SEISMIC ANALYSIS OF CONFINED MASONRY STRUCTURE USING ETABS

A DISSERTATION

**SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT
FOR THE AWARD OF DEGREE
OF
MASTER OF TECHNOLOGY
IN
STRUCTURAL ENGINEERING**

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CANDIDATE'S DECLARATION

I, AAMIR RAZA, Roll No. 2K/20/STE/01 student of M.Tech. (Structural Engineering). Hereby declare that the project dissertation titled "**SEISMIC ANALYSIS OF CONFINED MASONRY STRUCTURE USING ETABS**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma associateship or other similar title or recognition.

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CERTIFICATE

I, hereby certificate that the Project titled "**SEISMIC ANALYSIS OF CONFINED MASONRY STRUCTURE USING ETABS**" which is submitted by Aamir Raza, Roll No. 2K/20/STE/01, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

Place: Delhi
Date:

Dr. Nirendra Dev
(Professor)
Supervisor

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At the outset, I would like to express my sincere and deep gratitude to my supervisor, Dr. Nirendra Dev, Professor for his enlightening and inspiring guidance to complete my project work under her valuable guidance and supervision. His guidance has taught me valuable lesson for my career.

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ABSTRACT

Buildings are our basic needs. It protect us from rain, sun, theif e.t.c. We spend most of our time in a building whether it is residential, commercial, institutional, industrial. In Damage or collapsing of such types of vital structures leads to a lot of risk for human lives & results in monetary loss. So, the building should be earthquake resistant. One of the reasons of failure of structure is earthquake. It is found that the reasons behind these collapses are mostly due to the poor construction practices and substandard practices involved in the construction of building. As a structural engineer our duty should be to improve the seismic performance of structure with keeping economy in mind.

Confined masonry structure is a construction technology/typology in which first wall are constructed, followed by column and beam. It is similar to RCC and masonry structure in appearance but different in resisting the earthquake load. Due to the lack of relevant design and construction standards, confined masonry construction is currently not practiced in India. However, several initiatives have been launched to promote confined masonry construction over the last ten years.

This paper presents the seismic analysis of confined masonry structure using ETABS. Response spectrum method is used for analysis to study the in plane and out of plane behaviour under earthquake loading in seismic zone v. Effect of wall density and shape of column on the seismic performance of confined masonry structure has been also studied. To study the effect of wall density, analysis is done for 110 mm wall, 150mm wall and 230mm wall. To study the effect of shape of column, rectangular and square column is used. Performance of confined masonry and RC frame structure has been also studied. Results are compared on the basis of maximum storey displacement, max storey drift, base shear, overturning moment, modal mass participation ratio.

With the study it has been observed that by increasing the wall density seismic performance of confined masonry structure has been increased. In CMS, it has been observed that max storey displacement and drift was less but overturning moment & base shear was more as compare to RC frame structure.

KEYWORDS: Confined masonry structure, Software indulge (ETABS), Response spectrum method, Seismic response.

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ABBREVIATION

CMS = Confined Masonry Structure

RC = Reinforced Concrete

Rec. = Rectangle

IM = Infill Masonry

Max = Maximum

X-Dr = X-direction

Y-Dr = Y-direction

r/f = Reinforcement

WCM= Wide Column Model

SDS = Single Diagonal Strut

CDS = Cross Diagonal Strut

CHAPTER 1

INTRODUCTION

1.1. WHAT IS CONFINED MASONRY STRUCTURE

Confined masonry structure is a construction technology in which walls are first constructed then column followed by beam. It is an alternative to both RC frame construction and unreinforced masonry. Actually, it has features of both these technologies mention above. Confined masonry structure consists of masonry walls made either of clay brick or concrete block units and horizontal and vertical RC confining members built on all four sides of a masonry wall panel. Vertical members are called tie-columns, look like columns in RC frame structure except that it has far smaller cross-section. Horizontal elements are called tie-beams, look like beams in RC frame structure. But the function of these tie-beams and tie-columns are different from conventional beam and column. Tie-beam and Tie-column are also called horizontal ties and vertical ties.

Fig.1.1 Confined masonry structure (*source: Jain, Ghosh et al, 2014)*

1.1.1 The Structural Components of a Confined Masonry Building.

Masonry walls- It transmit gravity load and earthquake load both. For transferring earthquake load, walls act as a diagonal bracing. The effectiveness of wall depends upon the degree of confinement of wall by confining element.

Confining elements- Confining elements are also called tie-columns and tie-beams. It improves integrity and stability of masonry walls for in-plane and out-of-plane earthquake loading. These elements also prevent brittle failure of masonry walls and protect them from complete disintegration even in major earthquakes.

Floor and roof slabs- It transmit both gravity and lateral loads to the walls. During earthquake, slabs behave like horizontal beams and so called diaphragms.

Band- It is a horizontal member provided at lintel, sill and plinth level. Plinth band transfer the load from the walls to the foundation below. The main function of band is to confine the whole structure so that during an earthquake they act as a single unit.

Foundation- Loads from the structure to the ground is transmitted by it. Generally, continuous or strip foundation is used. It is made up of stone masonry or concrete.

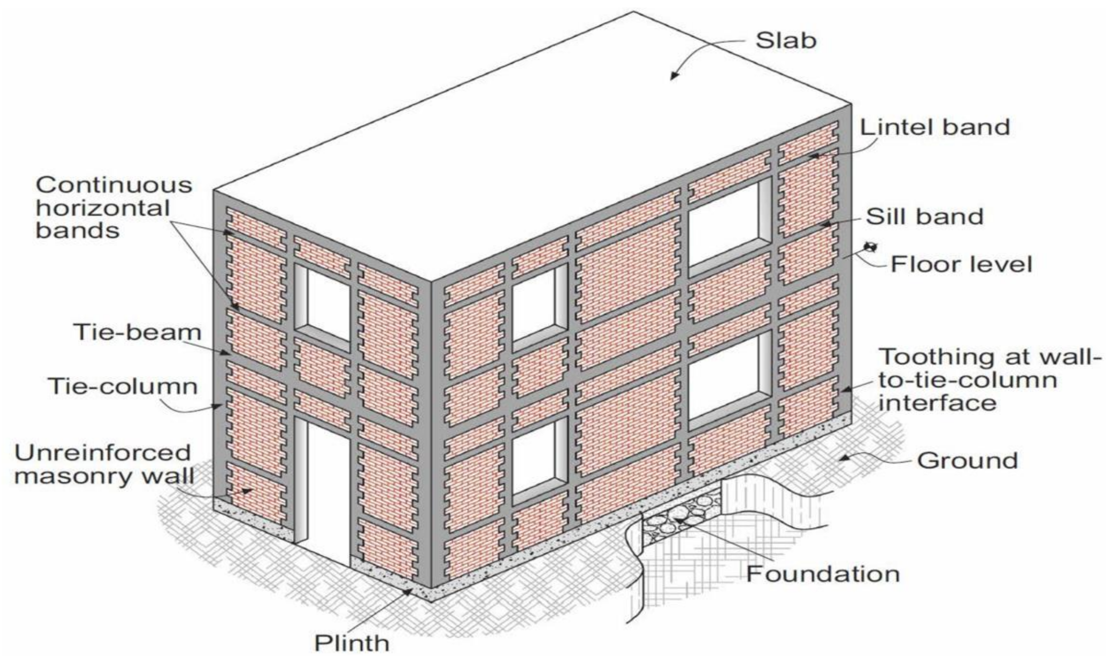


Fig.1.2 Component of confined masonry structure *(https://theconstructor.org)*

1.1.2 Function of Confining Element

- It enhances the stability of masonry wall for in-plane as well as out-of-plane earthquake load.
- It enhances the integrity of masonry wall for in-plane as well as out-of-plane seismic load.
- Under lateral load, it increases the resistance of masonry wall.
- Under earthquake or lateral loads, it reduces the brittleness of masonry walls. Hence improve their performance.

1.2 CONFINED MASONRY AND SIMILAR BUILDING TECHNOLOGIES

Confined masonry building technology is seldom similar to both reinforced masonry and reinforced concrete (RC) frame construction with infill walls. But, there are lot of differences between these building technologies in terms of construction sequence, complexity, and seismic performance.

1.2.1 Comparison between Reinforced Masonry and Confined Masonry

In reinforced masonry structure, horizontal and vertical reinforcement are provided. These reinforcement increase the ductility and strength of masonry walls. Masonry units are made of concrete or clay and they are usually hollow. Vertical reinforcement bars are placed in the hollow cores, and then grouted with a grout (cement-based) to anchor the reinforcement and to protect the reinforcement from corrosion. Vertical reinforcement is also placed at the wall corners and intersections, around the openings. Horizontal reinforcement is provided in the form of ladder-shaped wire reinforcement placed in horizontal joints. The vertical reinforced bar provided in hollow core should be continuous from foundation to floor level and specific mix proportion will be used for grouting to ensure the quality of reinforced masonry.

In confined masonry, the reinforcement bar is concentrated in horizontal and vertical ties while walls are free from reinforcement.

1.2.2 Comparison between Confined Masonry and RC Frames with Masonry Infill Walls

The appearance of finished surface of both the structure are same, however these two structures are entirely different. These differences are on the basis of construction sequence and the manner in which they resist gravity and earthquake load.

In confined masonry structure, masonry wall are constructed first. Then tie-columns are constructed followed by tie-beams and finally floor/roof slab. In RC frame structure with infill walls, first the RC frame is constructed followed by infill/masonry walls.

In confined masonry structure, masonry wall are load bearing wall. They resist most of the gravity load and at the same time they resist the earthquake load too while in the RC frame construction, infill walls are non-load bearing. Infill walls have insignificant stiffness as compare to RC frame and it is common to have gap in RC frame between underside of beam and walls because of this beam deflect without transfer gravity load.

In confined masonry structure, tie-beams and tie-columns are not designed as a moment resisting frame because of that they are smaller in cross-section. Hence, saving of material like concrete and steel. That’s why confined masonry is economical. While in RC frame structure with infill walls, beam and column are designed as a moment resisting frame. Hence, they are larger in cross section.

In confined masonry structure, Seismic behavior is due to composite (monolithic) action of a masonry wall and adjacent RC confining elements. This composite action exists due to the toothing between the walls and the tie-columns. In the absence of toothing, composite action can be achieved by means of horizontal reinforcement (dowels). While in the RC frame structure seismic behavior is due to frame action.

1.3 HOW CONFINED MASONRY STRUCTURE RESIST SEISMIC LOAD.

A confined masonry structure can be modeled as a vertical truss in which wall act as a diagonal strut subjected to compression only because of masonry wall have minimum or low tensile strength. Due to act as a diagonal strut it transfer earthquake load whenever subjected to seismic load, while the confining element subjected to compression and tension depending upon the direction of earthquake load.

Degree of strut action depends upon the degree of confinement of wall by confining element and composite action between wall and confining member. This composite action exists due to the toothing between the walls and the tie-columns. In the absence of toothing, composite action can be achieved by means of horizontal reinforcement (dowels).

Under severe earthquake ground shaking, the collapse of a confined masonry building may take place at the first story level (see Fig 1.3). The main reason of collapse occurs at the first story level is due to high seismic loads, these high seismic loads cause ample cracks in masonry which reduces the stiffness.

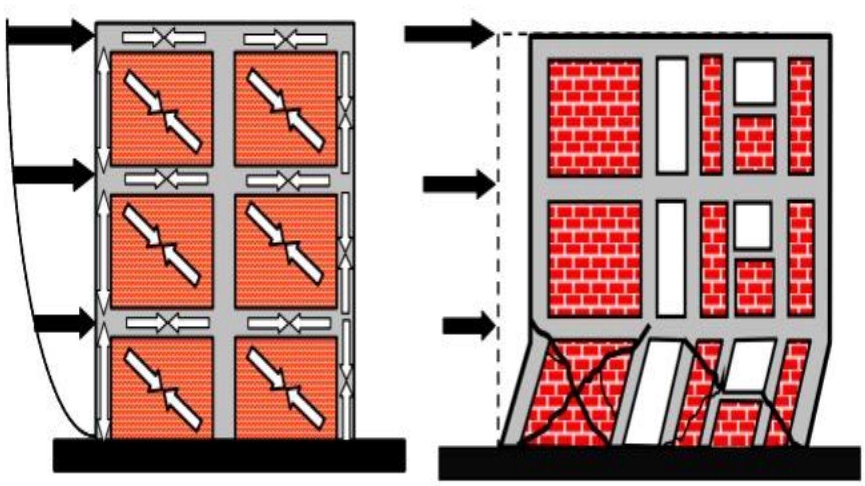


Fig.1.3 Load transfer mechanism (left) and failure mechanism (right) of CMS

(source: Alcocer et al., 2004).

1.3.1 Failure Modes in Confined Masonry Structure

Shear failure mode- shear failure is recognized by diagonal crack develop in wall. Diagonal crack is due to breaking of bond between brick and mortar unit. Initially, earthquake load is resisted by masonry wall due to composite action while RC confining column don't play any significant role. When the lateral load increases beyond the limiting value, cracks start develop in centre portion of wall. Further increase in lateral load resulting propogation of crack towards the corner. At this stage wall start pushes the adjacent confining column sideways. Hence, reinforcement in confining element engage in resisting tension or compression stresses. Finally, at higher load these cracks propagate into the tie-columns and the damage occurs in tie-column at the top and bottom of the panel.

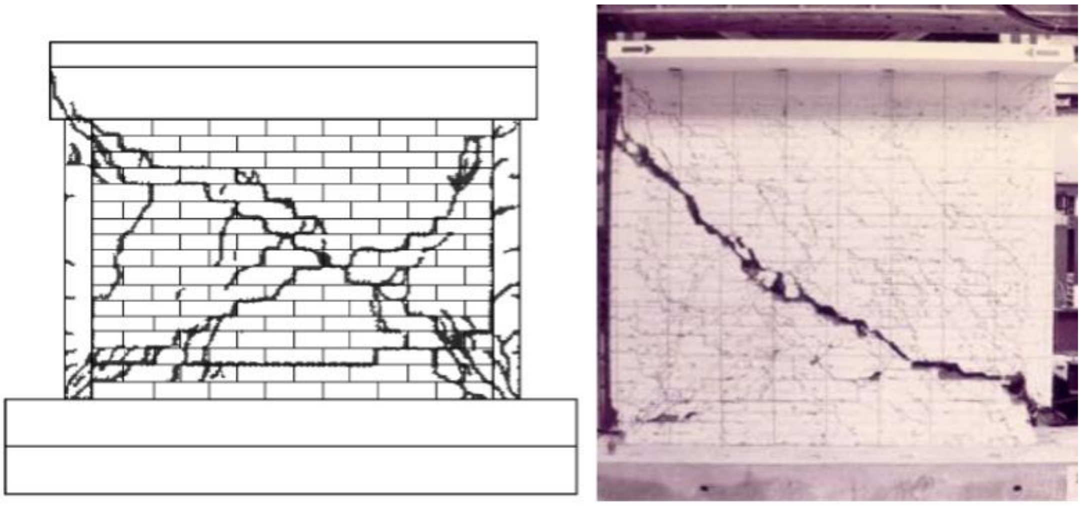


Fig.1.4 Shear failure of confined masonry wall*s*

(*Yoshimura et al., 2004-left; Aguilar and Alcocer, 2000- right*).

Flexure failure mode- It is due to in-plane, as well as out-of-plane lateral load. It is recognized by horizontal cracks develop at mortar bed joint on tension side of wall. When the composite action (means toothing between wall and tie-column) is absent, then separation column to wall is also observed in some cases. crushing and disintegration of masonry may take place at the bottom near wall and tie-column. Flexure failures don't causes brittle failure. Hence, it is not a critical failure.

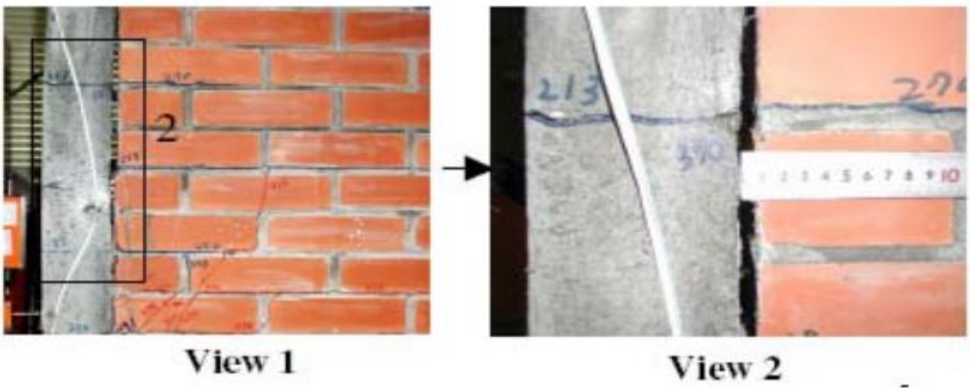


Fig.1.5 Flexural failure of confined masonry walls *(Yoshimura et al., 2004)*.

1.4 GUIDELINES FOR EARTHQUAKE RESISTANT CONFINED MASONRY STRUCTURE.

In past earthquake, it has been observed that properly designed and constructed confined masonry structure perform very well in major earthquake without any collapse, even in some cases there was no severe damage.

So, it is very important to design and construct confined masonry structure according to codal provision & requirements. Some of the architectural and construction guidelines are given below which we have to follow during planning and construction of confined masonry structure.

1.4.1 Architectural Guidelines

Architects play an important role in developing this conceptual design. Architectural guidelines consists of overall shape, size and dimensions of a building, position of opening, spacing between the tie-column to tie-column and tie-beam to tie-beam, wall layout, height of building and wall density. Structural engineers are responsible for providing structural safety and must work closely with architects to ensure that the design meets both structural and architectural requirements.

Building Layout

Building layout is one of the main requirement for good performance during earthquake. Some of the desirable and undesirable layouts are give below.

1) The building plan should be regular in shape.

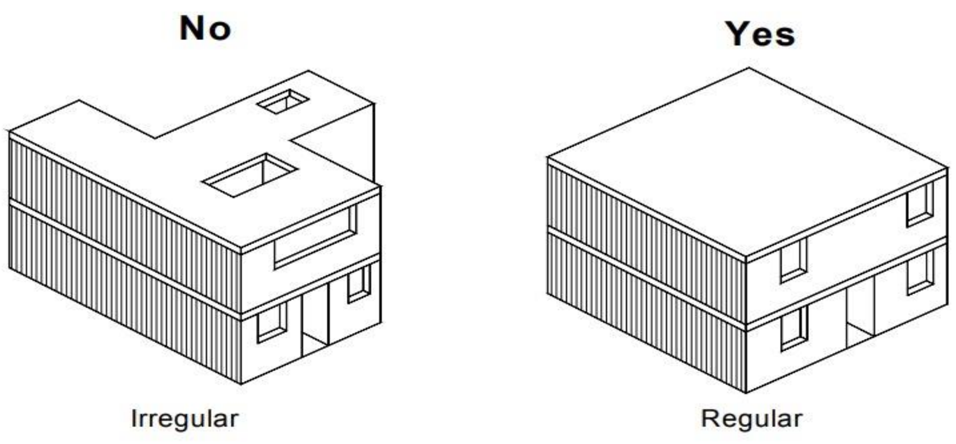


Fig.1.6 Regular building plan (*Meli et al, 2008*)

2) The building should not be too long. It's mean, the length-to-width ratio in plan should not greater than 4.

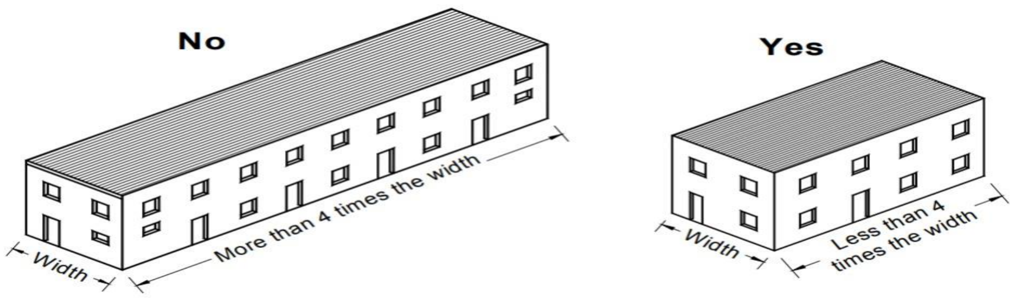


Fig.1.7 Length-to-width aspect ratio of building (*Svetlana Brzev, 2007*)

3) The walls should be symmetrical so that there is minimum or no torsional effects induce. it is not always possible to have a perfectly symmetrical wall layout. Figure shown on the right is much better than the figure on the left.

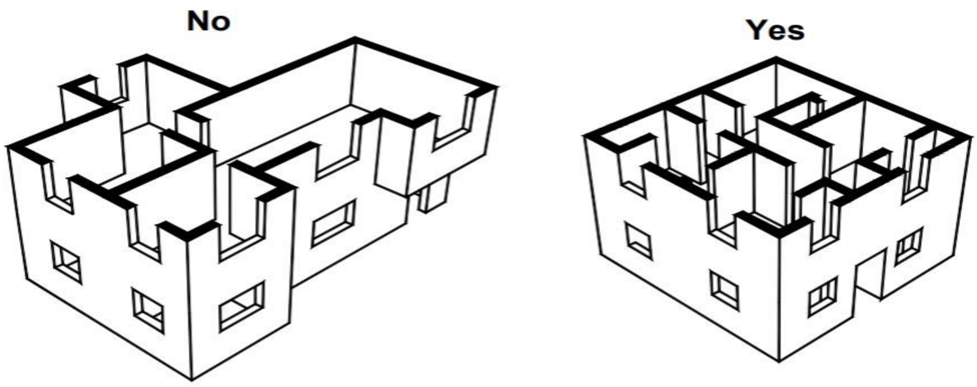


Fig.1.8 Layout of wall (*Boen et al, 2011*)

4) The walls should be continuous from the base to the height of building.

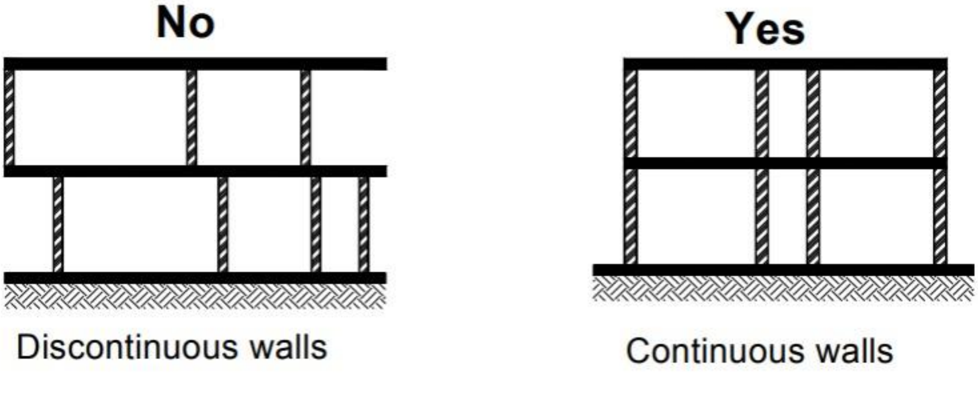


Fig.1.9 Continuity of walls up to the building height (*Hart & Quiun et al*).

5) Openings for doors and windows should be placed in the same position on each floor. If area of any opening is more than 1.5 m^2, tie-columns should be placed at both sides of opening to enable the diagonal strut action.

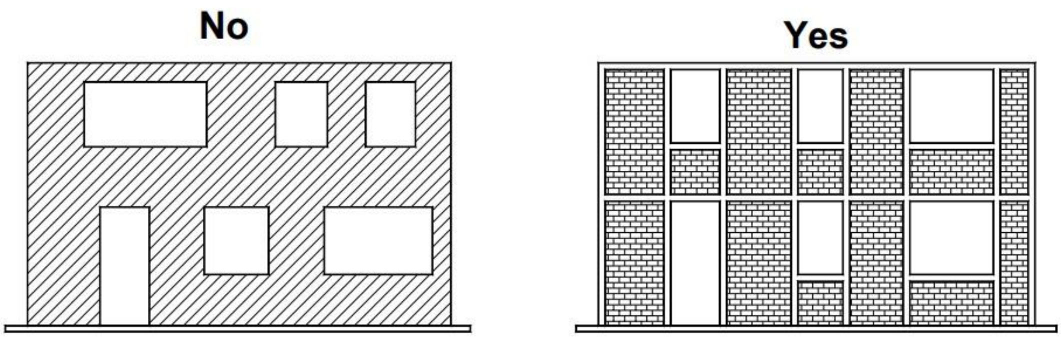


Fig.1.10 Location of openings in a building (*Svetlana Brzev, 2007*).

Confining Elements

6) Vertical spacing of tie-beams should not be greater than 3 m.

7) Maximum spacing between the tie-columns should be of 4 m. Tie-column should be placed at following location: (a) at the intersections of walls; (b) within the wall if necessary to ensure that 4 m spacing between the adjacent confining elements.

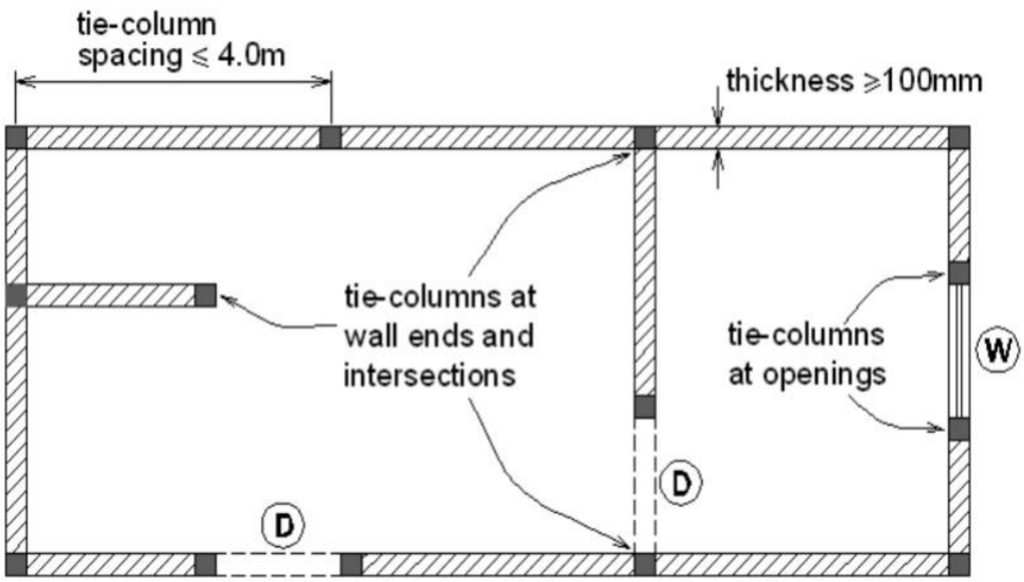


Fig.1.11 Floor plan sample showing the spacing and position of tie-columns

(*source: Brzev, 2008*)

Walls

8) At least two walls should be continuous in each direction from top to bottom. Also there should be an adequate number of walls in each direction (see Figure 1.14), because the seismic response of confined masonry buildings predominantly depends on the shear resistance of masonry walls.

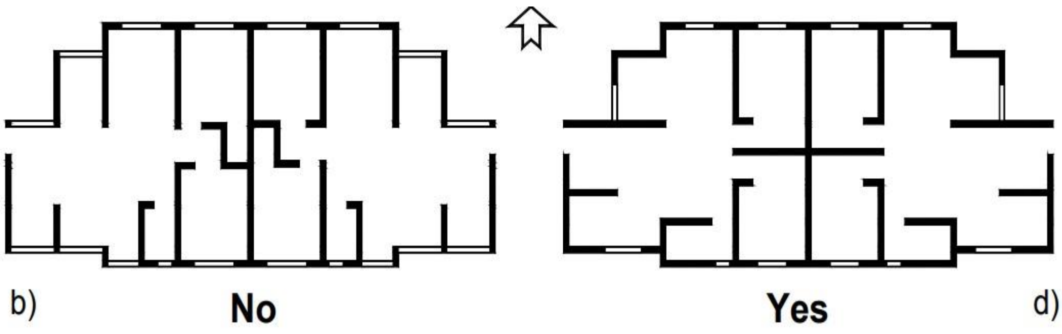


Fig.1.12 Wall distribution in plan: (b) not enough wall in E-W direction & (d) adequate wall in both direction (*Tomazevic et al, 2011*).

9) To ensure good performance of confined masonry structure during earthquake there should be at least 2% wall density in each of two mutually perpendicular directions. Wall density is the total cross sectional area of all walls in one direction divided by the sum of the total areas of all floors in a building.

Building Height

10) Confined masonry structure is suitable for low- to medium-rise building construction. Restrictions of confined masonry buildings height as per Eurocode 8 (1996) are: (a) For a site with design ground acceleration up to 0.2 g, the CMS height restricted up to 4-storey high in seismic zone III of India. (b) For a site with design ground acceleration up to 0.3 g, the CMS height restricted up to 3-storey high corresponding in seismic zone IV of India. (c) For a site with design ground acceleration up to 0.4 g, the CMS height restricted up to 2-storey high in seismic zone V of India.

1.4.2 Construction Guidelines

Performance of a confined masonry building during earthquake sternly depends on the quality of building materials, like bricks or blocks, mortar, concrete, reinforcing steel, good workmanship and proper detailing and designing. Some of the guidelines are given below:

Tie-columns

1) Before the construction of foundation, reinforcement of tie-columns for the first storey should be assembled (Figure 1.15, left). At least four vertical bars and cross-ties should be assembled and placed (see Figure 1.15, right). 135° hooks is more preferable in column-ties.

2) Reinforcement in tie-column depends on the number of storeys, the seismic zone and types of soil. Minimum four deformed bars of 10mm diameter (4 - 10 mm bars) are sufficient for a low-rise confined masonry building (up to two storeys high) for longitudinal reinforcement with a minimum 6 mm ties at 200 mm spacing should be provided at middle portion and 6 mm ties at 100 mm spacing in the top and bottom end of column as recommended by most of codes. Vertical bars should be lapped by a minimum 500 mm length. Splicing should take place at column mid-height, except for the ground floor level.

3) Cross-section of tie-column should not be less than (100 x 100) mm. Generally, the column width should be kept equal to the wall thickness.

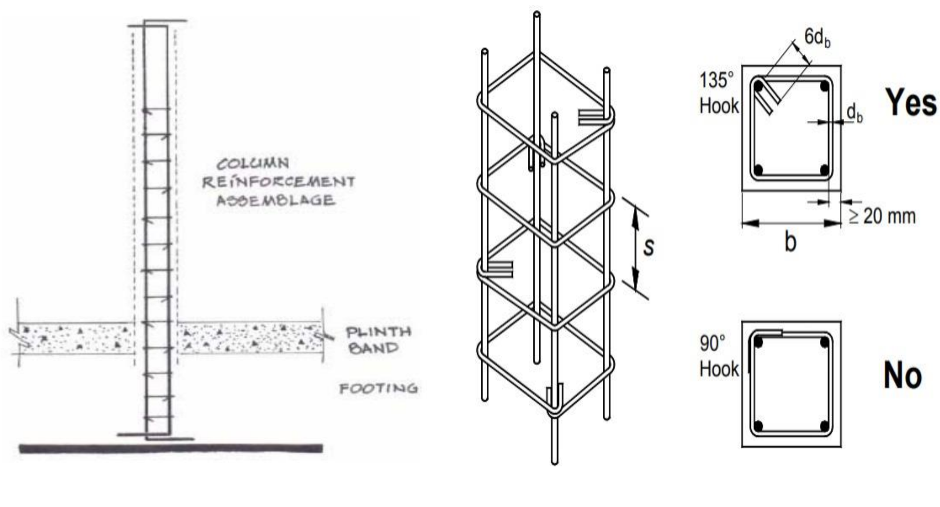


Fig.1.13 Placement of tie-column reinforcement before the construction of foundation and walls (left) and Tie-column reinforcement details (right).

Foundation and Plinth Construction

4) The foundation should be made up of either an un-coursed random rubble stone masonry footing or a RC strip footing. On top of the foundation a RC plinth band should be constructed. To prevent building settlements in soft soil areas plinth band is essential.

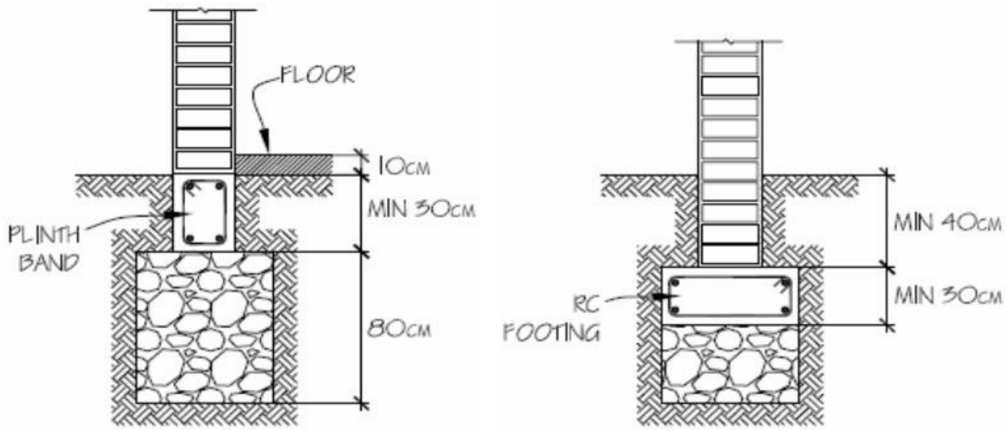


Fig.1.14 Stone masonry foundation with RC plinth band (left) and RC strip footing (right).

Wall construction

5) Thickness of wall should not be less than 100 mm and height to thickness ratio of wall should not be greater than 30. Maximum height of wall construction is limited to 1.2 m per day.

6) Each side of the wall should be toothed, (see Figure 1.17, left) because it helps to develop bond between wall and tie-column and also essential for adequate wall confinement. Due to confining, composite action develop. Hence, during earthquake it perform well. If the interface between the masonry wall and the concrete tie-column remains smooth, during an earthquake to ensure interaction between the masonry and the concrete, dowels bar should be provided in mortar bed joints (see Figure 1.17, right).

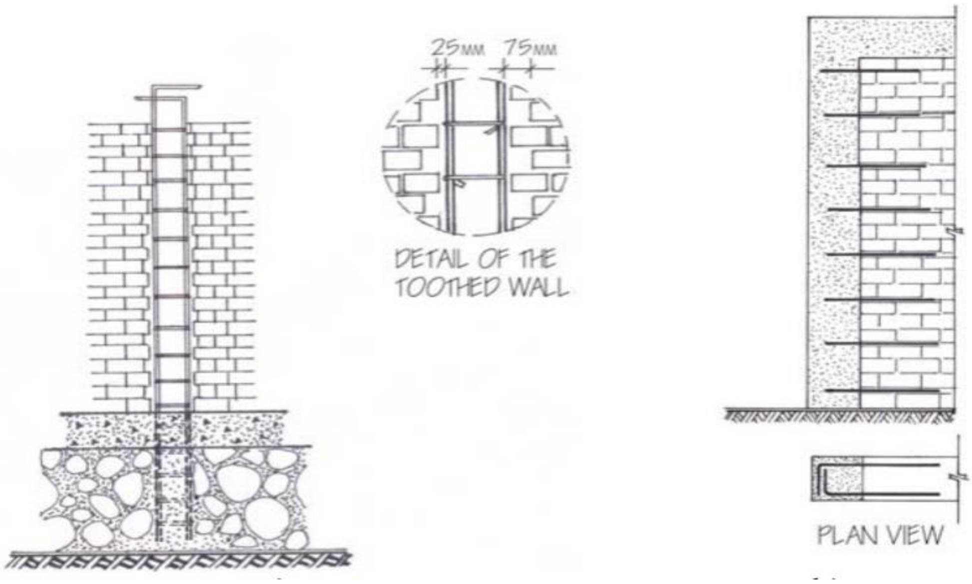


Fig.1.15 Toothed wall construction (left) & horizontal dowels bar at the wall-to-column interface (right).

7) After reaching the desired wall height, concrete in the tie-columns will be pour. From two sides masonry walls provide formwork for the tie-columns, however the formwork must be placed on the remaining two sides. We can see in the figure below:

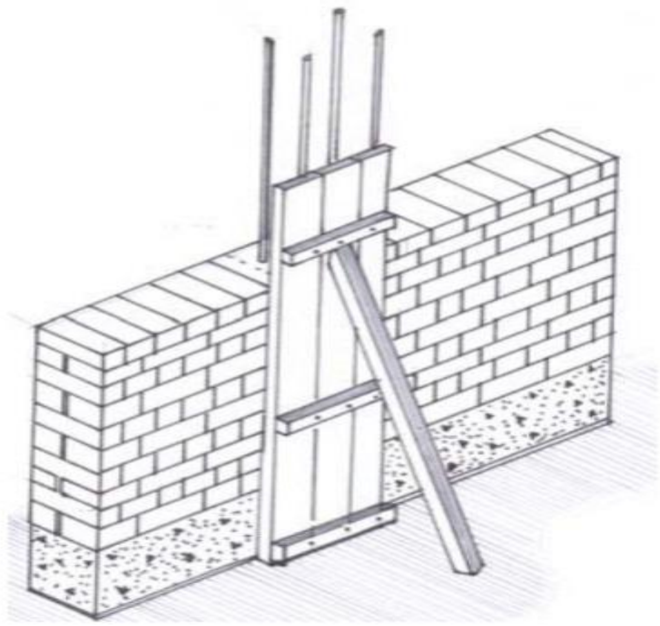
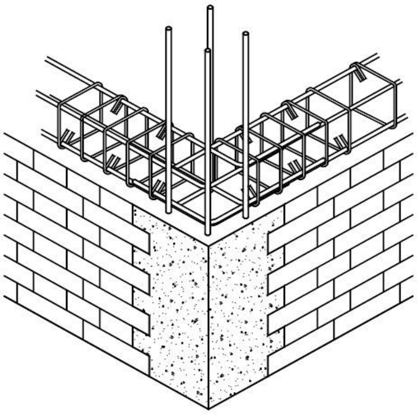


Fig.1.16 Formwork for tie-columns (*Meli et al*)

Tie-beams

8) Tie-beams will be construct on the top of the walls at each floor level. Minimum four deformed bar of diameter 10 mm (4-10 mm bars) are adequate for longitudinal reinforcement with at least 6 mm diameter bar at 200 mm spacing (6 mm @200) are for stirrups as per most of the codes. A minimum 500 mm length should be lapped in longitudinal bars. A 90° hooked anchorage should have in longitudinal bars at the intersections to ensure the effectiveness of tie-beams in resisting seismic loads. The hook length should be at least 500 mm.



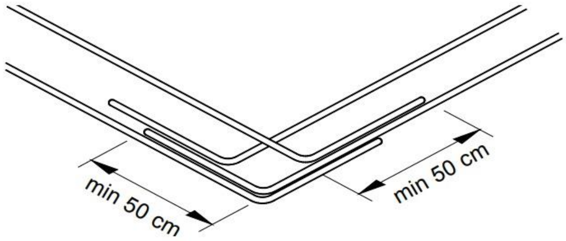


Fig.1.17 Tie-beam construction at wall intersections (left) and hooked anchorage for longitudinal reinforcement (right), (*Brzev, 2008*).

9) The cross sectional area of tie-beam should not be less than (100 x 100) mm. Width of beam should be equal to the thickness of wall.

10) When the width of openings exceeding 1.5 m, special lintel beams may be required across opening with additional reinforcement bars. Lintel beams can be integrated with the tie-beams at the floor level.

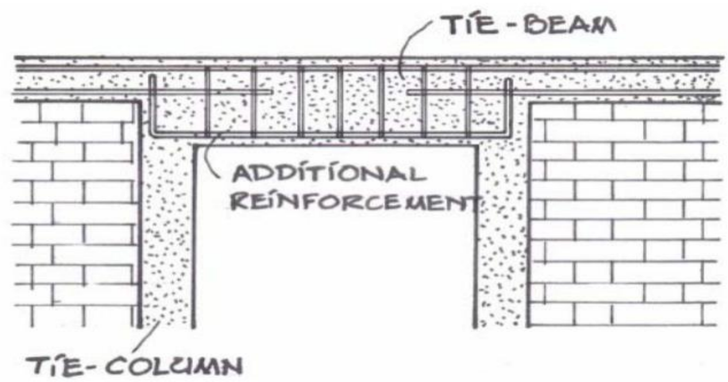


Fig.1.18 Lintel beam reinforcement (*Yamin et al, 2011*)

1.5 OBJECTIVE OF THE STUDY

The objective of the work are as follows:

- To evaluate the performance of RC frame structure and confined masonry structure under seismic loading.
- To study the effect of wall density on confined masonry structure by evaluating their response.
- To study the effect of shape of column (rectangular & square) on confined masonry structure by keeping the same gross sectional area so that we can decide which shape is better by comparing their response.
- To educate and familiarize structural engineers to understand the in-plane and out-of-plane seismic performance of confined masonry structure under different wall density and shape of column.

1.6 LIMITATION OF THE STUDY

Due to the lack of relevant design and construction standards, confined masonry construction is currently not practiced in India. However, several initiatives have been launched to promote confined masonry construction over the last ten years. Due to these initiatives, the first large scale application of confined masonry construction in India is in IIT Gandhinagar. Very less work has been done on confined masonry structure in India. Confined masonry structure can be built only upto G+ 4 storey but in some countries, it has been built upto G+6 storey. There is no code for confined masonry structures in India.

1.7 ORGANIZATION OF THESIS

The Dissertation titled **"SEISMIC ANALYSIS OF CONFINED MASONRY STRUCTURE USING ETABS"** is composed of five chapters.
Following are the chapters included in this dissertation.

Chapter 1 consists of the Introduction of confined masonry structure, structural component & their function, confined masonry & similar building technology, how confined masonry resist earthquake load, failure modes and construction and architectural guidelines. Objective, scope and limitation of thesis is also given in this chapter.

Chapter 2 comprises of literatures which have been reviewed, during the study.

Chapter 3 discussed about the different methods used in seismic analysis and the method used in this project work & elaborated with the given guidelines. It also deals the different types of loading, loading combination, modal & their description.

Chapter 4 contains details about the results obtained from the analysis and their interpretation in the form of tables and graphs.

Chapter 5 Conclusion and recommendations

Bibliography of the literatures which have been referred in the study is also provided.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter provides an introduction of confined masonry structure & their in-plane & out-of-plane behavior under seismic loading. It also provides information about macro-element modeling techniques, non-linear dynamic analysis, wide column model approach, in-plane cyclic loading for seismic assessment of confined masonry structures. The most significant analysis report are discussed in the following sections.

2.2 LITERATURE ON CONFINED MASONRY STRUCTURE

Ahmed, Shahzada et al., (2019) discussed the seismic assessment of un-reinforced masonry (URM) and confined masonry (CM) structures. For both the structures, one storey, two storey & 3 storey building option has been taken. Pushover analysis has been done and the lateral load response of unreinforced masonry (URM) and confined masonry (CM) structures is compared. URM and CMS is also compared with RC typology to calculate the reduction in cost. From the results, he concluded that by confining the wall ductility capacity increase which causes increase in energy dissipation. When compare to URM, lateral load capacity of CMS structure is increased by 300% for one storey, 70% for 2^{nd} storey and 50% for 3^{rd} storey. There was reduction in cost in CMS & URM structure by 28% & 20% as compare to RC structure.

Cuiqiang, Ying et al., (2011) studied the effect of infill walls on the RC frame structure under the seismic loading. For this non-linear dynamic analysis is performed on RC frame structure with & without infill walls. Modelling is done using CANNY software. Three model has been considered, one is RC bare frame, second is RC frame with discontinuous infill walls and third is RC frame with continuous infill wall. From the results, there is change in period is observed in RC structure with infill wall, this was due to increase in stiffness of RC frame. RC frame with infill wall also changed the distribution of strength causing change in failure pattern, which is strong beam & weak column. This indicates that the infill walls change the failure pattern of the frame, and it is necessary to consider them in the seismic design of the RC frame.

Marques and Lourenco (2013) first performed a lateral test on CM structure and the test results data are collected to find the shear strength. Shear strength obtained from the test was more accurate than the existing formulas. Then a confined masonry structure is model based on wide column approach and pushover analysis has been done. This approach are validated against existing formulas & experimental results obtained from the lateral test performed on CMS. The discrete element model give good estimation of initial stiffness & base shear strength but it overestimate the durability.

Borah and Singhal et al., (2020) designed a CM wall specimen and tested for combination of in-plane cyclic load & vertical load. Based on that numerical model is developed using FEM techniques in ABAQUS. The data obtained from experimental test results are inputed in numerical model to make the model able to capture the cracking pattern & non-linear response which help to understand the variation of geometry, material e.t.c. It is observed that the numerical results are similar to experimental results. Therefore, the proposed model can be used to model the confined masonry walls.

Rangwani and Brzev (2017) studied the linear elastic analysis of CMS using wide column approach. After the analysis, results are obtained in term of shear forces, bending moment, stiffness & lateral displacement. Then these results are compared with FEM results. From the conclusion, they concluded that there is no difference in model in term of internal forces. A gradual increase in displacement or drift due to increase in wall aspect ratio was also observed.

Kumazawa and Ohkubo (2000) tested two confined masonry wall under static cyclic loading. Lateral reinforcement is provided in mortar joint at wall corners. The specimen was tested for a target axial stress of 0.96N/mm^2. Other specimen is tested without lateral reinforcement for a stress of 1.36 N/mm^2. At the horizontal deflection angle of 1/100 rad. ultimate strength was 0.8-0.9 N/mm^2. Due to effect of lateral r/f, delay in diagonal crack & distribution of shear crack is observed at wall corner.

Asteris and Asce (2003) discussed the influence of opening in masonry infill panel in the reduction of stiffness. To study the effect on infilled frame, the position and the percentage of masonry infill panel opening is taken as a parameter for the parametric study. From the study, he concluded due to increase in opening percentage, there is decrease in lateral stiffness of infilled frame. This decrease was upto 87% for bare frame. The presence of infill wall causes decrease in shear force on column. Decrease of lateral displacement upto 77% is observed in all three stories in infilled frame with infill wall.

Gilmore et al., (2008) performed the seismic assessment of low height confined masonry structure using displacement based evaluation. First, to obtained the inelastic roof displacement of CM building, coefficient method is used. Second, pushover analysis is done on CM building to estimate the capacity curve.

Kubhar, Shirsath et al., (2019) discussed about seismic analysis of confined masonry building and their results are compare to equivalent RCC frame structure. Apart from manual calculation, ETABS has been used for analysis. Results are compared in term of base shear, storey drift, lateral displacement etc. Increase in base shear & reduction in storey displacement in CMS is observed in both static and response spectrum method.

Sattar, Liel et al., (2010) evaluate the collapse performance of a set of RC frame with and without infill walls. For this study, 13 RC frame building has been modelled with clay brick masonry wall. Building is model by keeping the 1920s-era construction in Los Angeles. Walls are modelled as strut. Non-linear time history analysis has been done. It was finded that RC frame with infill walls are more vulnerable to collapse than bare frame because masonry infill wall increases the stiffness and mass causing brittle shear failure in column. Because of weak wall absorb low earthquake forces, RC frame with weaker wall show better performance than the RC frame with strong infill walls.

Furtado, Varum et al., (2016) studied the out-of-plane non-linear behaviour of IM walls with & without previous in plane damage. The study is done to develop a solution to prevent collapse and in future earthquake & to improve their performance. For study the behaviour, three infill wall panels are constructed & subjected to out-of-plane monotonic and cyclic loading. The results are presented in term of hysteresis force-displacement curve, damage evolution, stiffness degradation and energy dissipation. Finding show that, different out-of-plane behaviour of IM walls with & without previous in-plane damage has been observed in each test. Infill wall 2 & 3 showed vertical cracking and the detachment of infill wall from surrounding RC frame has been observed from top & bottom joints.

Desai et al., (2017) comparison of CM wall and UM wall has been carried out on the basis of their analysis and design. Excel worksheet is prepared to design CM wall. The main focus of this study was to determine the more economic construction between UM & CM.

Stoica and Barnaure (2015) investigated the structural behavior of confined masonry structures. Various parameters are considered to check the influence on structural behaviour. These parameters are the way of defining loads, the wall & the coupling beam dimensions, the r/f of beam & column. For this study, a 5 storey building with 3m floor height was considered. The walls are modelled as a grid linear element & their geometry are defined by section design features. End of column and beam is assigned with non-linear hinges. Pushover analysis is carried out using ETABS software. From the results, they concluded that there was no influence of beam r/f on max displacement of building. When the beam length was lower, a lower displacement capacity of building was observed. Higher ratio of r/f causes max increase in base shear.

Tomazevic and Klemenc (1997) tested plain and confined masonry walls with h/l ratio equal to 1·5, made at 1:5 scale and the results have been used to develop a rational method for modelling the seismic behaviour of confined masonry walls. A tri-linear model of lateral resistance-displacement envelope curve has been proposed, where the resistance is calculated as a combination of the shear resistance of the plain masonry wall panel and dowel effect of the tie-columns' reinforcement. Lateral stiffness, however, is modelled as a function of the initial effective stiffness and damage, occurring to the panel at characteristic limit states. The method has been also verified for the case of prototype confined masonry walls with h/l ratio equal to 1·0.

Caliò, Marletta et al., (2012) introduced an advanced model, based on the definition of a plane macro-element, for the simulation of the seismic behaviour and the evaluation of the seismic vulnerability of unreinforced masonry buildings. The proposed model has been conceived to provide a simulation method capable of predicting the seismic behaviour of a masonry structure at a low computational cost, compared to a nonlinear finite element simulation. A considerable reduction of the computational cost is achieved since the nonlinear behaviour of a masonry portion is described by very few degrees of freedom and by means of uniaxial nonlinear springs. The presence of the interfaces between macro-elements allows also the modelling of the interaction with nonlinear frame elements. As a result infilled frame structures could also be modelled.

Naseer, Ibrar et al., (2022) discussed the seismic evaluation of a confined masonry wall having thickness 225 mm. the study has been done by varying confining elements size and reinforcement ratios in the confining elements. After varying these parameters, their effect is studied on stiffness, ductility & lateral strength of confined brick masonry wall. The results show that an increase of 16%, 10% & 5% has been observed in lateral strength, stiffness and ductility respectively when the confining element size increased from 75mm to 150mm. Due to change of vertical r/f in confining element, there was no significant change in lateral strength.

Ahmed & Shahzada et al., (2020) studied the non-linear behaviour of CMS. For this, macro-element modelling has done and the results are compared with the experimental results. Parametric study has done to evaluate the influence of wall density, masonry strength & properties of confining element. From the results, he concluded that there was a max influence of masonry compressive strength on lateral load capacity. By increasing the masonry strength from 2Mpa to 4Mpa, structure capacity is increased upto 80%. Influence of longitudinal r/f ratio in tie-column is observed on lateral resistance of confined masonry. Capacity of structure increases upto 26% when the r/f ratio increases from 0.05 to 0.4.

Sarrafi et al., (2014) described the specification and some equations given by different codes to estimate the lateral resistance of masonry wall. Then, to estimate the lateral strength of confined masonry walls an equation is developed according to the Iranian code. The developed equation is then validated with the test results conducted on seven confined masonry walls. It was found that the results obtained from the developed equation correlated with test results.

Ranjbaran, Hosseini et al., (2012) performed a set of non-linear static analysis to study the factors affecting the behaviour of confined masonry walls with & without opening. Numerical models are validated with experimental. Then, to express the relationship between lateral strength and wall specification, some simple formula has been given including ductility, stiffness & ultimate strength.

Alcocer et al., (2004) performed shaking table test to study the dynamic behaviour of CMS. For the study, one storey & three storey small scale specimens are modelled by keeping material identical for both model & prototype. Configuration of prototype kept nearly same to the real building constructed in Mexican city. Then the models are subjected to series of seismic motion recorded in epicentral region of Mexico. The aim of this research work was to check the building constructed in Mexico are safe or not.

2.3 GAP OF THE STUDY

Very less work has been done to study the behavior of CMS by changing the size of confining element and by changing the ratio of vertical reinforcement in confining element. Very less work has done on effect of height to length (h/l) ratio of wall on lateral strength, in-plane & out of plane behavior of CM wall.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

This chapter discuss the different methods of analysis used for a structure subjected to earthquake loading. This chapter also deals with the method used for analysis of CMS in this current study or project. Different methods of analysis are static analysis and dynamic analysis.

Static analysis are further classified into linear static analysis and non-linear static analysis. Dynamic analysis are further classified into linear dynamic analysis and non-linear dynamic analysis.

3.2 LINEAR STATIC ANALYSIS

It is also called equivalent static analysis. This analysis is used for regular structure with limited height. In this method, the structure is treated as a discrete system in which masses is concentrated at each floor levels and the weight of columns and walls are uniformly dispersed/distributed to the floors above and below the storey. Forces and displacement on each due to each horizontal component of ground motion are determined separately by idealizing the building into one degree of freedom at each floor in the direction of ground motion being considered. Non-linearity of structure and dynamic impact are ignored in linear static analysis. In linear static analysis, equivalent lateral force method are used.

3.2.1 Equivalent Lateral Force Method

This method is also called seismic coefficient method. This method is based on the assumption that lateral loading is equivalent to dynamic (actual) loading. This method is very simple to use because the shape and period of higher natural modes of vibration are not required except the fundamental natural period. This is the simplest method because computation work is less and it is based on the formula given in the code. In this method, 1^{st} total mass or seismic weight of building is calculated. Then, base shear is calculated using formula given in the code. This base shear is distributed along the height of building at each storey level as storey shear.

3.2.2 Seismic Base Shear

It is the total design lateral (seismic) force acting on a structure along any principal direction. It is denoted by V_B. It can be calculated according to formula given in IS code 1893:2016 (part 1).

$V_B = A_h * W$ (Clause 7.6.1, IS 1893(part 1):2016)…..…….(1)

Where,

A_h = Design horizontal acceleration spectrum value using the fundamental natural period T' in the considered direction of vibration.

W= Seismic weight of building. (Clause 7.4, IS 1893(part 1):2016)

Design horizontal seismic coefficient (Ah) is calculated by:

$A_h = Z*I*Sa/2gR$ (Clause 6.4.2, IS 1893(part 1):2016)………….(2)

Where,

Z= Seismic zone factor (Table 3; IS 1893(part 1):2016)

I= Importance factor (Table 8; Clause 7.2.3, IS 1893:2016)

R= Response reduction factor (Table 9; Clause 7.2.6, IS 1893:2016)

Sa/g= Design acceleration coefficient for different types of soil (Clause 6.4.2.1)

3.2.3 Seismic Weight

Total Seismic weight of the building is the sum of seismic weight of each floor. Seismic weight of each floor is equal to full dead load plus some portion of imposed/live load as per Table 10; clause 7.3.1 of 1893(part1):2016. For calculating the seismic weight of each floor, weight of wall & column on each floor is equally distributed to the floor above and below storey. Any weight distributed between storey will be distributed to floor.

3.2.4 Distribution of Design Shear Force

The building and their element should be designed in such a way that they resist the total design base shear. First total design base shear is calculated, then it is distributed to each floor level i.e, storey shear. Then, the design seismic force at each floor level is further distributed to each lateral load resisting element. Formula for distribution of design shear force at each floor is given below:

$$Q_i = \left(\frac{W_i H_i^2}{\sum_{j=1}^{n} W_j H_j^2}\right) V_B$$

(Clause 7.6.3, IS code 1893(part 1):2016)………(3)

Where

Q_i= design lateral force at i floor

W_i= seismic weight at i floor

H_i= height of i floor from base

n= number of storey in the building.

3.3 LINEAR DYNAMIC ANALYSIS

This method is also used to compute the design seismic force on the structure. This is suitable for medium to high rise building with irregularities in shape, mass, stiffness, torsional irregularities e.t.c. the difference between the linear static and linear dynamic method is the magnitude of forces and their distribution along the height of building. This method shall be performed for all building except regular building lower than 15m in height in seismic zone II. In this method, building is idealized as a multi-degree of freedom system (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix.

Linear dynamic analysis is based on the concept of modal superposition. In this method, only linear property are taken into account. Two methods are used for linear dynamic analysis: (a) Response spectrum method, (b) linear (elastic) time history method.

3.3.1 Response Spectrum Method

This method is also called modal superposition. In this method peak response is obtained from design response spectrum curve for each mode of vibration based on modal frequency and modal mass and this peak response is combined by either CQC and SRSS method to obtain overall response of structure. Response spectrum is a curve between response acceleration coefficient on Y-axis and time period on X-axis for different types of soil. This method is applicable for those structure where modes other than the fundamental mode affect the response of structure. Either in time history method or response spectrum method, the calculated design base shear (V_B) shall not be less than design base shear (V_B) dash calculated by fundamental time period (Ta). We can calculate Ta as per clause 7.6.2 of IS code 1893:2016 (part1). If V_B is less than V_B dash, then the force response (storey shear force, base reaction) shall be multiplied by V_B dash/V_B.

3.3.1.1 *Number of Modes*

Number of modes to be used in analysis should be such that the total mass of these mode should be at least 90% of the total seismic weight. If a mode having natural frequency greater than 33Hz. Then, in modal combination it will not considered, natural frequency upto 33Hz should be only carried out for modal combination.

3.3.1.2 *Modes Combination*

There are two methods to combine the peak response of different modes. These methods are:

SRSS (Square Root of Sum of Squares)- In this method, overall/global peak response (member force, storey shear, storey force, base reaction, displacement) of a structure is calculated by combining the square root of sum of square of peak response of each mode shape. SRSS method give more accurate results when the modal frequencies are well separated. However when the frequencies of major contributing modes are very close together as that normally emerged in three dimensional systems, this method will give poor results. Hence, CQC method is proposed.

Suppose R_1, R_2, R_3 are the peak response of 1st, 2nd & 3rd mode respectively. Then according to SRSS method, the overall/max peak (resultant) response (R) will be

$$R^2 = R_1^2 + R_2^2 + R_3^2 \qquad \ldots\ldots\ldots\ldots\ldots.(4)$$

CQC (Complete Quadratic Combination)- This technique has good accuracy when the modal frequency are close together. Closely-spaced modes may interact with each other, so we should treat closely-spaced modes like the algebraic method. Hence CQC method is used. It reduces the error in modal combination. It is used as a replacement for SRSS method. This method is widely used by researchers, practitioners and also recommended by IS code. Success of this method is due to its simplicity, accuracy and practicality. This method is derived from random vibration theory.

$$\lambda = \sqrt{\sum_{i=1}^{N_m} \sum_{j=1}^{N_m} \lambda_i \ \rho_{ij} \ \lambda_j}$$

(Clause 7.7.5.3, IS code 1893:2016)………(5)

Where

λ= peak response quantity;

λ_i= response quantity in mode i with sign;

λ_j= response quantity in mode j with sign;

ρ_{ij}= cross-modal correlation coefficient;

$$= \frac{8\ \zeta^2 (1+\beta)\ \beta^{1.5}}{\left(1-\beta^2\right)^2 + 4\ \ \zeta^2\beta\ \ (1+\beta)^2};$$

Nm= number of mode considered;

β= natural frequency ratio= ω_j/ω_i

ζ= modal damping coefficient ratio;

ω_j= circular natural frequency in mode j;

ω_i= circular natural frequency in mode i;

3.3.1.3 Modal Analysis

In modal analysis, variation in mass and stiffness is considerd/accounted in the computation of lateral force coefficient. The expressions used for calculating various quantities are given below:

a) Modal mass- it is the part of total seismic mass of structure which are effective in a particular mode of vibration during horizontal and vertical ground acceleration. Modal mass M_k of mode k is given by

$$M_{\mathrm{k}} = \frac{\left[\sum_{i=1}^{n} W_{\mathrm{i}} \phi_{\mathrm{ik}}\right]^2}{\mathrm{g} \sum_{i=1}^{n} W_{\mathrm{i}} (\phi_{\mathrm{ik}})^2}$$

…………..(6)

Where

g= acceleration due to gravity

n= number of floor in the structure

$ø_{ik}$= mode shape coefficient at floor i in mode k

W_i= seismic weight of structure of floor i

b) Modal participation factor- the modal participation factor (P_k) in mode k of the structure is the amount by which natural mode k contribute to overall oscillation of structure during horizontal or vertical ground motion. It is given by equation:

$$P_{\mathrm{k}} = \frac{\sum_{i=1}^{n} W_{\mathrm{i}} \phi_{\mathrm{ik}}}{\sum_{i=1}^{n} W_{\mathrm{i}} (\phi_{\mathrm{ik}})^2}$$

(Clause 7.7.5.4 of IS 1893:2016)…………(7)

c) Design lateral force at each floor in each mode- Peak lateral force Q_{ik} at floor i in mode k is expressed by the formula given below:

$Q_{ik}= A_k Ø_{ik} P_k W_i$ ……………(8)

Where

A_k= design horizontal acceleration spectrum value using natural period of oscillation T_k of mode k. (Clause 6.4.2, IS 1893:2016)

d) Storey shear- it is the sum of design lateral force at all level above the storey under consideration. Peak shear force (V_{ik}) acting on a storey i in mode k is given by:

$$V_{ik} = \sum_{j=i+1}^{n} Q_{ik} \quad \text{……………(9)}$$

e) Storey shear force due to all mode- It shall be obtained by combining the peak shear force (V_{ik}) of i storey of each mode. Combination will be done by modal combination method discussed above.

f) Lateral force at each storey due to all load- Lateral force (F_i) at any floor is given by:

$F_{roof} = V_{roof}$, and $F_i = V_i - V_{i+1}$;

3.4 DIFFERENT TYPES OF LOADING

A structure is not subjected to self weight only, there are various load acting on the structure apart from self weight.

1) **Dead Load (DL)-** it consist of self weight of structure. Self weight of the structure is the sum of self weight of indivisual member. The imposed load which are not going to change their position during the life time of building is also come under dead load. Wall loads, plastering, floor finishing load (tiles) are come under this category.

   Software like ETABS automatically consider the self weight of beam, column & slab. Dead loads are given in IS 456:2000 (part 1).

2) **Live Load (LL)-** The imposed load which can change their position with respect to time, means all the movable load are live load. Load of machinery, human, table, chair, bed are come under this category.

   Software like ETABS, doesn't take/consider live load automatically. We apply live load. Live loads are given IS 456:2000 (part 2).

3) **Wind Load (WL)-** The load acting on the structure due to impact of wind is called wind load. This is also called lateral load. Wind load is given in IS 456:2000 (part 3).

4) **Earthquake Load (EQ)-** It is also called seismic load. When earthquake comes, rapid movement or vibration of structure takes place. This movement converted into earthquake load when the mass of structure is multiplied by the ground acceleration. So, it is also called inertia force. Seismic load is dynamic in nature and it depends upon the mass of structure and ground acceleration, which depend upon location. Other factor on which seismic load depend is building time period, which depend upon stiffness and mass of structure.
   Seismic load act in all the three direction (X, Y, Z). Generally, building is design for combination of X and Y direction load.
   In ETABS, we have to define seismic load. ETABS apply it on the structure automatically.

Note:- DL, LL & EQ are considered in my project work.

3.5 LOAD COMBINATIONS

Following load combination have been considered for the analysis in my project.

Number	**Combination**
DCon1	1.5DL
DCon2	1.5(DL+LL)
DCon3	1.2(DL+LL+EQx)
DCon4	1.2(DL+LL-EQx)
DCon5	1.2(DL+LL+EQy)
DCon6	1.2(DL+LL-EQy)
DCon7	1.5(DL+EQx)
DCon8	1.5(DL-EQx)

DCon9	1.5(DL+EQy)
DCon10	1.5(DL-EQy)
DCon11	0.9DL+1.5EQx
DCon12	0.9DL-1.5EQx
DCon13	0.9DL+1.5EQy
DCon14	0.9DL-1.5EQy
DCon15	1.2(DL+LL+RSA)
DCon16	1.5DL+1.5RSA
DCon17	0.9DL+1.5RSA

Where,

DL= Dead Load

LL= Live Load

EQx= Earthquake Load in X-direction

EQy= Earthquake Load in Y-direction

RSA= Response Spectrum Function

3.6 SOFTWARE ETABS ULTIMATE 18.1.1

ETABS ultimate is the revolutionary and innovative new software package for the structural analysis and design of buildings. It has fast linear and non-linear analytical power, complex and extensive design capabilities for a wide range of materials and perceptive graphic displays, reports and illustrative drawing that allows user to quickly and easily read and understand analysis and design results. From the start of design conception through the production of illustrative drawing, ETABS integrates every aspect of engineering design process. Creation of model have never been easier-instictive drawing command allow for the rapid generation of floor and elevation farming. CAD drawing can be converted directly into ETABS model. We can design steel frame, concrete frame, composite beam and column, steel joist, concrete and masonry shear wall using ETABS. Models may be realistically rendered and all results can be shown directly on the structure. Detail and customizable reports are available for all analysis and design output.

3.7 BASIC ASSUMPTION IN MODELLING

The following assumptions have been taken in modelling for the study.

Fixed Foundation- Building columns are considered to be fixed at their base on a rigid foundation. In this study, no influence of soil-structure interaction is taken into account. No vertical translation is applied to the buildings.

Lumped Mass at Floor Level- The masses and mass rotational moments of inertia of the structure are considered to be grouped together at the floor levels.

Rigid Diaphragm- Rigid diaphragm has been assigned to each floor.

3.8 PROBLEM STATEMENT

A G+3 storey confined masonry structure has been analysed for the study in seismic zone v. Soil type has been considered type II (medium). Building is taken as residential building with occupancy less than 200 (I= 1). Building has structural wall system (R=3). Slab are modelled as thin shell. Wall of building is made up of 1st class brick work with mortar of grade (MM 7.5). Height of parapet wall is taken 1m. Three different thickness of wall is used 110mm,150mm & 230mm.

Analysis has been done to study the effect of wall density on confined masonry structure. For this, two CMS (one with square column and other with rectangular column) has been models with different thickness of masonry wall. The following thickness are used: 110mm, 150mm & 230mm. Walls are modeled as a single diagonal strut as well cross diagonal strut and these models are analyzed.

Results of CMS with square column & rectangular column has been also compared to see the effect of shape of column.

Apart from these, a RC frame structure has been modeled & analyzed and their results are compared with CMS with masonry wall thickness 110mm to check their performance under seismic loading.

Linear dynamic analysis (response spectrum method) is used for analysis. ETABS software have been used for this project. Analysis is done as per IS code 1893:2016 (Part 1).

Different types of model analysed in this project are:

1) RC frame structure
2) CMS with square column
- For 110mm thick masonry wall.
- For 150mm thick masonry wall.
- For 230mm thick masonry wall.
3) CMS with rectangular column
- For 110mm thick masonry wall.
- For 150mm thick masonry wall.

Table.3.1 Description of Building

Particulars	**Dimensions/size/value**
Number of stories	4
Type of frame	Confined Masonry Structure
No of grids in X direction	4
No of grids in Y direction	3
Floor height	3
Ground floor height	3
Depth of Slab	150mm
Size of beam	(230*300)mm for square column & (200*300)mm for rectangular column
Size of column	(230*230)mm & (200*265)mm
Thickness of masonry wall	110mm,150mm & 230mm
Materials	Fe25, HYSD415
Density of concrete	25 KN/m^3
Density of masonry wall	19.2 KN/m^3
Strength of brick (1^{st} class)	10.5 N/mm^2
Strength of mortar (MM 7.5)	7.5 N/mm^2
Live load on each floor	2.5 KN/m^2
Live load on roof	1.5 KN/m^2
Floor finish	1 KN/m^2
Wall load for 110mm thickness	5.71 KN/m^2

Wall load for 150mm thickness	7.776 KN/m^2
Wall load for 230mm thickness	11.9232 KN/m^2
Parapet load	2.112 KN/m^2
Seismic zone	V
Type of soil	Medium (Type II)
Importance factor	1
Response reduction factor	3
Damping of structure	5%

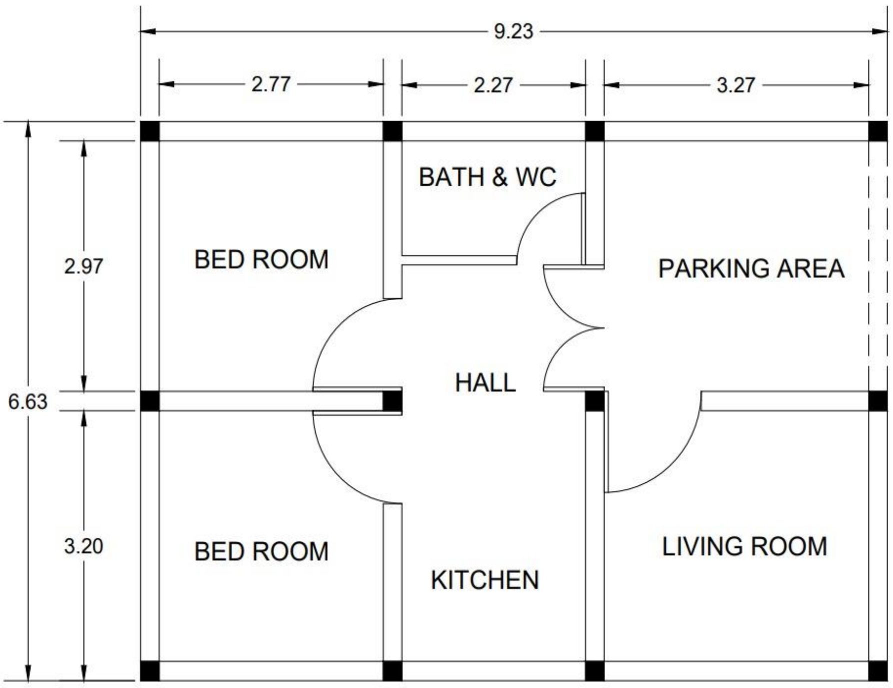


Fig.3.1 Plan of the Structure

3.9 CALCULATION OF EQUIVALENT WIDTH (w_{ds}) OF STRUT

To resist the lateral forces (seismic load), masonry wall is modelled as a equivalent diagonal strut in ETABS, While the thickness of strut is kept equal to thickness of wall. As per IS 1893:2016 (Part 1), the width of equivalent diagonal strut without any opening shall be taken as:

$w_{ds} = 0.175\alpha h^{-0.4} L_{ds}$ (Clause 7.9.2.2)

where

$$\alpha_h = h\left(\sqrt[4]{\frac{E_m t \sin 2\theta}{4 E_f I_c h}}\right)$$

where

E_m = modulus of elasticity of un-reinforced masonry wall (MPa),

= $550 f_m$ (Clause 7.9.2.1)

E_f = modulus of elasticity of RC MRF (Concrete),

I_c = moment of inertia of adjoining column,

L_{ds} = length of diagonal strut,

t = thickness of wall, and

Θ = angle of diagonal strut with the horizontal;

f_m = compressive strength of masonry prism (MPa) obtained as per IS 1905

= $0.433\, f_b^{0.64} f_{mo}^{0.36}$ (Clause 7.9.2.1)

where

f_b = compressive strength of brick (MPa),

f_m = compressive strength of mortar (MPa).

3.1.1 Calculation of width (w_{ds}) of equivalent diagonal strut for CMS with square column.

Column size: (230*230) mm & beam size: (230*300) mm.

Table.3.2 Width (w_{ds}) of equivalent diagonal strut for square column

Particulars	w_{ds} for 110mm thick wall	w_{ds} for 150mm thick wall	w_{ds} for 230mm thick wall
For 2.77m bay	400mm	386mm	370mm
For 2.27m bay	365mm	355mm	340mm
For 3.27m bay	440mm	425mm	410mm
For 2.97m bay	415mm	400mm	385mm

3.9.2 Calculation of width (w_{ds}) of equivalent diagonal strut for CMS with rectangular column.

Column size: (200*265) mm & beam size: (200*300) mm.

Table.3.3 Width (w_{ds}) of equivalent diagonal strut for rec. column

Particulars	w_{ds} for 110mm thick wall	w_{ds} for 150mm thick wall	w_{ds} for 230mm thick wall
For 2.77m bay	410mm	395mm	380mm
For 2.27m bay	375mm	360mm	345mm
For 3.27m bay	450mm	435mm	415mm
For 2.97m bay	430mm	415mm	400mm

3.10 ETABS MODEL

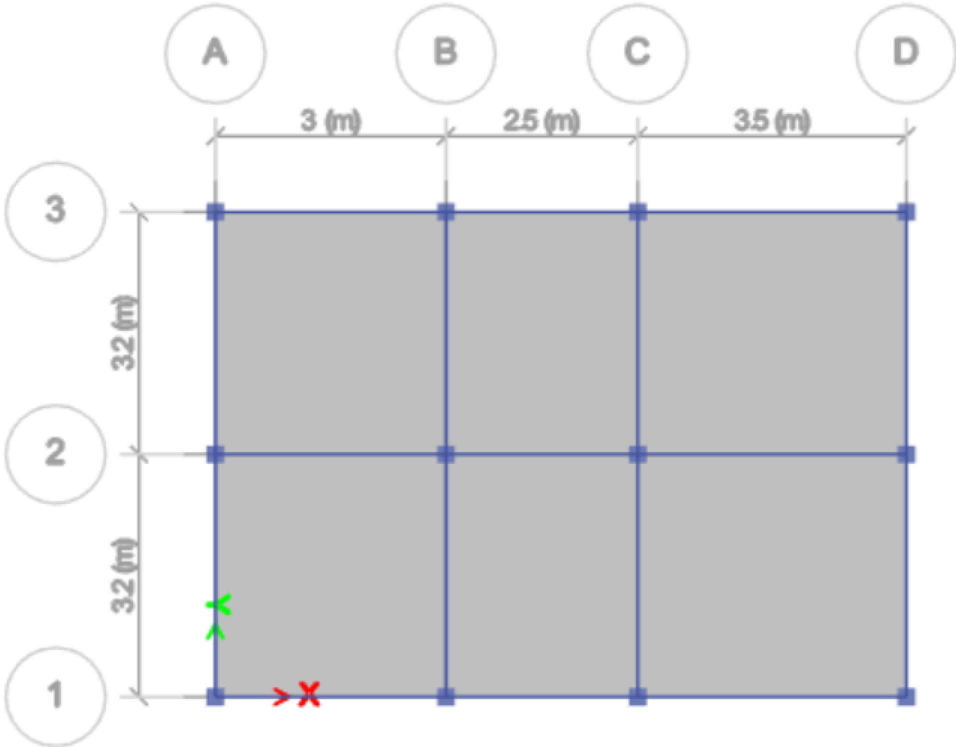


Fig.3.2 Model plan of RC frame with square column

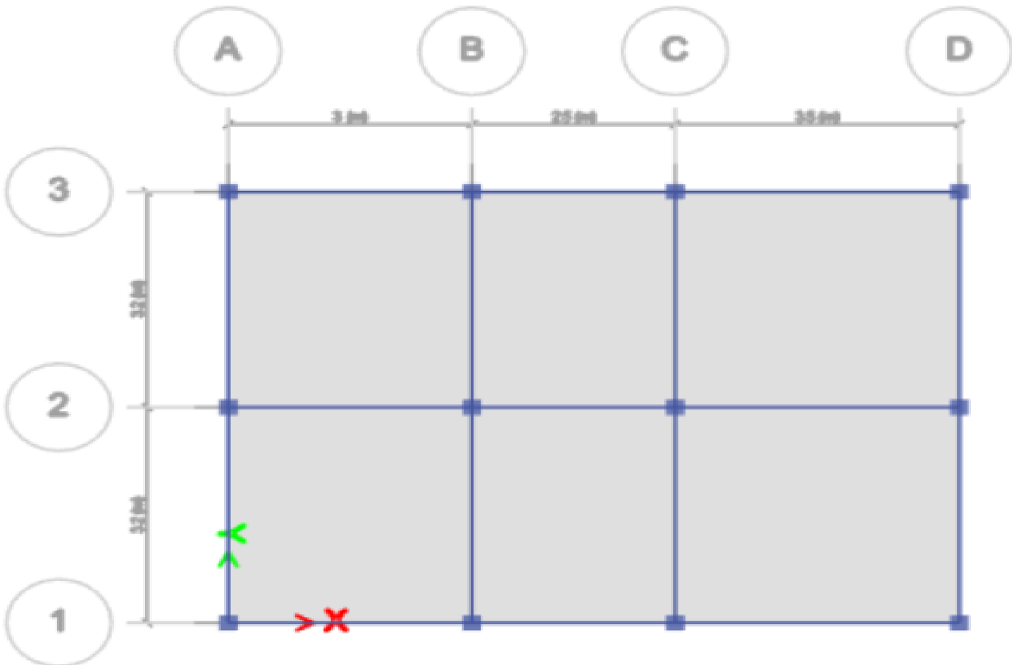


Fig.3.3 Model plan of CMS with square column

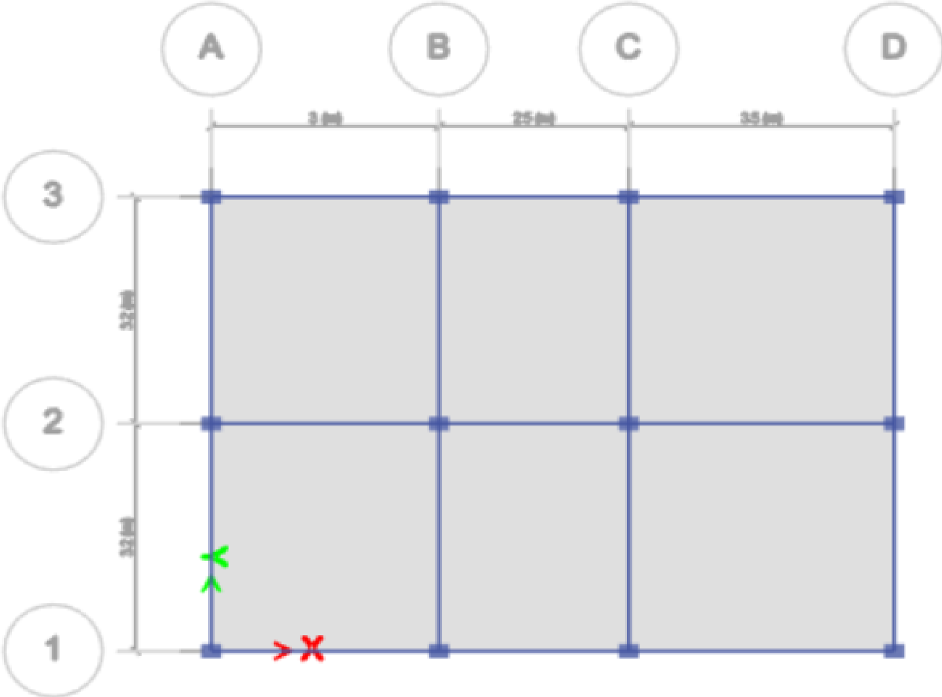


Fig.3.4 Model plan of CMS with rectangle column

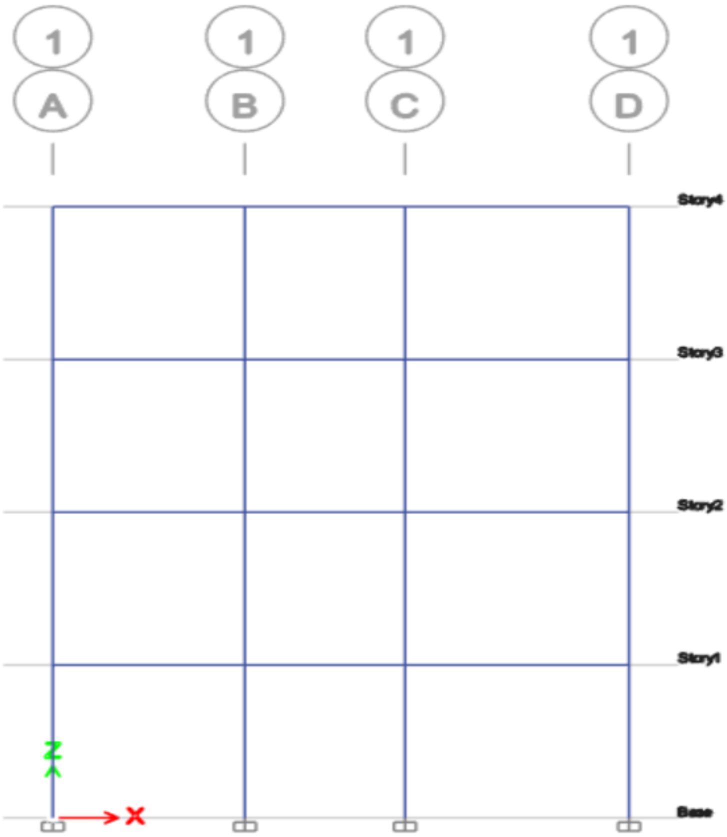


Fig.3.5 Elevation view of RC frame structure

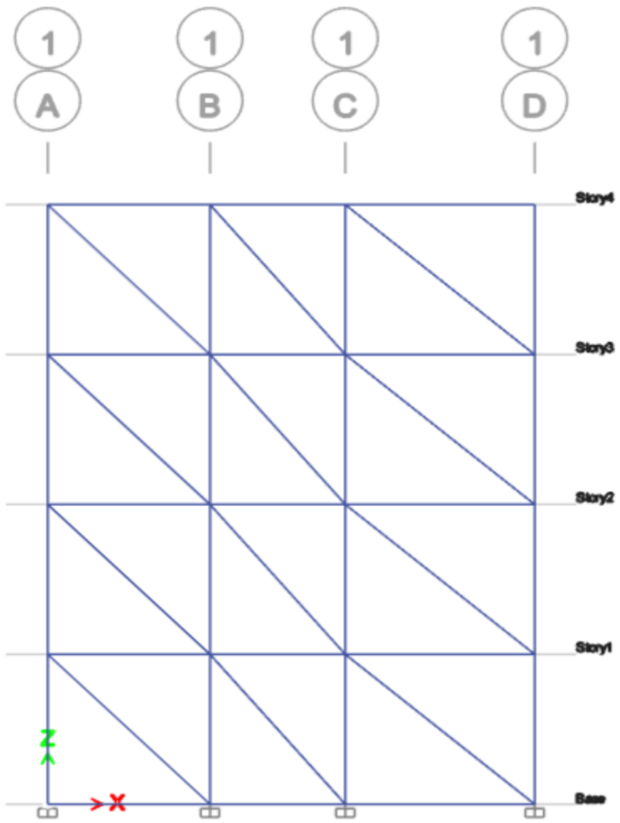


Fig.3.6 Elevation view of CMS with wall modeled as a single diagonal strut

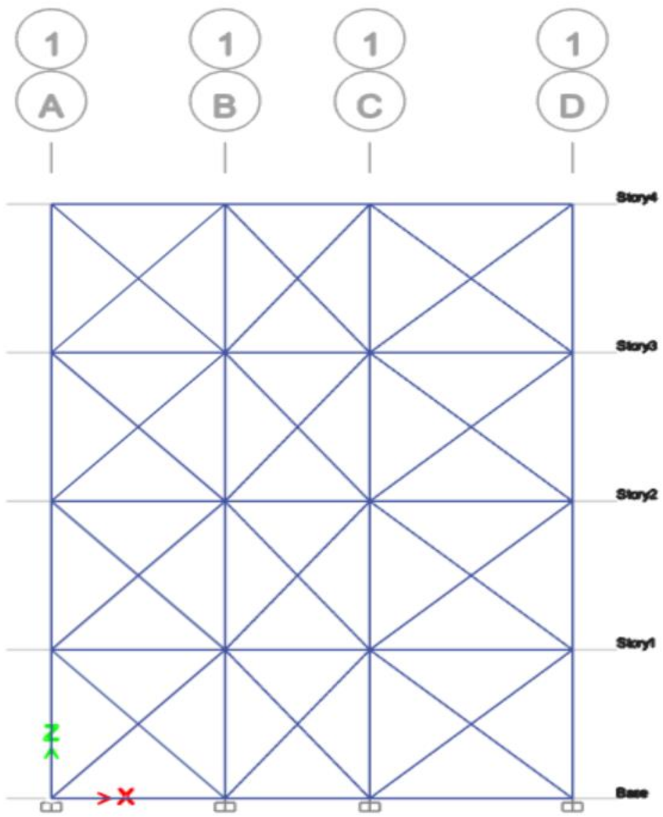


Fig.3.7 Elevation view of CMS with wall modeled as a cross diagonal strut

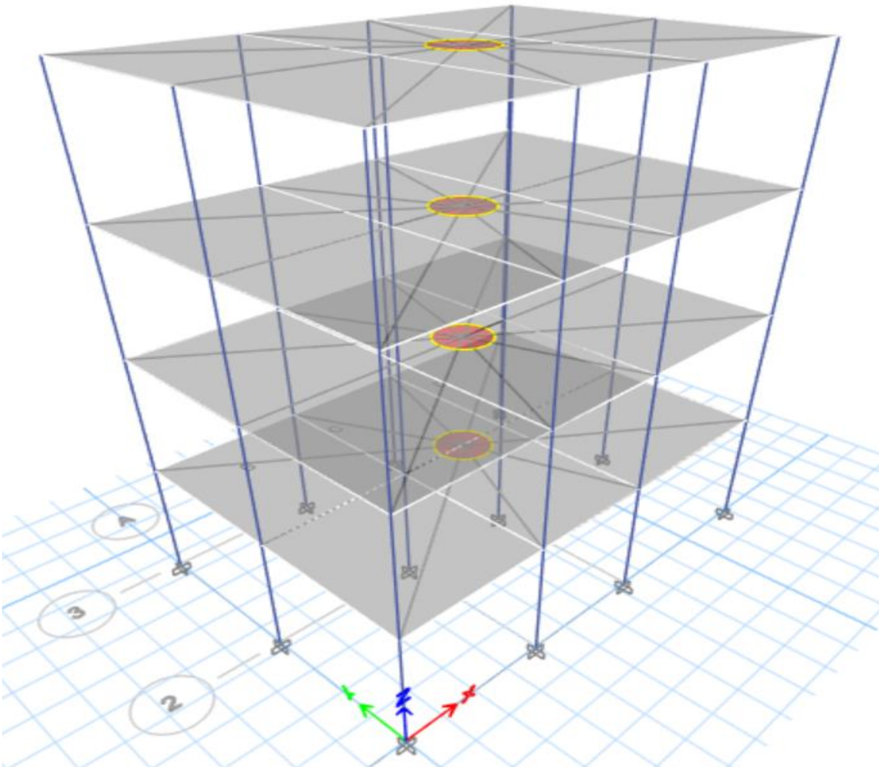


Fig.3.8 3D view of RC frame structure

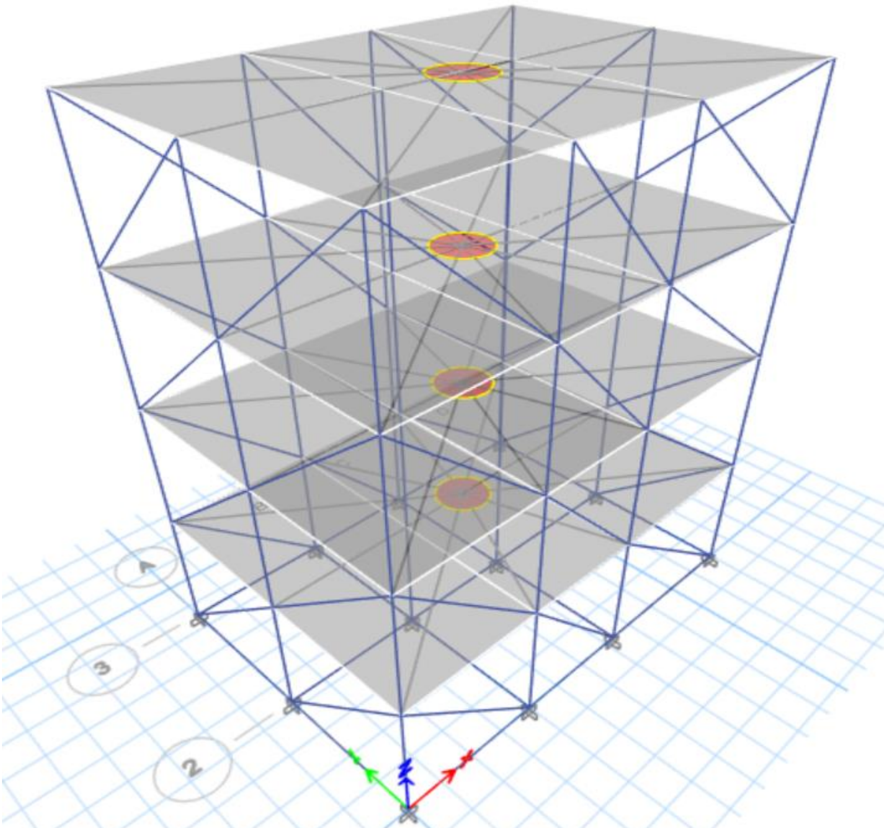


Fig.3.9 3D view of CMS with wall modeled as a single diagonal strut

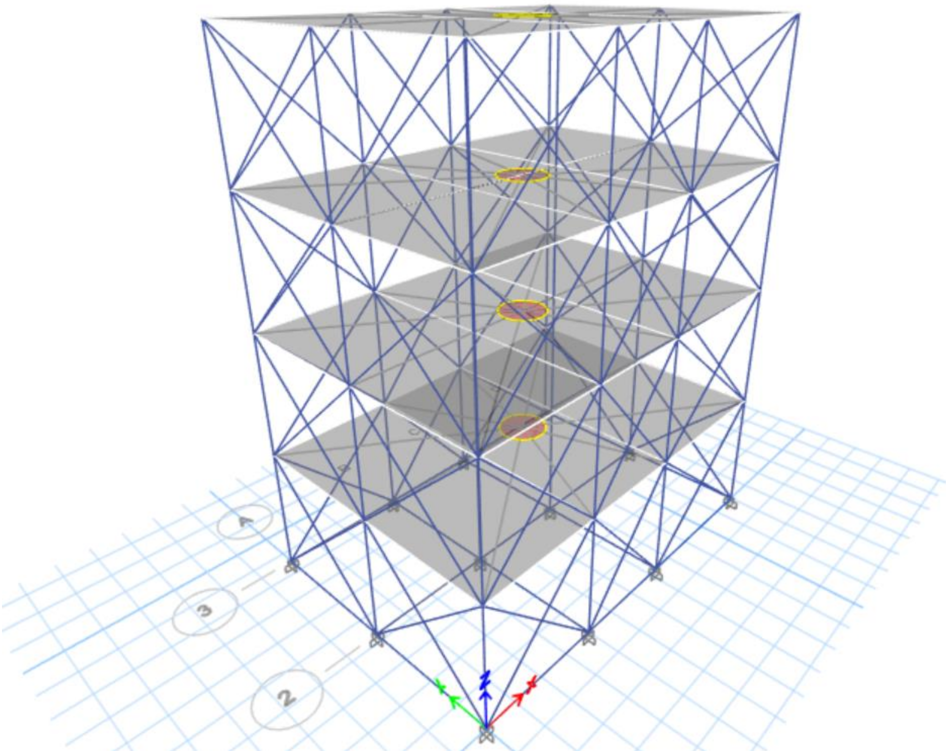


Fig.3.10 3D view of CMS with wall modeled as a cross diagonal strut

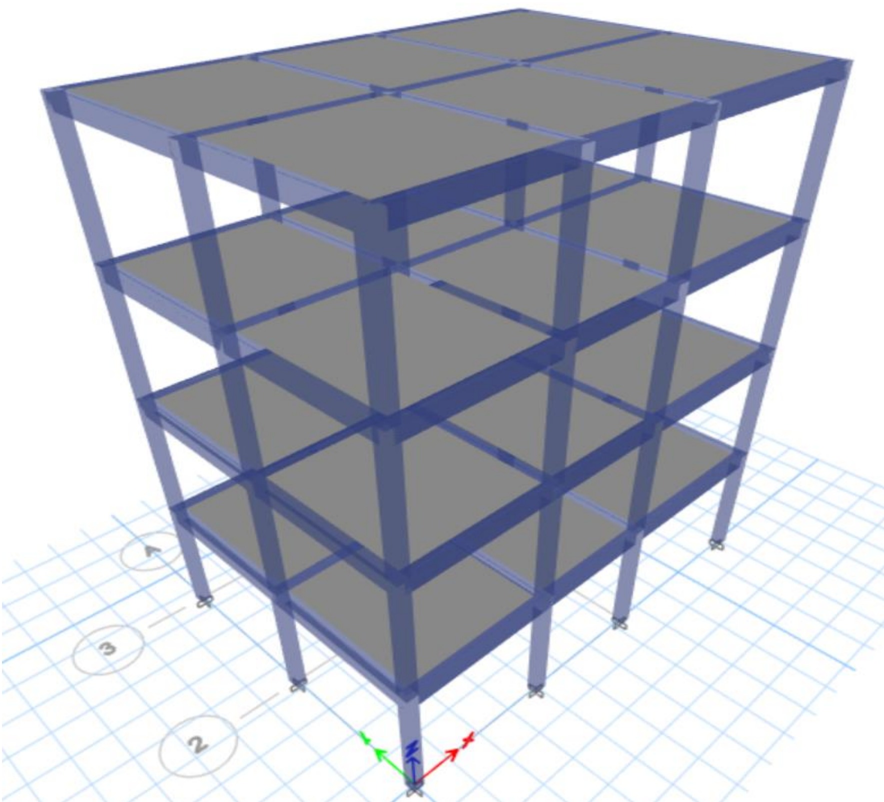


Fig.3.11 Rendering view of RC frame structure

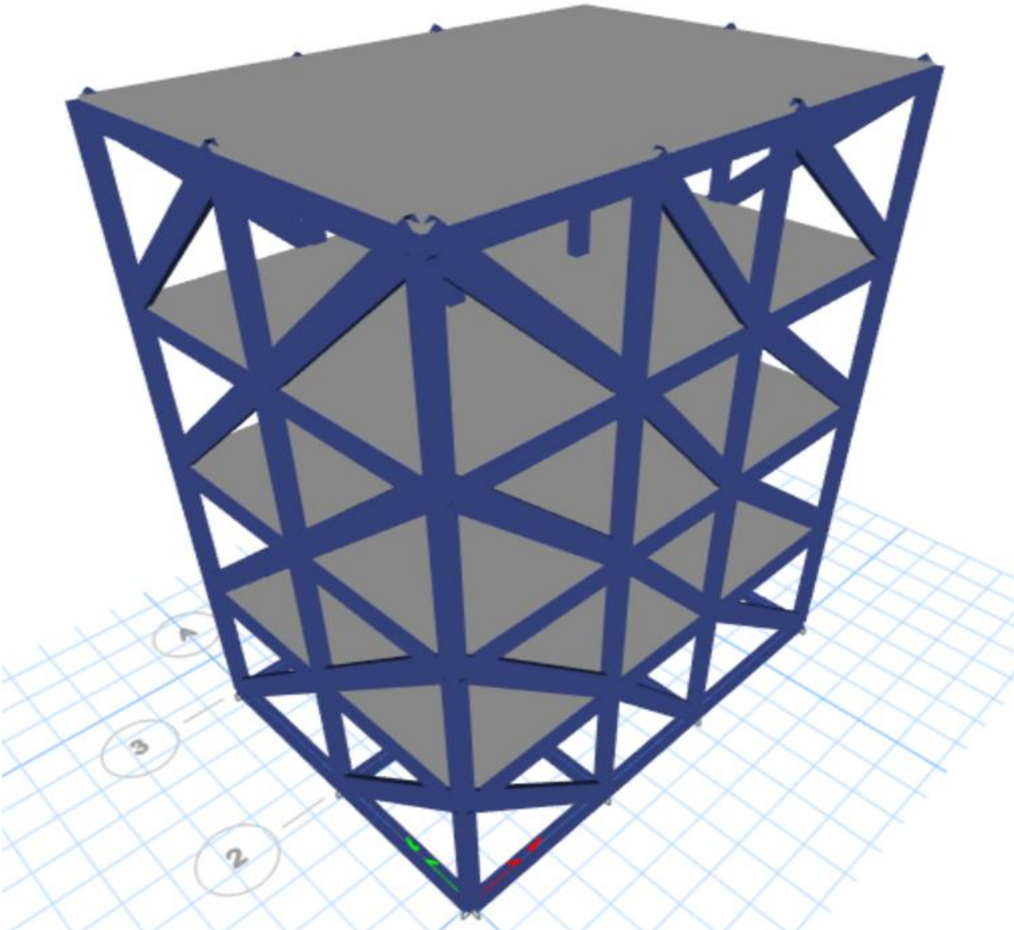


Fig.3.12 Rendering view of CMS with wall modeled as a single diagonal strut

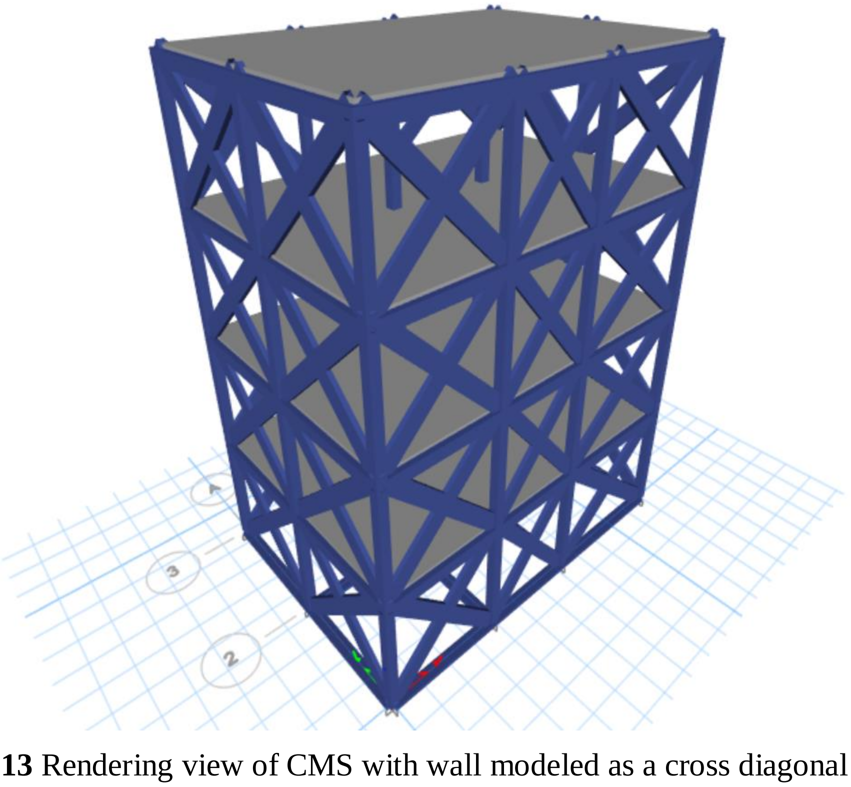


Fig.3.13 Rendering view of CMS with wall modeled as a cross diagonal strut

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GENERAL

Two CMS (one with square column and other with rectangular column) has been models with different thickness of masonry wall. The following thickness are used: 110mm, 150mm & 230mm. Walls are modeled as a single diagonal strut as well cross diagonal strut and these models are analyzed to see the effect of wall density.

Results of CMS with square column & rectangular column has been also compared to see the effect of shape of column.

Apart from these, a RC frame structure has been modeled and analyzed and their results are compared with CMS with masonry wall thickness 110mm to check their performance under seismic loading.

Models are compared based on the following parameter like base shear, storey shear, max storey drift & max storey displacement. Results are provided in the form of table and have been compared with graph.

4.2 SOME IMPORTANT DEFINITION

Storey displacement- It is the total displacement of a story with respect to base or ground.

Storey drift- It is the relative displacement of one floor with respect to the floor below.

Base shear- It is the total lateral design force acting on the base of a structure.

Storey shear- It is sum of designed lateral force acting at all floor level above the storey under consideration.

Modal participation mass ratio- It is the total seismic mass of a structure which participate or contribute in a particular mode of vibration.

Period- Time taken to complete one oscillation.

Frequency- Number of oscillation or complete vibration in one second.

4.3 RC FRAME STRUCTURE WITH SQUARE COLUMN

1) For 110mm wall thickness

Table.4.1 Max Storey Displacement (RC frame structure)

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	10.835	10.551
Story2	24.366	23.509
Story3	35.485	34.118
Story4	41.703	40.045

Table.4.2 Max Storey Drift (RC frame structure)

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.003612	0.003517
Story2	0.00451	0.00432
Story3	0.003706	0.003536
Story4	0.002072	0.001976

Table.4.3 Overturning Moment (RC frame structure)

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	13597.7175	-18427.1641
Story1	12895.4158	-17630.3572
Story2	9152.9858	-12576.6064
Story3	5492.4535	-7606.3799
Story4	2005.1938	-2813.402

Table.4.4 Base Shear (RC frame structure)

STOREY	Y-Dr (KN)	X-Dr (KN)
Base	157.947	161.6732

Table.4.5 Modal Period and Frequency (RC frame structure)

Case	**Mode**	**Period (Sec)**	**Frequency (cyc/sec)**	**Circ. Freq (rad/sec)**	**Eigen value (rad^2/sec^2)**
Modal	1	1.304	0.767	4.8198	23.2309
Modal	2	1.271	0.787	4.9448	24.4509
Modal	3	1.095	0.913	5.7396	32.9431
Modal	4	0.423	2.363	14.849	220.4923
Modal	5	0.415	2.41	15.14	229.221
Modal	6	0.359	2.787	17.5125	306.6891
Modal	7	0.258	3.874	24.3427	592.5669
Modal	8	0.255	3.918	24.6178	606.038
Modal	9	0.221	4.531	28.4661	810.3205
Modal	10	0.2	5.002	31.4313	987.9294
Modal	11	0.199	5.023	31.5598	996.0189
Modal	12	0.172	5.811	36.5085	1332.871

Table.4.6 Modal Participation Mass Ratio (RC frame structure)

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	1.304	0	0.8624	0	0	0.8624	0	0.1412	0	0.0036	0.1412	0	0.0036

Modal	2	1.271	0.869	0	0	0.869	0.8624	0	0	0.1384	0	0.1412	0.1384	0.0036
Modal	3	1.095	0	0.0035	0	0.869	0.8659	0	0.0005	0	0.8652	0.1417	0.1384	0.8688
Modal	4	0.423	0	0.0969	0	0.869	0.9628	0	0.7546	0	0.0004	0.8963	0.1384	0.8692
Modal	5	0.415	0.0957	0	0	0.9647	0.9628	0	0	0.7651	0	0.8963	0.9035	0.8692
Modal	6	0.359	0	0.0004	0	0.9647	0.9632	0	0.0033	0	0.0951	0.8996	0.9035	0.9643
Modal	7	0.258	0	0.0294	0	0.9647	0.9926	0	0.0575	0	0.0001	0.9571	0.9035	0.9644
Modal	8	0.255	0.0285	0	0	0.9932	0.9926	0	0	0.0549	0	0.9571	0.9584	0.9644
Modal	9	0.221	0	0.0001	0	0.9932	0.9928	0	0.0003	0	0.0287	0.9573	0.9584	0.9931
Modal	10	0.2	0	0.0072	0	0.9932	1	0	0.0425	0	3.53E-05	0.9998	0.9584	0.9931
Modal	11	0.199	0.0068	0	0	1	1	0	0	0.0416	0	0.9998	1	0.9931
Modal	12	0.172	0	3.56E-05	0	1	1	0	0.0002	0	0.0069	1	1	1

4.4 CMS HAVING SQUARE COLUMN WITH WALL MODEL AS SINGLE DIAGONAL STRUT

1) For 110mm wall thickness

Wall density = 2.69%

Table.4.7 Max Storey Displacement for110 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	11.353	9.711
Story2	22.479	19.086
Story3	31.928	26.929
Story4	37.477	31.368

Table.4.8 Max Storey Drift for110 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.003784	0.003237
Story2	0.003709	0.003125
Story3	0.00315	0.002614
Story4	0.001851	0.001484

Table.4.9 Overturning Moment for110 mm thick wall (Single Diagonal Strut**)**

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	17627.27	-23633.64
Story1	15728.29	-21299.81
Story2	10810.77	-14732.67
Story3	6143.226	-8460.895

Story4	2028.246	-2845.431

Table.4.10 Base Shear for 110 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Story1	498.3842	590.9422

Table.4.11 Modal Period and Frequency for110 mm thick wall (Single Diagonal Strut**)**

Case	Mode	Period sec	Frequency (cyc/sec)	Circ. Freq (rad/sec)	Eigen value (rad²/sec²)
Modal	1	0.696	1.437	9.0266	81.4799
Modal	2	0.584	1.713	10.765	115.885
Modal	3	0.429	2.331	14.6464	214.5167
Modal	4	0.242	4.133	25.9671	674.2899
Modal	5	0.203	4.915	30.8794	953.5378
Modal	6	0.158	6.335	39.802	1584.196
Modal	7	0.15	6.654	41.8071	1747.835
Modal	8	0.134	7.486	47.0373	2212.505
Modal	9	0.132	7.566	47.5355	2259.623
Modal	10	0.112	8.93	56.1088	3148.197
Modal	11	0.1	9.982	62.7186	3933.626
Modal	12	0.084	11.847	74.4357	5540.678

Table.4.12 Modal Participation Mass Ratio for110 mm thick wall (Single Diagonal Strut**)**

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	0.696	0.0002	0.8889	0	0.0002	0.8889	0	0.2948	0.0001	0.0001	0.2948	0.0001	0.0001
Modal	2	0.584	0.8916	0.0002	0	0.8918	0.8891	0	0.0001	0.2898	0.0004	0.2949	0.2899	0.0005
Modal	3	0.429	0.0004	0.0001	0	0.8922	0.8891	0	7.75E-06	4.08E-05	0.8992	0.2949	0.2899	0.8997
Modal	4	0.242	1.85E-05	0.0904	0	0.8922	0.9796	0	0.6602	0.0002	0.0001	0.9551	0.2901	0.8998
Modal	5	0.203	0.0876	2.20E-05	0	0.9798	0.9796	0	0.0001	0.6661	0.0001	0.9553	0.9562	0.8999
Modal	6	0.158	3.82E-06	0.0177	0	0.9798	0.9973	0	0.0228	3.90E-06	0.0001	0.9781	0.9562	0.8999
Modal	7	0.15	5.18E-06	1.60E-05	0	0.9798	0.9973	0	0.0001	0	0.0809	0.9781	0.9562	0.9808
Modal	8	0.134	0.0176	3.34E-06	0	0.9974	0.9973	0	3.77E-06	0.0213	1.65E-06	0.9781	0.9775	0.9808
Modal	9	0.132	0	0.0027	0	0.9974	1	0	0.0219	3.70E-06	0	1	0.9775	0.9808
Modal	10	0.112	0.0026	6.69E-07	0	1	1	0	5.00E-06	0.0225	8.31E-07	1	1	0.9808

Modal	11	0.1	0	0	0	1	1	0	0	1.14E-06	0.0169	1	1	0.9977
Modal	12	0.084	0	0	0	1	1	0	6.08E-07	0	0.0023	1	1	1

2) For 150mm thick wall

Wall density =3.3676%

Table.4.13 Max Storey Displacement for150 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	10.779	9.158
Story2	21.382	17.998
Story3	30.349	25.334
Story4	35.479	29.333

Table.4.14 Max Storey Drift for150 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.003593	0.003053
Story2	0.003534	0.002947
Story3	0.002989	0.002445
Story4	0.00171	0.001337

Table.4.15 Overturning Moment for150 mm thick wall (Single Diagonal Strut**)**

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	20280.956	-27102.963

Story1	18006.845	-24322.738
Story2	12232.489	-16635.287
Story3	6776.9646	-9322.8353
Story4	2028.2461	-2845.4309

Table.4.16 Storey Shear for150 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	604.8594	713.4211

Table.4.17 Modal Period and Frequency for150 mm thick wall (Single Diagonal Strut**)**

Case	**Mode**	**Period (sec)**	**Frequency (cyc/sec)**	**Circ. Freq (rad/sec)**	**Eigen value (rad^2/sec^2)**
Modal	1	0.645	1.551	9.7424	94.9143
Modal	2	0.539	1.854	11.6514	135.754
Modal	3	0.399	2.507	15.7546	248.2071
Modal	4	0.224	4.458	28.008	784.4466
Modal	5	0.188	5.316	33.4027	1115.742
Modal	6	0.146	6.848	43.0254	1851.182
Modal	7	0.14	7.151	44.9318	2018.867
Modal	8	0.123	8.108	50.9469	2595.589
Modal	9	0.123	8.13	51.0853	2609.703
Modal	10	0.104	9.614	60.4097	3649.326
Modal	11	0.093	10.717	67.3377	4534.367
Modal	12	0.079	12.651	79.4885	6318.416

Table.4.18 Modal Participation Mass Ratio for150 mm thick wall (Single Diagonal Strut**)**

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	0.645	0.0004	0.8878	0	0.0004	0.8878	0	0.3238	0.0001	0.0003	0.3238	0.0001	0.0003
Modal	2	0.539	0.8909	0.0003	0	0.8913	0.8882	0	0.0001	0.3175	0.0007	0.324	0.3176	0.001
Modal	3	0.399	0.0007	0.0002	0	0.892	0.8883	0	4.59E-06	0.0001	0.9004	0.324	0.3177	0.9013
Modal	4	0.224	3.16E-05	0.0921	0	0.8921	0.9805	0	0.6354	0.0003	0.0002	0.9593	0.3179	0.9015
Modal	5	0.188	0.0888	3.83E-05	0	0.9808	0.9805	0	0.0002	0.6424	0.0001	0.9596	0.9604	0.9016
Modal	6	0.146	6.05E-06	0.0173	0	0.9808	0.9978	0	0.0191	4.97E-06	0.0001	0.9787	0.9604	0.9017
Modal	7	0.14	9.06E-06	2.75E-05	0	0.9808	0.9978	0	0.0001	9.14E-07	0.0804	0.9788	0.9604	0.9822
Modal	8	0.123	0.017	2.40E-06	0	0.9979	0.9978	0	0	0.0175	2.13E-06	0.9788	0.9779	0.9822
Modal	9	0.123	3.19E-06	0.0022	0	0.9979	1	0	0.0212	0	7.84E-07	1	0.9779	0.9822
Modal	10	0.104	0.0021	9.56E-07	0	1	1	0	8.03E-06	0.0221	1.83E-06	1	1	0.9822

Modal	11	0.093	0	0	0	1	1	0	0	1.96E-06	0.0162	1	1	0.9983
Modal	12	0.079	0	0	0	1	1	0	6.90E-07	0	0.0017	1	1	1

3) For 230mm wall thickness

Wall density = 5.63%

Table.4.19 Max Storey Displacement for 230 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	10.273	8.108
Story2	20.431	15.907
Story3	28.964	22.284
Story4	33.659	25.556

Table.4.20 Max Storey Drift for230 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.003424	0.002703
Story2	0.003386	0.0026
Story3	0.002844	0.002126
Story4	0.001565	0.001096

Table.4.21 Overturning Moment for 230 mm thick wall (Single Diagonal Strut**)**

STORY	X-Dr (KN-m)	Y-Dr (KN-m)

Base	25447.222	-33199.939
Story1	22454.882	-29786.482
Story2	15000.65	-20109.181
Story3	8004.8063	-10925.954
Story4	2028.2461	-2845.4309

Table.4.22 Base Shear for 230 mm thick wall (Single Diagonal Strut**)**

STOREY	Y-Dr (KN)	X-Dr (KN)
Base	807.8152	872.2737

Table.4.23 Modal Period and Frequency for 230 mm thick wall (Single Diagonal Strut**)**

Case	**Mode**	**Period (Sec)**	**Frequency (cyc/sec)**	**Circ. Freq (rad/sec)**	**Eigen value (rad^2/sec^2)**
Modal	1	0.59	1.694	10.6455	113.3275
Modal	2	0.493	2.028	12.7403	162.3151
Modal	3	0.367	2.727	17.1362	293.6505
Modal	4	0.205	4.875	30.6283	938.0943
Modal	5	0.172	5.817	36.5502	1335.92
Modal	6	0.133	7.532	47.3263	2239.777
Modal	7	0.129	7.771	48.8273	2384.102
Modal	8	0.112	8.913	56.0005	3136.061
Modal	9	0.112	8.92	56.0447	3141.011

Modal	10	0.095	10.545	66.2532	4389.483
Modal	11	0.086	11.647	73.1821	5355.619
Modal	12	0.072	13.827	86.8769	7547.597

Table.4.24 Modal Participation Mass Ratio for 230 mm thick wall (Single Diagonal Strut**)**

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	0.59	0.0008	0.8856	0	0.0008	0.8856	0	0.3661	0.0003	0.0006	0.3661	0.0003	0.0006
Modal	2	0.493	0.8891	0.0007	0	0.8898	0.8863	0	0.0003	0.3576	0.0016	0.3664	0.3579	0.0022
Modal	3	0.367	0.0017	0.0004	0	0.8915	0.8867	0	0	0.0003	0.9012	0.3664	0.3582	0.9034
Modal	4	0.205	0.0001	0.0951	0	0.8916	0.9819	0	0.597	0.0005	0.0003	0.9635	0.3587	0.9037
Modal	5	0.172	0.0908	0.0001	0	0.9824	0.9819	0	0.0005	0.6057	0.0002	0.964	0.9644	0.9039
Modal	6	0.133	1.16E-05	0.0166	0	0.9824	0.9985	0	0.0159	7.96E-06	0.0005	0.9799	0.9644	0.9045
Modal	7	0.129	2.11E-05	0.0001	0	0.9824	0.9986	0	0.0002	3.39E-06	0.0796	0.98	0.9644	0.984
Modal	8	0.112	0.016	4.08E-06	0	0.9984	0.9986	0	0.0003	0.0141	3.11E-06	0.9803	0.9785	0.984

Modal	9	0.112	0.0003	0.0014	0	0.9987	1	0	0.0197	0.0002	2.68E-06	1	0.9786	0.984
Modal	10	0.095	0.0013	1.42E-06	0	1	1	0	1.59E-05	0.0214	4.91E-06	1	1	0.984
Modal	11	0.086	6.06E-07	0	0	1	1	0	0	3.50E-06	0.0152	1	1	0.9993
Modal	12	0.072	0	0	0	1	1	0	8.16E-07	7.04E-07	0.0007	1	1	1

4.5 CMS HAVING SQUARE COLUMN WITH WALL MODEL AS CROSS DIAGONAL STRUT

1) For 110mm wall thickness

Table.4.25 Max Storey Displacement for110 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	7.107	5
Story2	14.482	10.094
Story3	21.03	14.549
Story4	25.172	17.272

Table.4.26 Max Storey Drift for110 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0

Story1	0.002369	0.001667
Story2	0.002459	0.001698
Story3	0.002183	0.001485
Story4	0.001381	0.000908

Table.4.27 Overturning Moment for110 mm thick wall (Cross Diagonal Strut**)**

STORY	Y-Dr (KN-m)	X-Dr (KN-m)
Base	-25296.6881	19896.7634
Story1	-22504.4259	17328.7447
Story2	-15485.7206	11761.1378
Story3	-8796.9758	6525.2336
Story4	-2845.4309	2028.2461

Table.4.28 Base Shear for110 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr (KN)	X-Dr (KN)
Base	661.0213	658.9543

Table.4.29 Modal Period and Frequency for110 mm thick wall (Cross Diagonal Strut**)**

Case	**Mode**	**Period (Sec)**	**Frequency (cyc/sec)**	**Circ. Freq (rad/sec)**	**Eigen value (rad^2/sec^2)**
Modal	1	0.51	1.96	12.314	151.6355
Modal	2	0.425	2.356	14.8002	219.045
Modal	3	0.311	3.219	20.2236	408.9957

Modal	4	0.177	5.652	35.5136	1261.215
Modal	5	0.148	6.764	42.4986	1806.128
Modal	6	0.114	8.796	55.2679	3054.545
Modal	7	0.109	9.182	57.6924	3328.411
Modal	8	0.096	10.422	65.4855	4288.355
Modal	9	0.095	10.533	66.1803	4379.835
Modal	10	0.08	12.454	78.2531	6123.545
Modal	11	0.073	13.78	86.5827	7496.571
Modal	12	0.061	16.347	102.7105	10549.45

Table.4.30 Modal Participation Mass Ratio for110 mm thick wall (Cross Diagonal Strut**)**

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	0.51	0	0.8804	0	0	0.8804	0	0.3099	0	1.40E-05	0.3099	0	1.40E-05
Modal	2	0.425	0.8858	0	0	0.8858	0.8804	0	0	0.3014	4.86E-06	0.3099	0.3014	1.89E-05
Modal	3	0.311	0	7.68E-06	0	0.8858	0.8804	0	1.58E-05	0	0.8996	0.31	0.3014	0.8996
Modal	4	0.177	0	0.0984	0	0.8858	0.9788	0	0.6428	0	5.73E-06	0.9527	0.3014	0.8996
Modal	5	0.148	0.0935	0	0	0.9792	0.9788	0	0	0.6531	5.13E-07	0.9527	0.9545	0.8996

Modal	6	0.114	0	0.0184	0	0.9792	0.9972	0	0.0267	0	2.91E-05	0.9795	0.9545	0.8996
Modal	7	0.109	0	1.60E-05	0	0.9792	0.9972	0	4.38E-05	0	0.0812	0.9795	0.9545	0.9809
Modal	8	0.096	0.018	0	0	0.9973	0.9972	0	0	0.0242	0	0.9795	0.9786	0.9809
Modal	9	0.095	0	0.0028	0	0.9973	1	0	0.0205	0	1.10E-06	1	0.9786	0.9809
Modal	10	0.08	0.0027	0	0	1	1	0	0	0.0214	0	1	1	0.9809
Modal	11	0.073	0	5.60E-07	0	1	1	0	1.40E-06	0	0.0169	1	1	0.9977
Modal	12	0.061	0	0	0	1	1	0	0	0	0.0023	1	1	1

2) For 150mm wall thickness

Table.4.31 Max Storey Displacement for150 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	6.206	4.341
Story2	12.747	8.819
Story3	18.575	12.744
Story4	22.227	15.109

Table.4.32 Max Storey Drift for150 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.002069	0.001447
Story2	0.00218	0.001493
Story3	0.001943	0.001308
Story4	0.001217	0.000788

Table.4.33 Overturning Moment for150 mm thick wall (Cross Diagonal Strut**)**

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	22594.76	-28765.0082
Story1	19647.36	-25546.9632
Story2	13217.04	-17424.3019
Story3	7181.865	-9694.9863
Story4	2028.246	-2845.4309

Table.4.34 Base Shear for150 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr (KN)	X-Dr (KN)
Base	749.7856	747.6755

Table.4.35 Modal Period and Frequency for150 mm thick wall (Cross Diagonal Strut**)**

Case	**Mode**	**Period sec**	**Frequency (cyc/sec)**	**Circ. Freq**	**Eigen value (rad^2/sec^2)**

				(rad/sec)	
Modal	1	0.476	2.101	13.201	174.2673
Modal	2	0.394	2.536	15.9368	253.9806
Modal	3	0.29	3.453	21.6941	470.632
Modal	4	0.165	6.067	38.121	1453.212
Modal	5	0.137	7.288	45.7892	2096.654
Modal	6	0.105	9.485	59.5975	3551.859
Modal	7	0.102	9.846	61.8651	3827.29
Modal	8	0.089	11.269	70.8054	5013.41
Modal	9	0.088	11.301	71.0037	5041.53
Modal	10	0.075	13.394	84.1595	7082.819
Modal	11	0.068	14.765	92.771	8606.454
Modal	12	0.057	17.43	109.5174	11994.07

Table.4.36 Modal Mass Participation Ratio for 150 mm thick wall (Cross Diagonal Strut**)**

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	0.476	0	0.878	0	0	0.878	0	0.3405	0	2.23E-05	0.3405	0	2.23E-05
Modal	2	0.394	0.8843	0	0	0.8843	0.878	0	0	0.3303	6.63E-06	0.3405	0.3303	2.89E-05
Modal	3	0.29	0	7.65E-06	0	0.8843	0.878	0	1.79E-05	0	0.9012	0.3405	0.3303	0.9012

Modal	4	0.165	0	0.1014	0	0.8843	0.9795	0	0.6164	0	8.49E-06	0.9569	0.3303	0.9012
Modal	5	0.137	0.0958	0	0	0.9801	0.9795	0	0	0.6283	7.18E-07	0.9569	0.9586	0.9012
Modal	6	0.105	0	0.0181	0	0.9801	0.9976	0	0.0237	0	4.83E-05	0.9806	0.9586	0.9013
Modal	7	0.102	0	2.36E-05	0	0.9801	0.9976	0	0.0001	0	0.0808	0.9806	0.9586	0.9821
Modal	8	0.089	0.0177	0	0	0.9977	0.9976	0	0	0.0209	0	0.9806	0.9795	0.9821
Modal	9	0.088	0	0.0024	0	0.9977	1	0	0.0194	0	1.70E-06	1	0.9795	0.9821
Modal	10	0.075	0.0023	0	0	1	1	0	0	0.0205	0	1	1	0.9821
Modal	11	0.068	0	6.20E-07	0	1	1	0	1.57E-06	0	0.0162	1	1	0.9983
Modal	12	0.057	0	0	0	1	1	0	0	0	0.0017	1	1	1

3) For 230mm wall thickness

Table.4.37 Max Storey Displacement for 230 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)

Base	0	0
Story1	5.308	3.706
Story2	11.047	7.612
Story3	16.195	11.053
Story4	19.39	13.094

Table.4.38 Max Storey Drift for 230 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.001769	0.001235
Story2	0.001913	0.001302
Story3	0.001716	0.001147
Story4	0.001065	0.00068

Table.4.39 Overturning Moment for 230 mm thick wall (Cross Diagonal Strut**)**

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	27957.556	-35663.87
Story1	24255.5895	-31599.38
Story2	16106.0971	-21276.365
Story3	8481.1749	-11475.907
Story4	2028.2461	-2845.4309

Table.4.40 Base Shear for 230 mm thick wall (Cross Diagonal Strut**)**

STOREY	Y-Dr (KN-m)	X-Dr (KN-m)
Story1	927.0726	924.7737

Table.4.41 Modal Period and Frequency for 230 mm thick wall (Cross Diagonal Strut**)**

Case	Mode	Period sec	Frequency (cyc/sec)	CircFreq (rad/sec)	Eigenvalue (rad^2/sec^2)
Modal	1	0.44	2.275	14.2931	204.2934
Modal	2	0.363	2.755	17.3092	299.609
Modal	3	0.267	3.747	23.5447	554.3523
Modal	4	0.152	6.598	41.4535	1718.39
Modal	5	0.126	7.937	49.8712	2487.132
Modal	6	0.096	10.411	65.4111	4278.618
Modal	7	0.094	10.686	67.1419	4508.033
Modal	8	0.081	12.364	77.6876	6035.364
Modal	9	0.081	12.372	77.734	6042.577
Modal	10	0.068	14.663	92.1309	8488.098
Modal	11	0.062	16.029	100.7137	10143.24
Modal	12	0.053	19.004	119.403	14257.07

Table.4.42 Modal Participation Mass Ratio for 230 mm thick wall (Cross Diagonal Strut**)**

Case	Mode	Period	UX	UY	UZ	SumUX	SumUY	SumUZ	RX	RY	RZ	SumRX	SumRY	SumRZ
Modal	1	0.44	0	0.874	0	0	0.874	0	0.3847	0	3.48E-05	0.3847	0	3.48E-05
Modal	2	0.363	0.8815	0	0	0.8815	0.874	0	0	0.3724	9.39E-06	0.3847	0.3724	4.42E-05

Modal	3	0.267	0	8.34E-06	0	0.8815	0.874	0	2.05E-05	0	0.9033	0.3847	0.3724	0.9034
Modal	4	0.152	0	0.1065	0	0.8815	0.9805	0	0.5768	0	1.23E-05	0.9615	0.3724	0.9034
Modal	5	0.126	0.0998	0	0	0.9813	0.9805	0	0	0.5905	1.06E-06	0.9615	0.9629	0.9034
Modal	6	0.096	0	0.0178	0	0.9813	0.9983	0	0.021	0	0.0001	0.9825	0.9629	0.9035
Modal	7	0.094	0	4.61E-05	0	0.9813	0.9983	0	0.0001	0	0.0803	0.9826	0.9629	0.9838
Modal	8	0.081	0	0.0017	0	0.9813	1	0	0.0174	0	2.69E-06	1	0.9629	0.9838
Modal	9	0.081	0.0172	0	0	0.9985	1	0	0	0.0182	0	1	0.9811	0.9838
Modal	10	0.068	0.0015	0	0	1	1	0	0	0.0189	0	1	1	0.9838
Modal	11	0.062	0	6.99E-07	0	1	1	0	1.82E-06	0	0.0154	1	1	0.9992
Modal	12	0.053	0	0	0	1	1	0	0	0	0.0008	1	1	1

4.6 CMS HAVING RECTANGULAR COLUMN WITH WALL MODEL AS SINGLE DIAGONAL STRUT

1) For 110mm wall thickness

Table.4.43 Max Storey Displacement for rec. column for 110 mm wall thickness (Single Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	11.087	9.534
Story2	21.964	18.741
Story3	31.207	26.442
Story4	36.634	30.788

Table.4.44 Max Storey Drift for rec. column for 110 mm wall thickness (SDS)

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.003696	0.003178
Story2	0.003626	0.003069
Story3	0.003081	0.002567
Story4	0.001809	0.001453

Table.4.45 Overturning Moment for rec. column for 110 mm wall thickness (SDS)

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	17486.631	-23403.0382
Story1	15567.514	-21052.5033
Story2	10681.155	-14539.5488
Story3	6048.0311	-8324.4935
Story4	1975.1366	-2771.6819

Table.4.46 Base Shear for rec. column for 110 mm wall thickness (single diagonal strut**)**

STOREY	Y-Dr	X-Dr
Story1	503.1725	593.8412

Table.4.47 Modal Period and Frequency for rec. column for 110 mm wall thickness (single diagonal strut**)**

Case	**Mode**	**Period (Sec)**	**Frequency (cyc/sec)**	**Circ. Freq (rad/sec)**	**Eigen value (rad^2/sec^2)**
Modal	1	0.679	1.472	9.2504	85.5692
Modal	2	0.572	1.747	10.976	120.4734
Modal	3	0.419	2.386	14.9922	224.7665
Modal	4	0.236	4.234	26.6046	707.8068
Modal	5	0.2	5.01	31.4792	990.9408
Modal	6	0.154	6.493	40.7939	1664.146
Modal	7	0.147	6.81	42.7871	1830.737
Modal	8	0.131	7.632	47.9526	2299.454
Modal	9	0.129	7.751	48.6979	2371.488
Modal	10	0.11	9.099	57.1711	3268.54
Modal	11	0.098	10.215	64.1832	4119.483
Modal	12	0.083	12.116	76.1297	5795.727

Table.4.48 Modal Participation Mass Ratio

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	0.679	0.0002	0.8886	0	0.0002	0.8886	0	0.2984	0.0001	0.0001	0.2984	0.0001	0.0001
Modal	2	0.572	0.8915	0.0002	0	0.8917	0.8888	0	0.0001	0.293	0.0004	0.2985	0.2931	0.0006
Modal	3	0.419	0.0004	0.0001	0	0.8922	0.8889	0	7.01E-06	4.21E-05	0.8992	0.2985	0.2931	0.8998
Modal	4	0.236	2.08E-05	0.0907	0	0.8922	0.9796	0	0.657	0.0002	0.0001	0.9555	0.2933	0.8999
Modal	5	0.2	0.0877	2.47E-05	0	0.9799	0.9796	0	0.0002	0.6633	0.0001	0.9557	0.9566	0.9
Modal	6	0.154	4.29E-06	0.0177	0	0.9799	0.9973	0	0.0225	4.31E-06	0.0001	0.9782	0.9566	0.9
Modal	7	0.147	5.44E-06	1.70E-05	0	0.9799	0.9974	0	0.0001	0	0.0809	0.9782	0.9566	0.9809
Modal	8	0.131	0.0175	3.94E-06	0	0.9974	0.9974	0	4.73E-06	0.0209	1.74E-06	0.9782	0.9775	0.9809
Modal	9	0.129	0	0.0026	0	0.9974	1	0	0.0218	4.73E-06	0	1	0.9775	0.9809
Modal	10	0.11	0.0026	7.45E-07	0	1	1	0	5.62E-06	0.0225	1.00E-06	1	1	0.9809
Mod	11	0.0	0	0	0	1	1	0	0	1.29E	0.016	1	1	0.9

al		98								-06	8			977
M od al	12	0.0 83	0	0	0	1	1	0	5.9 4E -07	0	0.0 02 3	1	1	1

2) For 150mm wall thickness

Table.4.49 Max Storey Displacement for rec. column for 150 mm wall thickness (Single Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	10.531	8.878
Story2	20.905	17.448
Story3	29.683	24.556
Story4	34.706	28.419

Table.4.50 Max Storey Drift for rec. column for 150 mm wall thickness (Single Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.00351	0.002959
Story2	0.003458	0.002857
Story3	0.002926	0.002369
Story4	0.001674	0.001293

Table.4.51 Overturning Moment for rec. column for 150 mm wall thickness (Single Diagonal Strut**)**

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	20151.9757	-26754.7561
Story1	17851.3806	-23992.2228
Story2	12104.5733	-16395.1265
Story3	6681.1481	-9169.5762
Story4	1975.1366	-2771.6819

Table.4.52 Base Shear for rec. column for 150 mm wall thickness (Single Diagonal Strut**)**

STOREY	Y-Dr (KN)	X-Dr (KN)
Story1	611.3396	704.2201

Table.4.53 Modal Period and Frequency for rec. column for 150 mm wall thickness (Single Diagonal Strut**)**

Case	**Mode**	**Period (Sec)**	**Frequency (cyc/sec)**	**CircFreq (rad/sec)**	**Eigenvalue (rad^2/sec^2)**
Modal	1	0.63	1.588	9.9796	99.5924
Modal	2	0.53	1.886	11.8473	140.3578
Modal	3	0.39	2.563	16.1018	259.2678
Modal	4	0.219	4.566	28.687	822.9414
Modal	5	0.185	5.405	33.962	1153.419
Modal	6	0.142	7.018	44.0937	1944.256

Modal	7	0.137	7.308	45.9172	2108.386
Modal	8	0.121	8.246	51.8099	2684.261
Modal	9	0.12	8.33	52.3379	2739.26
Modal	10	0.102	9.774	61.4113	3771.346
Modal	11	0.091	10.953	68.82	4736.193
Modal	12	0.077	12.927	81.2227	6597.128

Table.4.54 Modal Participation Mass Ratio for rec. column for 150 mm wall thickness (Single Diagonal Strut**)**

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	0.63	0.0004	0.8875	0	0.0004	0.8875	0	0.3273	0.0001	0.0003	0.3273	0.0001	0.0003
Modal	2	0.53	0.8908	0.0004	0	0.8912	0.8879	0	0.0002	0.3205	0.0007	0.3275	0.3207	0.001
Modal	3	0.39	0.0008	0.0002	0	0.892	0.888	0	3.64E-06	0.0001	0.9004	0.3275	0.3208	0.9014
Modal	4	0.219	3.67E-05	0.0925	0	0.892	0.9805	0	0.6321	0.0003	0.0002	0.9596	0.3211	0.9016
Modal	5	0.185	0.0889	4.44E-05	0	0.9809	0.9806	0	0.0003	0.6397	0.0001	0.9599	0.9607	0.9017
Modal	6	0.142	7.02E-06	0.0172	0	0.9809	0.9978	0	0.0189	5.77E-06	0.0002	0.9788	0.9607	0.9018
Modal	7	0.137	9.69E-06	3.14E-05	0	0.9809	0.9978	0	0.0001	9.18E-07	0.0804	0.9789	0.9607	0.9823

Modal	8	0.121	0.017	5.90E-06	0	0.9979	0.9978	0	4.76E-06	0.0172	2.41E-06	0.9789	0.9779	0.9823
Modal	9	0.12	0	0.0022	0	0.9979	1	0	0.0211	6.24E-06	8.21E-07	1	0.9779	0.9823
Modal	10	0.102	0.0021	1.10E-06	0	1	1	0	9.31E-06	0.0221	2.17E-06	1	1	0.9823
Modal	11	0.091	0	0	0	1	1	0	0	2.20E-06	0.0161	1	1	0.9984
Modal	12	0.077	0	0	0	1	1	0	6.83E-07	0	0.0016	1	1	1

4.7 CMS HAVING RECTANGULAR COLUMN WITH WALL MODEL AS CROSS DIAGONAL STRUT

1) For 110mm wall thickness

Table.4.55 Max Storey Displacement for Rec. Column for 110 mm wall thickness (Cross Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	6.784	4.823
Story2	13.839	9.741
Story3	20.111	14.043
Story4	24.082	16.67

Table.4.56 Max Storey Drift for Rec. Column for 110 mm wall thickness (Cross Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.002261	0.001608
Story2	0.002352	0.001639
Story3	0.00209	0.001434
Story4	0.001324	0.000876

Table.4.57 Overturning Moment for Rec. Column for 110 mm wall thickness (Cross Diagonal Strut**)**

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	19651.9022	-24990.3653
Story1	17097.5403	-22206.9933
Story2	11593.3252	-15266.7463
Story3	6417.8749	-8653.6536
Story4	1975.1366	-2771.6819

Table.4.58 Base Shear for Rec. Column for 110 mm wall thickness (Cross Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	652.8219	650.9117

Table.4.59 Modal Period and Frequency for Rec. Column for 110 mm wall thickness (Cross Diagonal Strut**)**

Case	**Mode**	**Period** **sec**	**Frequency** **cyc/sec**	**Circ. Freq** **rad/sec**	**Eigen value** **rad²/sec²**
Modal	1	0.499	2.005	12.5999	158.7573
Modal	2	0.417	2.399	15.0738	227.2193
Modal	3	0.304	3.29	20.6716	427.3171
Modal	4	0.173	5.784	36.3418	1320.727
Modal	5	0.145	6.889	43.2819	1873.323
Modal	6	0.111	9.008	56.5974	3203.261
Modal	7	0.107	9.385	58.9662	3477.013
Modal	8	0.094	10.616	66.7053	4449.603
Modal	9	0.093	10.782	67.7478	4589.766
Modal	10	0.079	12.68	79.6727	6347.747
Modal	11	0.071	14.084	88.4932	7831.041
Modal	12	0.06	16.699	104.9208	11008.38

Table.4.60 Modal Participation Mass Ratio for Rec. Column for 110 mm wall thickness (Cross Diagonal Strut**)**

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Modal	1	0.499	0	0.8799	0	0	0.8799	0	0.3138	0	1.58E-05	0.3138	0	1.58E-05
Mod	2	0.4	0.885	0	0	0.8	0.8	0	0	0.304	4.98E	0.3	0.3	2.08E-

al		17	7			857	799			6	-06	138	046	05
Modal	3	0.304	0	6.80E-06	0	0.8857	0.88	0	1.59E-05	0	0.8997	0.3138	0.3046	0.8997
Modal	4	0.173	0	0.0988	0	0.8857	0.9788	0	0.6393	0	6.41E-06	0.9531	0.3046	0.8997
Modal	5	0.145	0.0936	0	0	0.9793	0.9788	0	0	0.6503	5.26E-07	0.9531	0.9549	0.8997
Modal	6	0.111	0	0.0184	0	0.9793	0.9972	0	0.0265	0	3.47E-05	0.9796	0.9549	0.8997
Modal	7	0.107	0	1.78E-05	0	0.9793	0.9972	0	4.61E-05	0	0.0812	0.9797	0.9549	0.981
Modal	8	0.094	0.018	0	0	0.9973	0.9972	0	0	0.0238	0	0.9797	0.9787	0.981
Modal	9	0.093	0	0.0028	0	0.9973	1	0	0.0203	0	1.19E-06	1	0.9787	0.981
Modal	10	0.079	0.0027	0	0	1	1	0	0	0.0213	0	1	1	0.981
Modal	11	0.071	0	5.56E-07	0	1	1	0	1.44E-06	0	0.0168	1	1	0.9978
Modal	12	0.06	0	0	0	1	1	0	0	0	0.0022	1	1	1

2) For 150mm wall thickness

Table.4.61 Max Storey Displacement for Rec. Column for 150 mm wall thickness (Cross Diagonal Strut**)**

STOREY	Y-Dr (mm)	X-Dr (mm)
Base	0	0
Story1	5.928	4.211
Story2	12.192	8.558
Story3	17.783	12.369
Story4	21.293	14.663

Table.4.62 Max Storey Drift for rec. column for 150 mm wall thickness (Cross Diagonal Strut**)**

STOREY	Y-Dr	X-Dr
Base	0	0
Story1	0.001976	0.001404
Story2	0.002088	0.001449
Story3	0.001863	0.00127
Story4	0.00117	0.000765

Table.4.63 Overturning Moment for rec. column for 150 mm wall thickness (Cross Diagonal Strut**)**

STORY	X-Dr (KN-m)	Y-Dr (KN-m)
Base	22353.486	-28464.66
Story1	19416.967	-25251.4
Story2	13049.687	-17206.48
Story3	7074.679	-9552.173
Story4	1975.1366	-2771.682

Table.4.64 Base Shear for rec. column for 150 mm wall thickness (CDS)

STOREY	Y-Dr (KN)	X-Dr (KN)
Base	741.675	739.7397

Table.4.65 Modal Period and Frequency for rec. column for 150 mm wall thickness (Cross Diagonal Strut**)**

Case	**Mode**	**Period**	**Frequency**	**Circ. Freq**	**Eigen value**
Modal	1	0.465	2.149	13.5003	182.2582
Modal	2	0.388	2.576	16.1856	261.9739
Modal	3	0.284	3.523	22.1383	490.1032
Modal	4	0.161	6.206	38.9965	1520.723
Modal	5	0.135	7.402	46.5064	2162.843
Modal	6	0.103	9.712	61.0247	3724.017
Modal	7	0.1	10.048	63.1308	3985.497
Modal	8	0.087	11.449	71.9368	5174.906
Modal	9	0.086	11.569	72.689	5283.697
Modal	10	0.074	13.604	85.4768	7306.283
Modal	11	0.066	15.069	94.6843	8965.109
Modal	12	0.056	17.787	111.7583	12489.92

Table.4.66 Modal Participation Mass Ratio for rec. column for 150 mm wall thickness (Cross Diagonal Strut**)**

Case	**Mode**	**Period**	**UX**	**UY**	**UZ**	**SumUX**	**SumUY**	**SumUZ**	**RX**	**RY**	**RZ**	**SumRX**	**SumRY**	**SumRZ**
Mod	1	0.4	0	0.877	0	0	0.8	0	0.344	0	2.38E	0.3	0	2.38E-

al		65		5			775		2		-05	442		05
Modal	2	0.388	0.8842	0	0	0.8842	0.8775	0	0	0.3334	6.74E-06	0.3442	0.3334	3.05E-05
Modal	3	0.284	0	7.15E-06	0	0.8842	0.8775	0	1.79E-05	0	0.9012	0.3442	0.3334	0.9013
Modal	4	0.161	0	0.102	0	0.8842	0.9795	0	0.6129	0	8.93E-06	0.9571	0.3334	0.9013
Modal	5	0.135	0.0959	0	0	0.9801	0.9795	0	0	0.6255	7.31E-07	0.9571	0.9589	0.9013
Modal	6	0.103	0	0.0181	0	0.9801	0.9976	0	0.0236	0	0.0001	0.9807	0.9589	0.9013
Modal	7	0.1	0	2.76E-05	0	0.9801	0.9976	0	0.0001	0	0.0809	0.9808	0.9589	0.9822
Modal	8	0.087	0.0176	0	0	0.9978	0.9976	0	0	0.0206	0	0.9808	0.9796	0.9822
Modal	9	0.086	0	0.0024	0	0.9978	1	0	0.0192	0	1.74E-06	1	0.9796	0.9822
Modal	10	0.074	0.0022	0	0	1	1	0	0	0.0204	0	1	1	0.9822
Modal	11	0.066	0	6.16E-07	0	1	1	0	1.60E-06	0	0.0162	1	1	0.9984
Modal	12	0.056	0	0	0	1	1	0	0	0	0.0016	1	1	1

4.8 Comparison of Results of CMS (Model as a SDS) and RC Frame Structure with Square Column and Thickness of Wall=110mm

1) Max Storey Displacement

Fig.4.1 max storey displacement for CMS & RC frame structure in X-Dr

Fig.4.2 max storey displacement for CMS & RC frame structure in Y-Dr

2) Max Storey Drift

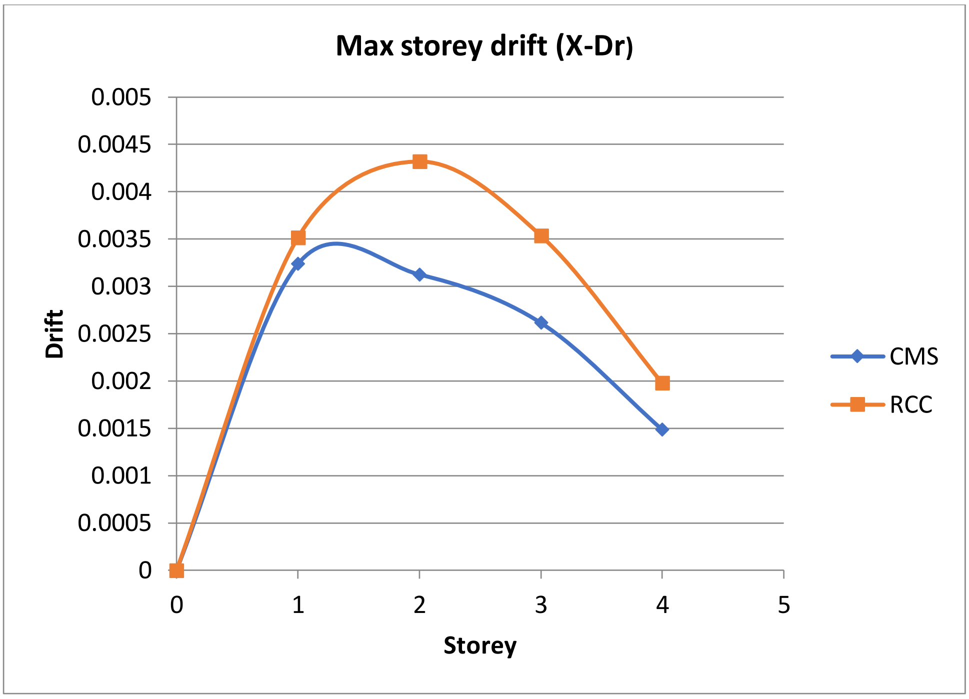


Fig.4.3 max storey drift for CMS & RC frame structure in X-Dr

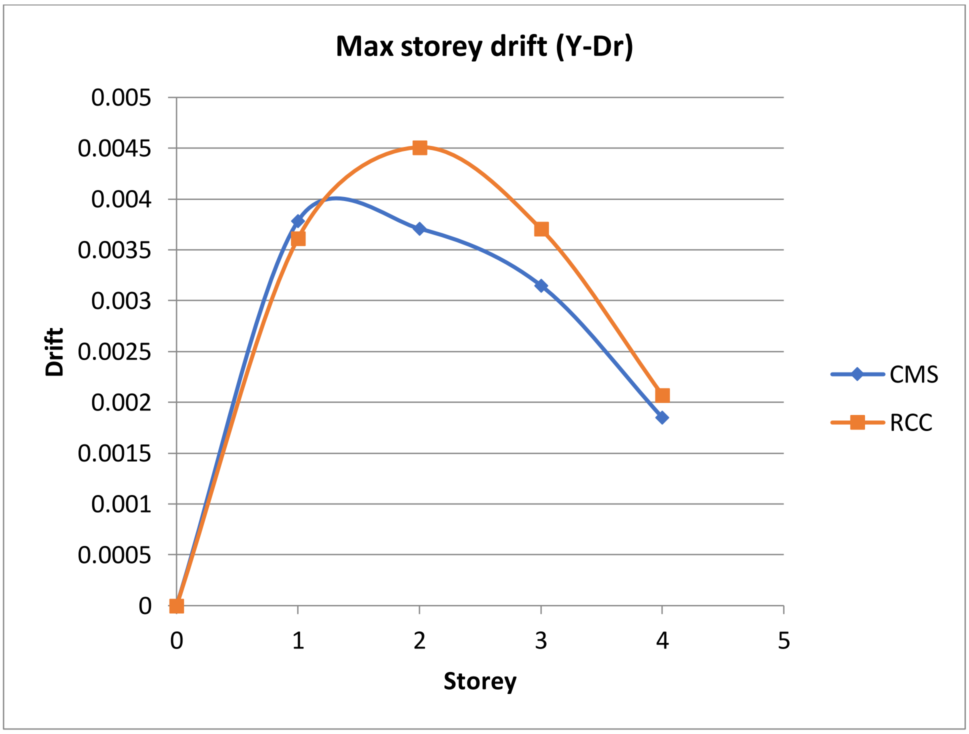


Fig.4.4 Max Storey Drift for CMS & RC Frame Structure in Y-Dr

3) Max Overturning Moment

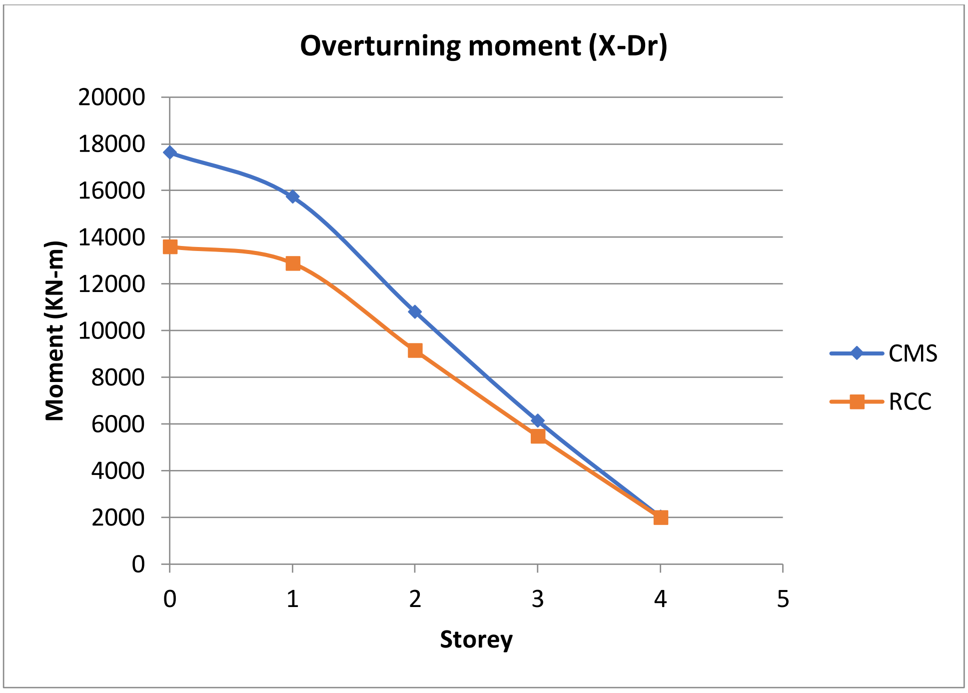


Fig.4.5 Max overturning moment for CMS & RC frame structure in X-Dr

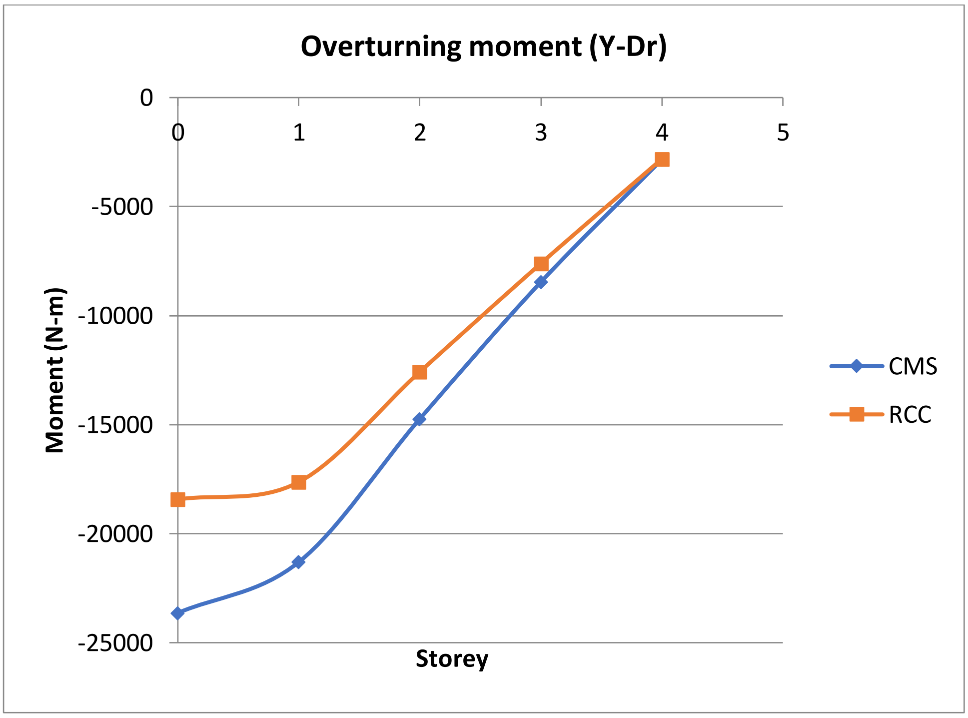


Fig.4.6 Max overturning moment for CMS & RC frame structure in Y-Dr

4) Base Shear

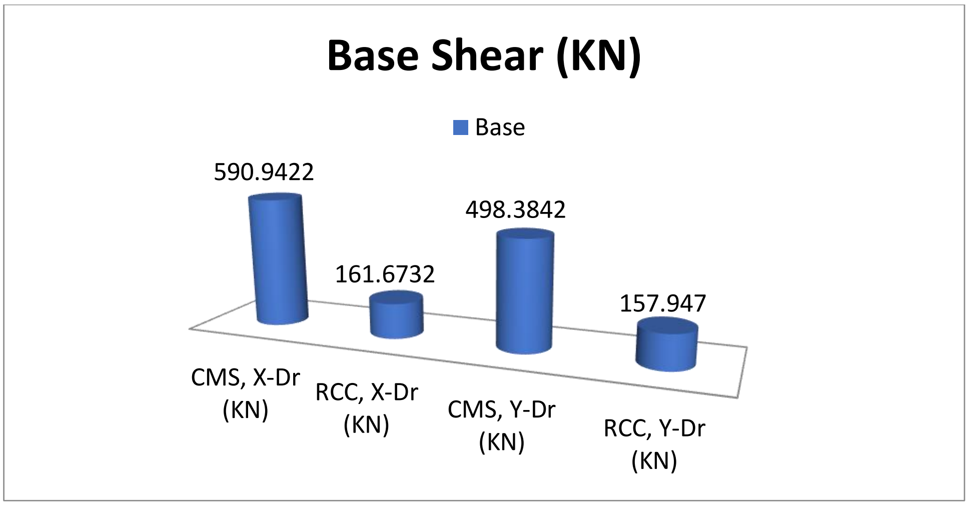


Fig.4.7 Base shear for CMS & RC frame structure in X & Y-Dr

4.9 COMPARISON OF EFFECT OF WALL DENSITY ON CMS (MODELED AS SINGLE DIAGONAL STRUT) WITH SQUARE COLUMN

1) Max Storey Displacement

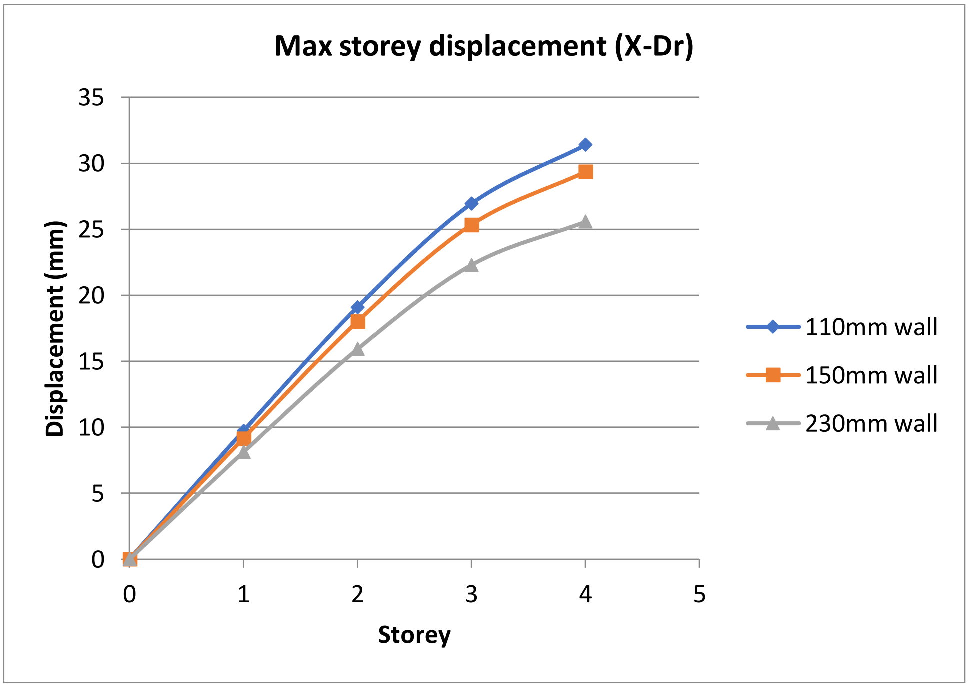


Fig.4.8 Max storey displacement for 110mm, 150mm & 230mm thick wall in X-Dr

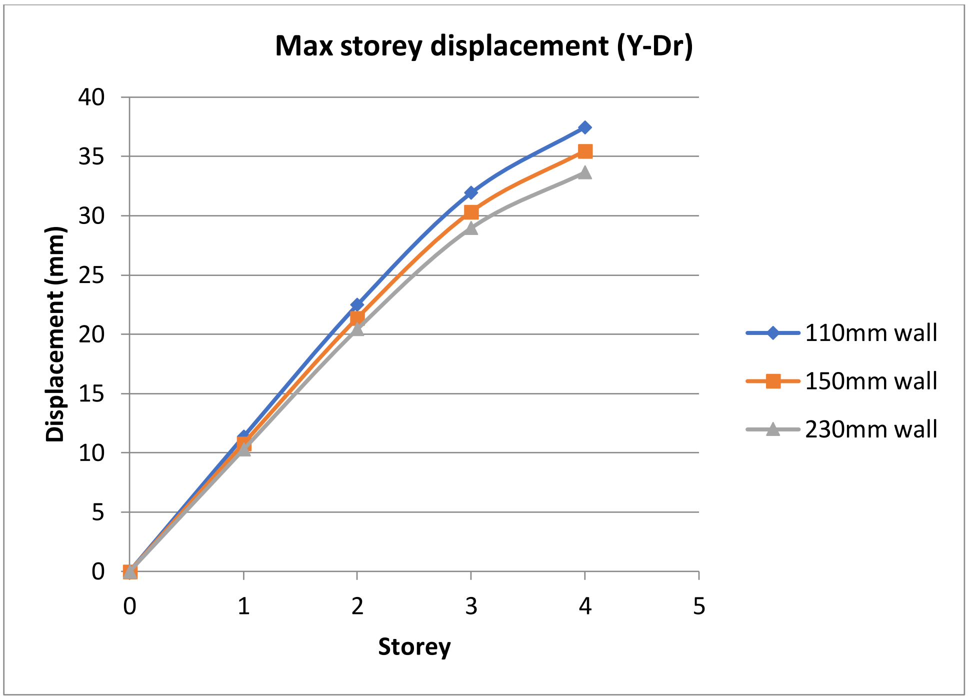


Fig.4.9 Max storey displacement for 110mm, 150mm & 230mm thick wall in Y-Dr

2) Max Storey Drift

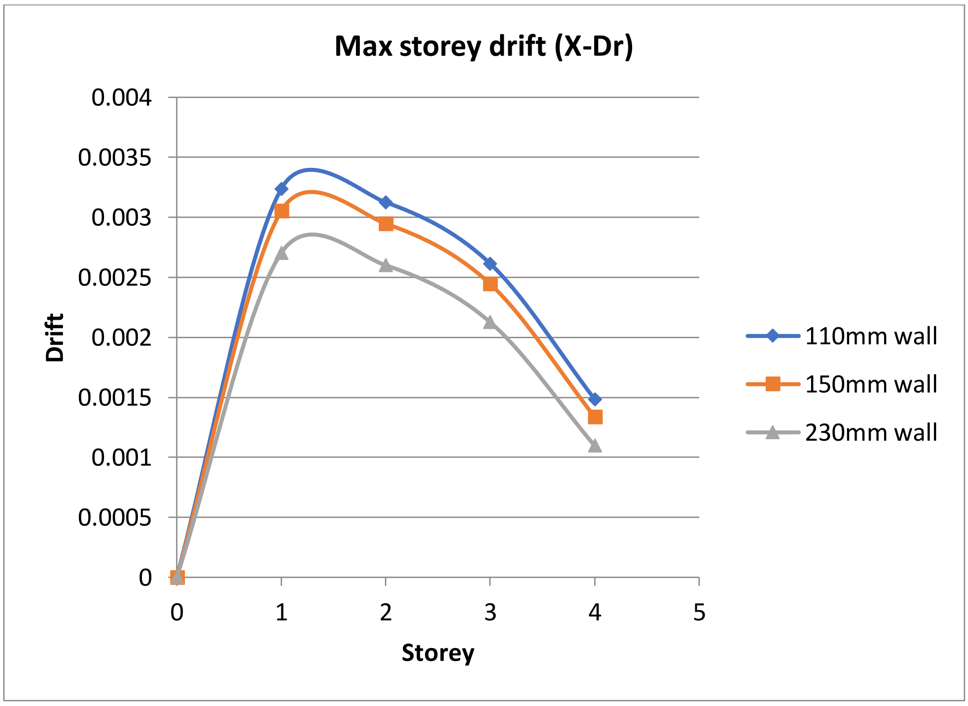


Fig.4.10 Max storey drift for 110mm, 150mm & 230mm thick wall in X-Dr

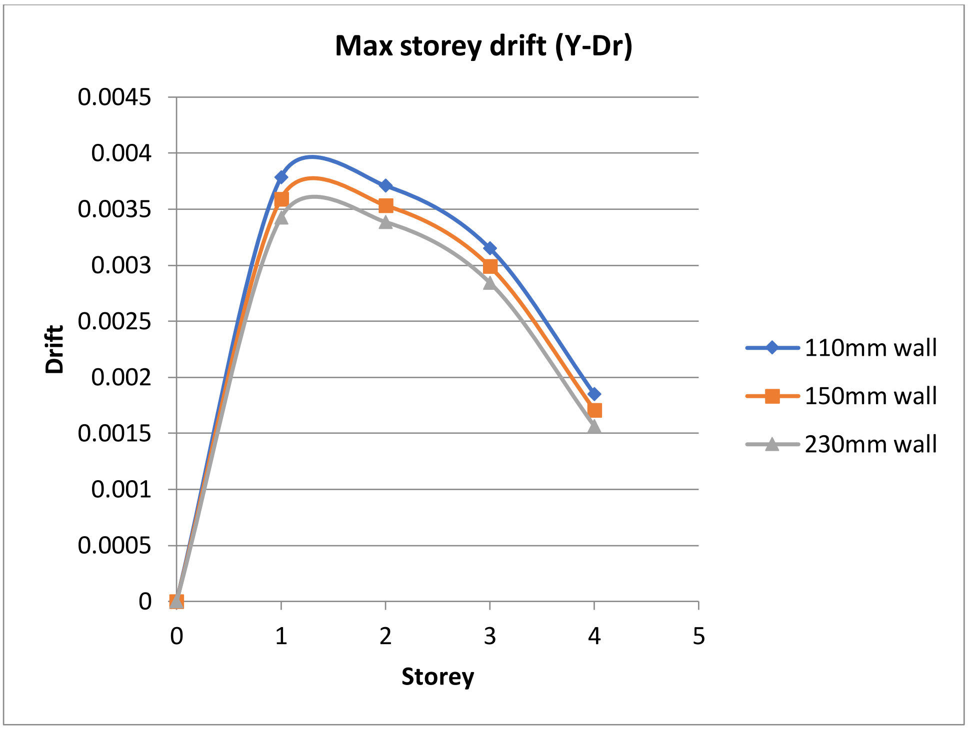


Fig.4.11 Max storey drift for 110mm, 150mm & 230mm thick wall in Y-Dr

3) Overturning Moment

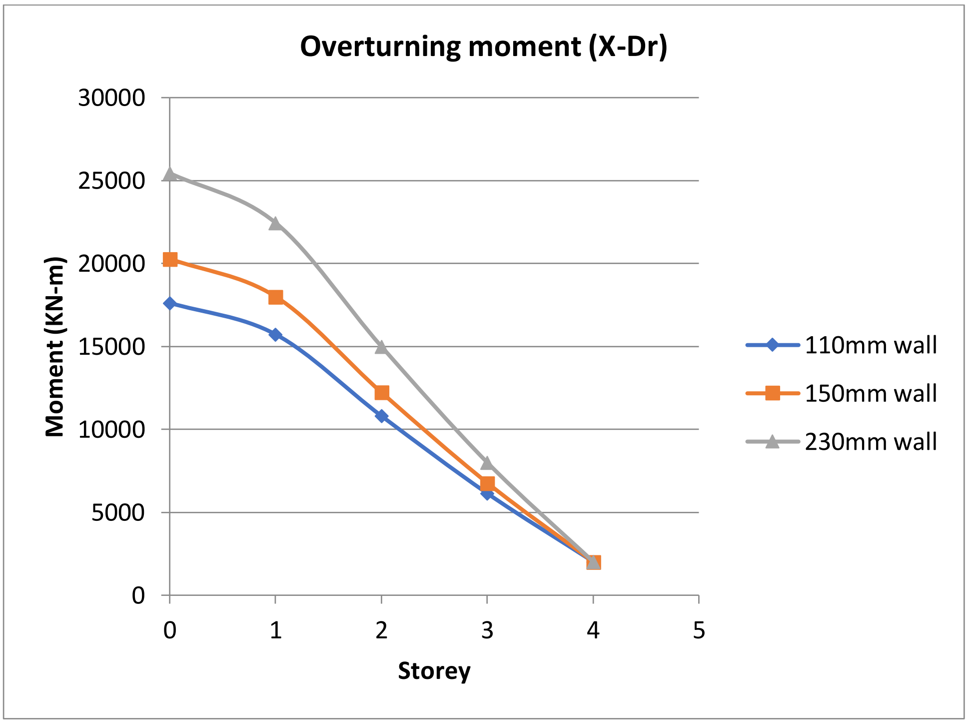


Fig.4.12 Overturning moment for 110mm, 150mm & 230mm thick wall in X-Dr

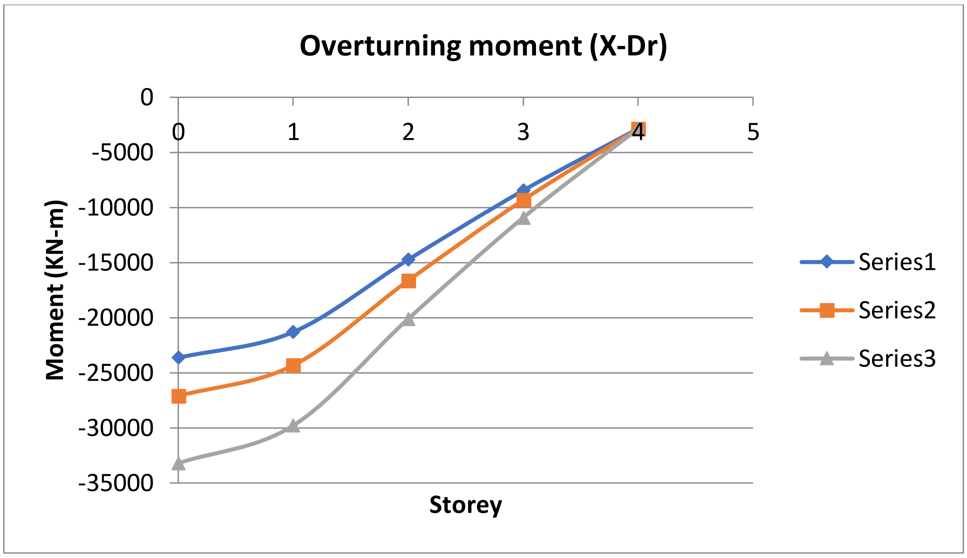


Fig.4.13 Overturning moment for 110mm, 150mm & 230mm thick wall in Y-Dr

4) Base Shear

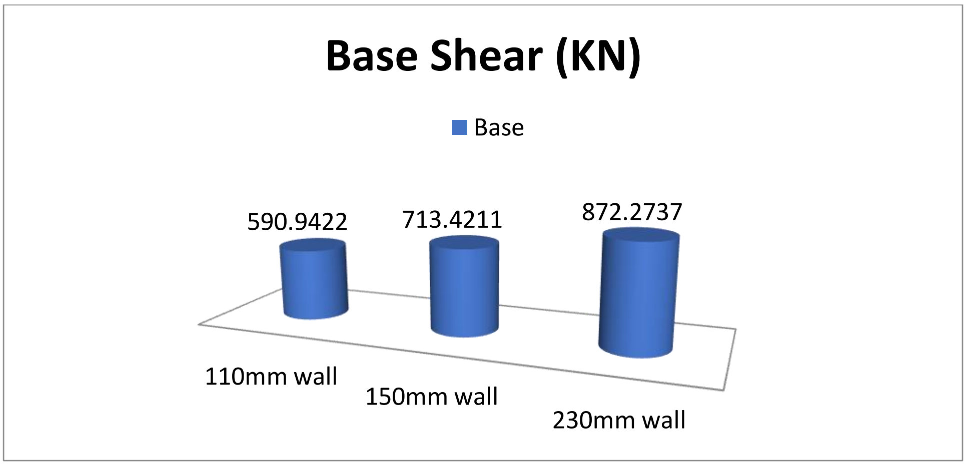


Fig.4.14 Base shear for 110mm, 150mm & 230mm thick wall in X-Dr

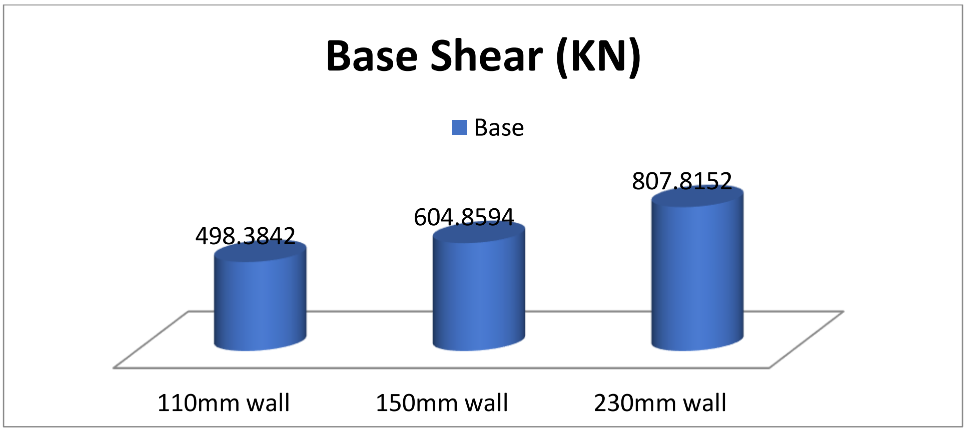


Fig.4.15 Base shear for 110mm, 150mm & 230mm thick wall in Y-Dr

4.10 Comparison of Effect of Wall Density on CMS (Modeled as Cross Diagonal Strut) with Square Column

1) Max Storey Displacement

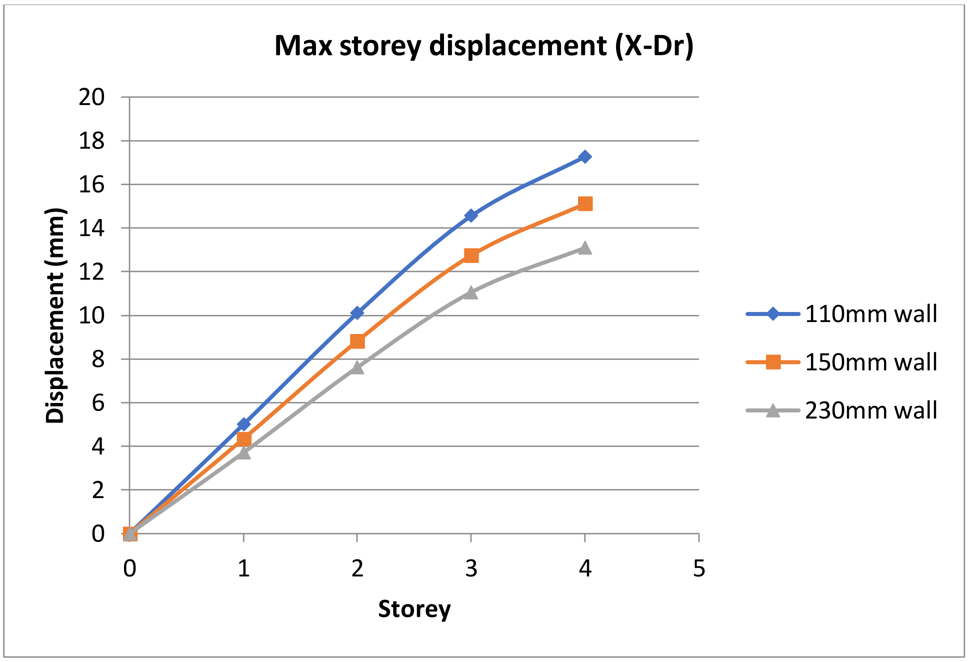


Fig.4.16 Max storey displacement for 110mm, 150mm & 230mm thick wall in X-Dr

Fig.4.17 Max storey displacement for 110mm, 150mm & 230mm thick wall in Y-Dr

2) **Max Storey Drift**

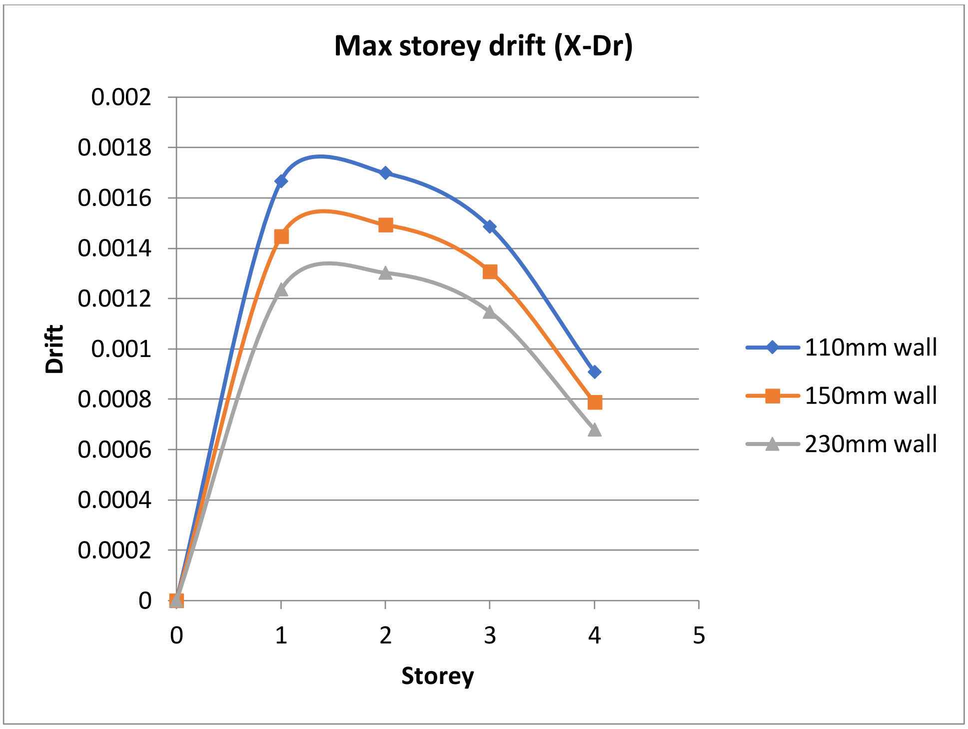


Fig.4.18 Max storey drift for 110mm, 150mm & 230mm thick wall in X-Dr

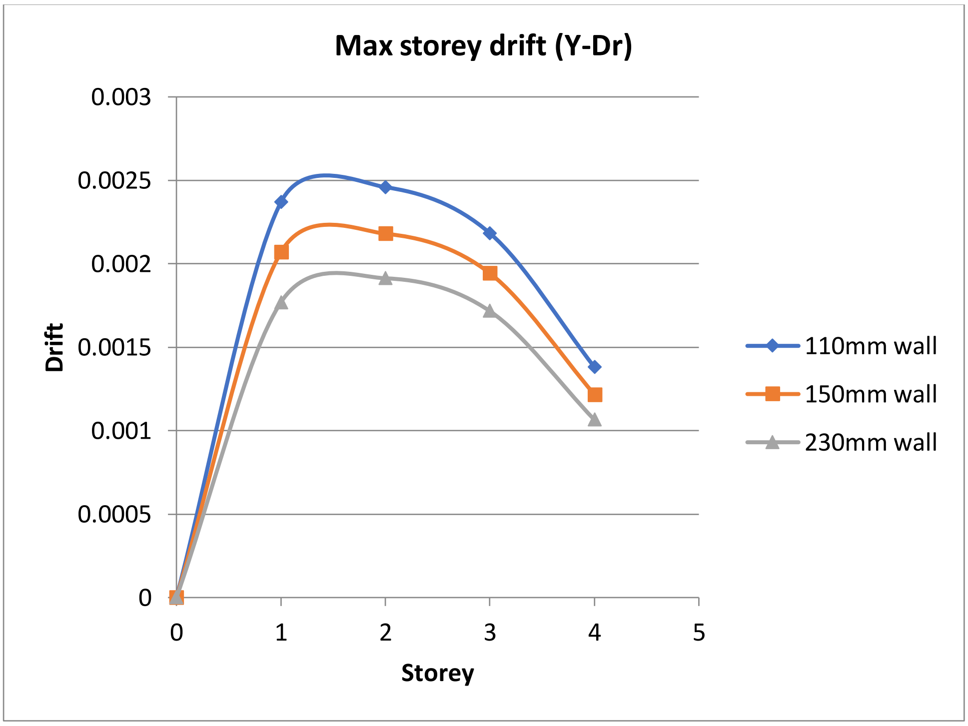


Fig.4.19 Max storey drift for 110mm, 150mm & 230mm thick wall in Y-Dr

3) Overturning Moment

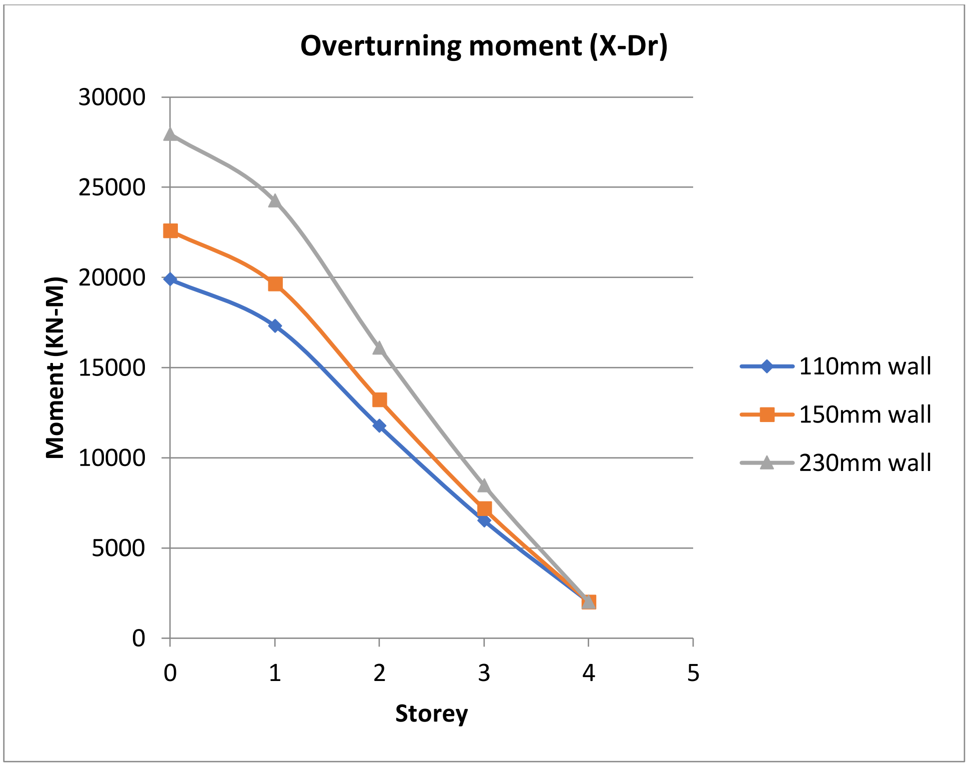


Fig.4.20 Overturning moment for 110mm, 150mm & 230mm thick wall in X-Dr

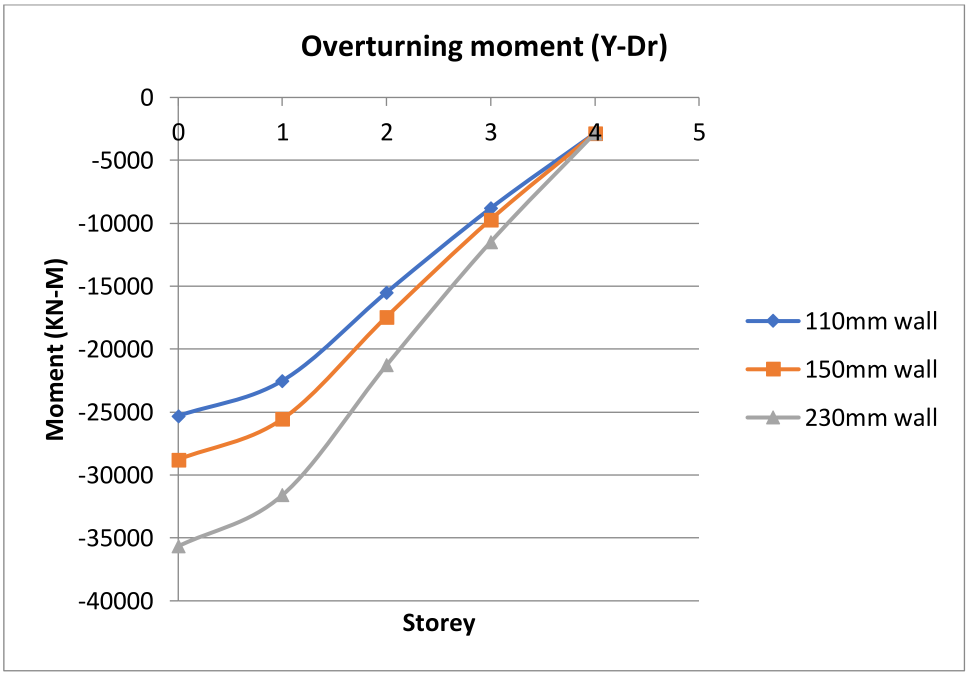


Fig.4.21 Overturning moment for 110mm, 150mm & 230mm thick wall in Y-Dr

4) Base Shear

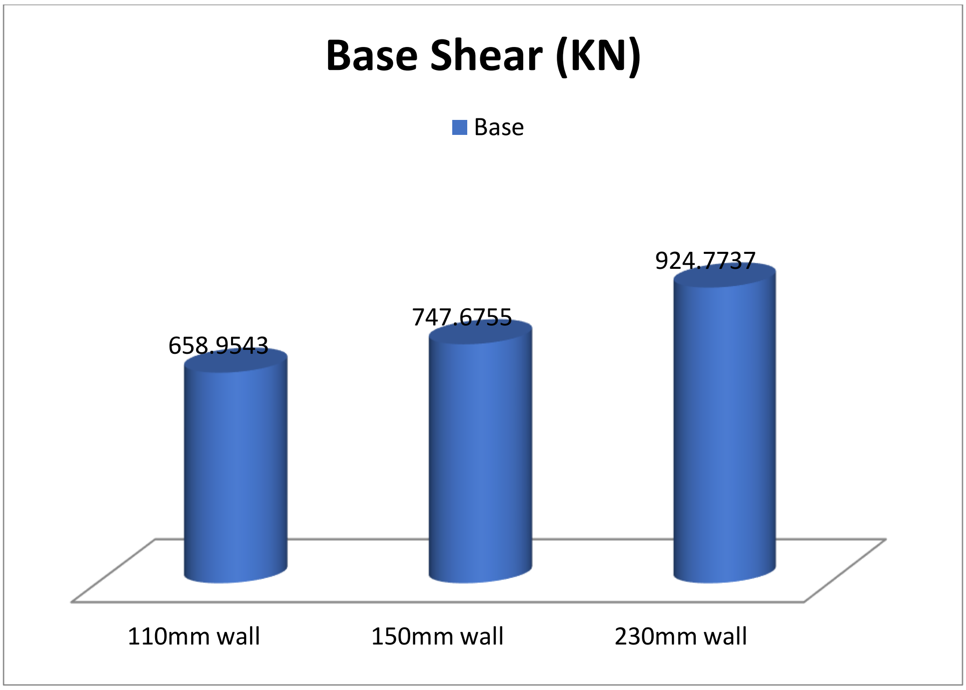


Fig.4.22 Base shear for 110mm, 150mm & 230mm thick wall in X-Dr

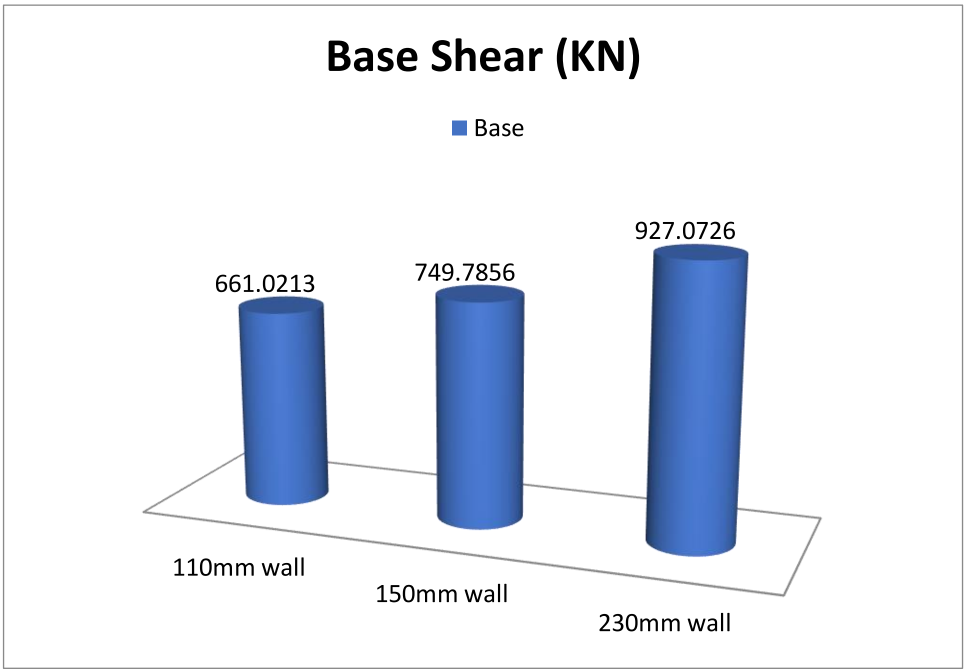


Fig.4.23 Base shear for 110mm, 150mm & 230mm thick wall in Y-Dr

4.11 COMPARISON OF CMS WITH SQUARE COLUMN AND CMS WITH RECTANGULAR COLUMN (WALL MODELED AS SINGLE DIAGONAL STRUT

1) Max Storey Displacement

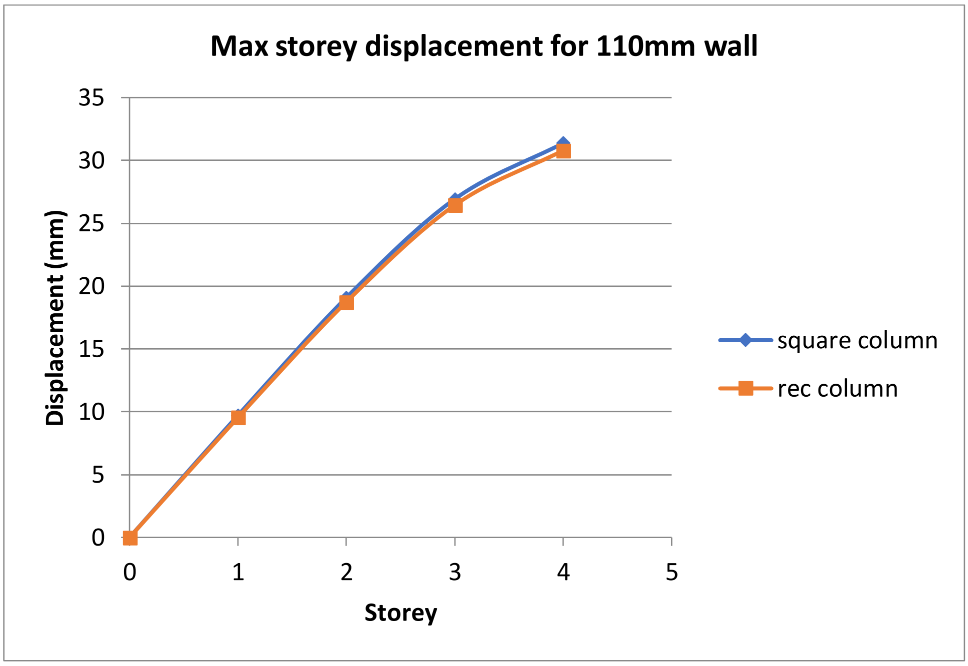


Fig.4.24 Max storey displacement of CMS with square & rec. column X-Dr (SDS)

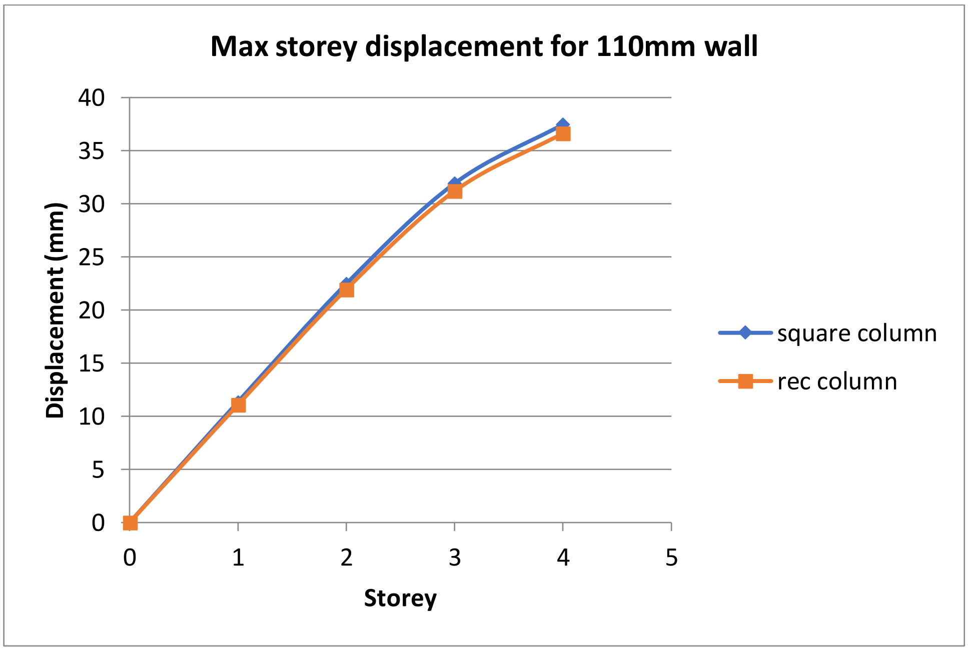


Fig.4.25 Max storey displacement of CMS with square & rec. column Y-Dr (SDS)

2) Max Storey Drift

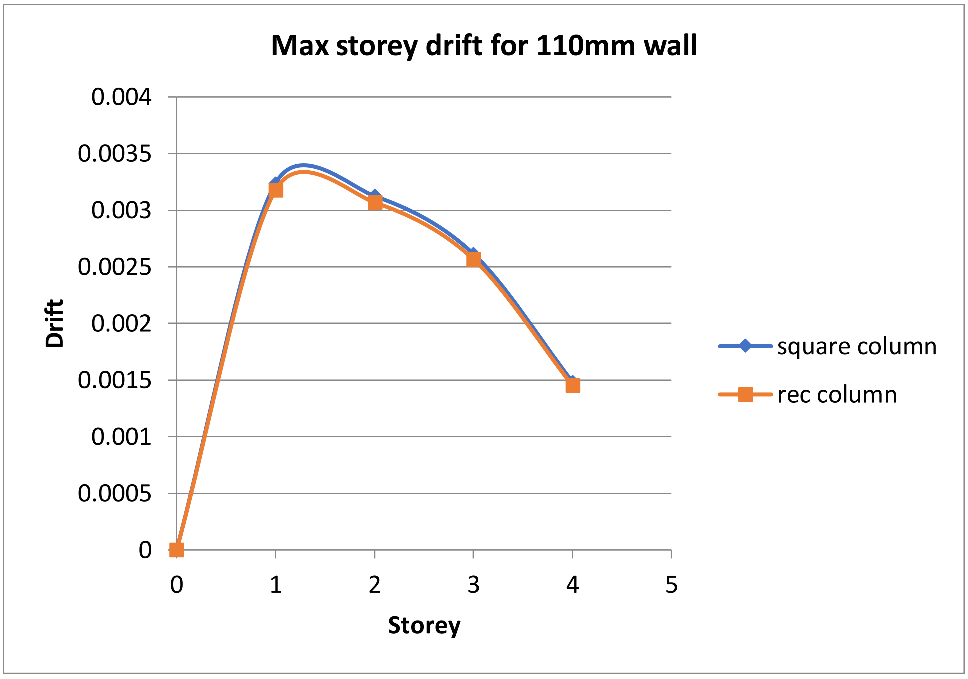


Fig.4.26 Max storey drift of CMS with square & rec. column in X-Dr (SDS)

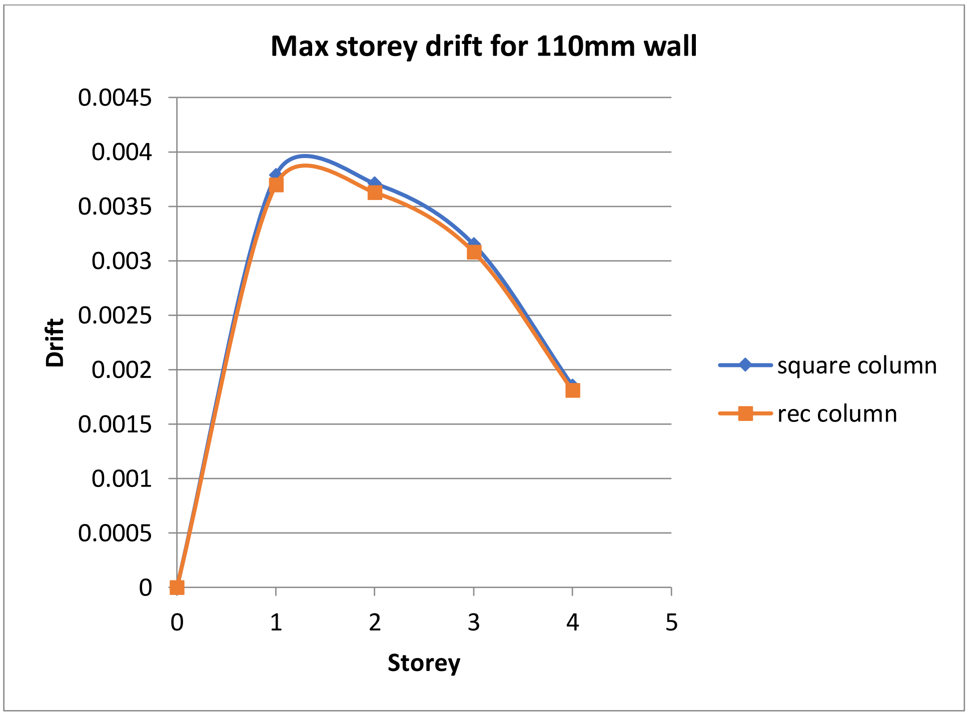


Fig.4.27 Max storey drift of CMS with square & rec. column in Y-Dr (SDS)

3) Overturning Moment

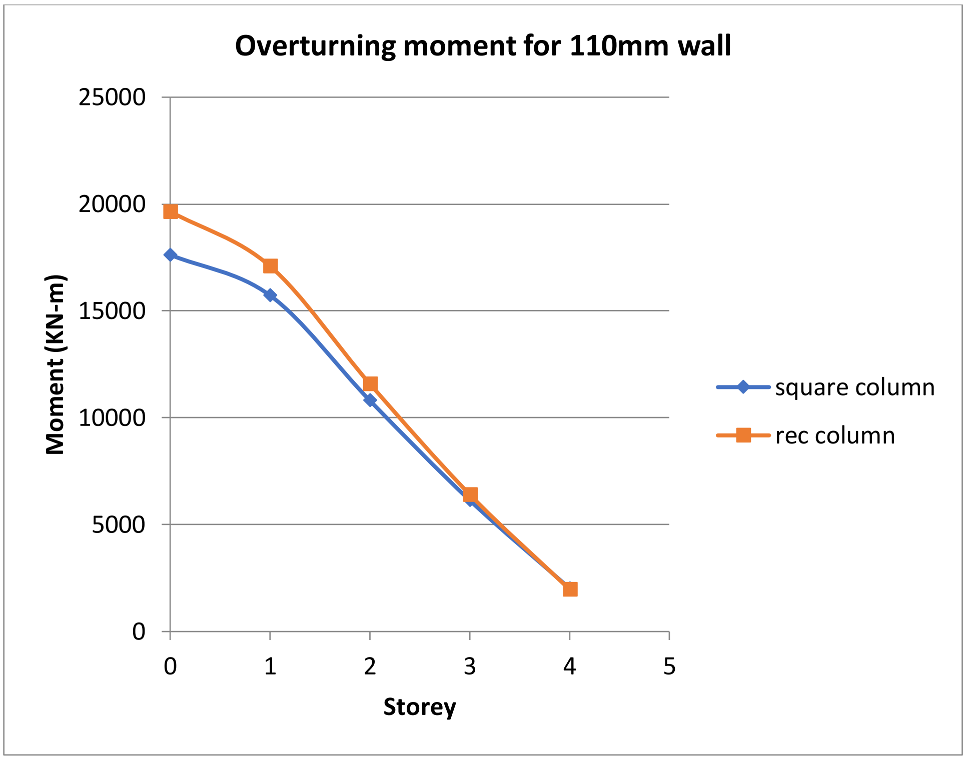


Fig.4.28 Overturning moment of CMS with square & rec. column in X-Dr (SDS)

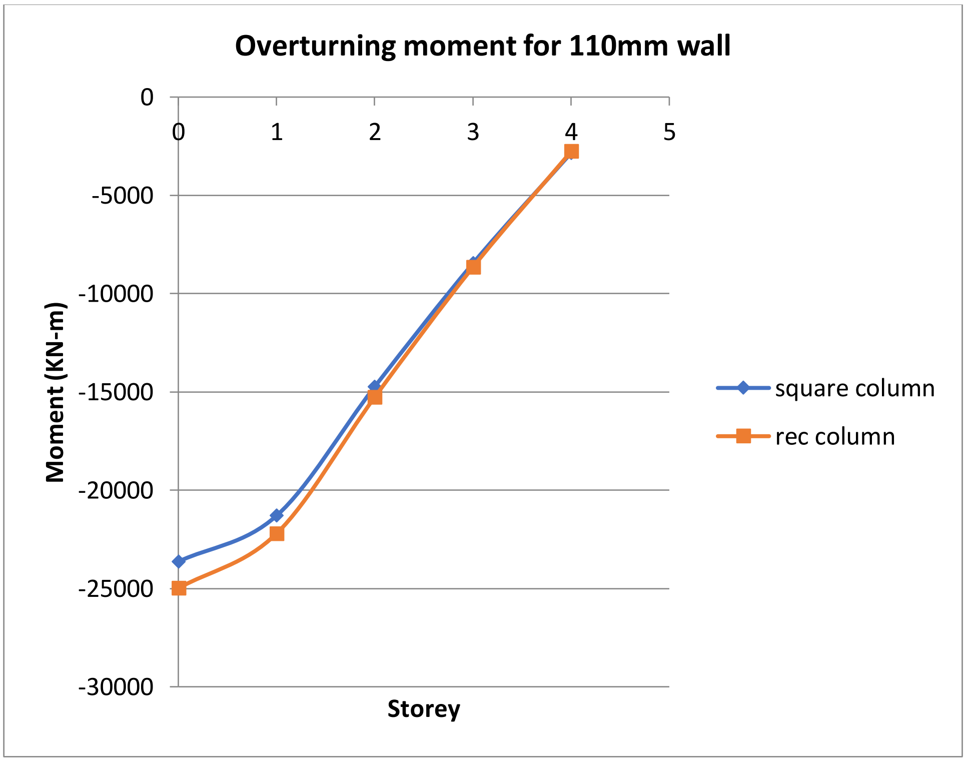


Fig.4.29 Overturning moment of CMS with square & rec. column in Y-Dr (SDS)

4) Base Shear

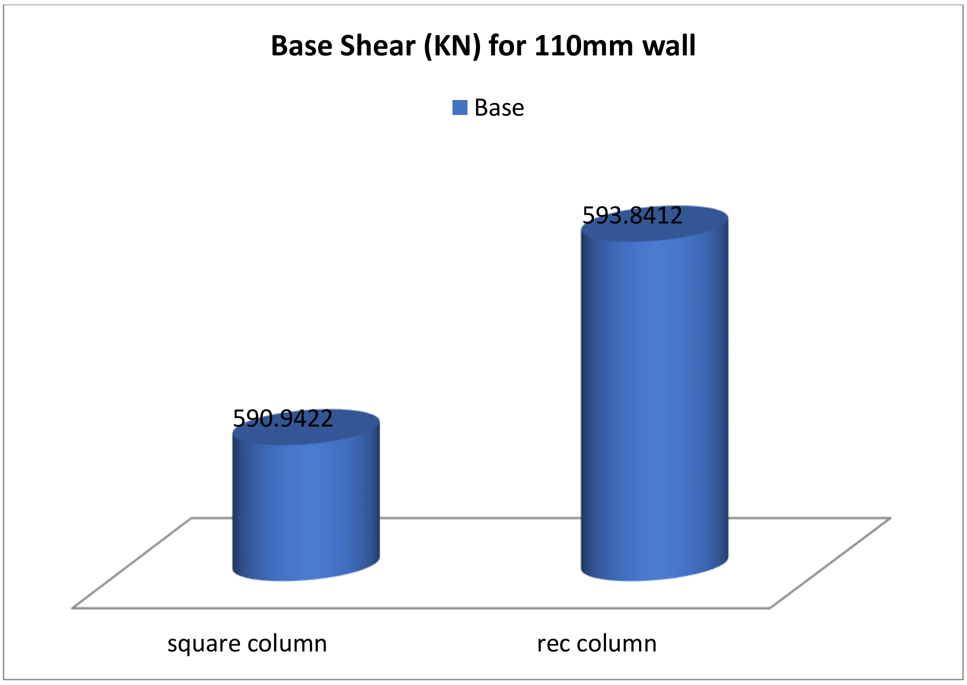


Fig.4.30 Base shear of CMS with square column & rec. column in X-Dr (SDS)

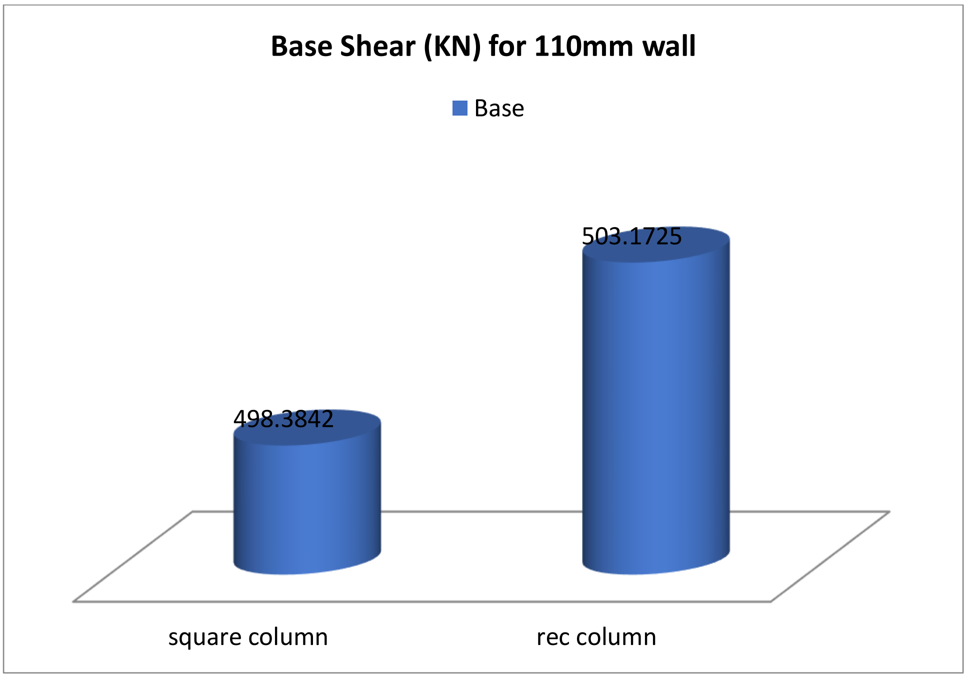


Fig.4.31 Base shear of CMS with square column & rec. column in Y-Dr (SDS)

For 150mm wall

1) Max Storey Displacement

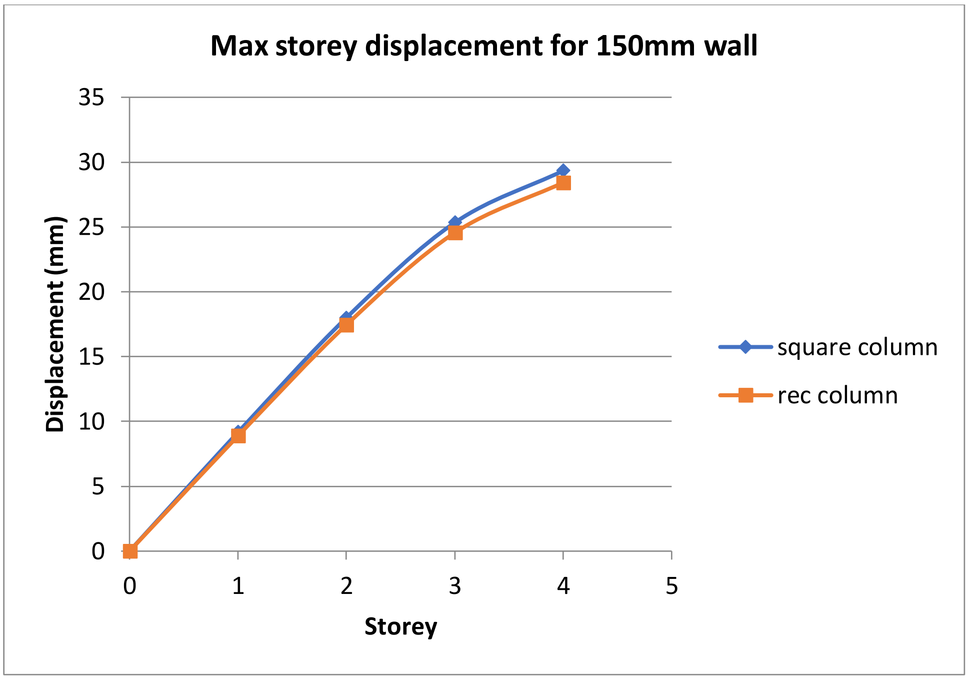


Fig.4.32 Max storey displacement of CMS with square & rec. column in X-Dr (SDS)

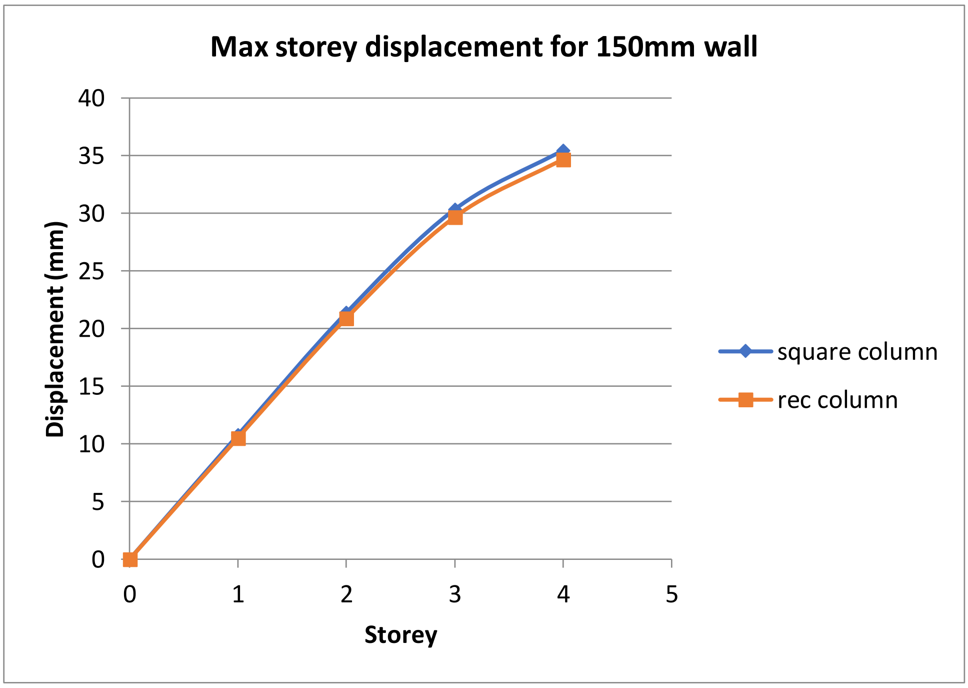


Fig.4.33 Max storey displacement of CMS with square & rec. column in Y-Dr (SDS)

2) Max Storey Drift

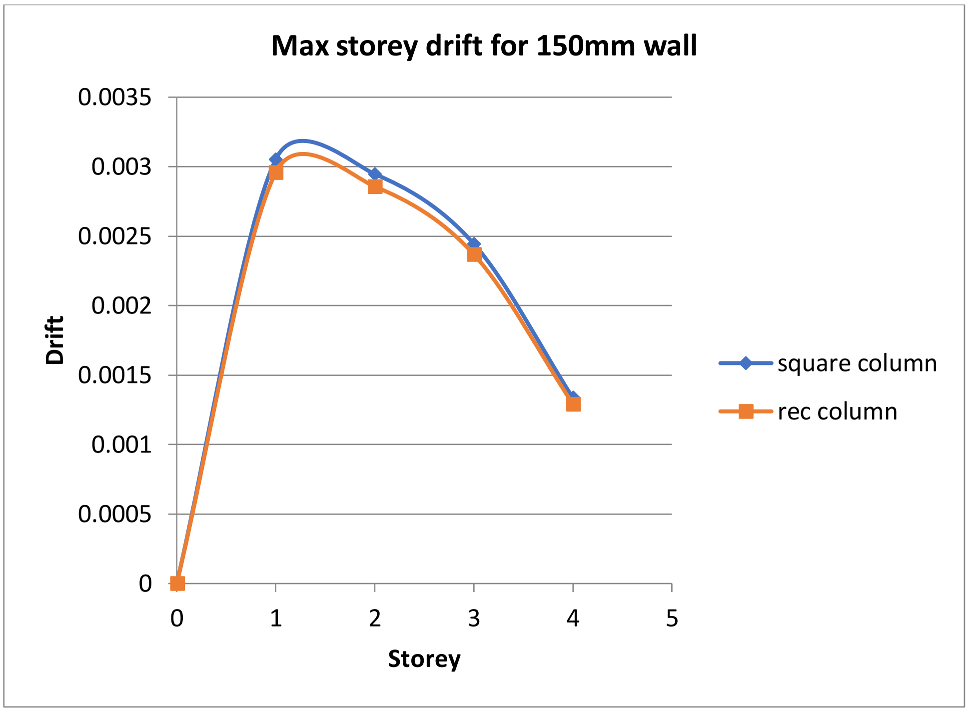


Fig.4.34 Max storey drift of CMS with square & rec. column in X-Dr (SDS)

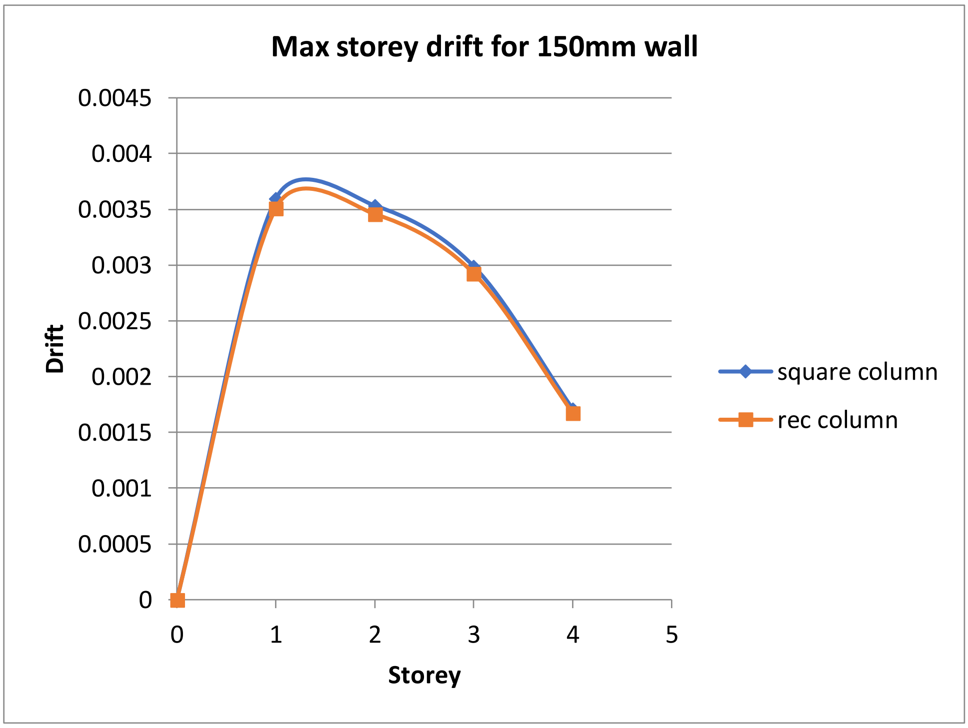


Fig.4.35 Max storey drift of CMS with square & rec. column in Y-Dr (SDS)

3) Overturning Moment

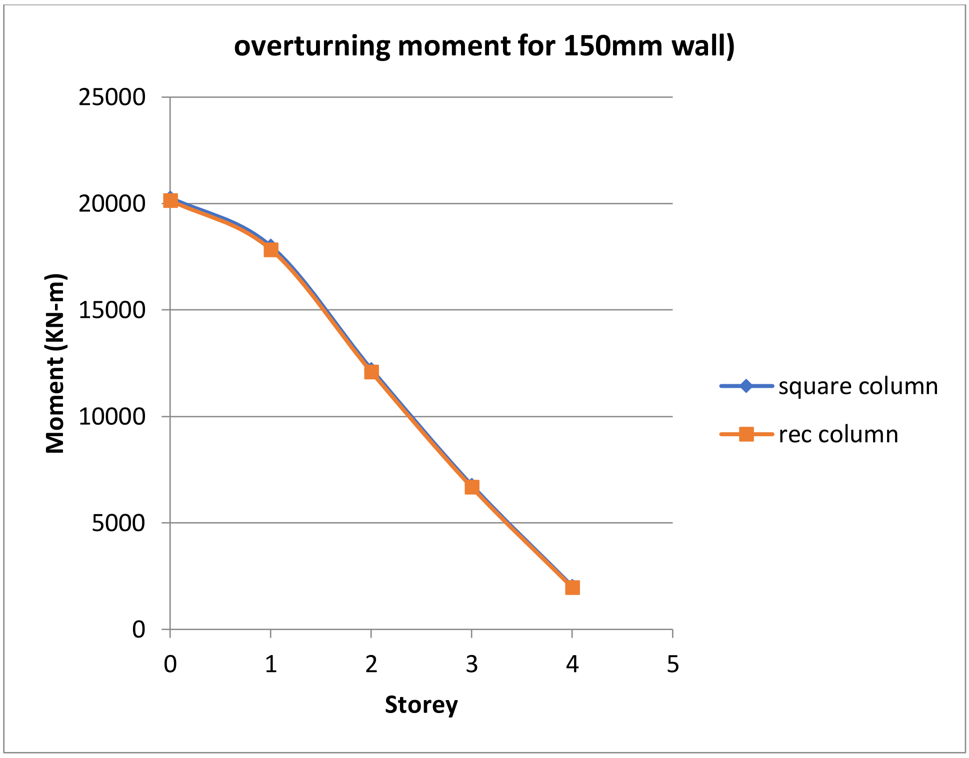


Fig.4.36 Overturning moment of CMS with square & rec. column in X-Dr (SDS)

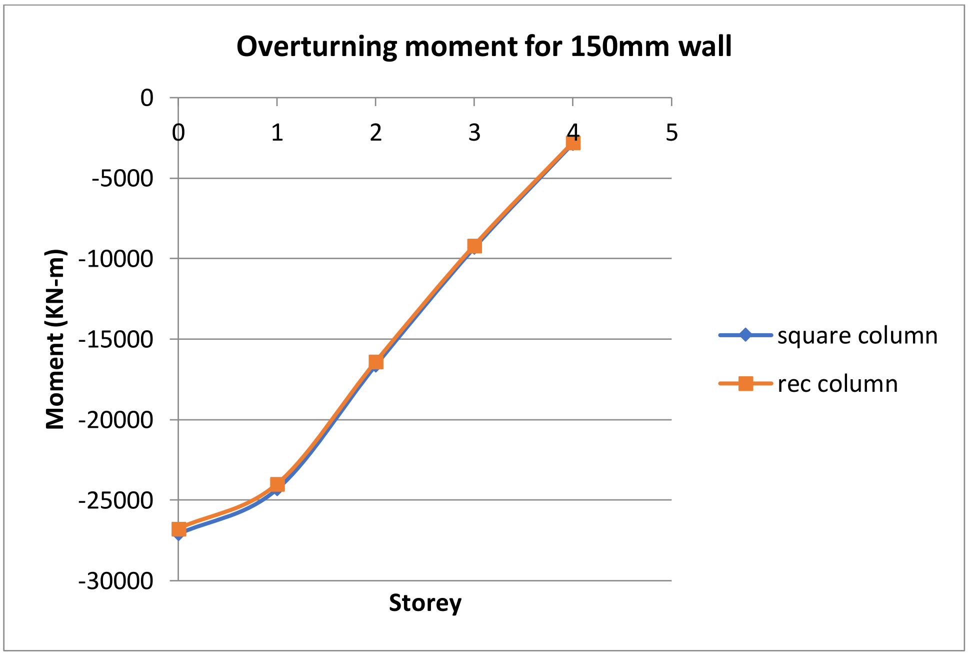


Fig.4.37 Overturning moment of CMS with square & rec. column in Y-Dr (SDS)

4.12 COMPARISON OF CMS WITH SQUARE COLUMN AND CMS WITH RECTANGULAR COLUMN (WALL MODELED AS CDS)

1) Max Storey Displacement

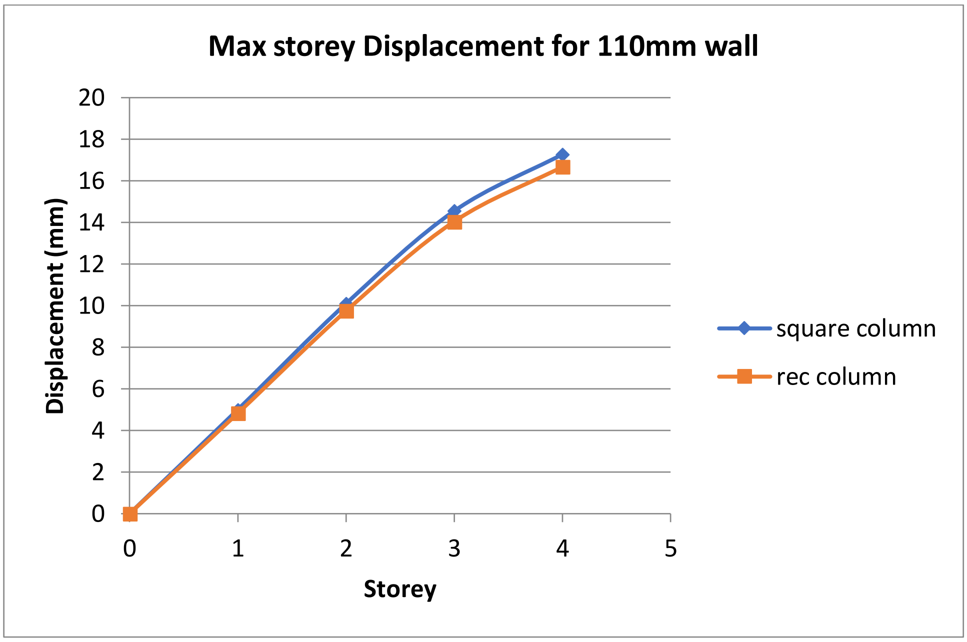


Fig.4.38 Max storey displacement for square & rec. column in X-Dr (wall model as CDS)

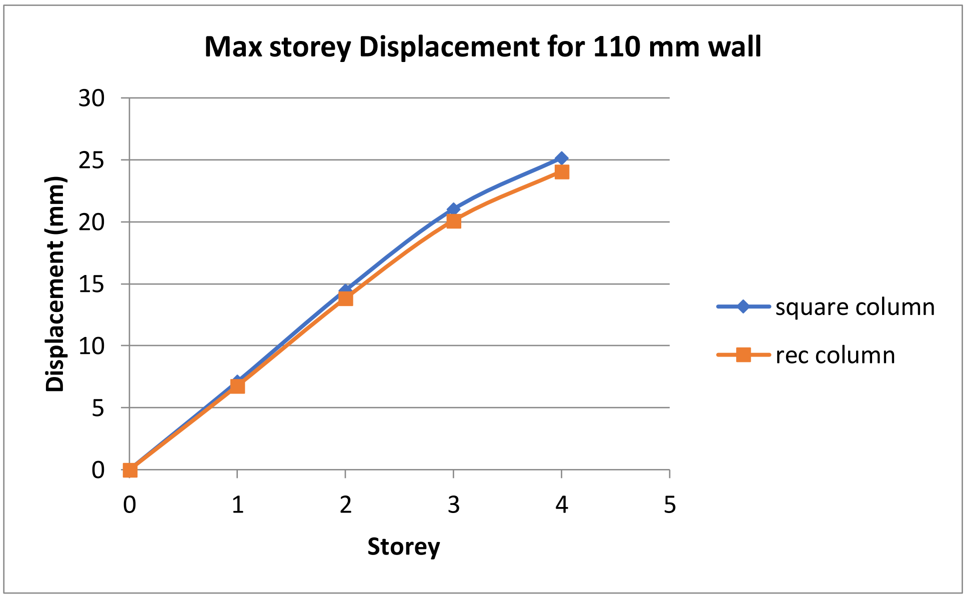


Fig.4.39 Max storey displacement for square & rec. column in Y-Dr (wall model as CDS)

2) Max Storey Drift

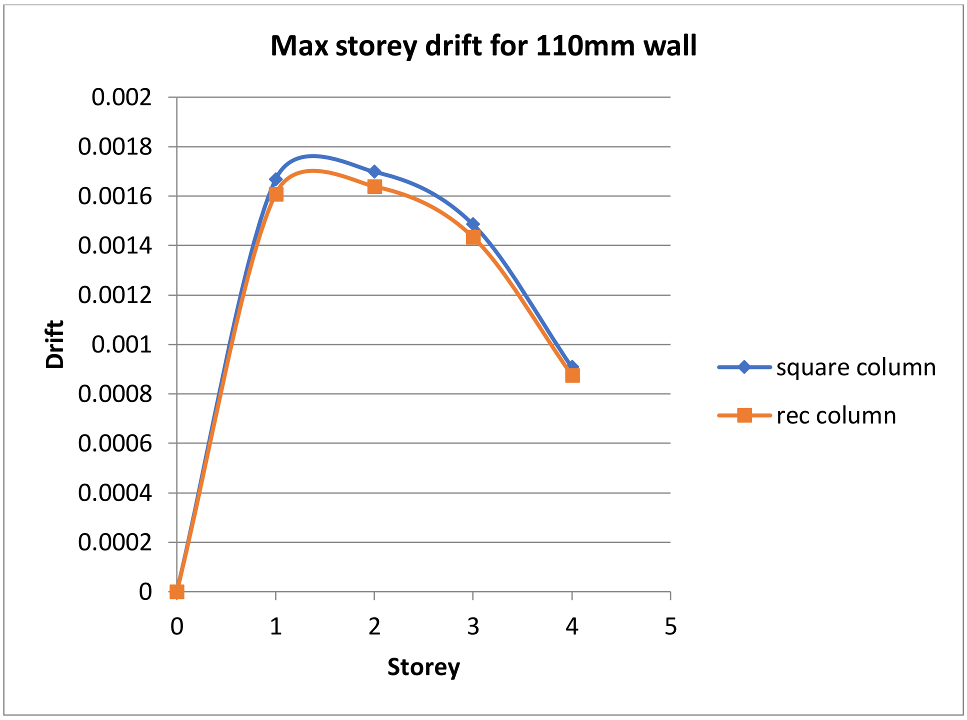


Fig.4.40 Max storey drift for square & rec. column in X-Dr (wall model as CDS)

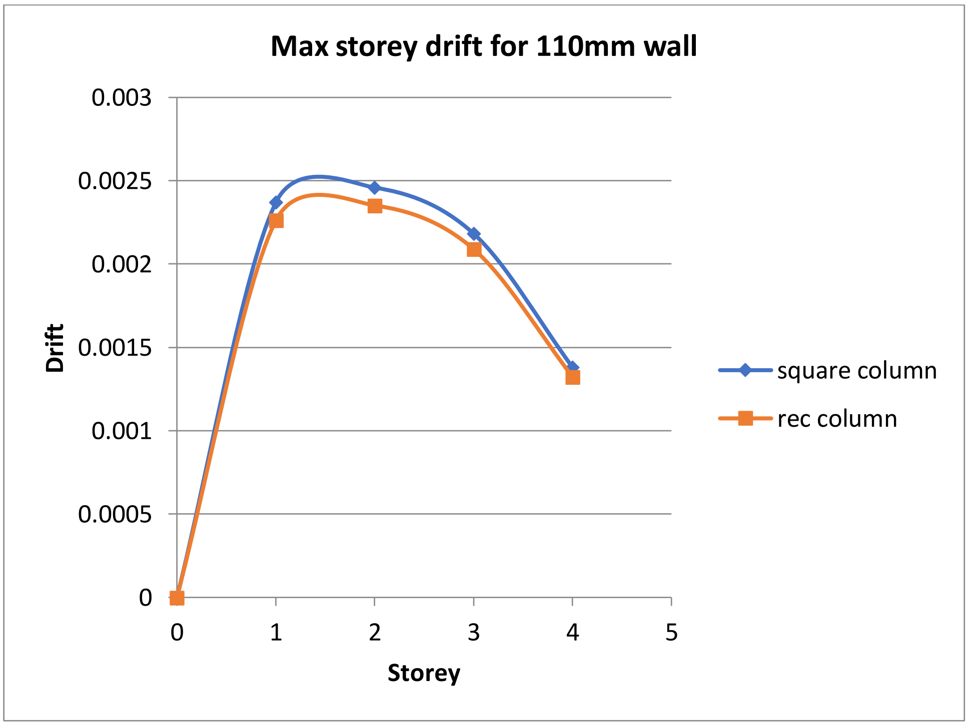


Fig.4.41 Max storey drift for square & rec. column in Y-Dr (wall model as CDS)

3) Base Shear

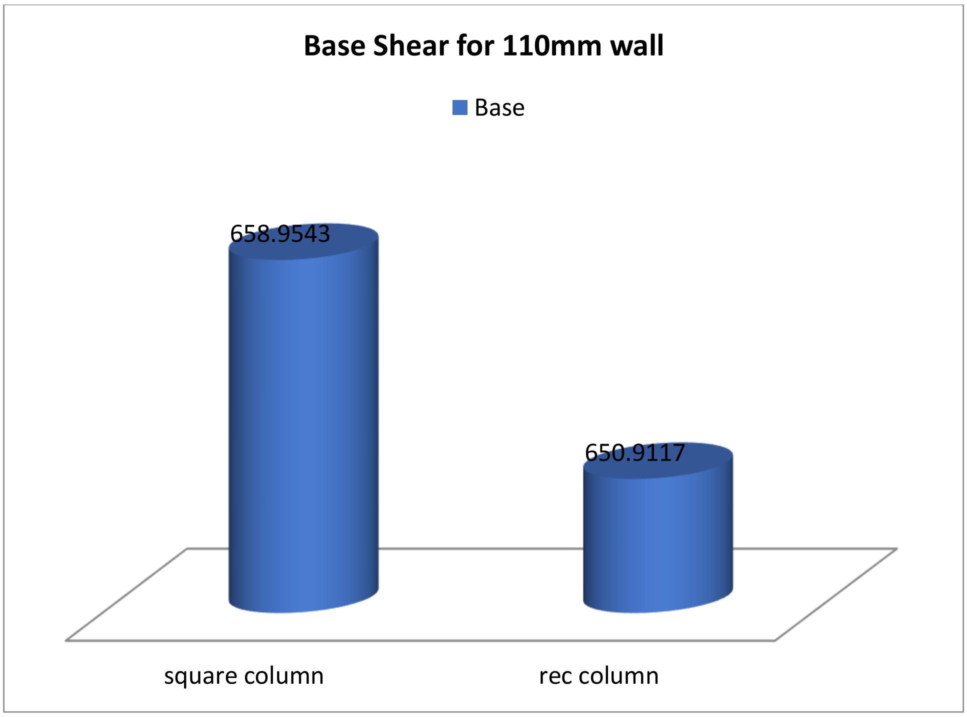


Fig.4.42 Base shear for square column & rec. column in X-Dr (wall model as CDS)

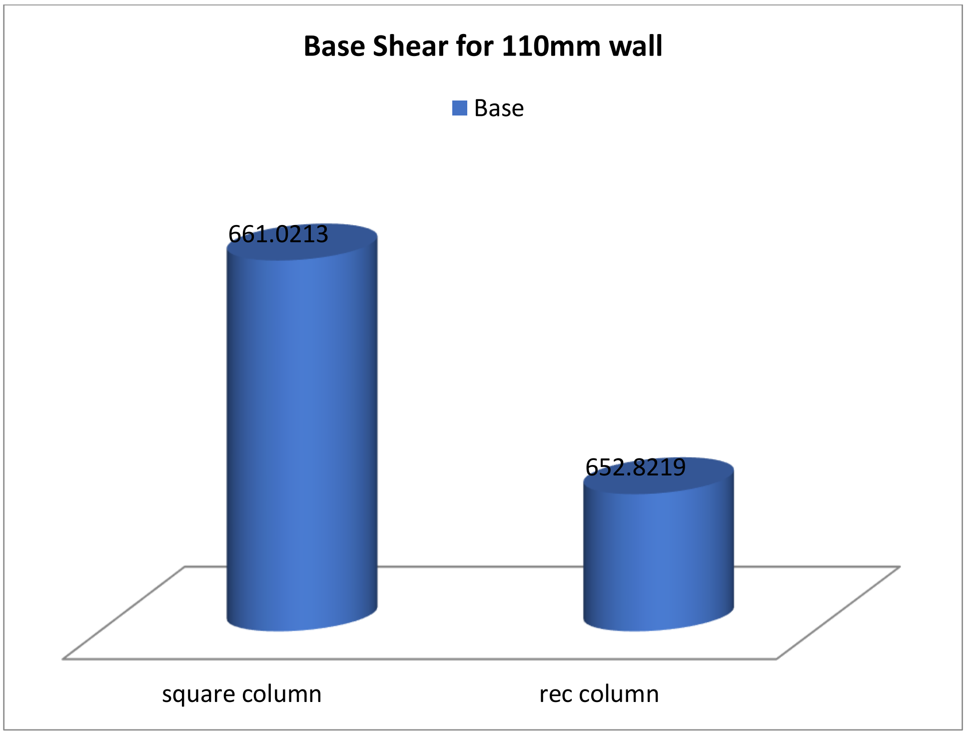


Fig.4.43 Base shear for square column & rec. column in Y-Dr (wall model as CDS)

CHAPTER 5

CONCLUSION

After analyse the various models, the results are compared on the basis of max storey displacement, max storey drift, base shear, overturning moment. It has been observed that the worst load combination are 1.5(DL-EQy) in global Y-Dr and 1.5(DL-EQx) in global X-Dr for max storey displacement, max storey drift and base shear and for overturning moment, the worst load combination are 1.5(DL+EQx) in global Y-Dr and 1.5(DL+EQy) in global X-Dr.

From the results, it has been concluded that,

5.1 CONCLUSION CONCLUDED FROM THE COMPARISON OF RC FRAME STRUCTURE AND CONFINED MASONRY STRUCTURE (Wall Model as a Equivalent Single Diagonal Strut).

- In case of RC frame structure, an increase of 27.66% in max storey displacement in X-Dr & 11.27% in Y-Dr are observed as compare to CMS and an increase of 131.84% & 65.6% in X and Y direction respectively, observed when compare to CMS (model as a cross diagonal strut).
- At 2nd storey, max increase in storey drift is observed by 38% in RC frame structure in X-Dr as compare to CMS & 21.56% in Y-Dr
- An increase of base shear has been observed in CMS by 265% & 217% in global X-Dr and Y-Dr respectively, as compare to RC frame structure.
- Max overturning moment was at the base & it was 29.64% greater in CMS as compare to RC frame structure.

5.2 EFFECT OF WALL DENSITY ON CMS (Wall Model as a Equivalent Single Diagonal Strut).

- A decrease of 6.48% & 12.876% was observed in storey displacement in X-Dr and a decrease of 5.33% & 5.13% was observed in Y-direction when the thickness of wall was increased from 110mm to 150mm and from 150mm to 230mm respectively.

- A max decrease of 9.90% & 18.025% was observed in storey drift at top floor in X-Dr and 7.617% & 8.479% in Y-Dr when the thickness of wall was increased from 110mm to 150mm and from 150mm to 230mm respectively.
- Increase in overturning moment was observed by 15.05% & 25.47% in X-Dr when the thickness of wall was increased from 110mm to 150mm & from 150mm to 230mm respectively.
- 20.726% & 22.324% increase in base shear is observed in X-Dr and 21.36% & 25.124% in Y-Dr when the thickness of wall was increased from 110mm to 150MM & FROM 150MM TO 230MM RESPECTIVELY.

5.3 EFFECT OF WALL DENSITY ON CMS (Wall Model as a CDS)

- A decrease of 13.18% & 14.627% in storey displacement was observed in X-Dr, 12.67% & 14.46% in Y-Dr. Similarly, a decrease in storey drift by max 13.197% & 14.65% in X-Dr and 12.66% & 14.50% in Y-Dr was observed at 1st floor when the thickness of wall was increased from 110mm to 150mm & from 150mm to 230mm respectively.
- Max increase of 13.55% & 23.73% in overturning moment at base was observed in X-Dr when the thickness of wall was increased from 110mm to 150mm & from 150mm to 230mm respectively.
- An increase of 13.46% & 23.686% has been observed in base shear in global X-Dr and 13.42% & 23.645% in Y-Dr in CMS when the thickness of wall was increased from 110mm to 150mm & from 150mm to 230mm respectively.
- A very little difference (almost same results) has been observed in CMS model with square column & rectangular column.

5.4 FUTURE SCOPE OF THE STUDY

In this paper, I have studied the effect of wall density and effect of shape of column on confined masonry. Comparison of confined masonry structure and RC frame structure has been also done. We can study the behaviour of CMS by changing the size of confining element and ratio of vertical reinforcement in confining element for future work. Effect of height to length (h/l) ratio on lateral strength, in-plane & out-of-plane behaviour of CM wall can also be study.

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