.74	2,105.19
	Storey3			16,841.48	12,631.11	8,420.74	2,105.19
	Storey4			16,841.48	12,631.11	8,420.74	2,105.19
	Storey5			16,841.48	12,631.11	8,420.74	2,105.19
	Storey6			16,841.48	12,631.11	8,420.74	2,105.19
	Storey7			16,841.48	12,631.11	8,420.74	2,105.19
	Storey8			16,841.48	12,631.11	8,420.74	2,105.19
	Storey9			16,841.48	12,631.11	8,420.74	2,105.19
	Storey10			16,841.48	12,631.11	8,420.74	2,105.19

3.7. 2nd Order Effects of Gravity Loading

A first order computer analysis of a building structure for simultaneously applied gravity and horizontal loading results in deflections and forces that are a direct superposition of the results of the two types of loading considered separately. Any interaction between the effects of gravity loading and horizontal loading is not accounted for by the analysis.

In reality, when horizontal loading acts on a building and causes it to drift, the resulting eccentricity of the gravity loading from the axes of the walls and columns produces additional external moments to which the structure responds by drifting further. The additional drift induces additional internal moments sufficient to equilibrate the gravity load moments. This effect of gravity loading acting on the horizontal displacements, δ is known as P-Delta effect.

Although translational P-Delta effect is the most obvious case to consider, a torsional P-Delta mode is possible. A torsional P-Delta occurs when a building twists. And its wall and frame displace at each floor about some center of rotation. As a result the gravity loading, which is distributed over the building plan, is vertically misaligned with the axes of the resisting elements causing, in effect, an additional torque and the external P-Delta torque are in equilibrium. Since the P-Delta torque and the torsional resistance of the structure depend on the plan locations of the gravity loading and of the walls and frames, these locations must be included in the parameters of a stability analysis.

Simultaneous 1st Order and P- Δ Analysis:

The effect of P-Delta analysis is considered by modifying the structural model so that when analyzing for the actual horizontal loading, the resulting values of drift and member forces include P-Delta effects. A single computer run is then sufficient to analyze the structure and include P-Delta effects. This causes the horizontal displacement terms of the first order matrix of the structure to be automatically

augmented so as to incorporate the effects of gravity loading acting on the lateral displacements. The first order matrix is therefore augmented into 2nd order matrix.

4. Modeling the Problem

Modeling is the simulation of a physical structure or physical process by means of a substitute, analytical or numerical construct. It is not simply preparing a mesh of nodes and elements.

4.1. Approximate Representation of Structural Walls

The structure is simplified by replacing the structural walls by equivalent columns. Where each member has stiffness equal to the sum of the individual stiffness of the original bent. Equivalent columns and columns surrounding them are structural elements which carry gravity and lateral loads but the contribution of columns surrounding the walls is ignored due to their small stiffness when compared to the structural walls (equivalent columns). The application of gravity loads are made by fraction until the columns attain their critical load for buckling.

4.2. Shear Center Computation

The equivalent columns are located at a distance, e , from the centroidal axis of the thin walled web which is the shear center plane so that there is no torsion. Thus the plane in which the force p must be applied so as to cause no twist in the channel is called the shear center. And the distance locating the shear center is the eccentricity, e .

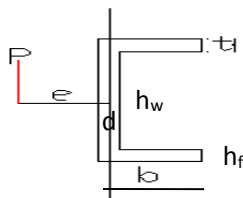


Figure 4-1: Thin Wall Section

$$b=1.4\text{m}, h_w=2.7\text{m}, t(h_f)=0.3\text{m}, d=0.55\text{m}$$

The eccentricity, e, for a “C” channel can be computed as follows.

Wall Sections

$$I_x = \frac{bwhw^3}{12} + 2\frac{bfhf^3}{12} + Adf^2$$

$$I_y = \frac{hwtw^3}{12} + 2\left(\frac{hfbf^3}{12} + Adf^2\right)$$

Determination of Shear Center will be:

$$e = \frac{b^2h^2t}{4I}$$

b=1.17, h=2.93, t=0.3,

I=Ix=2.445075

Substituting; e= 0.413m.

Hence each structural wall is replaced by equivalent column of the above section.

And is located 0.413m away from the web of the channel.

Note that for better results an equivalent square section of 2m by 2m is assumed instead of the rectangular frame section.

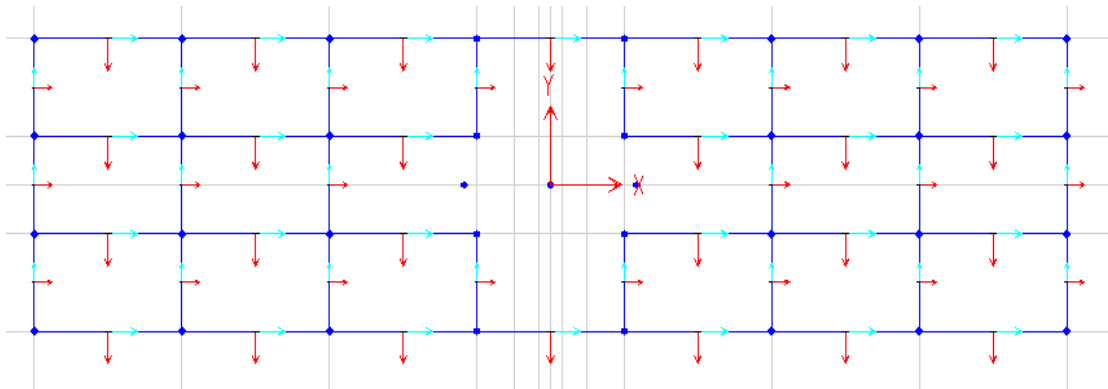


Figure 4-2: Structural Wall at Axis 0_1, Type A

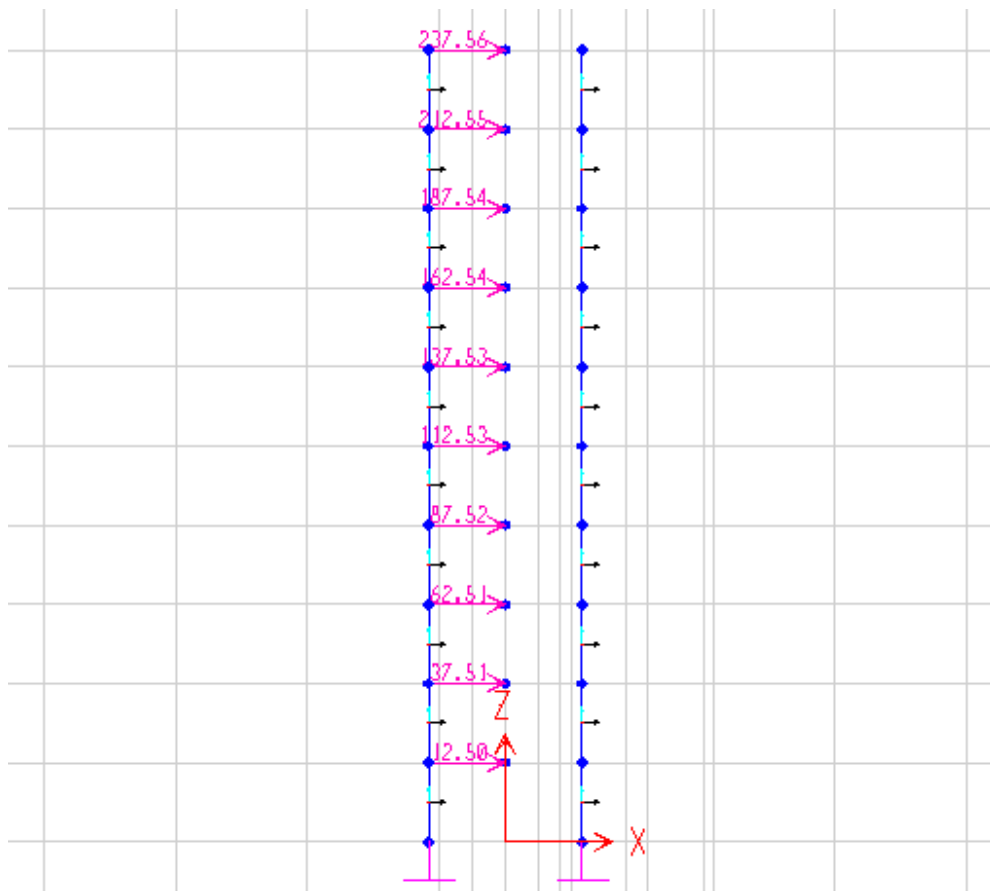


Figure 4-3: Type A in Elevation

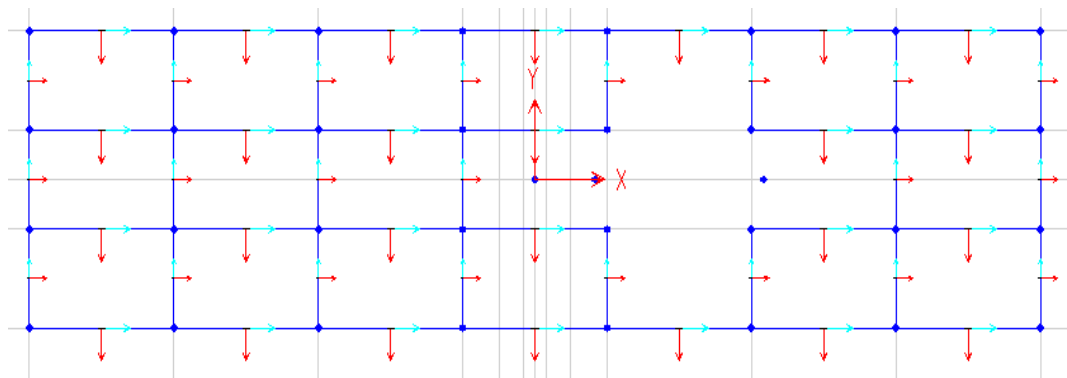


Figure 4-4: Structural Wall at Axis 1_2, Type B

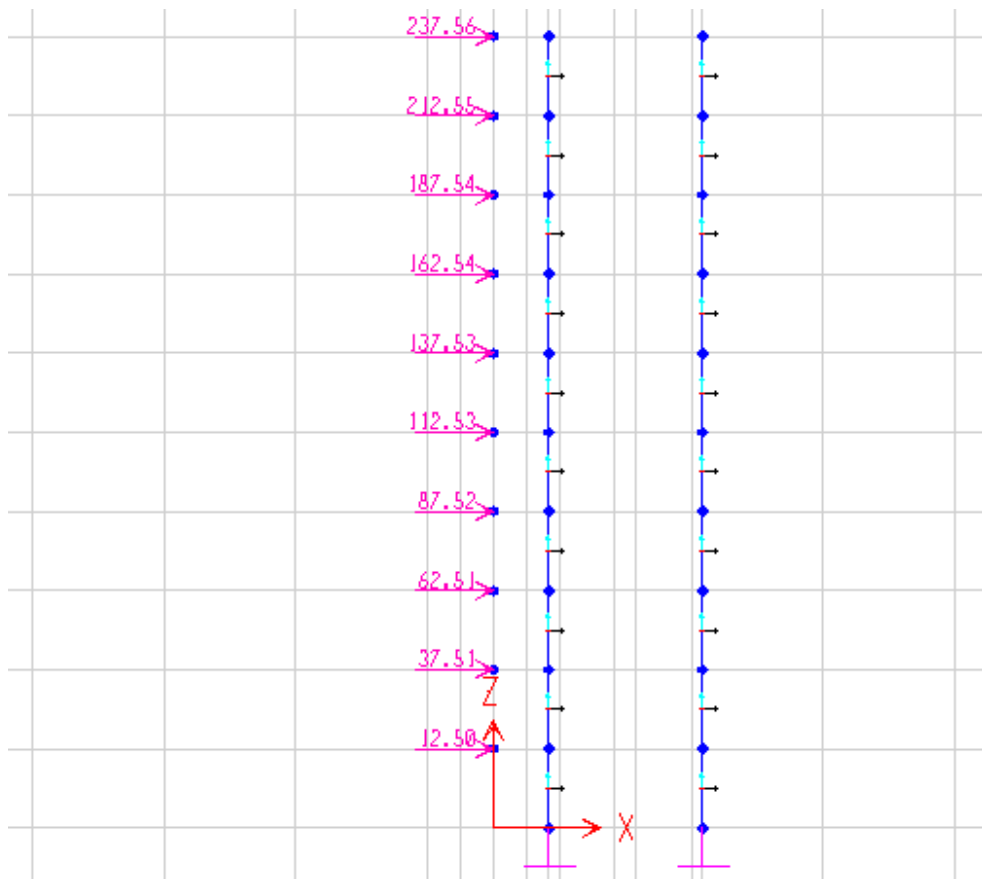


Figure 4-5: Type B in Elevation

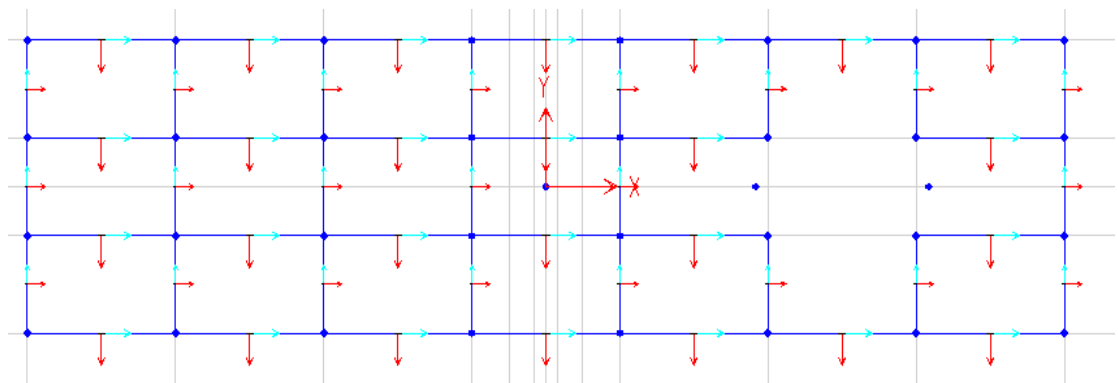


Figure 4-6: Structural Wall at Axis 2_3, Type C

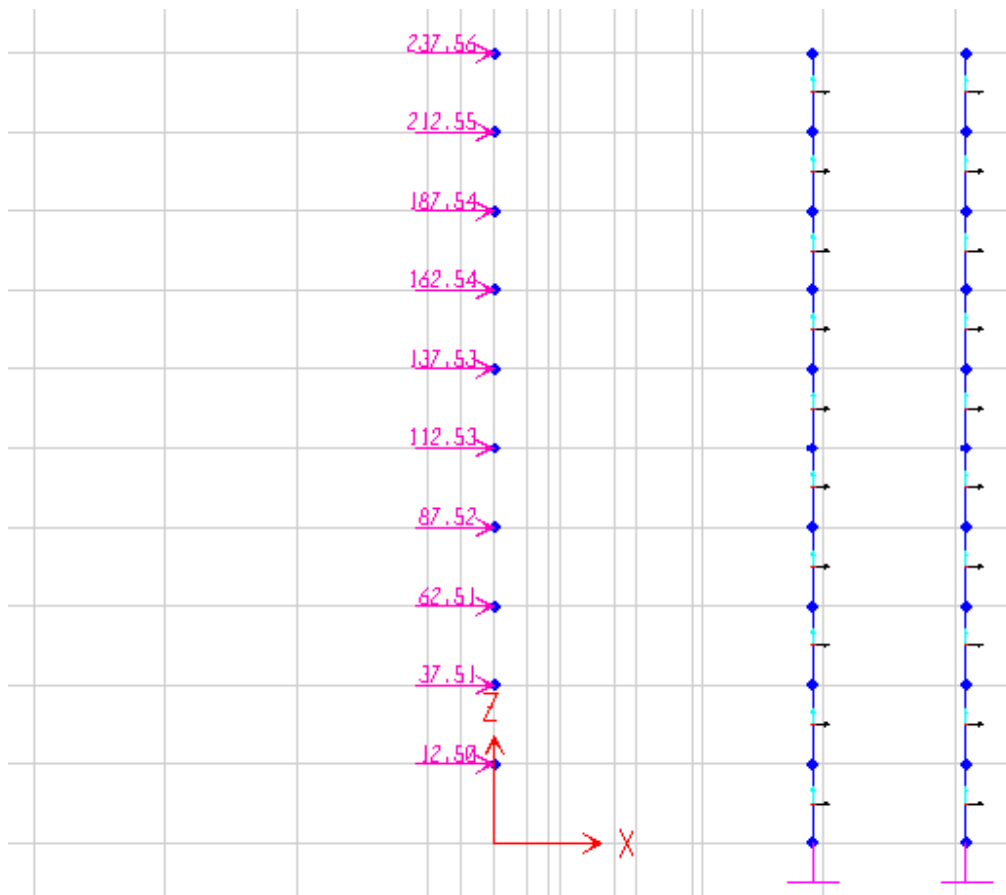


Figure 4-9: Type D in Elevation

4.3. Release and Support Condition

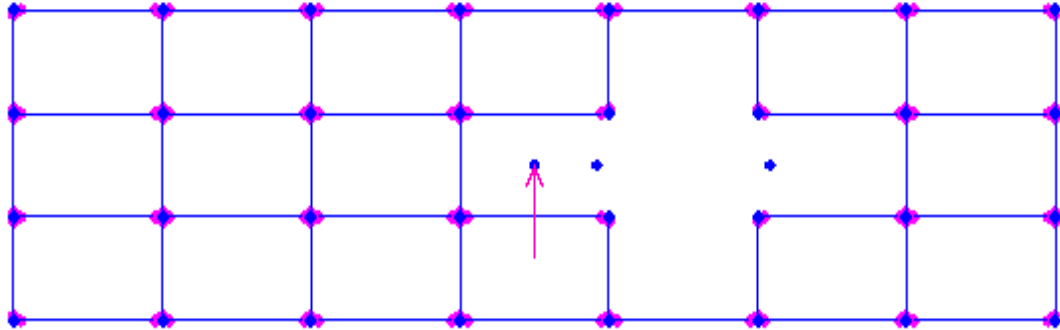
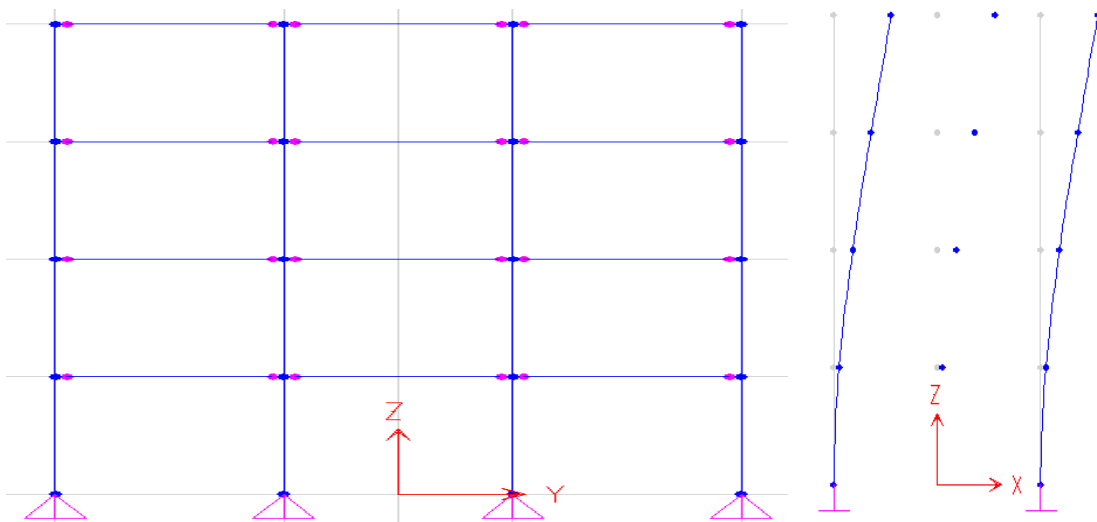


Figure 4-10: Beams Released to M33



A. Pin Supported Columns Surrounding Walls
Walls

B. Fixed End Structural

Figure 4-11: Support Condition

4.4. Equivalent Columns Modeled as Flexural Cantilever

Buildings with braced frames or shear walls, and tall buildings with un braced frames or tubular frames, usually have lateral load deformation characteristics that approach those of a flexural cantilever.

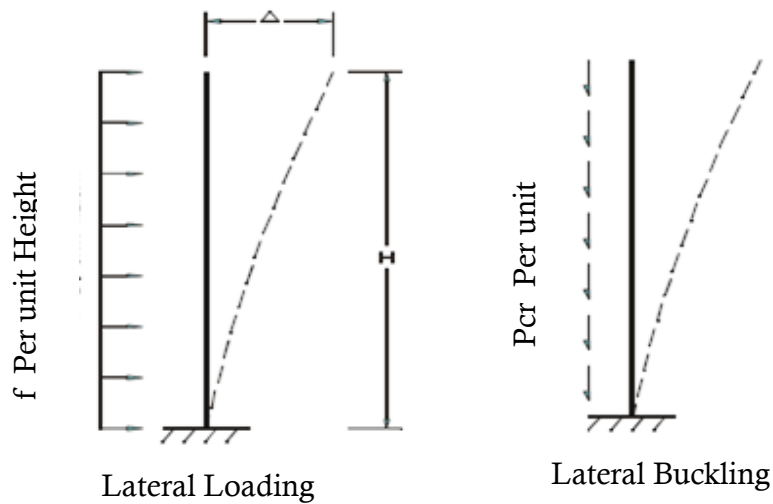


Figure 4-12: Building Modeled as Flexural Cantilever

The buckling load can be computed by the approximate buckling load analysis method with a boundary coefficient, $k=2$.

5. Analysis of Model

The procedure used for the study was based on linear elastic analysis. The analysis procedure actually consists of two steps. Lumping the actual structure into an equivalent model and subjecting the model into the applied loads.

5.1. Computation of Global Lateral Stiffness

Lateral stiffness is defined as a unit of the lateral load to the lateral displacement of a given building. However the lateral displacement in this case is not only due to the lateral loads but also due to gravity.

Hence the lateral stiffness in this paper is assumed as global lateral stiffness.

$$D = \frac{V}{\Delta} \dots \dots \dots (1)$$

Where; D =Global lateral stiffness of a building.

V =Lateral and gravity load of a building.

Δ = Lateral displacement at center of rotation of a building.

Note that lateral displacements are considered at the center of rotation of the building. Due to the large stiffness of the coupled shear walls, the center of stiffness of the whole building is located at the center of stiffness of the coupled shear walls.

From the load-displacement diagram, the global lateral stiffness is computed and then global lateral stiffness of eccentric models is compared relative to the control model.

To study the effect of torsion on lateral stability of building structures, the reduction in global lateral stability is computed as,

$$Rd(\%) = \frac{D_c - D_e}{D_c} * 100 \dots \dots \dots (2)$$

Where;

Rd (en) = Percent of reduction of global lateral stability in an eccentric model relative to the control model.

Dc=global lateral stability of centric model

De=global lateral stability of eccentric model

To study the effects of axial loading in the lateral stability of building structures, the reduction in global lateral stability is computed as

$$Rd(a) = \frac{D_{max} - D_{min}}{D_{max}} * 100 \dots\dots\dots (3)$$

Where;

Rd (a) = Percent of reduction in global lateral stability due to axial loading.

Dmax= Maximum global lateral stiffness of a building when axial loading is not considered.

Dmin=Minimum global lateral stability of a building attained before buckling.

Likely, the influence of storey number in the global lateral stability is computed as

$$Rd(hn) = \frac{DL - Dn}{DL} * 100 \dots\dots\dots (4)$$

Where;

Rd (hn) = Percent of reduction in global lateral stability

DL=global lateral stability of least storey

Dn=global lateral stability of considered storey

5.1.1. Effects of Torsion on Lateral Stability of Building Structures

Table 5-1: λ - Δ , Analysis Results for One Story, Various Wall Configurations

e (m)	V (KN)	λ	Δ (mm)	D= V/ Δ (KN/mm)
0	175.97	0	0.04	4941.59
5			0.04	4938.82
10			0.04	4933.28
15			0.04	4924.99
0		0.2	0.04	4915.36
5			0.04	3988.44
10			0.06	2831.83
15			0.06	3150.20
0		0.4	0.04	4889.41
5			0.07	2471.84
10			0.15	1160.75
15			0.13	1406.63
0		0.6	0.04	4862.39
5			0.12	1435.27
10			0.34	523.72
15			0.29	600.99
0		0.8	0.04	4835.67
5			0.21	852.15
10			0.67	261.74
15			0.71	249.00
0	1	0.04	4809.24	
5		0.34	524.50	
10		1.22	144.24	
15		2.11	83.40	

5.1.2. Effects of Axial Loading on Lateral Stability of Building Structures

Table 5-2: λ - Δ , Analysis Results for One Story, Various Wall Configurations

e (m)	V (KN)	λ	Δ (mm)	D (KN/mm)
0	175.97	0	0.03	6507.77
5			0.03	6507.77
10			0.03	6507.77
15			0.03	6507.77
0		0.125	0.03	6507.77
5			0.03	6507.77
10			0.03	6507.77
15			0.03	6507.77
0		0.25	0.05	3370.43
5			0.05	3370.43
10			0.05	3370.43
15			0.05	3370.43
0		0.375	0.04	3999.32
5			0.04	3999.32
10			0.04	3999.32
15			0.04	3999.32
0		0.5	0.83	211.83
5			0.83	211.83
10			0.83	211.83
15			0.83	211.83

5.1.3. Effects of Storey Number on Lateral Stability of Building Structures

Table 5-3: λ - Δ , Analysis Results for Various Stories

NS	V (KN)	λ	Δ_c (mm)	$D = V/\Delta$
4	307.95	0	3.74	82.34
8	262.10		42.87	6.11
10	237.56		93.47	2.54
4	307.95	0.25	4.56	67.53
8	262.10		50.65	5.17
10	237.56		110.21	2.16
4	307.95	0.5	5.83	52.82
8	262.10		61.87	4.24
10	237.56		134.24	1.77
4	307.95	0.75	8.10	38.02
8	262.10		79.48	3.30
10	237.56		171.66	1.38
4	307.95	1	13.24	23.26
8	262.10		111.10	2.36
10	237.56		237.95	1.00
4	307.95	1.25	36.27	8.49
8	262.10		184.43	1.42
10	237.56		387.55	0.61

6. Analysis Results and Discussion

6.1. Effects of Torsion on Lateral Stability of Building Structures

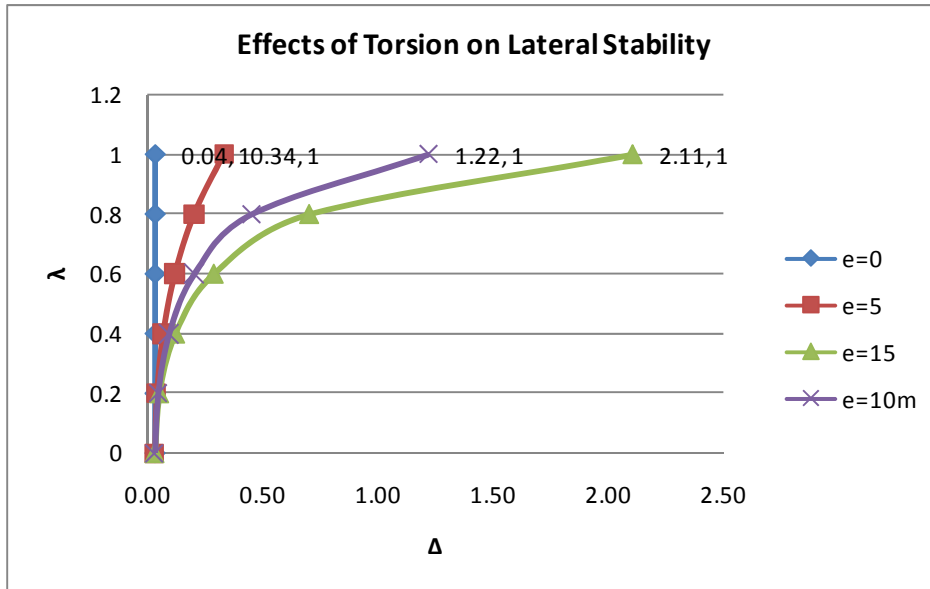


Figure 6-1: Load- Displacement Various Wall Configurations

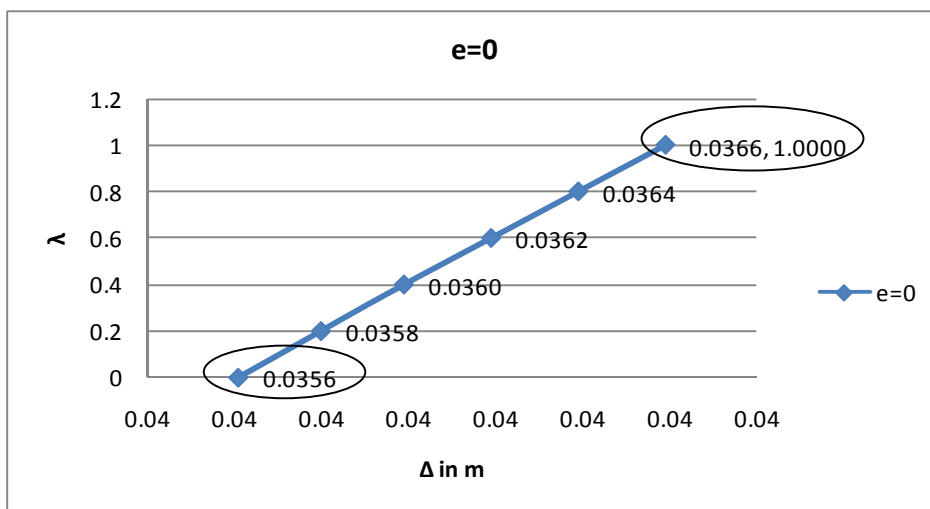


Figure 6-2: Load- Displacement Dig., E=0

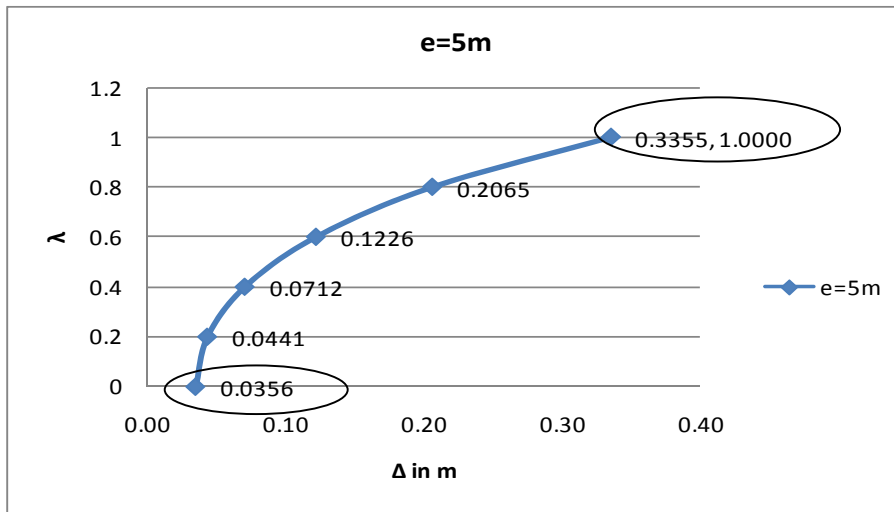


Figure 6-3: Load- Displacement Dig.,E=5m

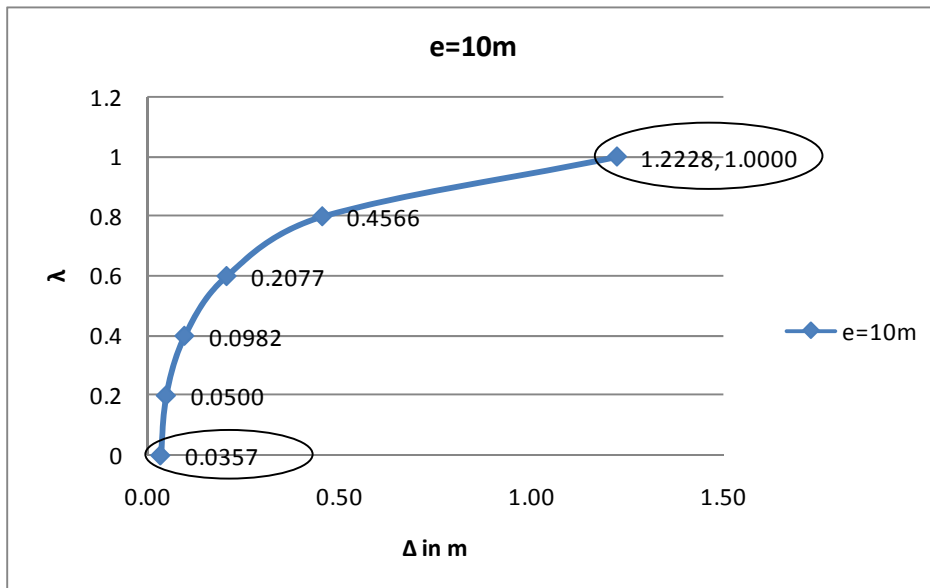


Figure 6-4: Load- Displacement Dig.,E=10m

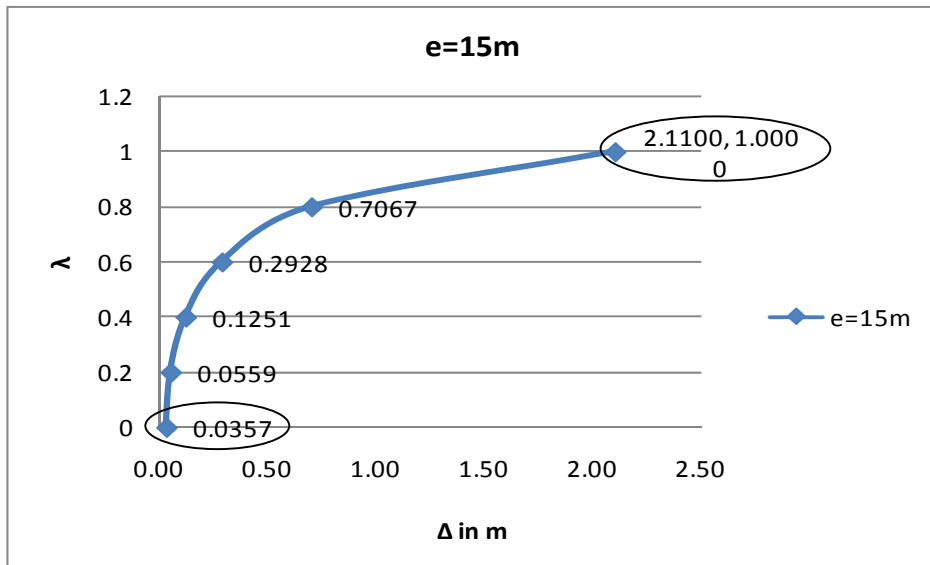


Figure 6-5: Load- Displacement Dig.,E=15m

Table 6-1: Summary of Reduction in Global Lateral Stiffness due to Torsion

Reduction in Global Lateral Stiffness of Eccentric Buildings Relative to the Control Model Due to Pure Torsion		
e (m)	D=V/Δ	Rde (%)
0	4809.2	0
5m	524.5	89
10m	144.2	97
15m	83.4	98

6.2. Effects of Axial Loading on Lateral Stability of Building Structures

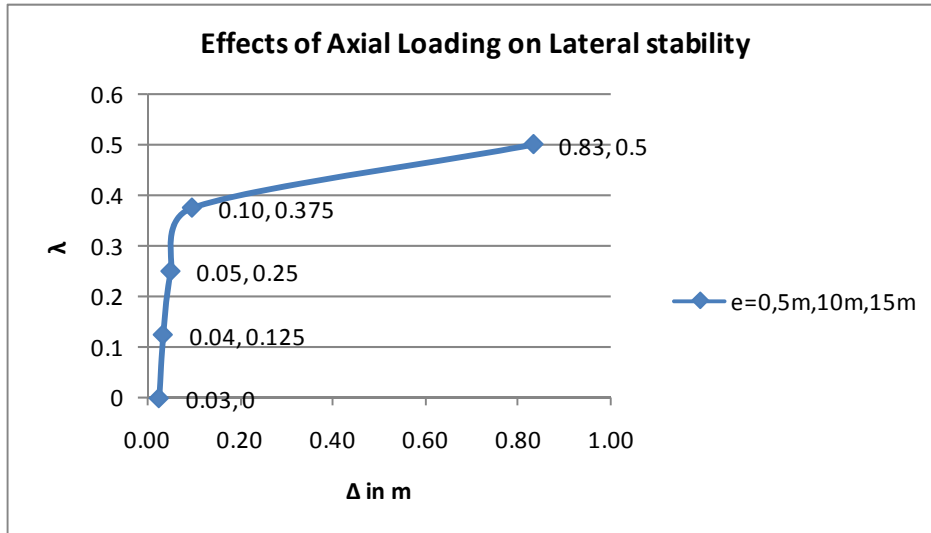


Figure 6-6: Load-Displacement Dig., $E=0=5m=10m=15m$

Table 6-2: Summary of Reduction in Global Lateral Stiffness due to Axial Loading

Reduction in Lateral stiffness of a configuration Due to Axial load		
P/Pcr	Lateral stiffness (D)=V/ Δ	Rd%
0.00	6510.54	0
0.13	5114.21	21
0.25	3368.68	34
0.38	1792.42	47
0.50	211.69	88

6.3. Effects of Number of Stories on Lateral Stability of Building Structures

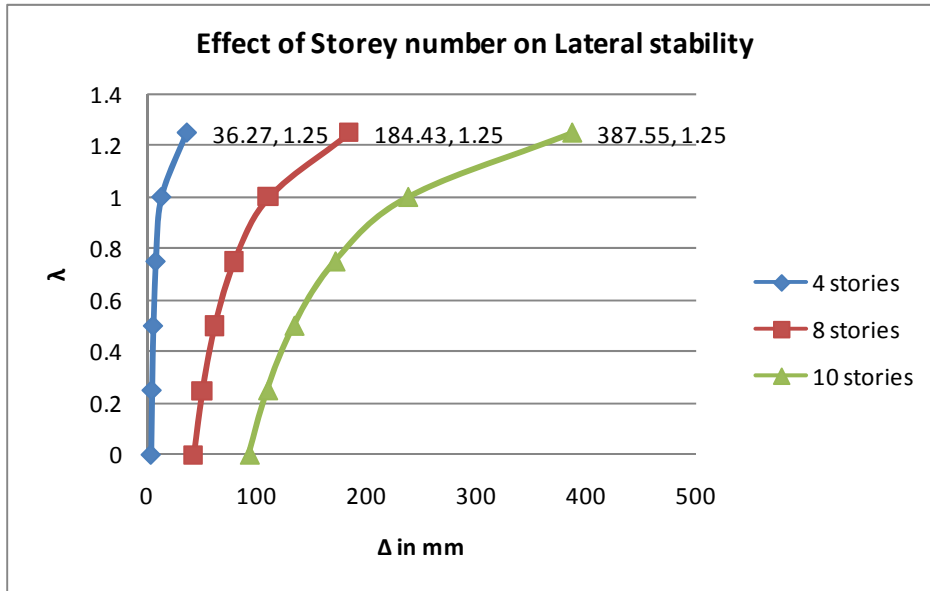
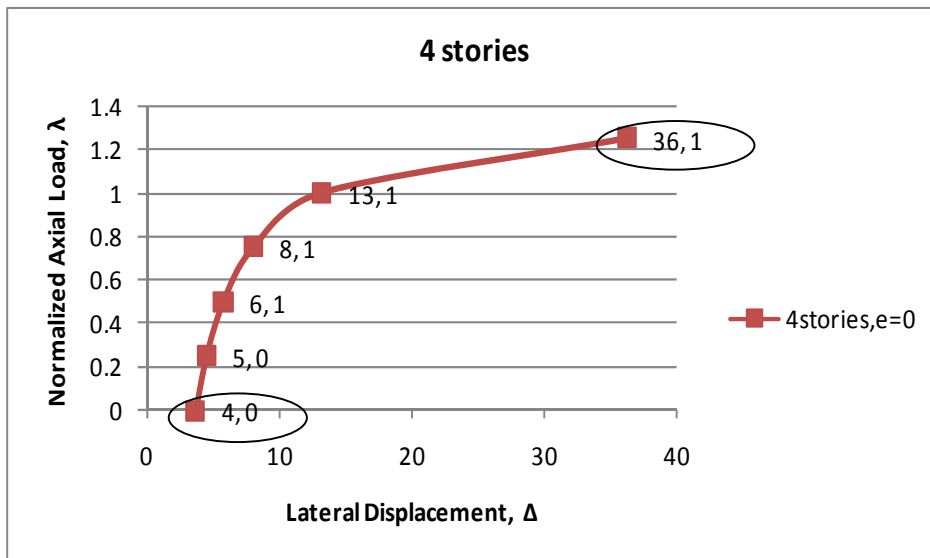


Figure 6-7: Load -Displacement dig for 4, 8 &10 Stories (2nd order analysis case)



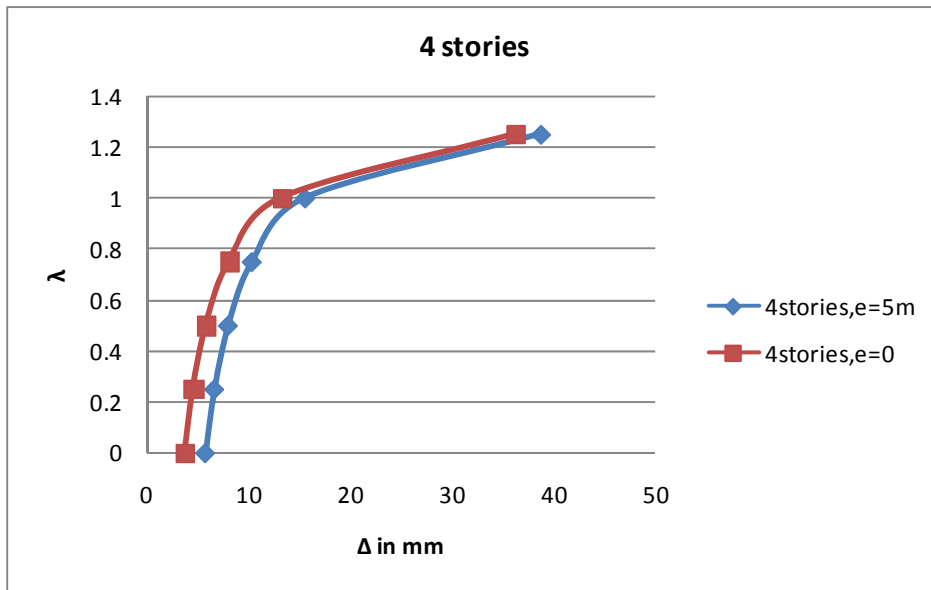
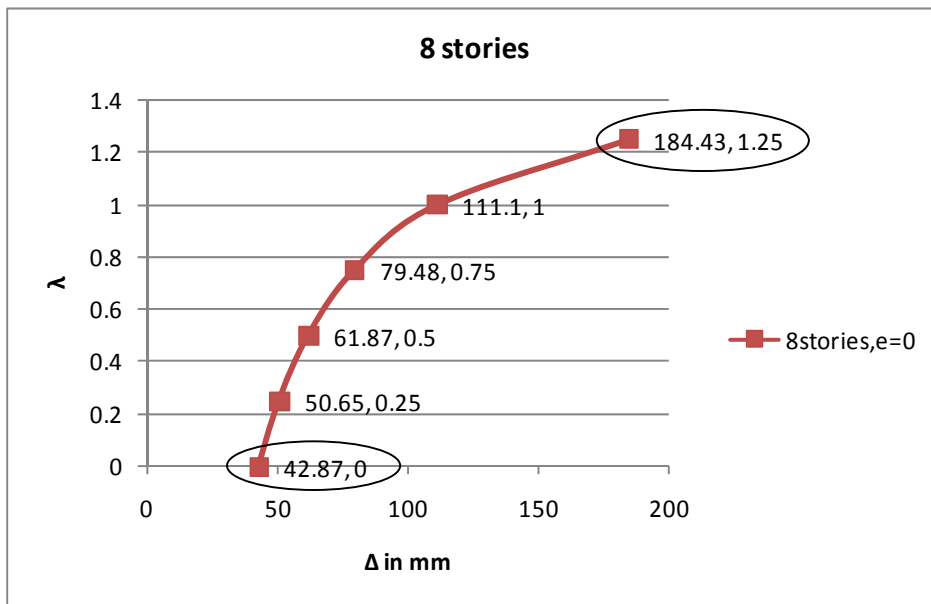


Figure 6-8: Load-Displacement Diagram, 4 Stories



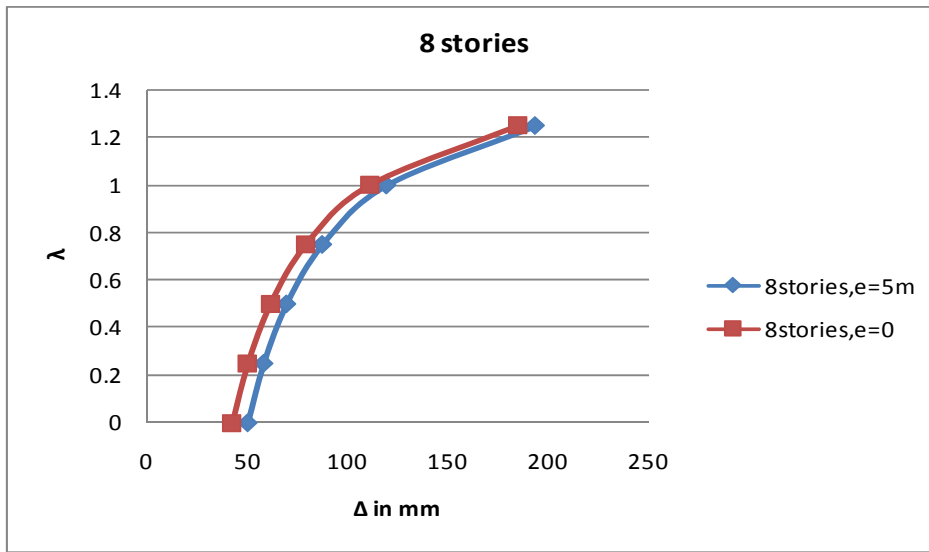
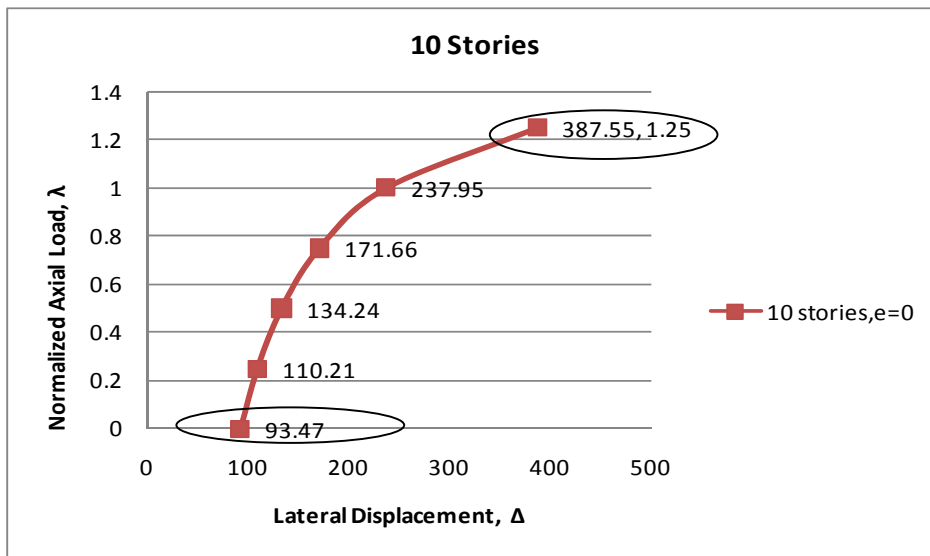


Figure 6-9:Load_Displacement,8 Stories



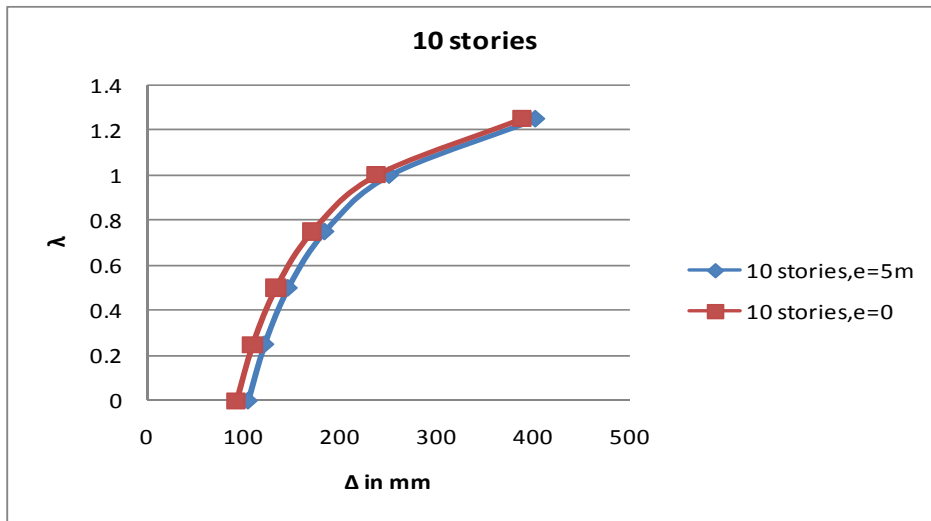


Figure 6-10: Load-Displacement,10 Stories

Table 6-3: Summary of Reduction in Global Lateral Stiffness Due to Increase in Storey Number

Reduction in Global Lateral Stiffness of a Building Relative to the Least Storey Building		
NS	$D=V/\Delta$	Rd%
4	19.41	0
8	6.06	69
10	3.23	83

6.4. Commentary

The following observations are drawn from the outcome of the parametric study.

- ❖ Shear force distribution of centric building shows that there is uniform shear distribution between wall 1 and wall 2 however shear distribution of eccentric buildings is non uniform (unbalanced). This implies that torsion causes unbalanced stress on structural elements of a building.
- ❖ Analysis results show that lateral displacement of centric buildings is uniform throughout the grids.
- ❖ On the contrary drift is more on one side of grids than the other for eccentric wall configuration of buildings.
- ❖ For the same application of loading, lateral displacement of a building increases while eccentricity increases.
- ❖ Load-deflection diagrams shows that centric buildings respond linearly while that of eccentric buildings is non linear. This implies that torsion causes non linear stability failure.
- ❖ Axial loading affects the lateral stability of a building structure unfavorably. In all the series buildings whether it is centric or eccentric, the lateral stability is equally affected by axial loading. This is because the centers of stiffness of all the series models lie in the center of the walls.
- ❖ Analysis results of various stories Figure 6-8: Figure 6-10 shows that the lateral displacements increase as storey number increases.

7. Conclusions and Recommendations

- ❖ Torsion has an adverse effect on lateral stability of buildings.
- ❖ With the same magnitude of lateral and axial load, the lateral stability of a building decreases with increase in the eccentricity between center of mass and center of rotation. Thus, the current construction practices with buildings having large eccentricities between center of mass and center of rotation should be avoided.
- ❖ In highly seismic areas, excessive lateral drift should be minimized by selecting the most centric configuration compatible with architectural requirements. However if architectural considerations like space and circulation require eccentric placement of the lift shafts, torsion must be minimized by providing balancing structural elements.
- ❖ For the same location of walls, lateral stability of a building decreases as its storey number increases. Thus high rise buildings should be designed to have good lateral stiffness to maintain their stability during high seismic hazards.
- ❖ Lateral stability of a building is affected by axial loading. Hence superstructure axial loads should be considered while designing buildings.

8. Suggestions for Future Work

Further investigations can be done on various topics remarking the effects of torsion

- ❖ Most buildings are combinations of frame and wall structures, therefore further studies can be done on such topic considering both wall and frames as moment resisting structures.
- ❖ The demand of architects and clients is becoming extra ordinary. Further Studies can be done by considering irregular plan configurations or irregular stories in elevation.

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