JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Comparative Study on Evaluating and Improving Seismic Load Resistance of Multistorey Buildings with Floating Columns

A Research Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

BY

HIKA BENTI

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DECLARATION

I declare that this research entitled "Comparative Study on Evaluating and Improving Seismic Load Resistance of Multistorey Buildings with Floating Columns" is my original work and has not been presented by any other person for an award of a degree in this or any other University.

HIKA BENTI	________________	________________
Name of the student:	Signature:	Date:

Approved by:

Eng. ELMER C.AGON	________________	________________
Advisor	Signature	Date
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Co-Advisor	Signature	Date

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ABSTRACT

In the present scenario, due to less availability of space and more population, in multi-storey buildings (both residential and commercial) an open space is reserved for parking, assembly hall or for auditorium purposes at any level or storey by using floating columns.

This floating column is a vertical member which rest on a transfer beam but does not transfer the load directly to the foundation. The floating column acts as a point load on the transfer beam and this beam transfers the load to columns found below it. However, deviation or discontinuity in this load transfer path results in poor seismic resistance of the building, which raised interest on this research.

This research study is attempted to compare the parameters which includes the effect of floating column provision on seismic resistance of buildings, assessing optimum position of floating column that can better resist seismic force, evaluating effect of critical beam and column dimension increment on building with floating columns, evaluating percentage effect of lift shear wall provision on seismic resistance of building with floating columns. It was done on symmetrical 6-storey building, by comparing three critical parameters; storey displacement; storey drift and storey shear using ETABS 2016.00 as per ES EN 1998-1:2015.

As per comparison made, provision of floating column at ground floor edge corner increased maximum lateral displacement of the building without floating column by 31.4% due to structural irregularity occurred in discontinuity of load transfer path, while changing position of floating column from ground floor edge corner to fourth floor parallel position led to decrement of lateral displacement by 4.4%. Increment of critical beam and column dimension reduced lateral displacement of optimized position floating column building by 0.69% and 8.21% respectively. Providing Center lift shear wall on optimized position floating column building reduced lateral displacement by 22.17%, using combination of lift shear wall and critical member dimension increment reduced lateral displacement of optimized position floating column building by 28.03%.

Generally, the result show that provision of floating column reduce seismic resistance of buildings which can be improved by moving floating column from outer edge to inner edge, from lower to upper floor, increasing column supporting transfer beam and using lift shear wall for vertical transportation.

Keywords: *ETABS 2016.00, Floating Column, Seismic load resistance*

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ACRONYMS AND SYMBOLS

DCM	Medium Ductility
ELF	Equivalent Lateral Force
ES EN	Ethiopian Standard Based on European Norm
ETABS	Extended Three Dimensional Analysis of Building System
Fb	Seismic base shear force
FC	Floating Column
Fi	Horizontal force acting on storey i;
GF	Ground Floor
HCM	High Ductility
mi, mj	Story masses
M	Total mass of the building above the foundation or top of a rigid basement
RC	Reinforced Concrete
RSA	Response Spectrum Analysis
T	Vibration period of a linear single degree of freedom system
ao	Bedrock acceleration
q	Behavior factor.
qo:	Basic value of the behavior factor
RC	Reinforced Concrete
si, sj	Displacements of masses mi, mj in the fundamental mode shape
λ	Correction factor.
γ_1	Importance factors
@	at
β	Lower bound factor for the horizontal design spectrum.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Floating column is a vertical member but its lower end has no connection with the foundation. Its lower end rest on beam that is a horizontal member, this beam transfer the load of floating column to other columns below it. There are numerous projects in which floating columns are implemented, particularly above the ground floor, where transmission girders are hired, so that additional exposed space is obtainable in the ground floor. These exposed spaces are required due to shortage of space, population, aesthetic and functional requirements essential for assembly hall or parking purpose. (Naveed FR, et al 2018)

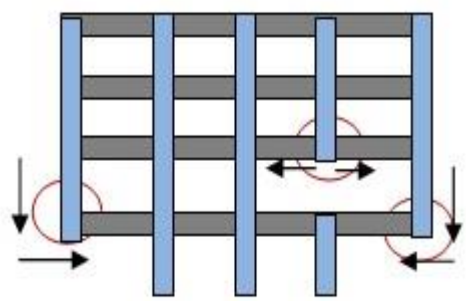
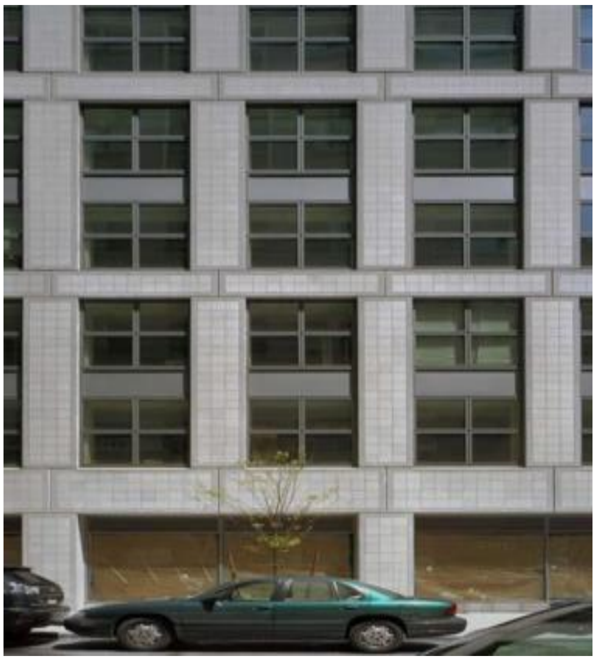
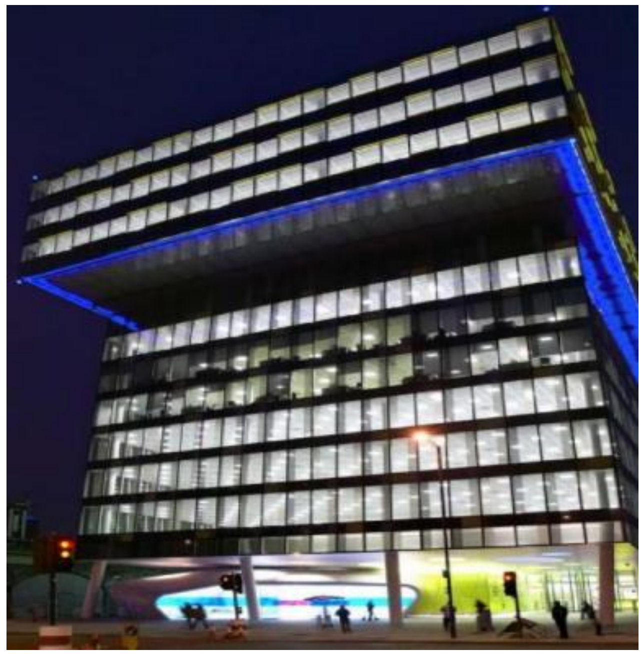


Figure 1. 1 Floating or Hanging Column

These floating columns are highly disadvantageous in a building built in seismically active areas. The earthquake forces that are developed at different floor levels in a building need to be carried down along the height to the ground by the shortest path. Deviation or discontinuity in this load transfer path results in poor performance of the building. The behavior of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. Many buildings with an open ground storey intended for parking collapsed or were severely damaged in Gujarat during the 2001 Bhuj earthquake. (S.K. Duggal, 2010).

To optimize this shortage of space and poor seismic performance of buildings with floating columns, interest on this research raised which deals with evaluating effect of floating columns and improving seismic load resistance of multistory buildings with floating columns. Measurements like changing position of floating columns, increasing dimension of critical column and beam, providing lift shear wall at the center had been done. Storey displacement, storey drift and base shear, of each building were compared and the best method that resist seismic load was recommended.

240 Park Avenue South in New York, USA   Palestra in London, United Kingdom.

Figure 1. 2 Buildings with floating columns (Raveed et al, 2018)

1.2 Statement of the problem

It is known that population of the world is increasing day to day which leads to shortage of space and making multistory buildings mandatory. So that good aesthetic view, auditorium hall and car parking area is becoming mandatory in or under these multistorey buildings. To make available space for these functions, floating column is introduced in these buildings.

In Ethiopia, applying floating column and providing car parking in multistory building is very less, even though using main road for car parking is the one of the major cause of traffic over crowd especially in a capital city Addis Ababa. It must be due to lack of specific guide lines and research on the idea in the country.

Floating column, which is interrupted and supported on beams are associated with a poor seismic behavior due to disrupted and longest load transfer path and incapability of transferring inertia forces safely to ground. A clear load path will not available in a floating column during earthquake for transferring the lateral forces to the foundation. (Harugoppa and Muranal, 2019)

Floating columns, though highly discouraged, are still an important part of the construction industry. It is on structural engineers hands to make it capable of resisting all loads encounter it. The detail effect of this floating column on resisting seismic loads and methods to improve this load resistant should be known.

In this research seismic analysis of multistorey buildings with floating column at different floors and various positions in a floor is studied. Then, the base shear, storey displacement, and storey drift of each building is compared. Comparing the above value optimum position is selected, and then some mechanisms like increasing dimensions of critical members and using shear wall at center as a lift was considered. Finally conclusion and recommendation was drawn on the effect of floating column and on improving seismic resistant. Modeling and analysis is carried out by using ETABS 2016 as per ES EN 1998-1:2015

1.3 Research questions

1) What is the effect of floating Columns at different positions on seismic resistance of buildings in terms response spectrum analysis?
2) Where is the optimum position of providing floating columns such that it will better resist seismic load?
3) What is the effect of changing size of critical columns and supporting beams on seismic resistance of buildings?
4) What is effect of using lift shear wall at center on seismic performance of multistory buildings with floating columns?

1.4 Objectives

1.4.1 General objective

- ✓ The general objective of the study was to evaluate the effects of floating column and comparing seismic resistant of multistory buildings with floating columns improved with different methods.

1.4.2 Specific objectives

- ✓ To study the seismic effect of floating columns on multistorey buildings.
- ✓ To assess optimum position of floating columns along plan and elevations.
- ✓ To evaluate the effect of increasing size of critical beams and columns on seismic resistance of multistorey buildings with floating columns.
- ✓ To evaluate the percentage effect of using lift shear wall at center on seismic performance of multistorey buildings with floating columns.

1.5 Significances of the study

This research can play a great role by enhancing applicability of floating column buildings such as transferring car parking on the main road into main building so that traffic congestion will be reduced.

It can also use as a reference point of view for owners, contractors and consultants so that they will understand apparently, where and how to provide floating columns considering seismic resistant capability.

It will also allow the researchers and institutions to gain knowledge on the effect of floating columns and improving seismic resistance of buildings, and provide base for further career improvement.

Generally, importance of this study deals with knowing the effect of floating columns on seismic resistance of a building and taking measurements to enhance seismic resistance.

1.6 Scope of the study

Seismic response of 6 storey building without floating column was compared with building with floating column at different positions, then some measurements were taken to improve seismic resistance of building with floating column such as changing position of floating column, increasing dimension of critical column and beam and providing shear wall at the center.

It was done using ETABS 2016.00 as per ES EN 1998-1:2015. Response parameters like storey displacement, storey drift and storey shear were studied for critical seismic zone.

The main gap filled in this research was that much attention was given to improving seismic resistant of multistory buildings while most of previous researchers were concerned on effects of floating columns on shear , moment and reinforcement requirements of multistory buildings with floating columns.

CHAPTER TWO

RELATED LITERATURE REVIEW

2.1 Earthquake loading

A large portion of the modern urban infrastructure comprises of irregular buildings. Floating columns provided in a multi-story building makes an irregular building. Multi-storey framed building with floating columns in one or more positions are at risk to collapse during strong earthquakes. But in recent times, buildings in urban cities are required to have column free space due to aesthetic and functional requirements. During earthquake, the forces developed at different floor levels in a building are needed to be carried down by the shortest path.[Agarwal and Shrikhande, 2006] Multistory buildings with Floating columns are categorized under irregular structures in elevation since it runs with interruption from their foundations to the top of the building. (ES-EN 1998 2015).

2.2 Criteria for structural regularity

For the purpose of seismic design, building structures are categorized into being regular or non-regular.

Table 2. 1 Consequences of structural regularity on seismic analysis and design

Regularity		Allowed simplification		Behavior factor
Plan	Elevation	Model	Linear Elastic Analysis	(for linear analysis)
Yes	Yes	planar	Lateral force	Reference Value
Yes	No	planar	modal	Decreased Value
No	Yes	spatial	Lateral force	Reference Value
No	No	spatial	Modal	Decreased Value

2.2.1 Criteria describing regularity in plan

- ✓ Symmetric in plan w.r.t. two orthogonal directions
- ✓ Compact plan configuration (no H, I, X shapes)
- ✓ In-plane stiffness of floors sufficiently large compared to stiffness of vertical elements

- ✓ Under the equivalent static seismic force, maximum displacement in the direction of seismic force does not exceed avg. displacement by 20%.
- ✓ The slenderness λ = Lmax/Lmin of the building in plan shall be not higher than 4, where Lmax and Lmin are respectively the larger and smaller in plan dimension of the building, measured in orthogonal directions.
- ✓ In single storey buildings, the center of stiffness is defined as the center of the lateral stiffness of all primary seismic members. The torsional radius r is defined as the square root of the ratio of the global torsional stiffness with respect to the centre of lateral stiffness, and the global lateral stiffness, in one direction, taking into account all of the primary seismic members in this direction.
- ✓ In multi-story buildings, only approximate definitions of the centre of stiffness and of the torsional radius are possible. A simplified definition, for the classification of structural regularity in plan and for the approximate analysis of torsional effects, is possible if the following two conditions are satisfied:

  a) All lateral load resisting systems, such as cores, structural walls, or frames, run without interruption from the foundations to the top of the building,

  b) The deflected shapes of the individual systems under horizontal loads are not very different. This condition may be considered satisfied in the case of frame systems and wall systems. In general, this condition is not satisfied in dual systems.

2.2.2 Criteria for regularity in elevation

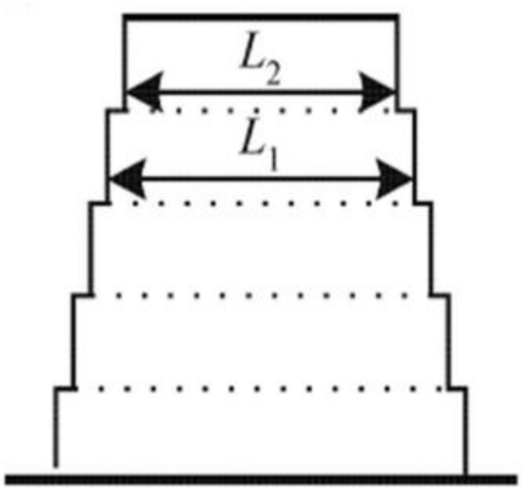
- ✓ All lateral load-resisting systems, such as cores, structural walls, or frames, shall run without interruption from their foundations to the top of the building or, if setbacks at different heights are present, to the top of the relevant zone of the building.
- ✓ Both lateral stiffness & mass of story's remain constant or reduce gradually without abrupt changes.
- ✓ Ratio of actual storey resistance to required resistance should not vary disproportionately between adjacent stories.
- ✓ When setbacks are present, the following additional conditions as per ES-EN 1998-1of section 4.2.3.3 (5) will be applied.

a) For gradual setbacks preserving axial symmetry, the setback at any floor shall be not greater than 20 % of the previous plan dimension in the direction of the setback (see Figure 2.1.a and Figure 2.1.b);

b) For a single setback within the lower 15 % of the total height of the main structural system, the setback shall be not greater than 50 % of the previous plan dimension (see Figure 2.1.c). In this case, the structure of the base zone within the vertically projected perimeter of the upper stories should be designed to resist at least 75% of the horizontal shear forces that would develop in that zone in a similar building without the base enlargement;

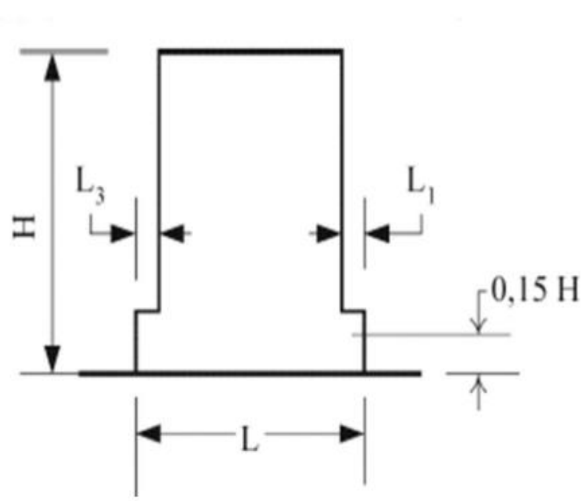
c) If the setbacks do not preserve symmetry in each face, the sum of the setbacks at all stories shall be not greater than 30 % of the plan dimension at the ground floor above the foundation or above the top of a rigid basement and the individual setbacks shall be not greater than 10 % of the previous plan dimension (see Figure 2.1.d) (*ES EN 1998-1:201).*

(a)



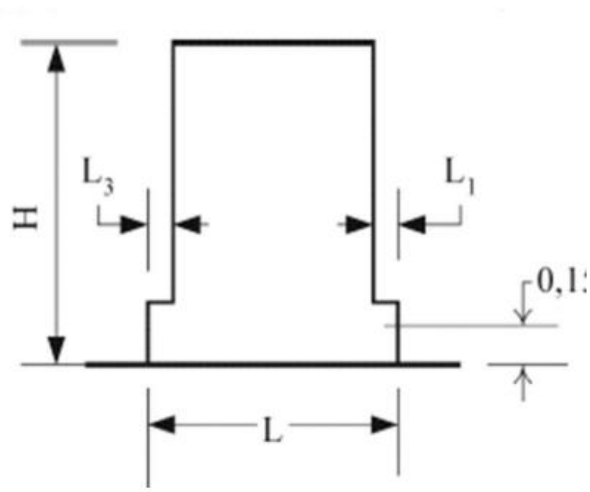
Criterion for (a): $\frac{L_1 - L_2}{L_1} \leq 0.20$

(b) (Setback occurs above 0.15 H)



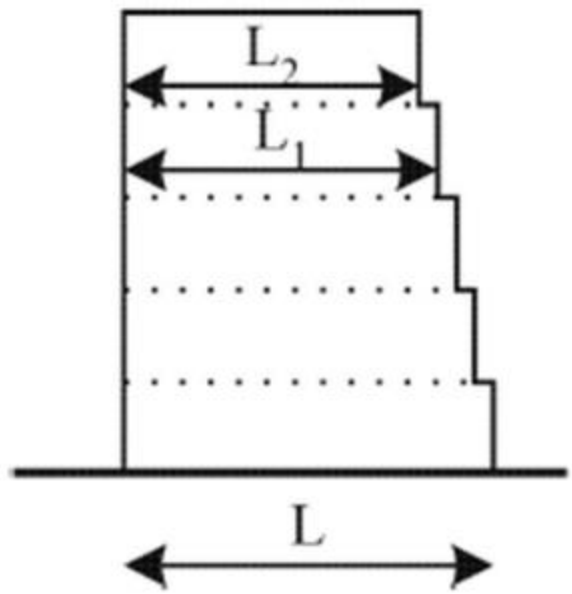
Criterion for (b) $\frac{L_3 + L_1}{L} \leq 0.20$

(c) (Setback occurs below 0.15 H)



Criterion for (c) $\frac{L_3+L_1}{L} \leq 0.50$

(d)



Criteria for (d) $\frac{L-L_2}{L} \leq 0.30$

$$\frac{L_1 - L_2}{L_1} \leq 0.10$$

Figure 2. 1 Criteria for regularity of buildings with setbacks (*ES EN 1998-1:2015)*

2.3 Floating columns.

Floating columns resting on the tip of taper overhanging beams without considering the increased vulnerability of lateral load resisting system due to vertical discontinuity. This type of construction does not create any problem under vertical loading conditions. However, during an earthquake a clear load path is not available for transferring the lateral forces to the foundation. Lateral forces accumulated in upper floors during the earthquake have to be transmitted by the projected cantilever beams. Overturning forces thus developed overwhelm the columns of ground floor. Under this situation the columns begin to deform and buckle, resulting in total collapse. This is because of primary deficiency in the strength of ground floor columns, projected cantilever beam and ductile detailing of beam-column joints. Ductile connection at the exterior beam-column joint is indispensable for transferring these forces. The below figure shows damage in reinforced concrete residential buildings (G+4) due to floating columns. This is the second most notable and spectacular cause of failure of buildings. The 15thAugust Apartment and Nilima Park Apartment buildings at Ahmedabad are typical examples of failure in which, infill walls present in upper floors are discontinued in the floors.

(a) (b)

Figure 2. 2 Failure of reinforced concrete buildings with floating columns

(a) 15th August Apartment, Ahmedabad, collapse of building on floating columns; (b) Nilima Park Apartment, Ahmedabad, large scale damage in the upper floors (Agarwal Pankaj, Shrikhande Manish, 2002

Figure 2. 3 Shear cracks in the cantilever stub beam supporting a floating column in a storey RC frame residential building in Ahmadabad. (Murthy et.al.2002)

Figure 2. 4 Large scale damage in the upper floors (Murthy et.al. 2002)

2.4) Design requirement for floating column under seismic forces.

Discontinuity of column in a structure, which is referred as floating/hanging column, is one of the factors for reduction in capacity of the structure. It is often induced in structures due to either client requirement or improper planning which becomes more vulnerable during earthquake. The cantilever spans and transfer girders supporting the floating columns develop very high shear force and bending moment under gravity loads. The load transferring mechanism in beam columns and its effect on ductility of a structure when columns are discontinued at various floors and positions is presented here. The dynamic linear and nonlinear static analysis is carried out to analyze ordinary moment resisting frame models with conventional and floating columns. The requirement of appropriate value of response reduction factor which effect ductility factor and stiffness irregularity is studied. The study proposed the response reduction factor and reinforcement detailing in members supporting floating columns to reduce the effect of discontinuity in column in ordinary moment resisting frames. Harugoppa.R, Muranal. S.M. (2019).

- ✓ Discontinuity at of column in any floor will increase the axial force, shear force and bending moment by 9, 1.5 and 2 times respectively in first storey columns and by 2 times in transfer girders in comparison with conventional structures.
- ✓ A response reduction factor higher than mentioned in IS 1893:2002 Part 1 need to considered during the design of ordinary moment resisting frames.
- ✓ Discontinuity of column leads to decreases the ductility of the structure up to 40% during earthquake.
- ✓ The additional development length to longitudinal reinforcement and confinement reinforcement is required at beam column joint to keep deflection and crack width within allowable limit. Harugoppa.R, Muranal. S.M. (2019)

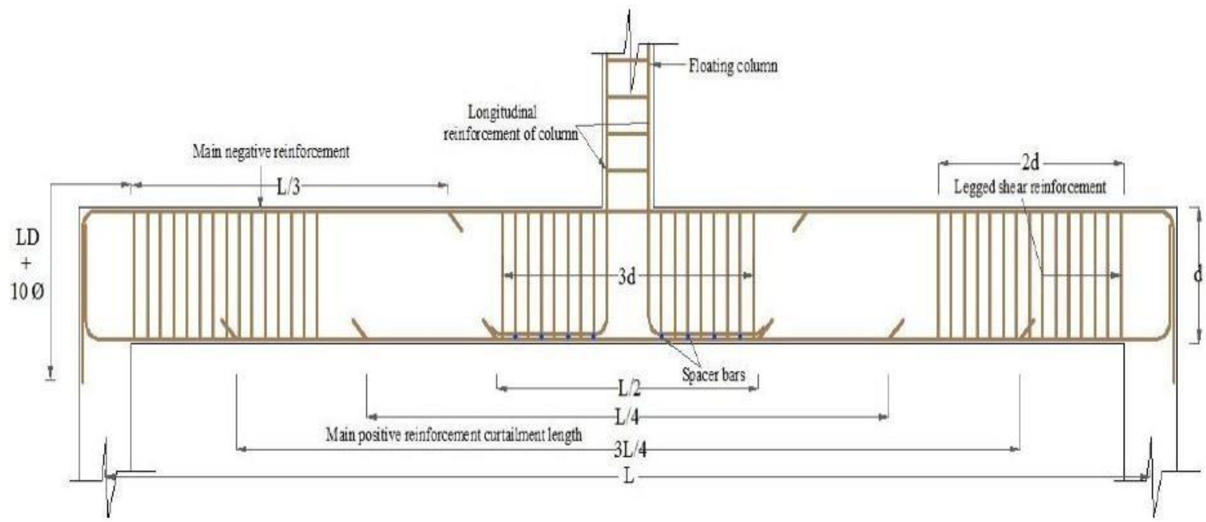


Figure 2. 5 Proposed reinforcement detailing of floating column and its supporting members Harugoppa.R, Muranal

2.5 Related literatures On analysis of buildings with floating columns

Malaviya P, Saurav (2014), had done their research work on comparative study on effect of floating columns on the cost analysis of a structure designed on stadd pro v8i.Various different models were prepared and analyzed. They determined that in the framed structure with no floating columns the nodal displacements is minimum with uniform distribution of stresses at all beams and columns. Which makes it most economical

Mundada AP and Sawdatkar SG (2014), deals with the comparative study of seismic analysis of multi-storied building without floating columns, with floating columns and floating columns with struts. The results of the investigation advocates that the chances of failure of buildings with floating column are much higher as compared to the buildings without floating column.

Nikhil1 & Pande (2014), Studied Seismic Behaviour of RC Building with Floating Columns. Emphases on the numerous kinds of irregularities like floating columns at several levels and locations. A G+06-storied building with dissimilar architectural difficulties such as external floating columns, internal floating columns and combination of internal and external floating columns is evaluated for several earthquake zones. Dissimilarity in several factors like, displacemnts, moments and forces on columns and beams at numerous floor level are associated and significant co-relationship between these values are recognized with graphs. Do not talk about floating column effects on story shear and story drift, and there is no solutions provided to improve effects of floating column effects.

Bhensdadia H. (2015): studied pushover analysis of frames with FC and soft storey in various earthquake areas. Pushover analysis will reflect the performance level of buildings, for designed capacity approved till the occurrence of failure, it aids in finding the collapse or failure load and ductile capacity of the framed building structures. For carrying studies on the performance response levels of the building, the analysis is done through both linear-static and non-linear static systems in agreement with IS:1893-2002 (part-1). ETABS, a finite element method based structural database is used for analysis and design purposes. Results advocates that push over analysis is precise and wellorganized method of analysis, and also the drift and movement of building starts increasing from minor quake prone regions to major quake prone regions.

Ms. Waykule S.B, et al (2016): Studied analysis of G+5 Building with and without floating column in highly seismic zone v. Two models are created with floating column at 1st and without floating column building. Linear static and time history analysis were carried out of both models. from linear static analysis seismic parameter such as time period, base shear, storey displacement, storey drift are compared. modeling and analysis done by using sap 2000v17 software. It was concluded that Building with floating column has more time period, less base shear, more Displacement and more storey drift as compared to building without floating column.

Sasidhar T, et al (2017) performed the analysis of multistoried building with and without floating column. Residential multistoried building consisting of G+5 has been chosen for carrying out project work. The work was carried out considering different cases of removal of columns in different positions and in different floors of the building. The equivalent static analysis is done on the mathematical 3-D model of building and results have been compared. All the work was carried out by using the software ETABS Version 9.7.4. Based on the test results, the following conclusions were made.

- ✓ Use of floating columns results in the increase in the bending moment, shear and Steel requirement.
- ✓ These floating columns are not suitable in the seismic zones in which load travel path will be disturbed due to earthquake and building may be damaged.
- ✓ Providing floating column at 2nd floor results in reduced moment and shear so that steel requirement of the whole building can be minimized
- ✓ Hence provision of floating column is advantageous in providing good floor space index but risky and vulnerability of the building increases

Naveed FR, et al (2018): Studied the Analysis of Multi-Storey Building with Floating Column. They explained only about how to analyze buildings with floating columns using ETABS.

Dheeraj,Pankaj (2018) studied Seismic analysis of buildings through floating column in matlab, They proved Storage displacement increases along the height of the building. Each model increased the displacement values of floating column buildings, especially for columns of floating columns. They verified that buildings with floating columns are more vulnerable to floating columns and they did not provide any recommendation that floating columns can be used.

Umeruddin P, et al (2017): studied the experimetal behaviour of multi storeyed building with floating column for seismic loads. The study is concerned with framing of the building having floating columns. Existing residential building comprising of G+10 structures has been selected for carrying out the project work. All building models are generated using the software STAAD Pro 8Vi and are analyzed using equivalent static method.

Kishalay Maitra et. al, (2018) performed Evaluation of Seismic Performance of Floating Column Building. In the modern multi-story construction, floating column is an unavoidable feature of buildings. Such features are highly undesirable in building built in seismic prone areas. This study highlights the performance of floating column building and compared with normal building under seismic load. In this study, static and dynamic analyses using response spectrum method have been carried out for multi-story building with and without floating column.

Abdul Azeed et al (2019) studied analysis and design of residential building with floating column, a residential multistoried building consisting of G+6 has been chosen for carrying out project work. The work was carried out considering different cases of removal of columns in different positions and in different floors of the building. The above building models are generated using the software E-TABs 2015 and are analyzed and designed by using IS 456-2000 guidelines. Various types of loads on a structures and requiring in consideration in design are, Dead load, Live load and Wind load. Based on the test result, the following conclusions were made:

- ✓ Moment, shear & steel requirement of the whole building can be minimized when floating column is at 1 st floor.
- ✓ Hence provide the floating column is advantageous in providing good floor space index but risky & vulnerability of the building increases.
- ✓ The use of floating column in modern building are increasing vastly.

Mo Farhan (2019): presents RCC framed building with floating column on first floor which is analyzed and designed under the normal loading condition. So, this research deals with the analysis and design of framed structure with floating column at ground floor of the building, the behaviour of floating. This research paper presents the behaviour of floating column in a building, its load distribution and continuity in structure. It was observed that floating columns don’t take load as much as those columns which are connected to foundation. The main points observed in this research are:

- ✓ The total variation in percentage of steel in the structure can be minimized by providing floating columns.
- ✓ The percentage of steel in case of beams get increased whereas in case of columns no increment takes place in case of reinforcing bars.
- ✓ In analysis process if grade of concrete increases the area of reinforcement decreases.

- ✓ The reinforcement percentage in edge and interior columns are more compare to exterior columns. The percentage reinforcement in external beams are more compared to internal beams.
- ✓ In case of beams, the reinforcement percentage in bottom middle portion is same in all cases.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Methodology

To determine seismic behavior of the buildings with floating columns the basic components like lateral storey displacement, inter storey drift and base shear has been analyzed using equivalent static method. Equivalent static analysis (also referred to as equivalent lateral force, ELF method) is the simplest type of analysis that is used to assess the seismic response of structures. It was assumed that the behavior is linear elastic (which corresponds to material linearity). The horizontal loads considered equivalent to the earthquake forces were applied along the height of the structure and were combined with vertical (gravity) loads.

3.2. Study area

The study was assumed to be conducted in one of highest seismic zone of Ethiopia, that is zone V (Elidar, Afar region randomly selected) where it is critical place to be affected by seismic load.

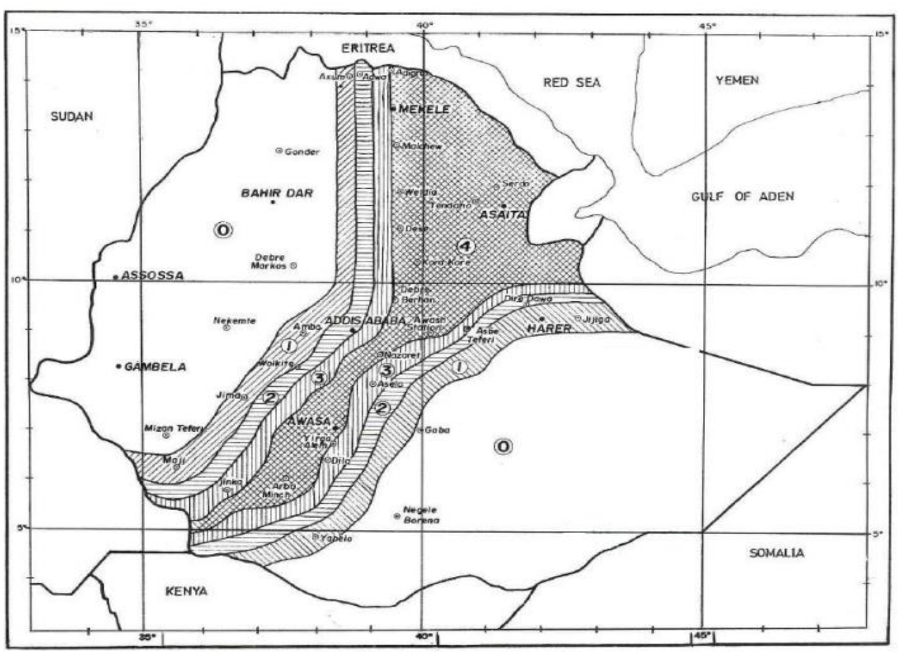


Figure 3. 1 Seismic hazard map of Ethiopia

(ES-EN 1998-2015)

3.2 Research design

In this research study, seismic response of building without floating column were compared with buildings having floating columns, then some methods of improving seismic performance like changing position of floating columns, increasing critical members dimension and providing lift shear wall at center were studied. The modeling of the buildings has been done using ETABS 2016 16.0.0 software, following the codes of ES EN 1998-1:2015 for horizontal loading resisting system, EC EN1991 -1 -1 for gravity loads and EBCS EN1992-1 -1 for aspects related with the behavior of the concrete. The model is 6 storey building with plan dimension 22.5mx22.5 m and storey height 3.15m.The plan is 6bayx6bay with each bay 4.5m length in both directions.

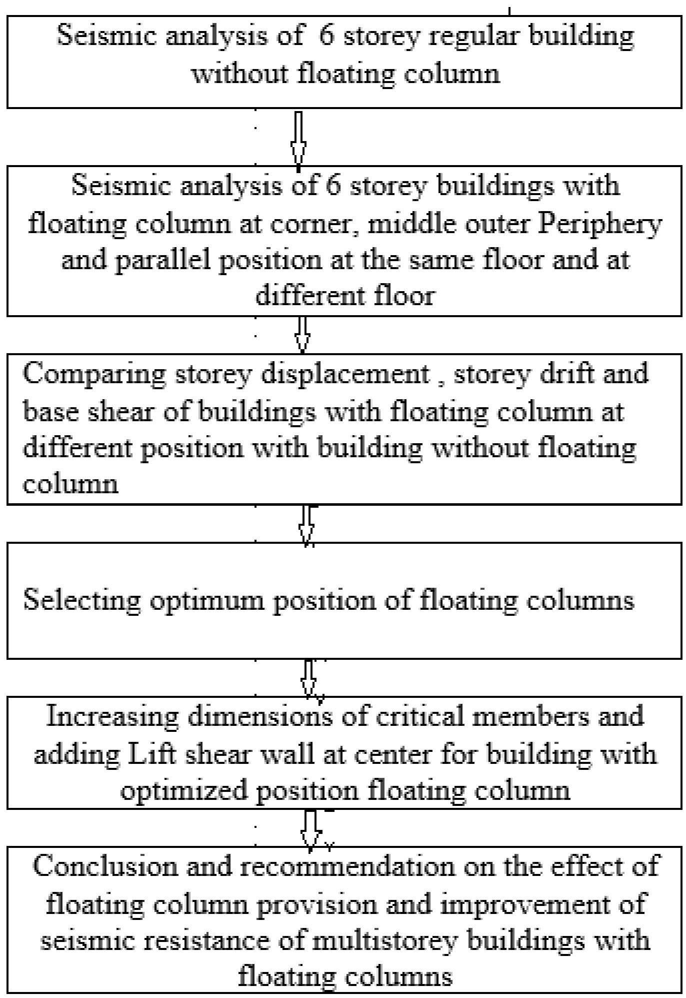


Figure 3. 2 Research design

3.3 Study variables

3.3.1 Dependent variables.

- ✓ Seismic responses (Story displacement, story drift and base shear)

3.3.2 Independent variables

- ✓ Presence and absence of floating Column
- ✓ Floating column positions on the same and different floors,
- ✓ Dimension of transfer beam and critical columns.
- ✓ Presence and absence of lift Shear wall at the center on building with floating column

3.4) Data quality assurance

In order to assure data quality the following measures were taken:

- ✓ The ETABS software was checked with manual calculation done using excel under ES EN 1998-1:2015 for regular 6 story building.
- ✓ In case of any unreliable (illogical) results due to some unobserved errors, the structure was re-modeled and re analyzed.
- ✓ A due attention and care was taken when extracting results from ETABS and plotting them in Excel

3.5 Sources of data

Every required data for this study was collected from Ethiopian building Code standard books and ETABS manual, outputs of ETABS and experts. The materials are for concrete (C-25/30….) and for steel (S-400).

3.6. Data collection process

Under the process of data collection, the following activities was done to keep the quality of the data.

- ✓ Preparing action plan
- ✓ Preparation of the required documentation formats and manuals
- ✓ Preparing all the required materials that use for recording and observation
- ✓ Modeling the frame, analyze and taking output from the software, modeling and material properties.

3.7 Data presentation and analysis

The data obtained from software outputs and manual numerical outputs were presented as graphical and chart by comparing and contrast between modeling method and parameters. Mainly the following outputs were discussed briefly.

- Effect of floating column at extreme corner, middle column outer periphery and middle column parallel position.
- Effect of floating column at different floor in a building.
- Effect of increasing dimension of Critical columns and beam.
- Effect of analysis with lift shear wall at center.

CHAPTER FOUR

STRUCTURAL MODELING AND ANALYSIS

4.1 Modelling description

Initially, a regular 6 storey building without floating column shown in fig 4.1 is analyzed using ETABS 2016.00 and using excel sheet to check whether ETABS 2016.00 is working well or not. Dimensions and specifications of the model are described in Table 4.2. The lateral load analysis of this study is based on ES EN 1998-1:2015.

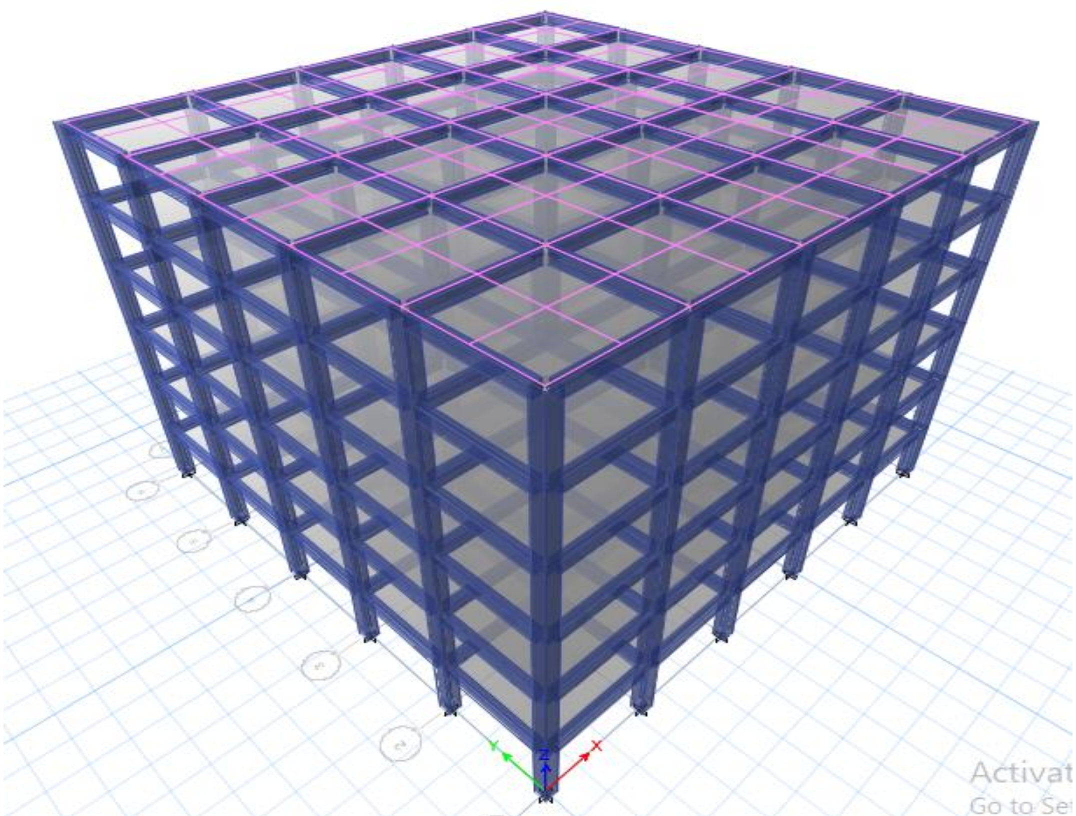
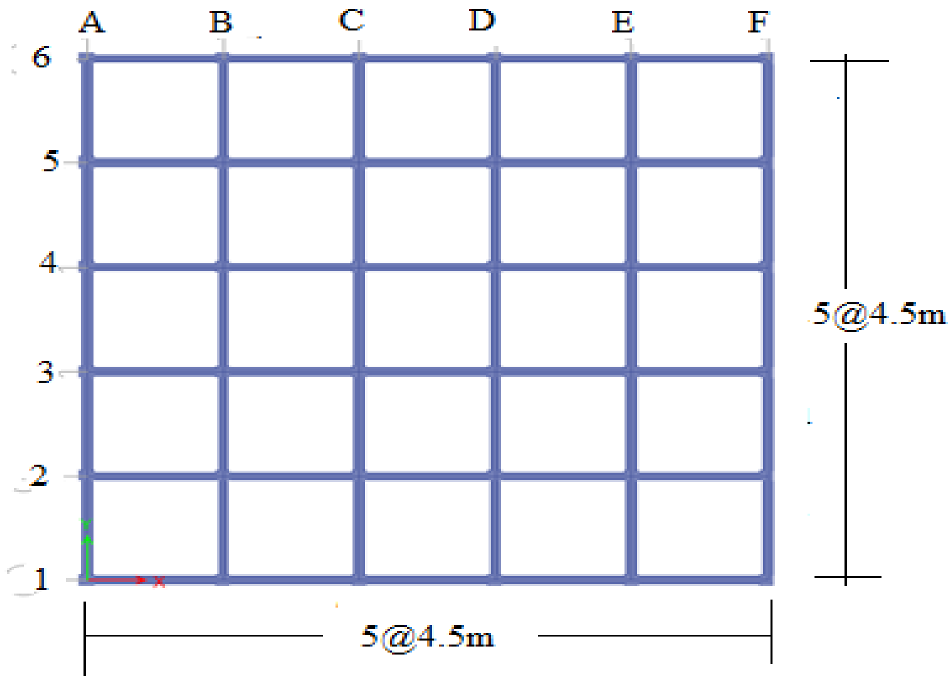
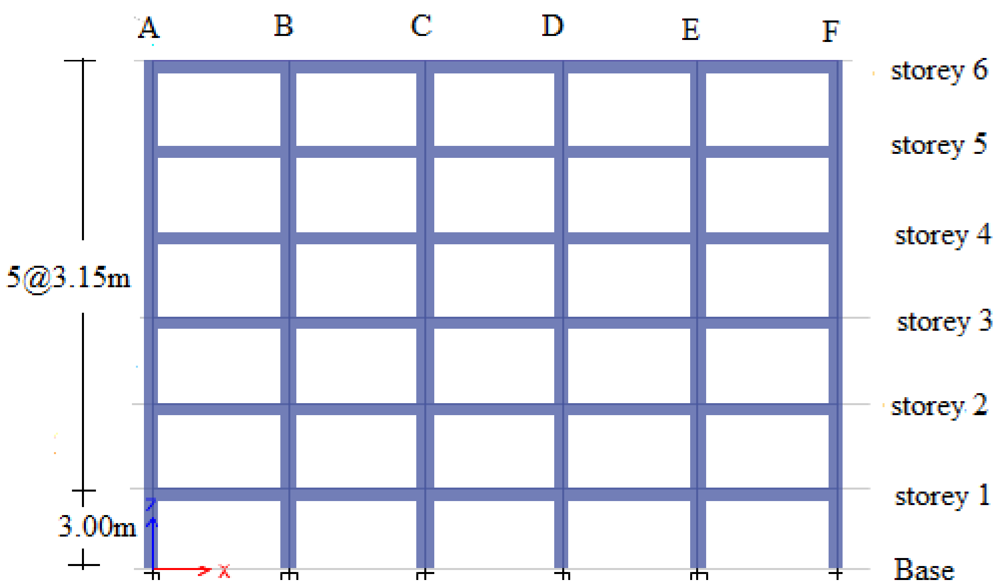


Figure 4. 1 3D view of sample building without floating columns



(a)



(b)

Figure 4. 2 Plan and Elevation view of sample building without floating columns

(Case 1)

Table 4. 1 modeling description

Model No.	Floating Column Position	Critical beam and Column dimension	Column Floor removed	Lift Shear wall
M1 (Case 1)	Normal building without floating column	Beam 300mm x 500mm, column 500 x 500	-	-
M2 (Case 2)	Extreme corner floated (A1, A6, F1, F6)	Beam 300mm x 500mm, column 500 x 500	Ground floor	No
M3 (Case-3)	Middle column outer periphery floated (B1,B6,E1,E6)	Beam 300mm x 500mm column 500mm x 500mm	Ground floor	No
M4 (Case 4)	Middle column 2nd row (at parallel position floated) (B2,B5,E2,E5)	Beam 300mm x 500mm column 500 x 500	Ground floor	No
M5 (Case 5)	parallel position on First Floor floated	Beam 300mm x 500mm column 500 x 500	1st Floor	No
M6 (Case 6)	parallel position on second floor floated	Beam 300mm x500mm column 500 x 500	2nd Floor	No
M7 (Case 7)	parallel position on third floor floated	Beam 300mm x 500mm column 500 x 500	3rd Floor	No
M8 (Case 8)	parallel position on fourth floor floated	Beam 300mm x 500mm column 500 x 500	4th Floor	No
M9 (Case 9)	Parallel position with increased critical beam dimension 300*600.	Beam 300mm x 600mm column 500 x 500	4th Floor	No
M10 (Case 10)	Parallel position with increased critical column dimension 600*600.	Beam 300mm x 500mm column 600 x 600	4th Floor	No
M11 (Case 11)	Parallel position with increased critical beam and column dimensions.	Beam 300mm x 600mm column 600 x 600	4th Floor	No
M12 (Case 12)	Floating column at parallel position with lift shear wall at the center.	Beam 300mm x 500mm column 500 x 500	4th Floor	Yes
M13 (Case 13)	Floating column at parallel position with increased critical beam and column dimensions and shear wall at the center.	Beam 300mm x 600mm column 600 x 600	4th Floor	Yes

Table 4. 2 Dimensions, loads, earthquake parameters and specifications

	Normal building	Floating column buildings
Specifications		
Grade of rebar	S-400	S-400
Grades of Concrete	C-25/30	C-25/30
dimensions		
Panel dimensions	4.5mX4.5m	4.5mX4.5m
Total length dimensions	22.5mX22.5m	22.5mX22.5m
Number of story	6	6
slab Thickness	150mm	150mm
Beams	300mmx500mm	300mmx500mm 300mmx600mm
Column	500mmx500mm	500mmx500mm 600mmx600mm
Shear wall consideration at center of plan view	No	No
		Yes
HCB wall thickness (Exterior)	200mm	200mm
HCB wall thickness (Interior)	150mm	150mm
Loads		
Unit weight of concrete	25KN/m^3	25KN/m^3
Floor loads		
Live load	3KN/m^2	3KN/m^2
Dead load	1 KN/m^2	1 KN/m^2
Roof loads		
Live load	1.5 KN/m^2	1.5 KN/m^2
Dead load 1	1 KN/m^2	1 KN/m^2
parameters for earth quake analysis		
Seismic zone factor	Zone 5	0.2
Importance factor		1
Ground type (assumed)		type B

4.2) Methods of analysis

The lateral load analysis of six storey building without floating column is done based on ES EN 1998-1:2015, using ETABS v2016.00 which is cross checked with Excel spread calculation of base shear force. After validating, seismic response of buildings with floating columns at different positions and different seismic improvement method had been evaluated using ETABS v2016.00.

4.2.1) Lateral force method of analysis

This type of analysis may be applied to buildings whose response is not significantly affected by contributions from modes of vibration higher than the fundamental mode in each principal direction. The requirement is deemed satisfied in buildings, which fulfill the condition that fundamental periods of vibration T_1 in the two main directions which are smaller than the following values.

$$T_1 \leq \begin{cases} 4.T_B \\ 2.0\ sec \end{cases} \tag{4.1}$$

Values of the parameters describing the recommended Type 1 elastic response spectra. (High and moderate seismicity region Ms > 5.5)

Table 4. 3 Values of parameters describing the recommended Type 1 elastic response spectra

Ground Type	S	TB (sec)	TC (sec)	TD (sec)
A	1.0	0.15	0.4	2
B	**1.2**	**0.15**	**0.5**	**2**
C	1.15	0.2	0.6	2
D	1.35	0.2	0.8	2
E	1.4	0.15	0.5	2

Fundamental period of vibration of the building (T1)

For buildings with heights of up to 40 m the value of *T*1 (in s) may be approximated by the following expression:

$$T1 = Ct \cdot H^{3/4} \tag{4.2}$$

Where

*C*t = 0.085 for moment resistant space steel frames;

*C*t = 0.075 for moment resistant space concrete frames; *C*t = 0.050 for all other structures;
H is the height of the building, in m, from the foundation or from the top of a rigid basement.

Ct=0.075 (for moment resistant space concrete frame) H=3+5*3.15=18.75

T1 = Ct·H ¾=0.075*$(18.75)^{3/4}$=0.63s<= (4*0.5=2, 2) =Ok!

Distribution of the horizontal seismic force (F_i)

(1) The fundamental mode shapes in the horizontal directions of analysis of the building may be calculated using methods of structural dynamics or may be approximated by horizontal displacements increasing linearly along the height of the building.

(2) P The seismic action effects shall be determined by applying, to the two planar models, horizontal forces *F*i to all stories.

$$Fi = Fb\frac{s_i.m_i}{\sum s_j.m_j} \tag{4.3}$$

Where, s_i

Fi is the horizontal force acting on story i;

Fb is the seismic base shear in accordance with expression (4.5);

si, sj are the displacements of masses mi, mj in the fundamental mode shape;

mi, mj are the story masses computed in accordance with 3.2.4(2).

(3) When the fundamental mode shape is approximated by horizontal displacements increasing linearly along the height, the horizontal forces F_i should be taken as being given

$$Fi = Fb\frac{z_i.m_i}{\sum z_j.m_j} \tag{4.4}$$

where

z_i, z_j are the heights of the masses m_i, m_j above the level of application of the seismic action (foundation or top of a rigid basement).

(4)P The horizontal forces F_i determined in accordance with this clause shall be distributed to the lateral load resisting system assuming the floors are rigid in their plane.

Seismic Base shear force (Fb)

The seismic base shear force Fb, for each horizontal direction in which the building is analyzed shall be determined using the following expression:

$$Fb = Sd\,(T1) \cdot m \cdot \lambda. \qquad (4.5)$$

Where:

Sd (T1): The ordinate of the design spectrum at period T1, **T1** is the fundamental period of vibration of the building for lateral motion in the direction considered.

M is the total mass of the building, above the foundation or above the top of a rigid basement,

λ is the correction factor, the value of which is equal to: λ= 0.85 if T1< 2 TC and the building has more than two storeys, or λ= 1.0 otherwise. NOTE The factor λ accounts for the fact that in buildings with at least three storeys and translational degrees of freedom in each horizontal direction, the effective modal mass of the 1 st (fundamental) mode is smaller, on average by 15%, than the total building mass.

Design Spectrum for elastic analysis (Sd (T1)

For the horizontal components of the seismic action the design spectrum, Sd(T), shall be defined by the following expressions:

$$0 \leq T \leq T_B: \quad S_d(T) = a_g . S . \left[\frac{2}{3} + \frac{T}{T_B} . \left(\frac{2.5}{q} - \frac{2}{3}\right)\right] \qquad (4.6)$$

$$T_B \leq T \leq T_C: \quad S_d(T) = a_g . S . \eta . \frac{2.5}{q} \qquad (4.7)$$

$$T_C \leq T \leq T_D: \quad S_d(T) = \begin{cases} = a_g . S . \frac{2.5}{q} . \left[\frac{T}{T_B}\right] \\ \geq \beta . a_g \end{cases} \qquad (4.8)$$

$$T_D \leq T: \quad S_d(T) = \begin{cases} = a_g . S . \frac{2.5}{q} . \left[\frac{T_C * T_D}{T^2}\right] \\ \geq \beta . a_g \end{cases} \tag{4.9}$$

The value of S, TB, TC and TD depend on ground type & obtained from Table 4.2.

ag is the design ground acceleration obtained from Table 4.4

S is the soil factor obtained from Table 4.3

T_B is the lower limit of the period of the constant spectral acceleration branch;
T_C is the upper limit of the period of the constant spectral acceleration branch;
T_D is the value defining the beginning of the constant displacement response range of the spectrum;

q is the behaviour factor

$S_d(T)$ is the design spectrum

β is the lower bound factor for the horizontal design spectrum.

NOTE: The value to be ascribed to β for use is found in the National Annex. The recommended value for β is 0, 2.

Hence Tc (0.5) <=T (0.63) ≤TD (2), Substituting into equation (4.8)

Bedrock Acceleration Ratio (αo)

The Seismic hazard map is divided into 5 zones, where the ratio of the design bedrock acceleration to the acceleration of gravity g = α_o for the respective zones.

Afar region in Ethiopia, Elidar is categorized under seismic zone 5. (Table D2 of EBC ES EN 1998-1:2015), ag/g=0.2

Table 4. 4 Bedrock Acceleration Ratio α_o

Zone	**5**	4	3	2	1	0
$\alpha_o = a_g/g$	**0.2**	0.15	0.1	0.07	0.04	0

Behavior factor (q)

The behavior factor q approximates the ratio of the seismic forces that the structure would experience if its response were completely elastic with 5% viscous damping, to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the structure. The upper limit value of the behavior factor q, account for energy dissipation capacity, shall be derived for each design direction is given by:

$$q = q_o \, k_w \geq 1.5 \tag{4.10}$$

Where

q_o is the basic value of the behaviour factor, dependent on the type of the structural system and on its regularity in elevation given in Table 4.4 below.

Table 4. 5 Basic value of the behavior factor, q_o, for systems regular in elevation

STRUCTURAL TYPE	DCM	DCH
Frame system, dual system, coupled wall system	$3.0\alpha_u/\alpha_1$	$4.5\alpha_u/\alpha_1$
Uncoupled wall system	3.0	$4.0\alpha_u/\alpha_1$
Torsionally flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

DC”M” (medium ductility)

Specific provisions for design and detailing to ensure inelastic behavior of the structure without brittle failure. Concrete class C 16/20, steel class B or C.

DC”H” (high ductility)

Special provisions for design and detailing to ensure stable mechanisms with large dissipation of hysteretic energy. Concrete class C 20/25 steel class C .For buildings, which are not regular in elevation, the value of q_o should be reduced by 20%.$q_o = 3.0\alpha_u/\alpha_1$

α1 is the value by which the horizontal seismic design action is multiplied in order to first reach the flexural resistance in any member in the structure. While all other design actions remain constant;

αu is the value by which the horizontal seismic design action is multiplied, in order to form plastic hinges in a number of sections sufficient for the development of overall structural instability, while all other design actions remain constant.

The factor αu may be obtained from a nonlinear static (pushover) global analysis. When the multiplication factor αu/α1 has not been evaluated through an explicit calculation, for buildings, which are regular in plan the following approximate values of αu/α1 may be used.

a) Frames or frame-equivalent dual systems.

One-story buildings: αu/α1=1.1;

multistory, one-bay frames: αu/α1=1.2;

multistory, multi-bay frames or frame-equivalent dual structures: αu/α1=1.3.

For buildings which are not regular in plan the approximate value of α_u/α_1 that may be used when calculations are not performed for its evaluation are equal to the average of (a) 1,0 and of (b) the value given above. For our case , αu/α1=1.3, from Table 4.4, qo=3.0αu/α1=3.0*1.3=3.9

The factor Kw reflecting the prevailing failure mode in structural systems with walls shall be taken as follows:

Kw = 1.00, for frame and frame-equivalent dual systems

kw = (1+ αo) /3<= 1, but not less than 0.5, for wall-equivalent and torsionally flexible systems

Whereαo is the prevailing aspect ratio of the walls of the structural system.

From equation 4.10, q= qo kw≥ 1.5 =3.9*1=3.9= $a_g.S.\frac{2.5}{q}.\left[\frac{T}{T_B}\right]$

From equation 4.8, $S_d(T) = a_g.S.\frac{2.5}{q}.\left[\frac{T}{T_B}\right]$ =$0.2 * 1.2.\frac{2.5}{3.9}.\left[\frac{0.5}{0.63}\right]$ =0.121

Using Excel Sheet, Total mass (m) =34334KN, From equation 4.5, Fb = Sd (T1)· m·λ. =0.121*34334*0.85=**3536.281KN**, λ= 0.85 if T1< 2 TC, (0.63<2*0.5) 0k

Horizontal force F_i is calculated and compared with ETABS result as shown in Table 4.6 below.

Table 4. 6 Validation of ETABS for horizontal force using Excel sheet for regular building without floating column

Story	Mass (KN)	Height (Z_i) (m)	$z_i.m_i$ (KN-m)	$\frac{z_i.m_i}{\sum z_j.m_j}$	$Fi = Fb\frac{z_i.m_i}{\sum z_j.m_j}$ (KN)	ETABS Out put (KN)	Difference (%)
Story 6	4182.76	18.75	78426.77	0.220	777.13	781.33	0.54%
Story 5	5968.05	15.6	93101.52	0.261	922.55	935	1.33%
Story 4	5968.05	12.45	74302.18	0.208	736.26	746.2	1.33%
Story 3	5968.05	9.3	55502.83	0.156	549.98	557.41	1.33%
Story 2	5968.05	6.15	36703.48	0.103	363.70	368.61	1.33%
Story 1	6279.05	3	18837.16	0.053	186.66	179.31	-1.60%
Total	34334.0		356873.9				
Fb	3536.28						

CHAPTER FIVE

RESULTS AND DISCUSSION

A comparative study and analysis of buildings with floating columns at various positions was done as per the specifications in ES-EN 1998-2015 using ETABS 2016.00.A detail study was carried out to find out the variations in the structural response of the building with floating columns at different positions observing the parameters like maximum displacements, storey drifts and base shears. Then recommendations such as increasing beam and column dimensions and provision of lift shear wall are analyzed and compared to check seismic resistance of buildings with floating columns. Thus, from these considerations, the models analyzed are discussed below.

5.1 Effect of floating column at different positions on the same floor.

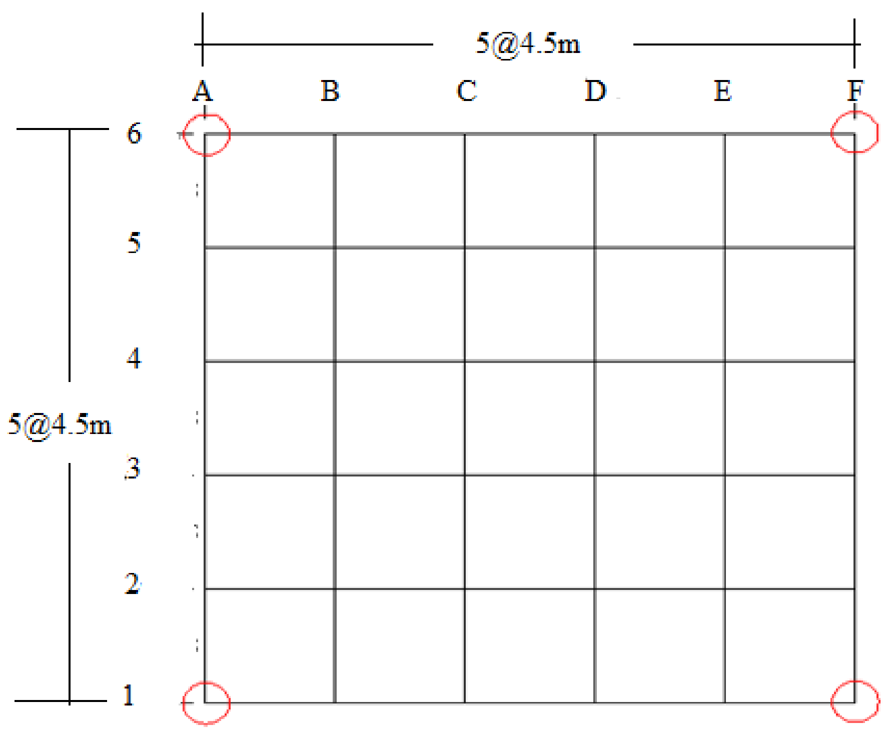


Figure 5. 1 Plan view of building with column floated at extreme corner of ground floor

(Case 2)

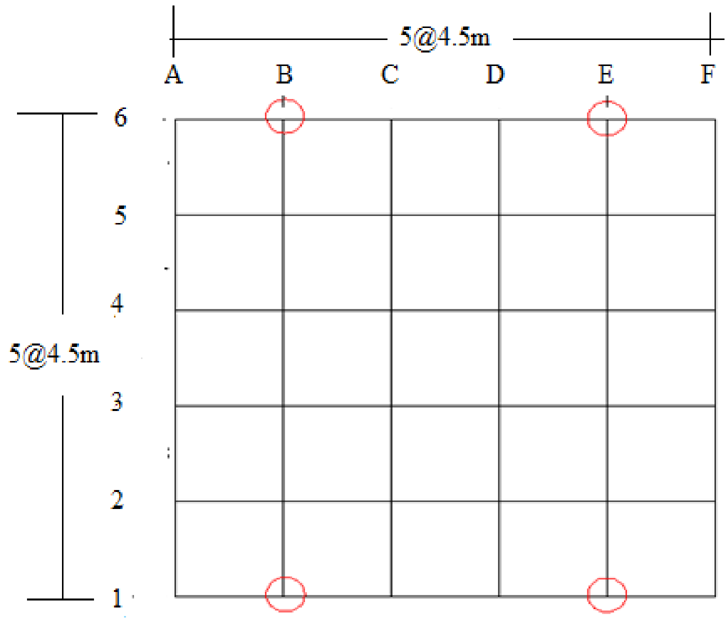


Figure 5. 2 Plan view of building with column floated at outer periphery of ground floor

(Case 3)

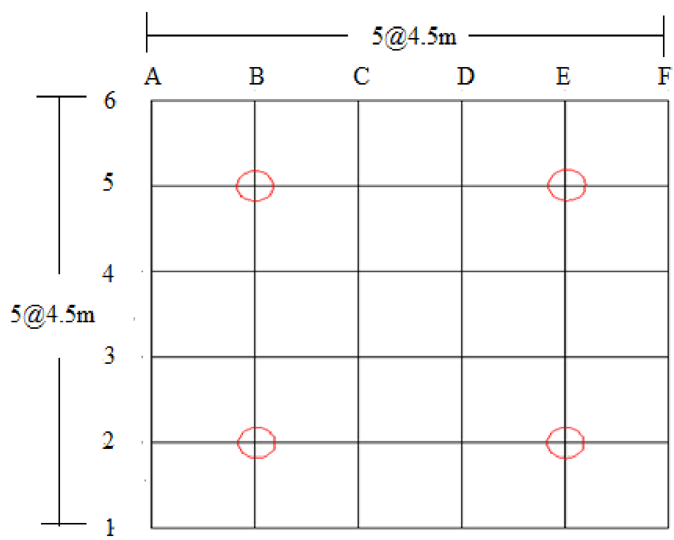


Figure 5. 3 Plan view of building with column floated at parallel position of ground floor

(Case 4)

Effect of floating column at different positions on the same floor on lateral displacement

From Figure 5.4 below, it is observed that maximum increase in storey displacement is 31.39%, 27.9%, and 27.5% from building without FC in storey displacement when floating column is provided at edge corner, middle column outer periphery and parallel position of ground floor respectively. It indicates storey displacement increases on provision of floating columns.

Additionally, there is 2.7 % and 2.94% reduction in storey displacement when changing floating column position from edge corner to middle column outer periphery and parallel position respectively. It indicates that storey displacement decreases as floating column position move from edge corner to around center of plan due to decrement in eccentricity.

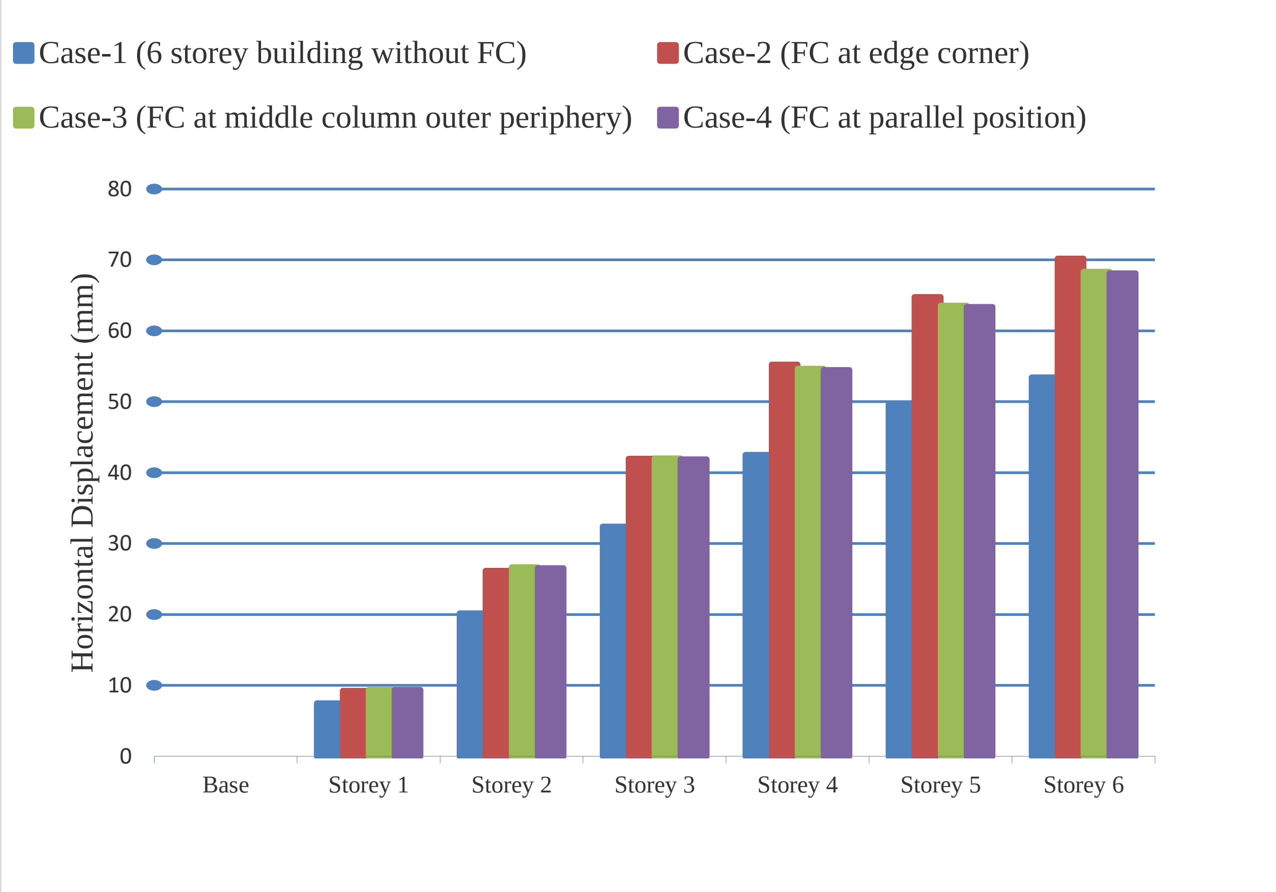


Figure 5. 4 Comparisons of maximum displacement of building without FC with buildings of different position of FC along plan.

Effect of floating column at different positions on the same floor on storey drift

From Figure 5.5 below, it is observed that maximum increase in storey drift is 33%, 31.3%, and 29.7% increment from building without floating column in storey drift when floating column is provided at edge corner, middle column outer periphery and parallel position of ground floor respectively. It indicates storey drift increases on provision of floating columns.

Additionally, there is 1.2% and 2.4% reduction in maximum storey drift when changing floating column position from edge corner to middle outer column and parallel position respectively. It indicates that storey drift decreases as floating column position move from edge corner to center of plan.

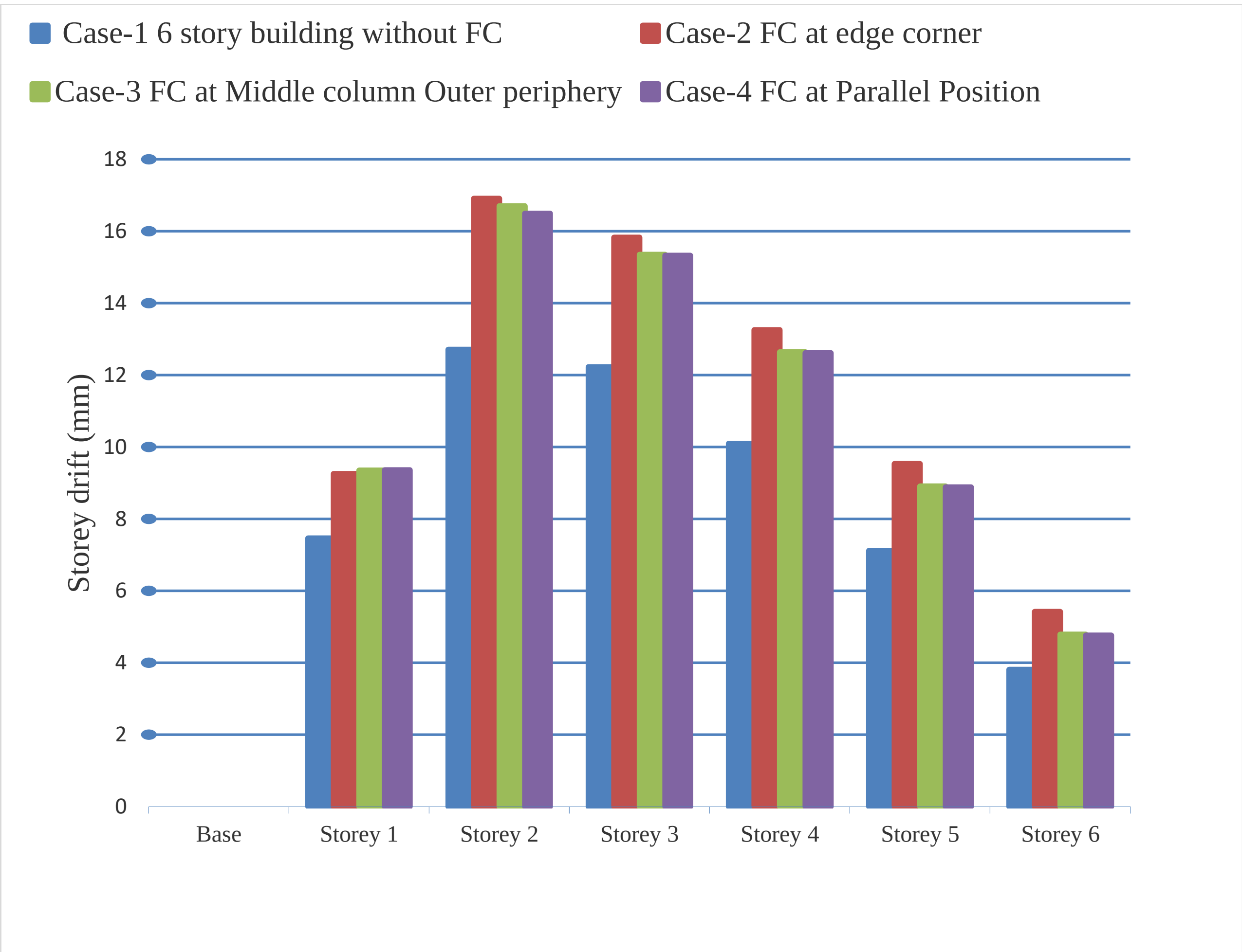


Figure 5. 5 Comparisons of storey drift of building without FC with buildings of different position of FC along plan.

Effect of floating column at different positions on the same floor on base shear

From Figure 5.6 below, it is observed that expected lateral force on base of the structure increased due to irregularity in elevation. The maximum increase in expected lateral force is 24.85% from regular building when floating column is provided at ground floor.

There is no significant change in base shear when changing floating column from exterior to interior hence there is no change in weight as shown in Figure 5.6.

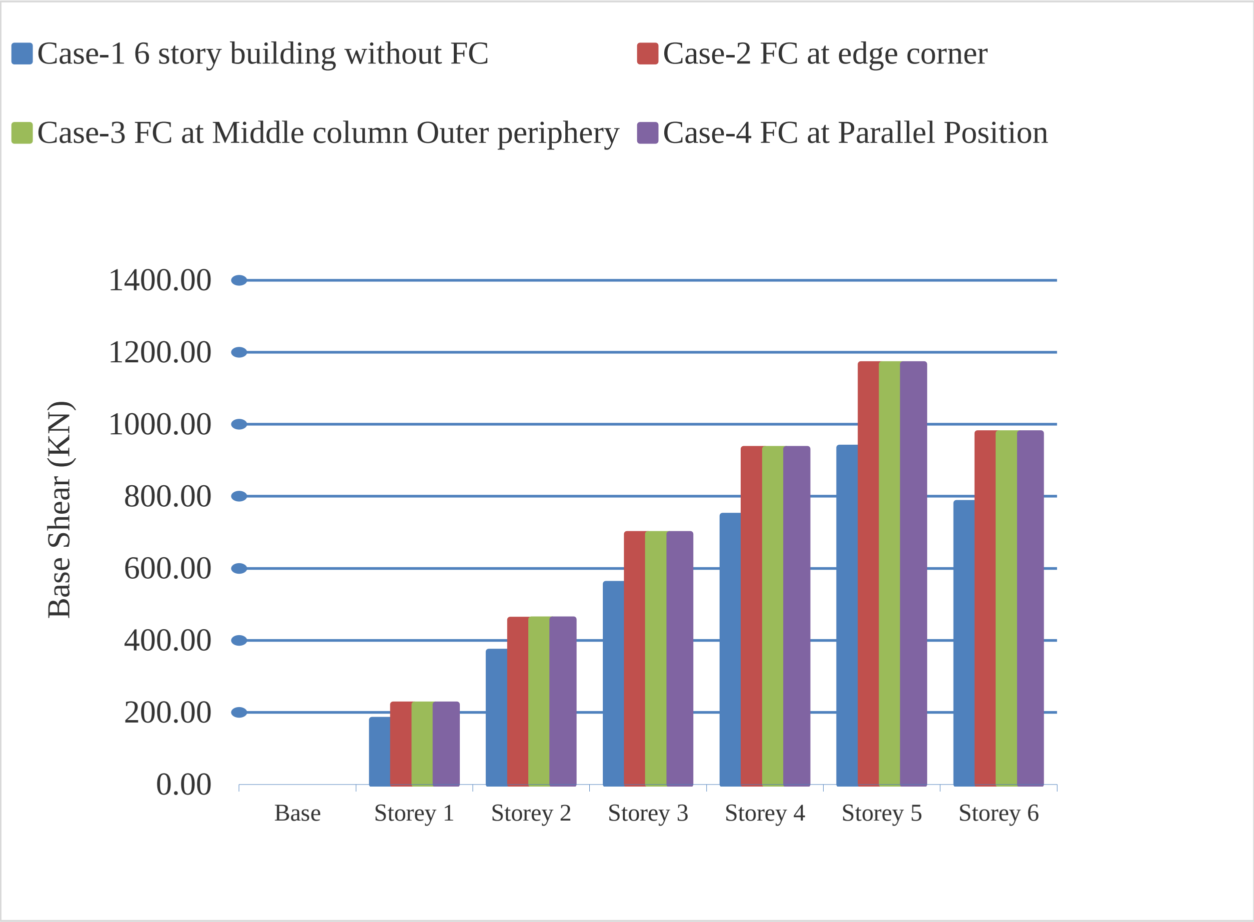


Figure 5. 6 Comparisons of base shear of building without FC with buildings of different position of FC along plan.

5.2 Effect of floating column at different floor

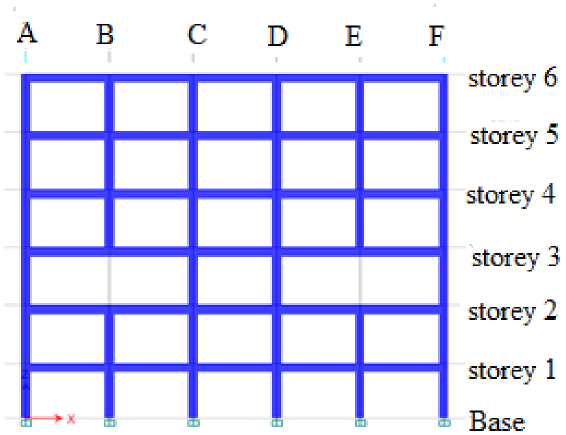


Figure 5. 7 Section view of buildings with floating column at parallel position, 1st floor

(Case 5)

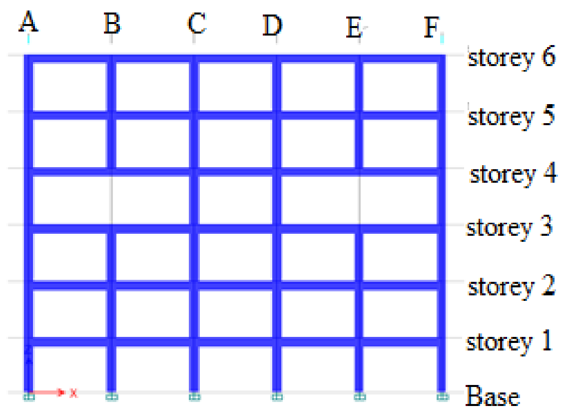


Figure 5. 8 Section view of buildings with floating column at parallel position, 2nd floor

(Case 6)

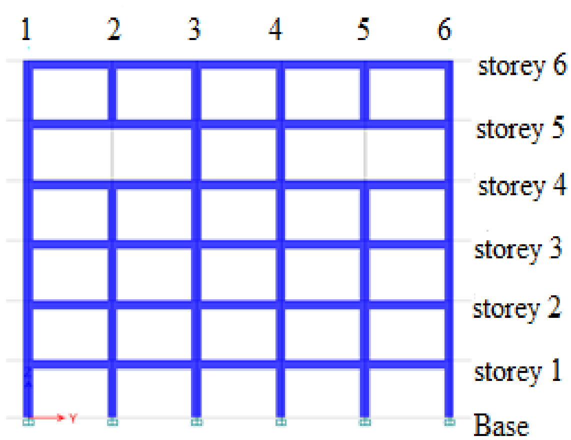


Figure 5. 9 Section view of buildings with floating column at parallel position, 3rd floor

(Case 7)

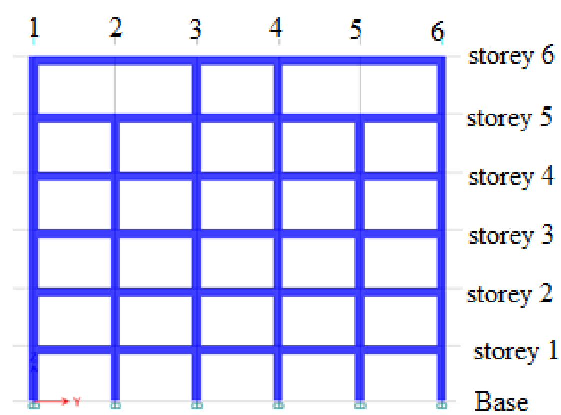


Figure 5. 10 Section view of buildings with floating column at parallel position, 4th floor

(Case 8)

Effect of floating column at different floor on lateral displacement

From Figure 5.11 below, it is observed that there is 0.18%, 0.55%, 1.08%, 1.5% reduction in storey displacement when changing floating column position from ground floor to 1st, 2nd, 3rd and 4th floor respectively.

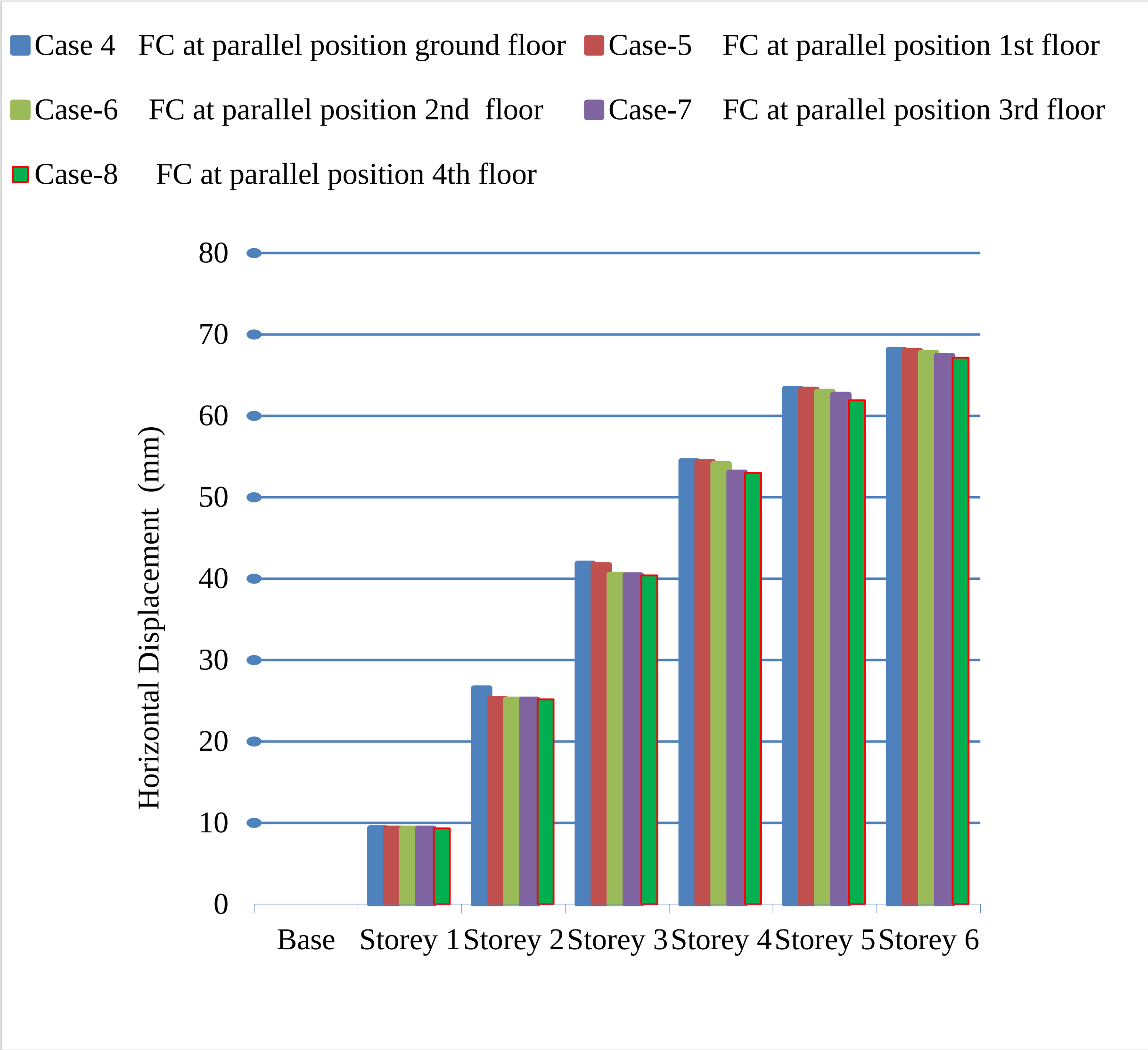


Figure 5. 11 Comparisons of maximum displacement of floating column at different floors

Effect of floating column at different floors on storey drift

From Figure 5.12 below, it is observed that there is 7.3%, 7.69%, 7.72, 7.74% reduction in maximum storey drift when changing floating column position Ground floor to 1^{st}, 2^{nd}, 3rd and 4^{th} floor respectively.

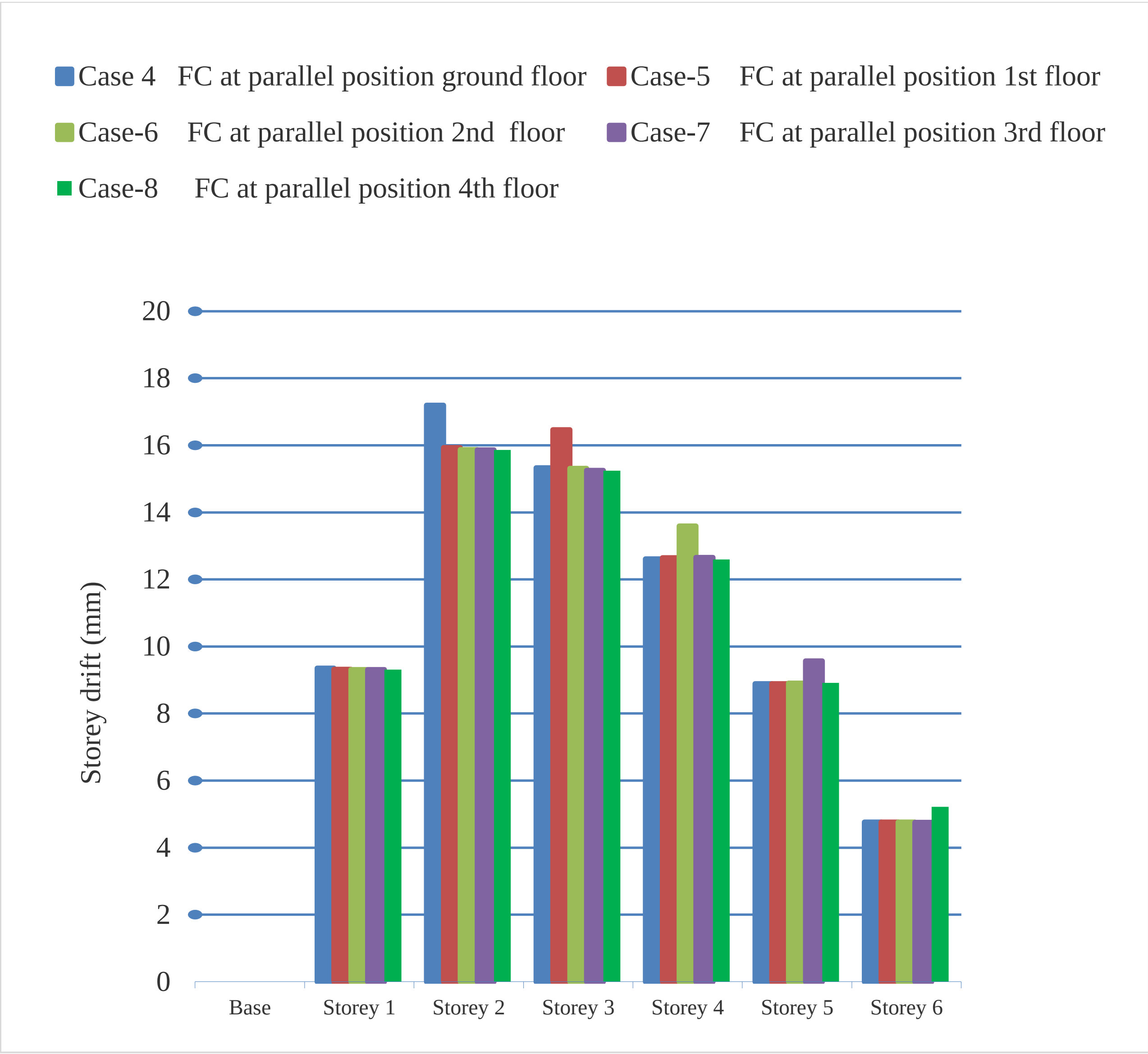


Figure 5. 12 Comparisons of maximum storey drift of floating column at different floors

Effect of floating column at different floors on base shear

From, Figure 5.13 below, it is observed that there is no significant change in base shear when changing floating column from Ground floor to 1st, 2nd, 3rd and 4th floor hence there is no change in weight.

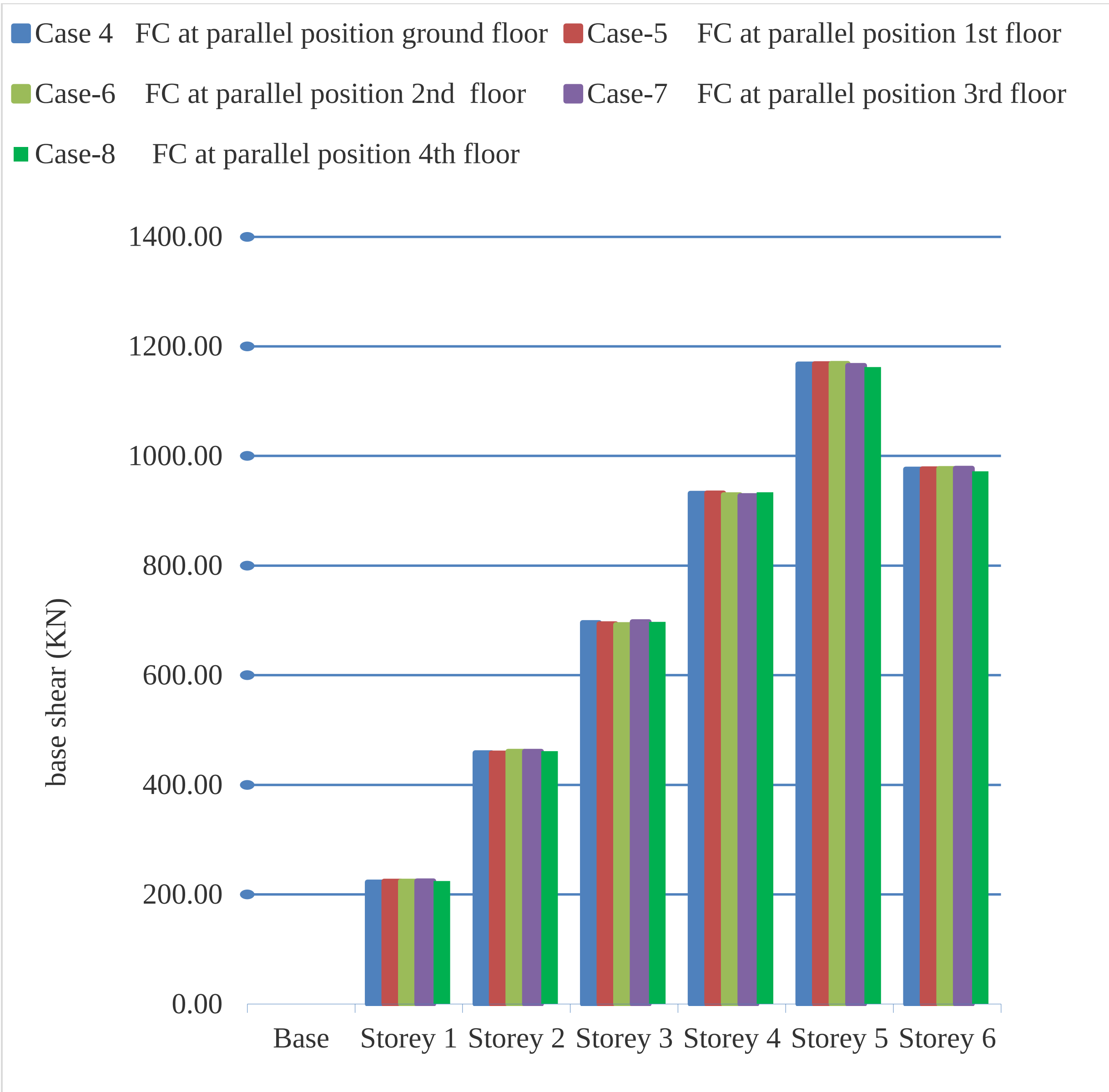


Figure 5. 13: Comparisons of maximum base shear of floating column at different floors

5.3 Effect of increasing critical beam and column dimensions on seismic performance of building with floating columns

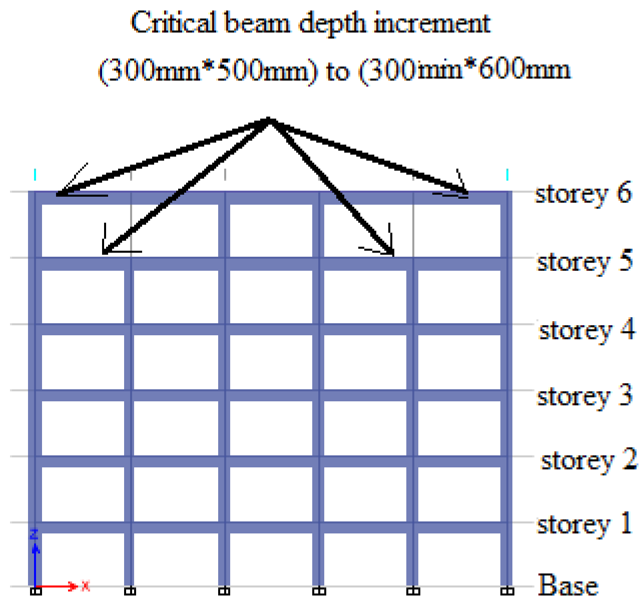


Figure 5. 14 Critical beam dimension increment section view

(Case 9)

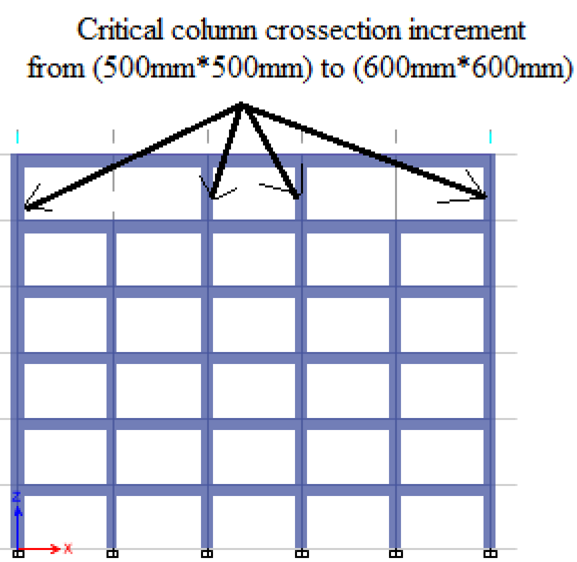


Figure 5. 15 Critical column dimension increment

(Case 10)

Effect of increasing critical beam and column dimensions on storey displacement

From Figure 5.16 below, there is 0.69%, 8.21%, 9.1% reduction in storey displacement when increasing only critical beam dimension from 300mm*500mm to 300mm*600mm, only critical column dimension from 500mm*500mm to 600mm*600mm and increasing both critical members dimension at a time respectively.

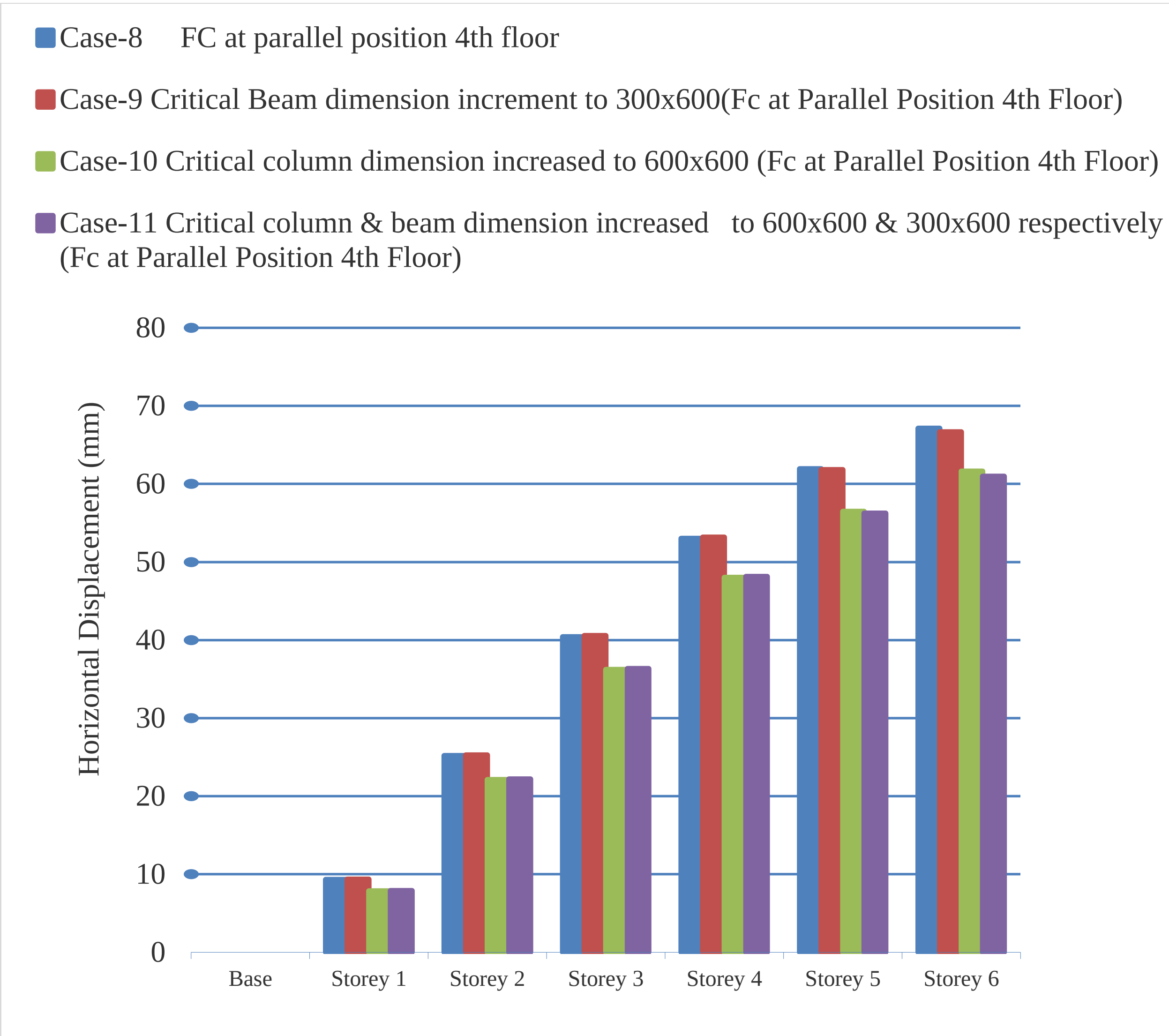


Figure 5. 16 Comparisons of maximum displacement of floating column buildings improved with critical member dimensions increment

Effect of increasing critical beam and column dimensions on storey drift

From Figure 5.17 below, there is 0.39%, 10.04%, 9.7% reduction in story drift when increasing only critical beam dimension from 300mm*500mm to 300mm*600mm, critical column dimension from 500mm*500mm to 600mm*600mm and increasing both critical members dimensions respectively.

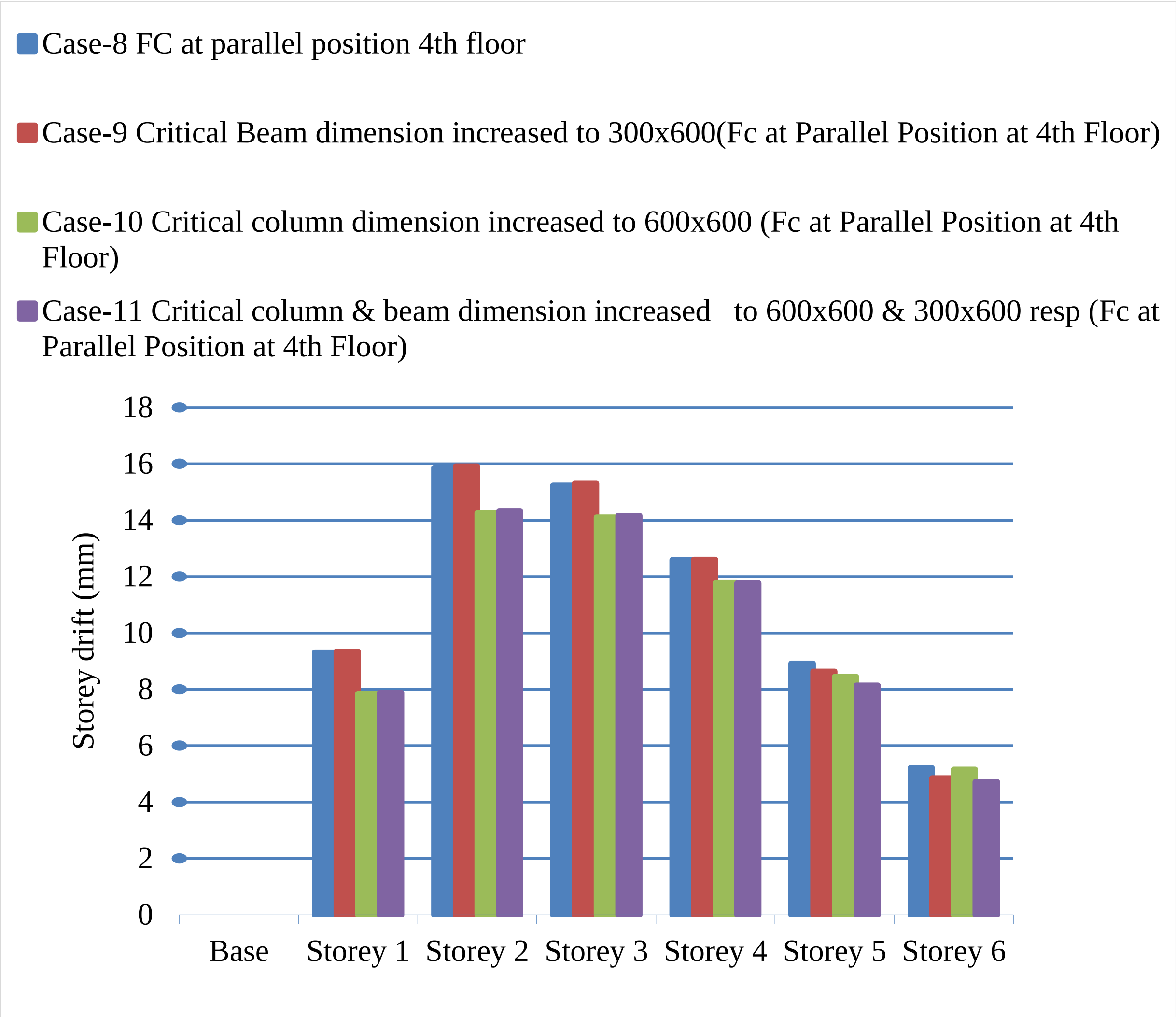


Figure 5. 17 Comparisons of storey drift of floating column buildings improved with critical member dimensions increment

Effect of increasing critical beam and column dimensions on base shear of building with FC

From Figure 5.18, there is 1.2%, 1.5%, 2.6% increase in base shear when increasing only critical beam dimension from 300mm*500mm to 300mm*600mm, only critical column dimension from 500mm*500mm to 600mm*600mm and increasing both critical members dimension at a time. It is due to increment of weight of members.

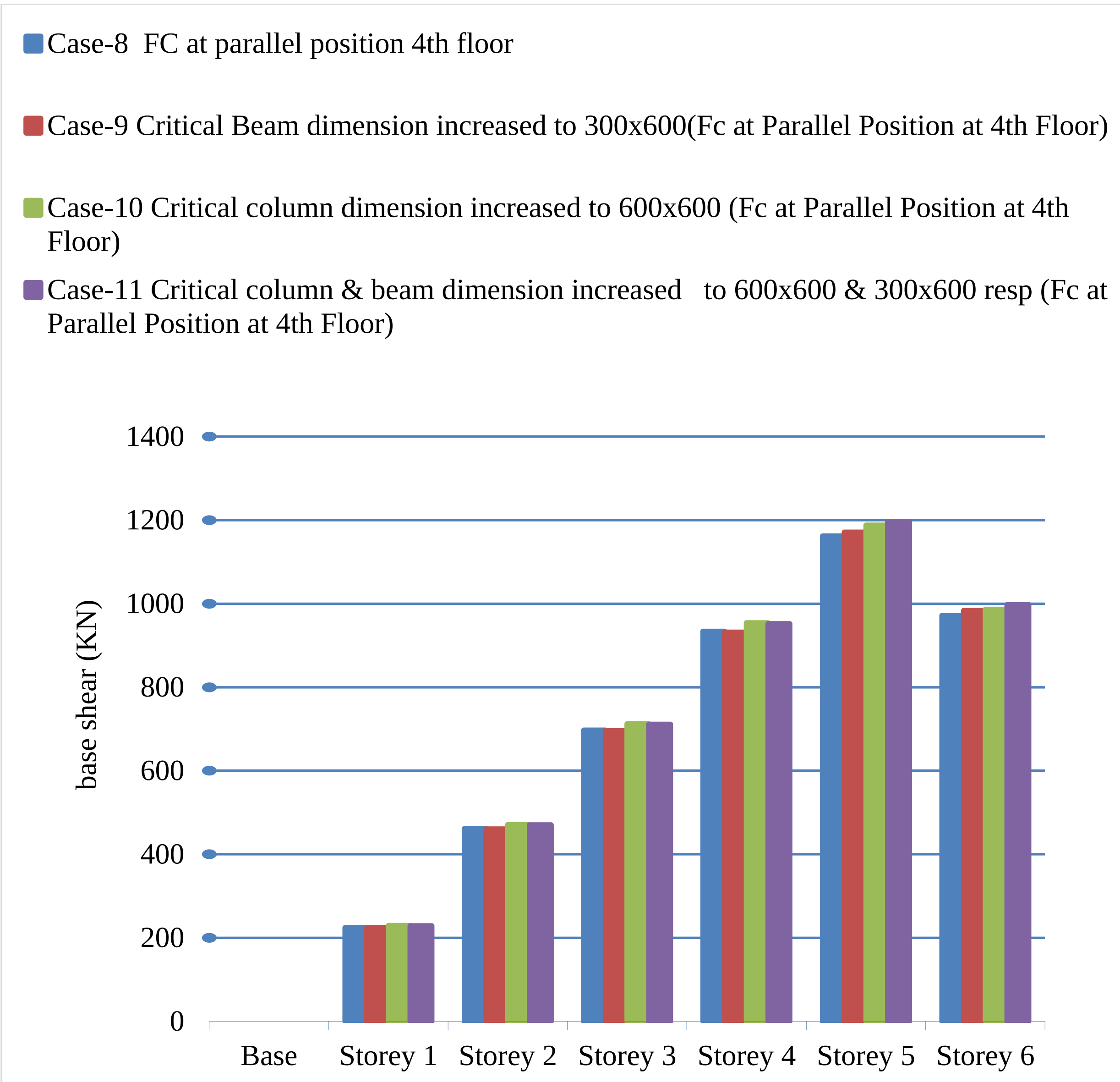


Figure 5. 18 Comparisons of base shear of floating column buildings improved with critical member dimensions increment

5.4 Effect of center lift shear wall provision on seismic performance of building with floating columns

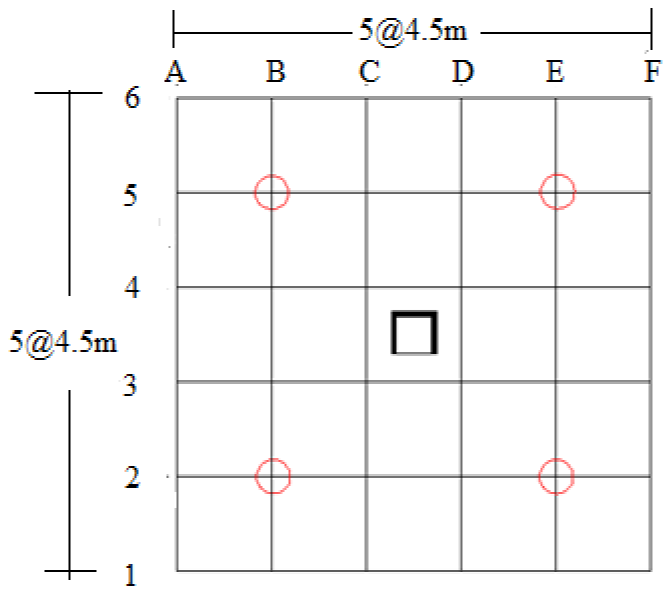


Figure 5. 19 Floating column at parallel position, 4th floor and lift shear wall at center

(Case 12)

Effect of lift shear wall provision on lateral displacement of building with FC

From Figure 5.20 below, there is 22.17% and 28.03% reduction in storey displacement when adding lift shear wall at the center and using combination of lift shear wall at the center and critical member dimension increment respectively.

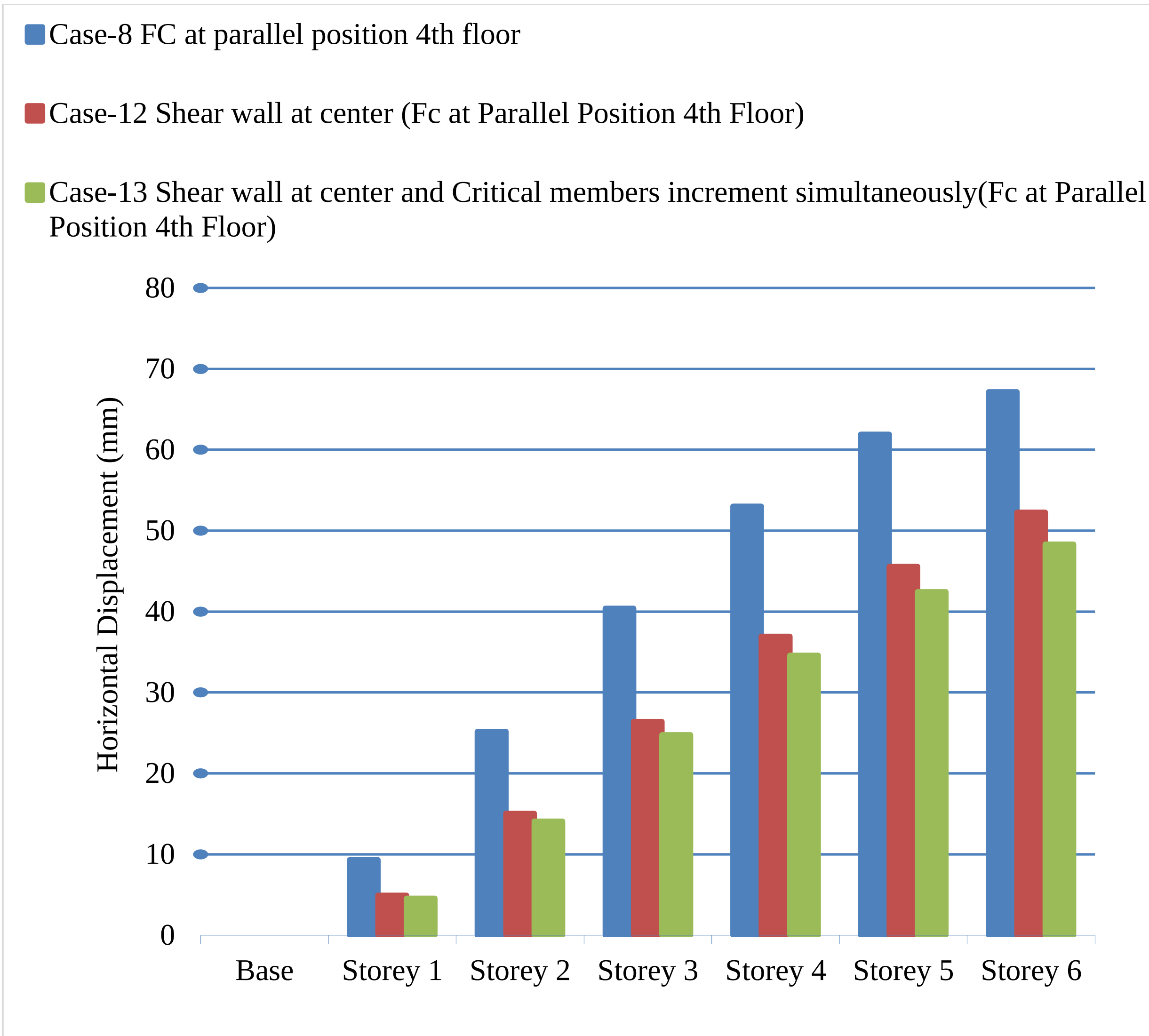


Figure 5. 20 Comparisons of maximum displacement of floating column buildings with provision lift shear wall and critical member dimension increment (mm)

Effect of lift shear wall provision on storey drift of building with FC

From Figure 5.21 below, there is 25.41% and 29.8% reduction in storey drift when adding lift shear wall at the center and using combination of lift shear wall at the center and critical member dimension increment respectively.

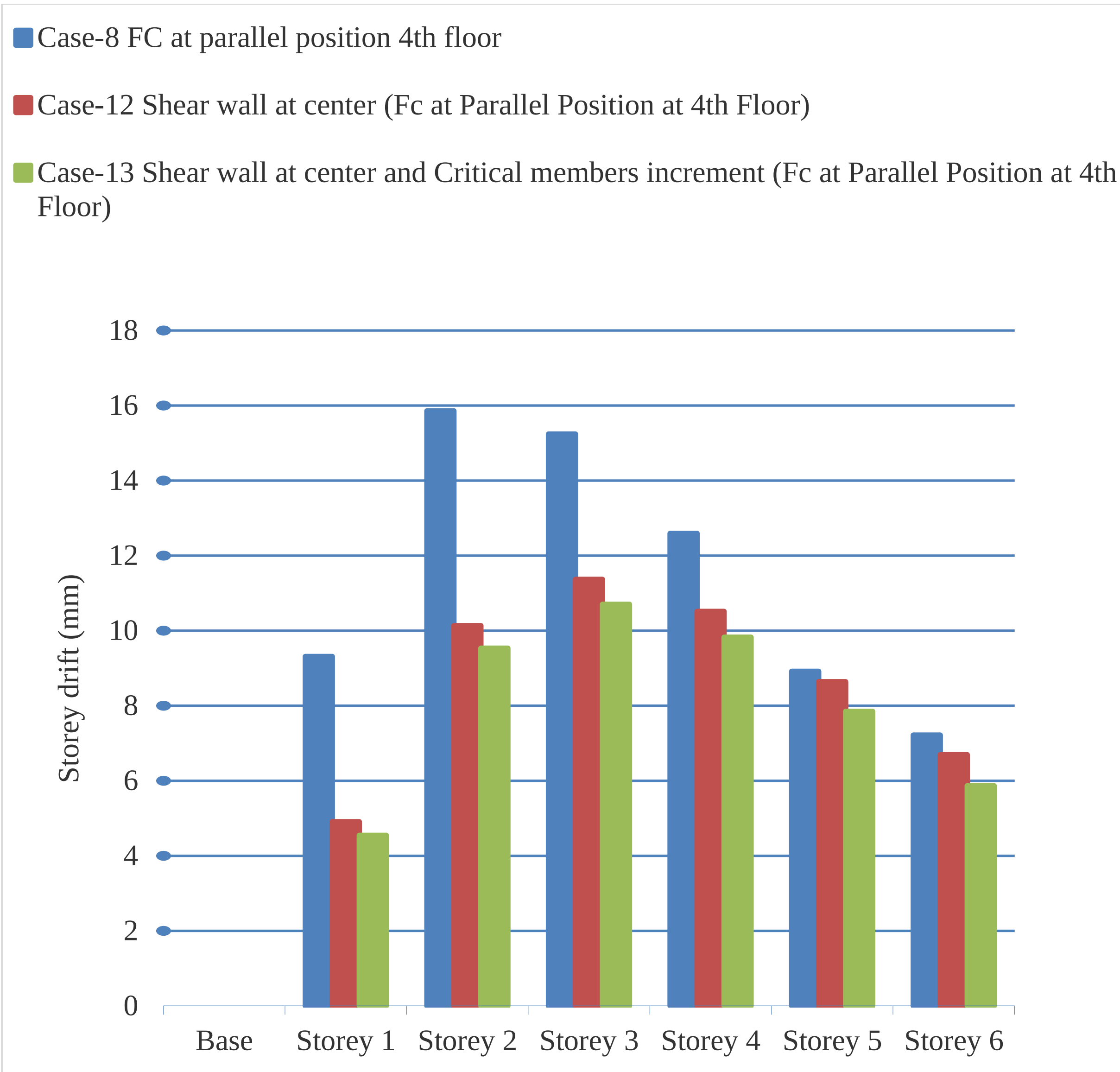


Figure 5. 21 Comparisons of maximum storey drift of floating column buildings with provision of lift shear wall and critical member dimension increment

Effect of lift shear wall provision on base shear of building with FC

From Figure 5.22, there is 1.4% and 4.4% increase in base shear adding lift shear wall at the center and using combination of lift shear wall at the center and critical member dimension increment respectively.

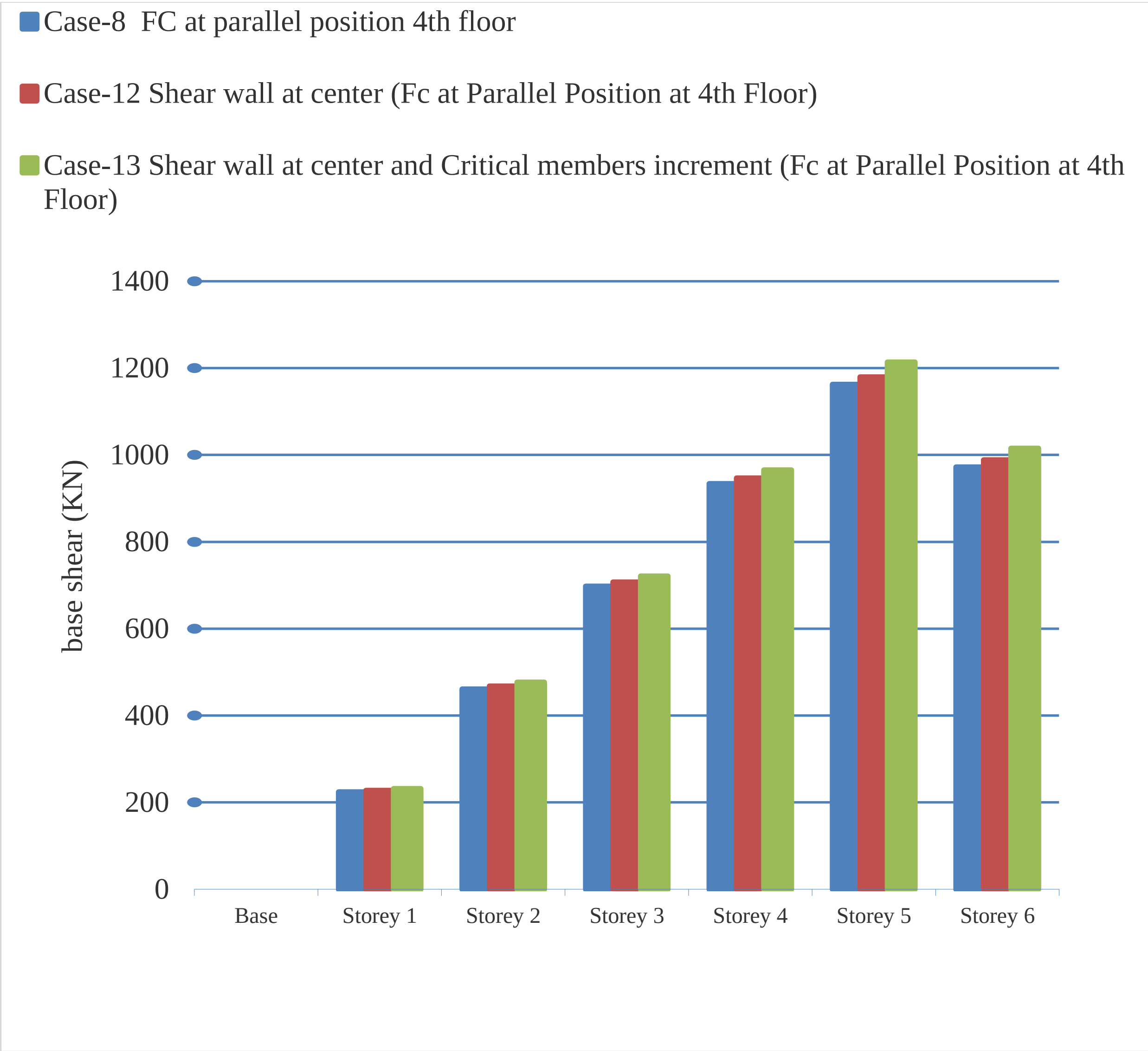


Figure 5. 22 Comparisons of maximum base shear of floating column buildings with provision of lift shear wall and critical member dimension increment

5.5 Summary of floating column buildings improved with different methods

Lateral displacements

Generally, from Figure 5.23, it can be observed that provision of floating column at ground floor edge corner increased maximum lateral displacement of regular building without floating column by 31.4% due to structural irregularity, while changing position of floating column from ground floor edge corner to fourth floor parallel position led to decrement of lateral displacement by 4.4%. Increment of critical beam and column dimension reduced lateral displacement of optimized position floating column building by 11.52% mostly due to column stiffness increment. Providing Center lift shear wall on optimized position floating column building reduced lateral displacement by 22.17%, using combination of lift shear wall and critical member dimension increment reduced lateral displacement of optimized position floating column building by 28.03%.

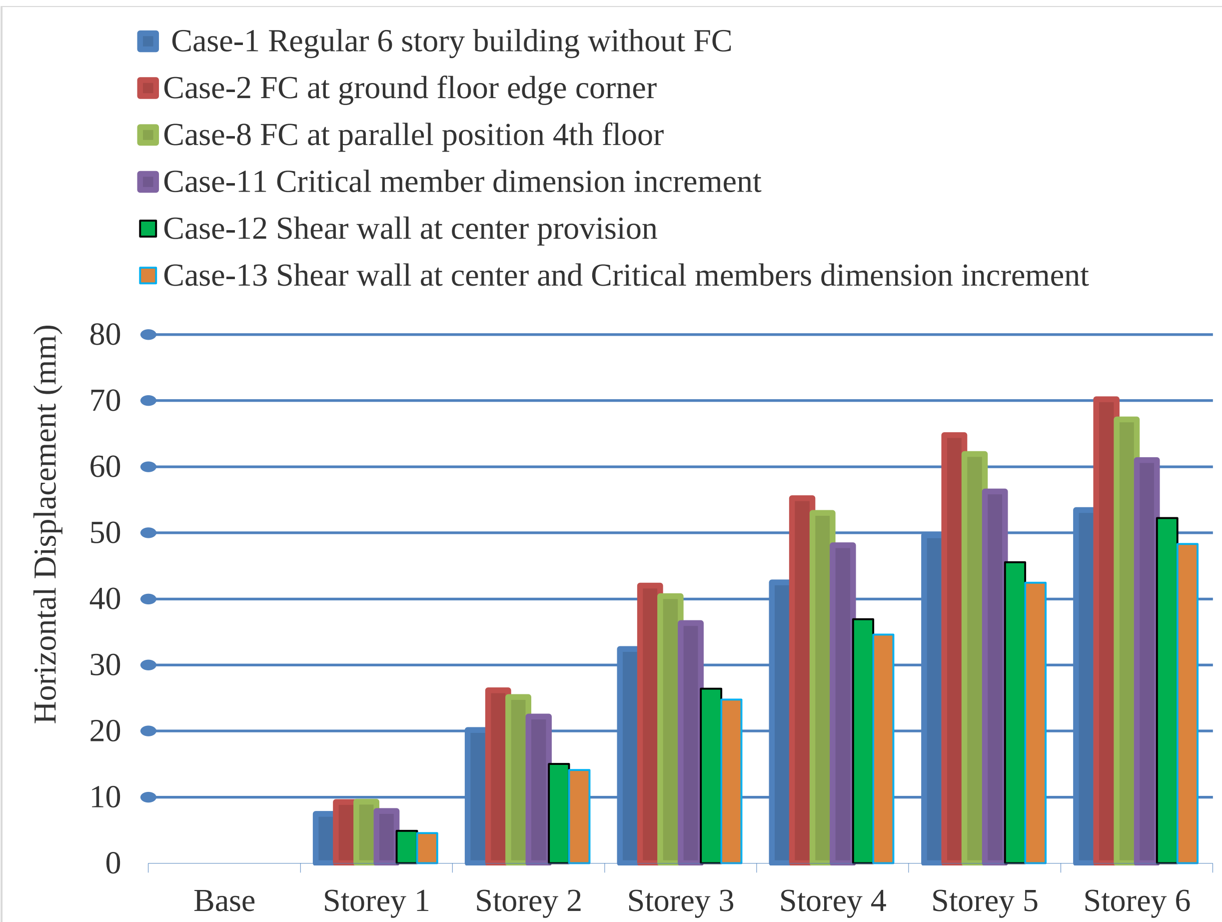


Figure 5. 23 Comparisons of storey displacements of buildings improved with different methods

Storey drift

From Figure 5.24, it can be observed that provision of floating column at ground floor edge corner increased maximum storey drift of regular building without floating column by 29.47% while changing position of floating column from ground floor edge corner to fourth floor parallel position led to decrement of storey drift by 3.7%. Increment of critical beam and column dimension reduced storey drift of optimized position floating column building by 7.11%, mostly due to column stiffness increment. Providing Center lift shear wall on optimized position floating column-building reduced storey drift by 25.4%, using combination of lift shear wall and critical member dimension increment reduced story drift of optimized position floating column building by 29.8%.

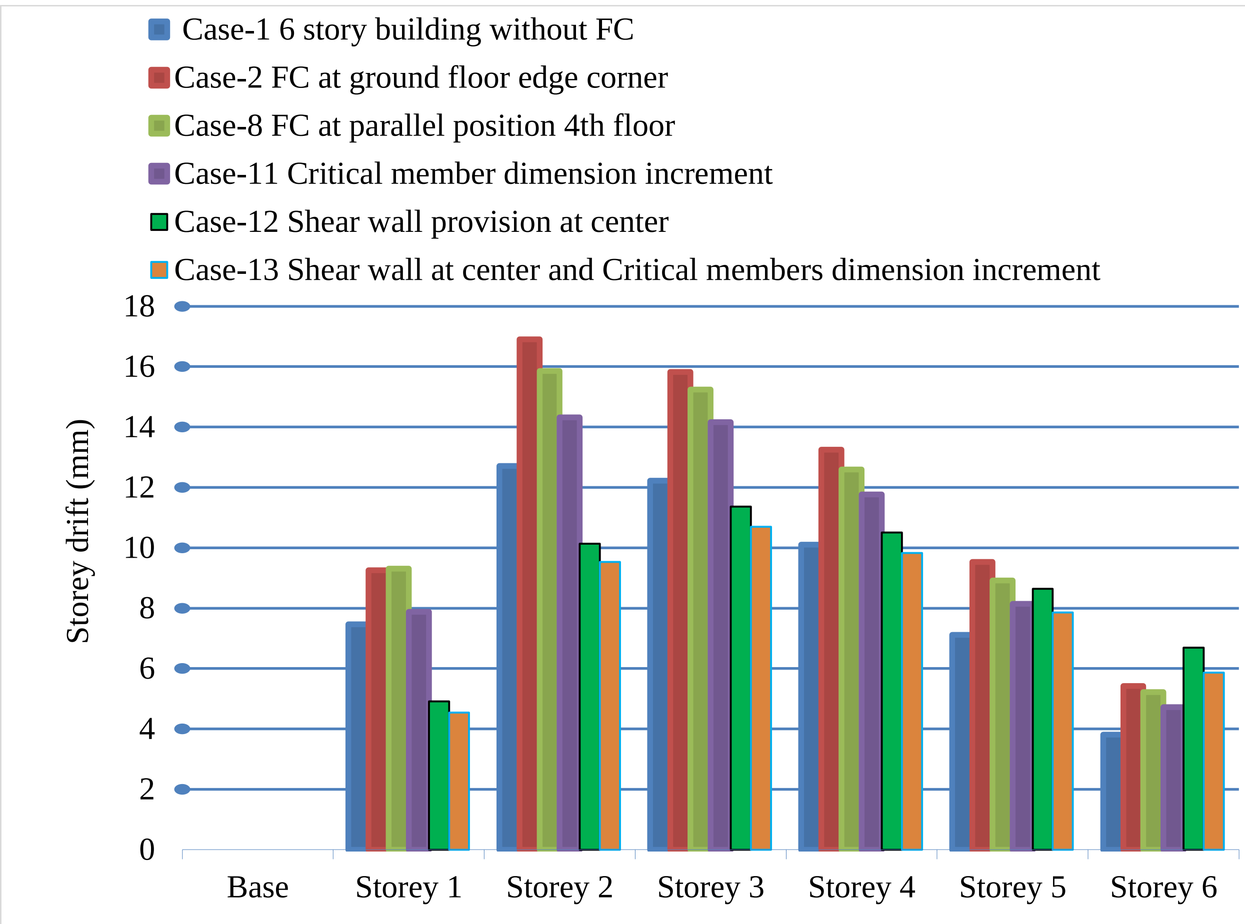


Figure 5. 24 Comparisons of storey drift of FC buildings improved with different methods

Limitation of interstorey drift

As per ES EN 1998-1:2015, section 4.4.3.2

a) For buildings having non-structural elements of brittle materials attached to the structure: $d_r v \leq 0.005h$

b) For buildings having ductile non-structural elements: $d_r v \leq 0.0075h$.

c) For buildings having non-structural elements fixed in a way so as not to interfere with structural deformations, or without non-structural elements: drv ≤ 0.010h

where: dr is the design interstorey drift as defined in 4.4.2.2(2); h is the storey height;

v is the reduction factor which takes into account the lower return period of the seismic action associated with the damage limitation requirement.

(4) The value of the reduction factor ν may also depend on the importance class of the building. Implicit in its use is the assumption that the elastic response spectrum of the seismic action under which the "damage limitation requirement" should be met (see 3.2.2.1(1)P). Has the same shape as the elastic response spectrum of the design seismic action corresponding to the "no-collapse requirement" Note the values to be ascribed to ν for use is found in the National Annex. Different values of ν may be defined for the various seismic zones, depending on the seismic hazard conditions and on the protection of property objective. The recommended values of ν are 0.4 for importance classes III and IV and ν = 0.5 for importance classes I and II.

For case 13, dr=10.7mm, v=0.5, h=9.3m

$d_r v \leq 0.005h$ *(10.7*0.5=5.35)<(0.005*9300=46.5) Ok!*

Base shear

From Figure 5.25, it can be observed that provision of floating column at ground floor edge corner increased expected lateral force by 24.85 %, due to vertical irregularity, that occurred in consequence of reduction in behavior factor q by 20%. Changing position of floating column from ground floor edge corner to fourth floor parallel position led to decrement of base shear by 0.42%. Increment of critical beam and column dimension increased base shear of optimized position floating column building by 2.96%, mostly due to weight increment. Providing Center lift shear wall on optimized position floating column-building wall increased base shear by 1.4%, using combination of lift shear wall and critical member dimension increment increased base shear of optimized position floating column building by 4.5%.

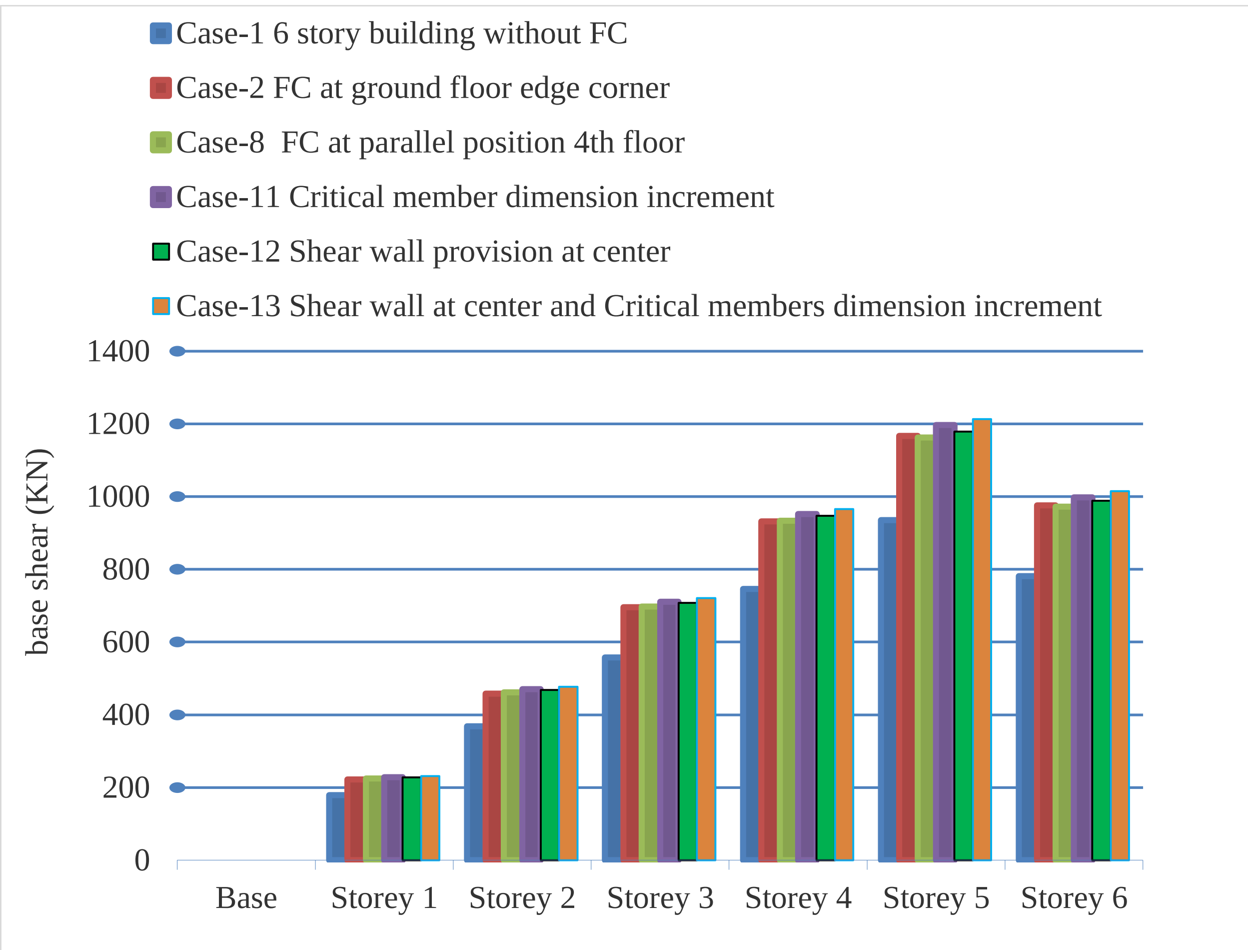


Figure 5. 25 Comparisons of base shear of FC buildings improved with different methods

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

[1] Provision of floating column at ground floor edge corner of 6 storey building increased maximum lateral displacement of regular building without floating column by 31.4%, storey drift by 29.47% and expected lateral force by 24.85 %, indicating that provision of floating columns reduces seismic resistance of buildings.

[2] Changing position of floating columns from edge corner to parallel position of ground floor reduced lateral displacement and storey drift by 2.94% and 2.4% respectively, indicating that it is better to provide floating around center of plan than around edge of plan. Changing position of floating columns from parallel position of ground floor to parallel position 4^{th} floor reduced lateral displacement by 1.5% and storey drift by 7.74%, indicating that it is better to provide floating around top floor than bottom floor. Considering base shear, there is no significant change on values of base shear while changing position of floating column due to constant weight.

[3] Increment of critical beam dimension supporting floating column from 300mm*500mm to 300mm*600mm reduced optimized position floating column building lateral displacement by 0.69% and storey drift by 0.39%, while increasing critical column supporting transfer beam from 500mm*500mm to 600mm*600mm reduced optimized position floating column building lateral displacement by 8.21% and storey drift by 10.04%, indicating that increasing critical column dimension has significant effect unlike increasing critical beam dimension which has negligible effect on seismic resistant improvement. Considering base shear, there is 1.2% and 1.5 % increment in base shear while changing critical beam dimension from 300mm*500mm to 300mm*600mm and critical column dimension from 500mm*500mm to 600mm*600mm respectively due to weight increment which can be considered as negligible change in base shear.

[4] Providing Center lift shear wall on optimized position floating column building reduced lateral displacement by 22.17% and storey drift by 25.4%, indicating that lift shear wall provision has greater significant effect than critical column dimension increment. Considering base shear, there was 1.4% increment in base shear while providing center lift shear wall due to weight increment which can be considered as negligible effect in base shear. Additionally, using combination of critical member dimension increment and center lift shear wall provision reduced lateral displacement and storey drift by 28.03% and 29.8% respectively.

Generally, the result show that provision of floating column has negative side effect on seismic resistance of buildings and it can be improved by moving floating column from outer to inner edge, from lower to upper floor, increasing dimension of column supporting transfer beam and using lift shear wall for vertical transportation.

6.2 Recommendations

- ✓ From the result, provision of floating column increased lateral displacement and storey drift by 31.4% and 29.47% respectively, indicating that floating column buildings are more tend to fail than buildings without floating columns in higher excitation, so using floating column building needs much attention during design and construction in high seismic zone.
- ✓ For a better resistant of seismic load, floating column at fourth floor parallel position around center is recommended over floating column at ground floor edge corner, increasing of critical column dimension is recommended over increasing beam dimension. Additionally using lift shear wall at center decreased lateral displacement of optimized position floating column building significantly by 22.17%, which can be selected as it is needed by checking limitation of interstorey drift.
- ✓ For future study, different number of floating column at different positions can be studied considering different types of irregularities and different seismic resistant improvement method.
- ✓ Study of torsion effect, time history analysis method and pushover analysis method can be also considered for future study.

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Appendix A: Weight calculation of building without floating columns for validation of ETABS out put

Table A. 1 Weight calculation of building without floating columns for storey 1

		L (m)	**W (m)**	**H (m)**	**U.Wt (KN/m3)**	**W (KN)**
Columns	C1--36	0.5	0.5	4.575	25.00	1029.38
Beams	B1-B12	22.5	0.3	0.5	25.00	1012.5
Slabs	S1-S25	4.5	4.5	0.15	25.00	1898.44
Wall	Wall 1-12	22.5			6.10	1647
Permanent Loads	Storey 1	22.5	22.5		1.00	506.25
Variable Loads	Storey 1	22.5	22.5		3.00	379.688
Total						**6279.05**

Table A. 2 Weight calculation of building without floating columns for storey 2-5

		L (m)	**W (m)**	**H (m)**	**U.Wt (KN/m3)**	**W*4 (KN)**
Columns	C1-36	0.5	0.5	3.15	25.00	2835
Beams	B1-12	22.5	0.3	0.5	25.00	4050
Sabs	S1-25	4.5	4.5	0.15	25.00	7593.75
Wall	Wall 1-12	22.5			6.10	6588
Permanent load	Story 2-5	22.5	22.5		1.00	2025
Variable load	Storey 2-5	22.5	22.5		3.00	1518.75
Total						**23872.185**

Table A. 3 Weight calculation of building without floating columns for storey 6

		L (m)	**W (m)**	**H (m)**	**U. Wt (KN/m3)**	**W (KN)**
Columns	C1-36	0.5	0.5	1.575	25.00	354.375
Beams	B1-12	22.5	0.3	0.5	25.00	1012.5
Slabs	S1-25	4.5	4.5	0.15	25.00	1898.44
Wall	Wall 1-4	22.5			4.60	414
Permanent Load	Story 6	22.5	22.5		1.00	506.25
Variable load	Story 6	22.5	22.5		1.00	126.563
Total						**4182.76**

Appendix B: Seismic response of building without FC versus buildings with FC at different position along plan.

Table B. 1: Storey displacement of building without FC versus buildings with FC at different position along plan.

Storey	Case-1 Building without FC (mm)	Case-2 FC at edge corner (mm)	Case-3 FC at middle column Outer periphery (mm)	Case-4 FC at Parallel Position (mm)
Base	0	0	0	0
Storey1	7.464	9.257	9.354	9.356
Storey2	20.178	26.167	26.657	26.547
Storey3	32.402	41.994	42.008	41.873
Storey4	42.501	55.249	54.646	54.487
Storey5	49.615	64.779	63.556	63.372
Storey6	53.429	70.202	68.345	68.135

Table B. 2: Storey drift of building without FC versus buildings with FC at different position along plan.

Storey	Case-1 Regular 6 story building without FC (mm)	Case-2 FC at edge corner (mm)	Case-3 FC at middle column outer periphery (mm)	Case-4 Fc at Parallel Position (at E2E5B2B5) (mm)
Base	0	0	0	0
Story1	7.464	9.257	9.354	9.356
Story2	12.714	16.91	16.703	16.491
Story3	12.224	15.827	15.351	15.326
Story4	10.099	13.255	12.638	12.614
Story5	7.114	9.53	8.91	8.885
Story6	3.814	5.423	4.789	4.763

Table B. 3: Base shear of building without FC versus buildings with FC at different position along plan.

Storey	Case-1 Building without FC (KN)	Case-2 FC at edge corner (KN)	Case-3 FC at middle column Outer periphery (KN)	Case-4 FC at Parallel Position (KN)
Base	0.00	0.00	0.00	0.00
Storey1	179.31	222.40	222.4102	222.4202
Storey2	368.61	457.78	458.0836	458.39
Storey3	557.41	695.92	695.952	695.9834
Storey4	746.20	931.64	931.6777	931.7197
Storey5	935.00	1167.35	1167.403	1167.456
Storey6	781.33	975.49	975.5295	975.5735

Appendix C: Comparisons of seismic response of buildings with FC at different floors

Table C. 1 Comparisons of maximum displacement of buildings with FC at different floors

Storey	Case 4 FC at parallel position(at ground floor) (mm)	Case-5 FC at parallel position (at 1st floor) (mm)	Case-6 FC at parallel position (at 2nd floor) (mm)	Case-7 FC at parallel position (at 3rd floor) (mm)	Case-8 FC at parallel position (at 4th floor) (mm)
Base	0	0	0	0	0
Storey1	9.356	9.315	9.314	9.312	9.312
Storey2	26.547	25.244	25.182	25.175	25.172
Storey3	41.873	41.711	40.497	40.425	40.415
Storey4	54.487	54.361	54.092	53.077	53.008
Storey5	63.372	63.246	62.996	62.641	61.925
Storey6	68.135	68.012	67.76	67.395	67.143

Table C. 2: Comparisons of storey drift of buildings with FC at different floors

Storey	Case 4 FC at parallel position (at ground) (mm)	Case-5 FC at parallel position (at first floor) (mm)	Case-6 FC at parallel position (at 2nd floor) (mm)	Case-7 FC at parallel position (at 3rd floor) (mm)	Case-8 FC at parallel position (at 4th floor) (mm)
Base	0	0	0	0	0
Storey1	9.356	9.315	9.314	9.312	9.312
Storey2	17.191	15.929	15.868	15.863	15.86
Storey3	15.326	16.467	15.315	15.25	15.243
Storey4	12.614	12.65	13.595	12.652	12.593
Storey5	8.885	8.885	8.904	9.564	8.917
Storey6	4.763	4.766	4.764	4.754	5.218

Table C. 3.Comparisons of base shear of buildings with FC at different floors

Storey	Case 4 FC at parallel position (at ground) (KN)	Case-5 FC at parallel position (at 1st floor) (KN)	Case-6 FC at parallel position (at 2nd floor) (KN)	Case-7 FC at parallel position (at 3rd floor) (KN)	Case-8 FC at parallel position (at 4th floor) (KN)
Base	0.00	0.00	0.00	0	0
Storey1	222.42	224.01	224.13	224.2596	224.3852
Storey2	458.39	457.50	460.76	461.02	461.2782
Storey3	695.98	693.56	692.22	697.1522	697.5427
Storey4	931.72	932.24	929.00	927.2012	933.8072
Storey5	1167.46	1168.11	1168.76	1164.698	1162.445
Storey6	975.57	976.12	976.67	977.2118	972.0846

Appendix D: Comparisons of seismic response of FC buildings with critical beam and column dimensions increment

Table D. 1 Comparisons of storey displacement of FC buildings with critical beam and column dimensions increment

Storey	Case-8 FC at parallel position (at fourth floor) (mm)	Case-9 Critical Beam dimension increased (mm)	Case-10 Critical column dimension increased (mm)	Case-11 Critical column & beam dimension increased (mm)
Base	0	0	0	0
Storey1	9.312	9.347	7.851	7.879
Storey2	25.172	25.269	22.118	22.198
Storey3	40.415	40.576	36.229	36.356
Storey4	53.008	53.186	48.014	48.126
Storey5	61.925	61.827	56.467	56.268
Storey6	67.143	66.681	61.627	60.988

Table D. 2 Comparisons of storey drift of FC buildings with critical beam and column dimensions increment

Storey	Case-8 FC at parallel position (mm)	Case-9 Critical Beam dimension increased (mm)	Case-10 Critical column dimension increased (mm)	Case-11 Critical column & beam dimension increased (mm)
Base	0	0	0	0
Storey1	9.312	9.347	7.851	7.879
Storey2	15.86	15.922	14.267	14.319
Storey3	15.243	15.307	14.111	14.158
Storey4	12.593	12.61	11.785	11.77
Storey5	8.917	8.641	8.453	8.142
Storey6	5.218	4.854	5.16	4.72

Table D. 3: Comparisons of base shear of FC buildings with critical beam and column dimensions increment

Storey	Case-8 FC at parallel position (at fourth floor) (KN)	Case-9 Critical Beam dimension increased (KN)	Case-10 Critical column dimension increased (KN)	Case-11 Critical column & beam dimension increased (KN)
Base	0	0.00	0.00	0
Storey1	224.3852	223.88	229.17	228.6766
Storey2	461.2782	460.25	471.34	470.3251
Storey3	697.5427	695.98	712.76	711.2234
Storey4	933.8072	931.72	954.19	952.1216
Storey5	1162.445	1171.44	1187.97	1196.8345
Storey6	972.0846	983.81	986.37	997.9382

Appendix E: Comparisons of seismic response of FC buildings with provision of lift shear wall and critical beam and column dimensions increment.

Table E. 1 Comparisons of storey displacement of FC buildings with provision of lift shear wall and critical member's dimensions increment.

Storey	Case-8 FC at parallel position (at fourth floor) (mm)	Case-12 Shear wall at center (Fc at Parallel Position at 4th Floor) (mm)	Case-13 Shear wall at center and Critical members increment (Fc at Parallel Position at 4th Floor) (mm)
Base	0	0	0
Storey1	9.312	4.91	4.544
Storey2	25.172	15.046	14.078
Storey3	40.415	26.415	24.778
Storey4	53.008	36.926	34.606
Storey5	61.925	45.566	42.458
Storey6	67.143	52.256	48.322

Table E. 2: Comparisons of storey drift of FC buildings with provision of lift shear wall and critical member's dimensions increment.

Storey	Case-8 FC at parallel position (at fourth floor) (mm)	Case-12 Shear wall at center (Fc at Parallel Position at 4th Floor) (mm)	Case-13 Shear wall at center and Critical members increment (Fc at Parallel Position at 4th Floor) (mm)
Base	0	0	0
Storey1	9.312	4.91	4.544
Storey2	15.86	10.136	9.534
Storey3	15.243	11.369	10.7
Storey4	12.593	10.511	9.828
Storey5	8.917	8.64	7.852
Storey6	5.218	6.69	5.864

Table E. 3 Comparisons of base shear of FC buildings with provision of lift shear wall and critical member's dimensions increment

Storey	Case-8 FC at parallel position (at fourth floor) (KN)	Case-12 Shear wall at center (Fc at Parallel Position at 4th Floor) (KN)	Case-13 Shear wall at center and Critical members increment (Fc at Parallel Position at 4th Floor) (KN)
Base	0	0.00	0.00
Storey1	224.3852	227.54	231.81
Storey2	461.2782	467.90	476.91
Storey3	697.5427	707.55	721.19
Storey4	933.8072	947.21	965.46
Storey5	1162.445	1179.24	1213.55
Storey6	972.0846	988.77	1015.28

Appendix F: Comparisons of seismic response of FC buildings improved with different methods

Table F. 1 Comparisons of story displacement of FC buildings improved with different methods

Storey	Case-1 Regular 6 story building without FC (mm)	Case-2 FC at edge corner (mm)	Case-8 FC at parallel position (at fourth floor) (mm)	Case-11 Critical column & beam dimension increased (mm)	Case-12 Shear wall at center (Fc at Parallel Position at 4th Floor) (mm)	Case-13 Shear wall at center and Critical members increment (Fc at Parallel Position at 4th Floor) (mm)
Base	0	0	0	0	0	0
Storey1	7.464	9.257	9.312	7.879	4.91	4.544
Storey2	20.178	26.167	25.172	22.198	15.046	14.078
Storey3	32.402	41.994	40.415	36.356	26.415	24.778
Storey4	42.501	55.249	53.008	48.126	36.926	34.606
Storey5	49.615	64.779	61.925	56.268	45.566	42.458
Storye6	53.429	70.202	67.143	60.988	52.256	48.322

Table F. 2 Comparisons of story drift of FC buildings improved with different methods

Storey	Case-1 Regular 6 story building without FC (mm)	Case-2 FC at edge corner (mm)	Case-8 FC at parallel position (at fourth floor) (mm)	Case-11 Critical column & beam dimension increased (mm)	Case-12 Shear wall at center (Fc at Parallel Position at 4th Floor) (mm)	Case-13 Shear wall at center and Critical members increment (Fc at Parallel Position at 4th Floor) (mm)
Base	0	0	0	0	0	0
Storey1	7.464	9.257	9.312	7.879	4.91	4.544
Storey2	12.714	16.91	15.86	14.319	10.136	9.534
Storey3	12.224	15.827	15.243	14.158	11.369	10.7
Storey4	10.099	13.255	12.593	11.77	10.511	9.828
Storey5	7.114	9.53	8.917	8.142	8.64	7.852
Storey6	3.814	5.423	5.218	4.72	6.69	5.864

Table F. 3 Comparisons of base shear of FC buildings improved with different methods

Storey	Case-1 Regular 6 story building without FC (KN)	Case-2 FC at edge corner (KN)	Case-8 FC at parallel position (at fourth floor) (KN)	Case-11 Critical column & beam dimension increased (KN)	Case-12 Shear wall at center (Fc at Parallel Position at 4th Floor) (KN)	Case-13 Shear wall at center and Critical members increment (Fc at Parallel Position at 4th Floor) (KN)
Base	0	0.00	0	0	0	0
Storey1	179.3058	222.40	224.3852	228.6766	227.5355	231.8113
Storey2	368.6066	457.78	461.2782	470.3251	467.8991	476.9137
Storey3	557.4051	695.92	697.5427	711.2234	707.5548	721.1865
Storey4	746.2036	931.64	933.8072	952.1216	947.2105	965.4594
Storey5	935.0021	1167.35	1162.445	1196.8345	1179.2419	1213.546
Storey6	781.3255	975.49	972.0846	997.9382	988.7708	1015.281

Appendix G: Deformed shape of floating column buildings

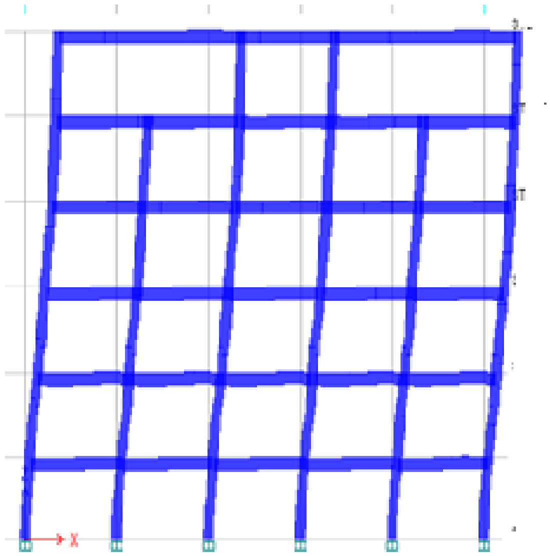

Figure G. 1 Deformed shape of building without FC

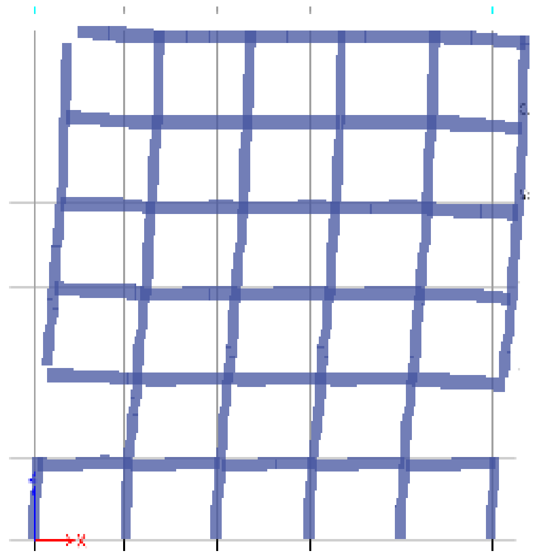

Figure G. 2: Deformed shape of building with FC at ground floor edge corner

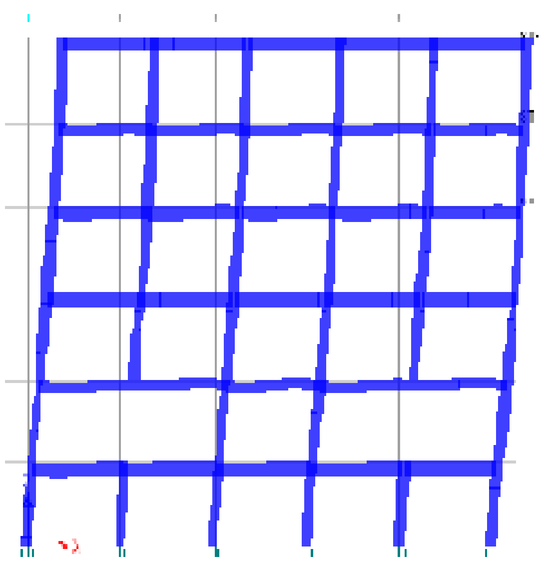

Figure G. 3: Deformed shape of building with FC at GF parallel position

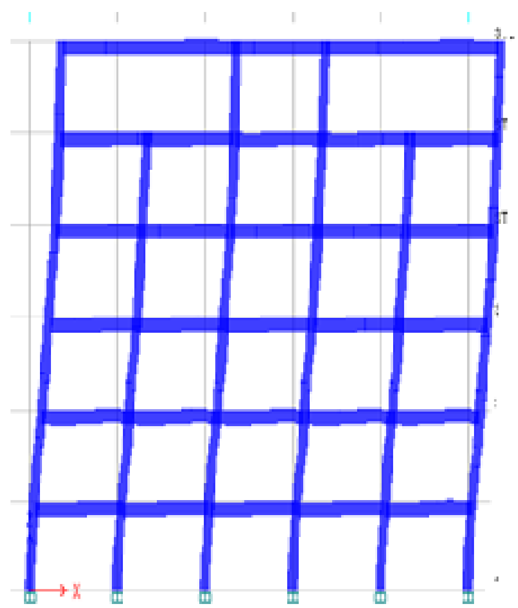

Figure G. 4: Deformed shape of building with FC at 4th parallel position

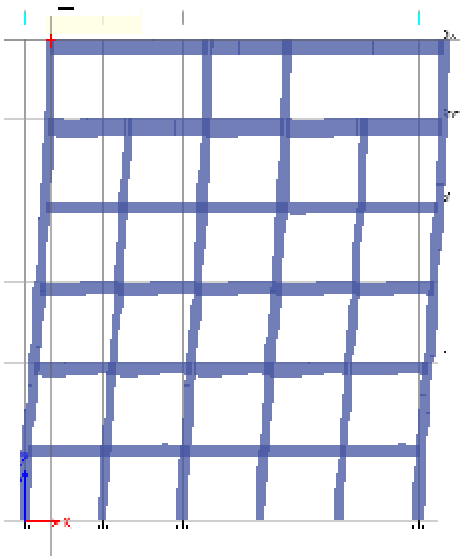

Figure G. 5: Deformed shape of FC building with increased critical beam and column dimension

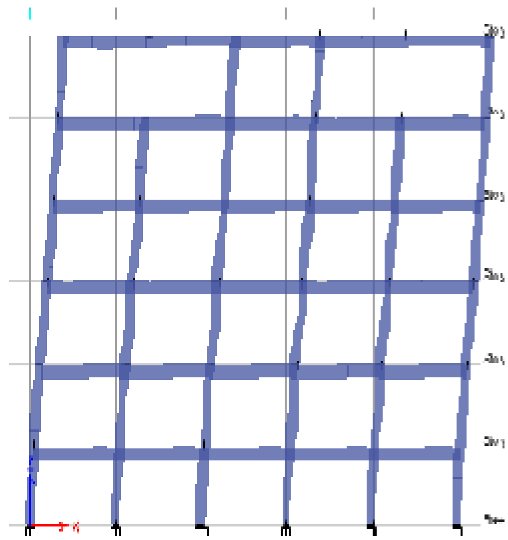

Figure G. 6: Deformed shape of FC building with lift shear wall provision

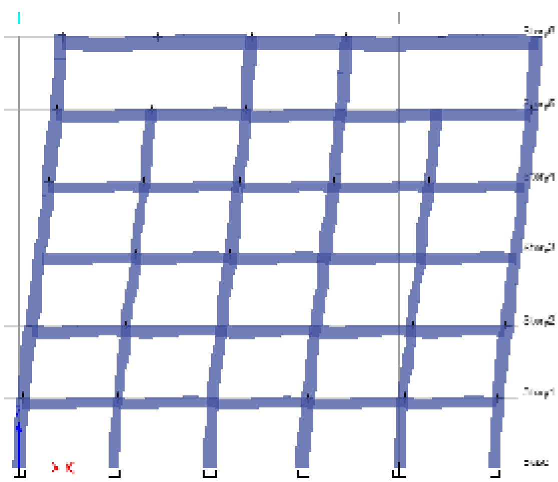

Figure G. 7: Deformed shape of FC building with combined lift shear wall provision and critical members dimension increment