

A Thesis on

**DETERMINATION OF THE OPTIMUM POSITION OF
SHEAR WALL IN A MULTISTORY BUILDING WITH
REINTERANT CORNER**

Submitted for partial fulfillment of award of

MASTER OF TECHNOLOGY
Degree in
STRCUTURAL ENGINEERING

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DECLARATION

I, declare that the research thesis entitled “**Determination of Optimum Position of Shear Wall in a multistory building with reinterant corner**” is the bonafide research work carried out by me, under the guidance of **Mr. Rajiv Banerjee, Associate Professor, Department of Civil Engineering, Integral University, Lucknow**. Further I declare that this has not previously formed the basis of award of any degree, diploma, associate-ship or other similar degrees or diplomas, and has not been submitted anywhere else.

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CERTIFICATE

*Certified that the thesis entitled “**Determination of the Optimum Position of Shear Wall in a Multistory Building with Reinterant Corner**” is being submitted by **Mr. Rishabh Srivastava (Roll No. 1801431014)** in partial fulfillment of the requirements for the award of Degree of Master of Technology (Structures) of the Integral University, Lucknow, is a record of candidate’s own work carried out by him under my guidance and supervision.*

The results presented in the thesis have not been submitted to any other university or institute for the award of any other Degree or Diploma.

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Abstract

The thesis is based on a comparative study of configuration of shear walls for buildings irregular in plan. With the increase in demand of high rise buildings, the concern for safety also increases. High Rise Buildings are vulnerable against lateral forces like wind load and seismic loads. To ensure safety against these factors, many tools are applied in the structure.

Shear Wall is a vertical planer structural element which is used in structures to induce lateral stiffness. The effectiveness of shear wall is based on its location in building. Specially in building where there is inborn eccentricity, location of shear wall becomes very important. This gives birth to optimum location or optimum configuration of shear wall in building.

In this thesis, we have studied various configuration of shear wall in a building with irregular plan (L shape). For the study, we have considered ten test models, out of which one model is not having shear wall. This model is called bare frame. From the bare frame model other nine test models with shear wall is compared in order to define the optimum location of shear wall for L shaped building.

Dynamic Analysis is done for the comparative study of the models. We have used standard software package of CSI ETABS ver. 16.0.0 for the modeling and analysis of the structure. Under dynamic analysis, we have limited ourselves to Response Spectrum Analysis and Time History Analysis. Both of these analyses are done under elastic limit. For Response Spectrum Method, we have considered the graph for Seismic Zone V with medium soil for a damping ration of 5% and importance factor as '1'. The Response Spectrum Analysis is done as per IS 1893 (Part-1):2016 by using CSI ETABS ver. 16.0.0. For Time History Analysis, we have used the time history data of Array Recording Station, El Centro, USA. The data is under the software package.

We have determined the optimum configuration of shear wall in 'L' shaped building, on various ground of comparison which is defined in the thesis.

Chapter-1

Introduction

1.1 Shear Wall in a RCC framed building-



Fig. 1.1 Shear Wall in building (Source: www.theconstructor.org)

High rise buildings have become the symbol of urbanization. The trend of construction of high rise building is increasing rapidly. The reasons which are responsible for this trend are scarcity of land, increase in population. This causes high cost of land in urban areas. So we realize now today and in future land is composed of tall buildings more than trees. As we know our world is affected by natural disasters like earthquakes due to seismic activities inside earth. Earthquake is one of the nature's greatest hazards to properties and human lives. It poses a unique engineering design problem. An intense earthquake constitutes severe loading to which most civil engineering structures may possibly be subjected. The number of earthquakes reported worldwide, are usually followed by enormous death and injury. Not only life but also economy that are threatened from this disaster. The approach of engineering design is to design the structures in such a way that it can survive under the most severe earthquakes, during their service lives to minimize the loss of life and the possibility of damage. Such disasters affect tall

building most, this compel structural engineers to design buildings which should have sufficient resistant to lateral load.

An introduction of shear wall represents a structurally efficient solution to stiffen a building structural system because the main function of a shear wall is to increase the rigidity for lateral load resistance. In modern tall buildings, shear walls are commonly used as a vertical structural element for resisting the lateral loads that may be induced by the effect of wind and earthquakes

Buildings with shear wall and moment frames are best suited for the lateral load resistant; such systems are called dual systems. The dual system with moment frame to resist lateral load in longitudinal direction and shear wall contribute to the resistance of overturning moments, story shear forces and story torsion in lateral direction. The term "shear wall" is rather misleading as such a wall behave like flexural members. They are usually used in tall buildings and have been found to be of immense use to avoid total collapse of buildings under seismic forces. It is always advisable to incorporate them in buildings built in region likely to experienced earthquake of large intensity or high winds. The design of these shear wall for wind are design as simple concrete walls. The design of these walls for seismic forces requires special considerations as they should be safe under repeated loads. Shear walls may become imperative from the point of view of economy and control of lateral deflection. Parameters like story torsion, base shear, story shear forces, overturning moments depends upon its geometric configuration, orientation & location within the building Therefore, the arrangement of shear wall in the building with dual structural system is essential in order to have building with good resistance of lateral loads.

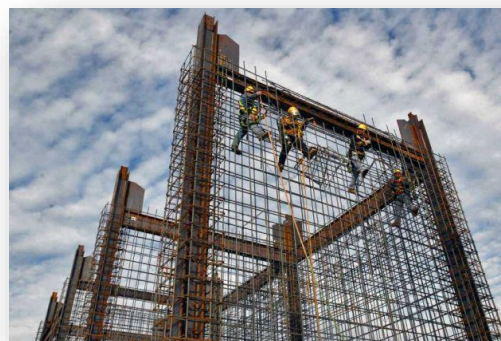


Fig 1.2 Reinforcement cage for a shear wall (Source: www.researchgate.in)

The structural wall parallel to lateral forces and subjected to in plane (shear) forces and bending are called shear walls. They are mainly flexural members and usually provided in high rise buildings to avoid the total collapse of the high rise buildings under seismic forces. When building is designed without shear wall, beam and column sizes are quite heavy and there is problem arises at these joint and it is congested to place and vibrate concrete at these places and displacement is quite heavy which induces heavy forces in building member. Shear wall may become essential from the point of view of economy and control of horizontal displacement.

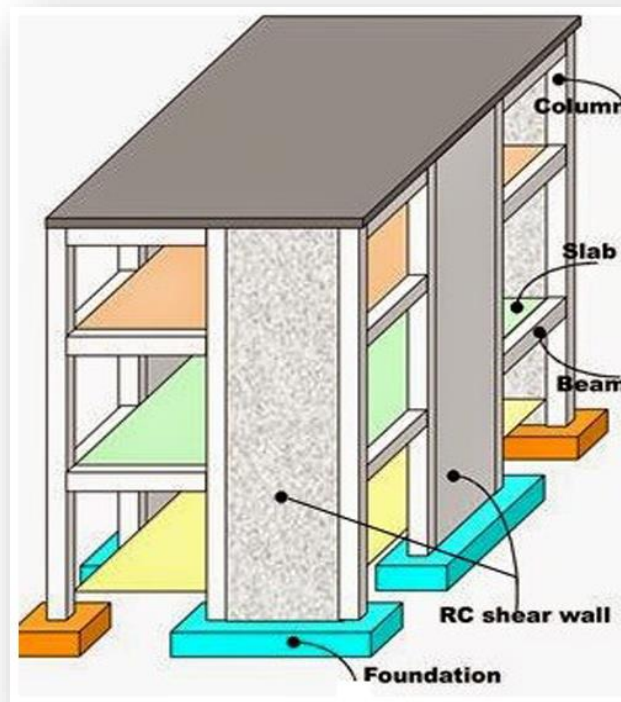


Fig. 1.3 Different geometry of shear wall (Source: www.civisnapshots.com)

1.2 FUNCTION OF SHEAR WALL

Strength: Shear walls are more efficient in resisting lateral loads in multi storied buildings. Shear walls are made with steel, reinforced concrete are kept in major positions of multi storied buildings which are made in consideration of earthquake forces, wind forces. Shear wall must provide necessary lateral strength to resist horizontal earthquake. When shear wall are strong

enough, they will transfer these horizontal forces to the next element in the load path below them, such as other shear wall, floors, foundation walls, footings.

Stiffness: Shear wall also provide lateral stiffness to prevent the roof or floor above from excessive side - sway, when shear wall are stiff enough, they will prevent floor and roof framing member from moving off their support, also buildings that sufficiently stiff will usually suffer less non-structural damage.

1.3 IMPORTANCE

- Shear walls are especially important in high-rise buildings.
- In residential buildings, shear walls form an external box which provides all of the lateral support for the building.
- Resist : Lateral loads , Seismic loads , Vertical Forces (gravity)
- Reduces lateral sway of the building
- Provide large strength and stiffness to buildings in the direction of their orientation.
- Rigid vertical diaphragm transfers the loads into Foundations

1.4 APPLICATION

- Shear walls are not only designed to resist gravity / vertical loads but designed for lateral loads of earthquakes / wind.
- Walls are structurally integrated with roofs / floors (diaphragms)
- Other lateral walls running across at right angles, thereby giving the three dimensional stability for the building structures.
- Walls have to resist the uplift forces caused by the pull of the wind.
- Walls have to resist the shear forces that try to push the walls over.
- Walls have to resist the lateral force of the wind that push the walls in and pull them away from the building.
- Shear wall structural systems are more stable.
- When shear walls are stiff enough, they will prevent floor and roof framing members from moving off their supports.
- Also, buildings that are sufficiently stiff will usually suffer less non-structural damage.

1.6 FORCES ACTING

Shear walls resist two types of forces:

- Shear forces and uplift forces.
- Shear forces are generated in stationary buildings: By external forces like Wind and Waves.
- Uplift forces greater on tall short walls and less on low long walls.
- Equal length shear walls should be placed symmetrically.
- It can also provide in interior, if exterior wall can't provide sufficient strength and stiffness.

Chapter-2

Literature Review

- 1) **Mario De Stefano & Barbara Pintucchi (2007)** - The paper presents an overview of the progress in research regarding seismic response of plan and vertically irregular building structures. Three areas of research are surveyed. The first is the study of the effects of plan-irregularity by means of single-storey and multi-storey building models. The second area encompasses passive control as a strategy to mitigate torsional effects, by means of base isolation and other types of devices. Lastly, the third area concerns vertically irregular structures and setback buildings. Although, fewer papers have been published in this last area with respect to the former ones, this state of the art reports extensively on research efforts and progress into the seismic behavior of irregular buildings in elevation to show the growing interest among specialists in the field.

- 2) **Hee-San Chung, Byoung-Wook Moon¹, Sung-Kyung Lee¹, Ji-Hun Park And Kyung-Won Min (2009)** - Shear wall systems in high-rise apartments are governed by the flexural behavior of members such as a cantilever beam. The installation of the damper-brace system in a structure governed by flexural behavior is not suitable. Because of the relatively high lateral stiffness of the shear wall, a load is not concentrated on the brace and the brace cannot perform the role of a damping device. In this paper, a friction damper that applies the flexibility of a shear wall is proposed in order to reduce the deformation of the structure. To evaluate the performance of the proposed friction damper, a nonlinear time history analysis is executed by the seismo-struct analysis program, and a multiple vertical linear element model is used for simulating flexural behavior of the shear wall. It is found that the control performance of the proposed friction damper is superior to that of a coupled wall with a rigid beam. In conclusion, this study verified that the optimal control performance of the proposed friction damper is equal to 45% of the maximum shear force induced in the middle floor beam with the rigid beam.

- 3) **Bulent Erkmen & Arturo E. Schultzself (2009)** - Centering ability of unbonded post-tensioned precast concrete shear walls has been attributed to the presence of post tensioning

force. However, the experimental results presented in this paper indicate that the post-tensioning force may completely die out during cyclic loading while the walls are able to retain their superior self-centering characteristic. Moreover, the analytical study presented in this article indicates that with proper configuration of end-anchorage for post-tensioned tendons, self centering of post-tensioned walls can be achieved even when the post-tensioning force vanishes. This study also investigates the effects of tendon layout, tendon end-anchorage configuration, and external vertical load on the self-centering ability of unbounded precast concrete shear walls subjected to earthquake loading.

- 4) **R.S. Malik, S.K. Madan, V.K. Sehgal (2011)**- In this paper, the use of shear wall which certain curtailment has been discussed. For the comparison, three buildings of height 10, 20, 30 are compared with curtailment at various heights. The results showed that, the curtailment posterior wall up to 50% height of the building as a marginal effect on distribution of horizontal story shear wall frames and interior frames. But the height of the building a significant role in storage share distribution.

- 5) **Romy Mohan & C Prabha (2011)** - As the world move towards the implementation of Performance Based Engineering philosophies in seismic design of Civil Engineering structures, new seismic design provisions require Structural Engineers to perform both linear and nonlinear analyses for the design of structures. While Linear Equivalent Static Analysis is performed for regular buildings up to 90m height in zone I and II, Dynamic Analysis should be performed for regular and irregular buildings in zone IV and V. Dynamic Analysis can take the form of a full nonlinear dynamic Time History Analysis or of a linear Response Spectrum Analysis. In present work, two multi storey buildings, one of six and other of eleven storeys have been modeled using software package SAP 2000 version 12 for earthquake zone V in India. Six different types of shear walls with its variation in shape are considered for studying their effectiveness in resisting lateral forces. The paper also deals with the effect of the variation of the building height on the structural response of the shear wall. Dynamic responses under prominent earthquake, El-Centro have been investigated. This paper highlights the accuracy and exactness of Time History analysis in comparison

with the most commonly adopted Response Spectrum Analysis and Equivalent Static Analysis.

- 6) **P. S. Kumbhare & A. C. Saoji (2012)** - Shear wall is one of the most commonly used lateral load resisting in high rise building. Shear wall has high in plane stiffness and strength which can be used to simultaneously resist large horizontal load and support gravity load. The scope of present work is to study the effect of seismic loading on placement of shear wall in medium rise building at different alternative location. The residential medium rise building is analyzed for earthquake force by considering two type of structural system i.e. Frame system and Dual system. Effectiveness of shear wall has been studied with the help of four different models. Model one is bare frame structural system and other four models are dual type structural system. Analysis is carried out by using standard package ETAB. The comparison of these models for different parameters like Shear force, Bending Moment, Displacement, Storey Drift and Story Shear has been presented by replacing column with shear wall.

- 7) **Ashish S. Agrawal & S. D. Charkha (2012)** - RC multi-storey buildings are adequate for resisting both the vertical and horizontal load. When such building is designed without shear wall , beam and column sizes are quite heavy and there is lot of congestion at these joint and it is difficult to place and vibrate concrete at these places and displacement is quite heavy which induces heavy forces in member. Shear wall may become imperative from the point of view of economy and control of lateral deflection. In RC multi-storey building lift well or shear wall are usual requirement. Centre of mass and stiffness of the building is ideal for a structure. However, on many occasions the design has to be based on the off centre position of lift and stair case wall with respect to centre of mass which results into an excessive forces in most of the structural members, unwanted torsional moment and deflection. Incorporation of shear wall has become inevitable in multi-storey building to resist lateral forces .It is very necessary to determine effective, efficient and ideal location of shear wall. In this paper, study of 25 storeys building in zone V is presented with some preliminary investigation which is analyzed by changing various position of shear wall with different shapes for determining parameters like storey drift, axial load and displacement. This analysis is done by using standard package ETAB.

- 8) **Wakchaure M.R, Ped S. P (2012)**- In this paper the effects of masonry infill panels on the response of RC frame structures is been presented. Infill behaves like compression strut between column and beam and compression forces are transferred from one node to another. For the analysis of G+ 9 RCC framed building is modelled. The analysis is done in ETABS. The comparison of base share, story drift, story displacement is done. the result show that infill was reduced displacement, time period and increases base shear.
- 9) **Ehsan Salimi Firozabad, Dr. K. Rama Mohan Rao, Bahadir Baheri (2012)**- In this paper, comparative study of buildings which shear wall under seismic loading is done. the comparison of dynamic behaviour of the building is carried out in the software package like SAP 2000. The buildings have a certain configuration of the shear wall and the comparison was done to obtain the optimum configuration shear wall in the multi storey building.
- 10) **P.P. Chandurkar, Dr. P.S. Pajgade (2013)**- In this paper, a comparative study is been done with for buildings with and without shear walls. This was a regular building which certain positions of share wall and the analysis of various responses were carried out for determining the optimum position of shear in the regular building. The software package was ETABS for analysis and comparison.
- 11) **Varsha R. Harne (2014)** - Shear wall systems are one of the most commonly used lateral load resisting systems in high-rise buildings. Shear walls have very high in plane stiffness and strength, which can be used to simultaneously resist large horizontal loads and support gravity loads, making them quite advantageous in many structural engineering applications. There are lots of literatures available to design and analyze the shear wall. However, the decision about the location of shear wall in multistory building is not much discussed in any literatures. In this paper, therefore, main focus is to determine the solution for shear wall location in multistory building. A RCC building of six storey placed in NAGPUR subjected to earthquake loading in zone-II is considered. An earthquake load is calculated by seismic coefficient method using IS 1893 (PART-I):2002. These analyses were performed using STAAD Pro. A study has been carried out to determine the strength of RC shear wall of a

multistoried building by changing shear wall location. Three different cases of shear wall position for a 6 storey building have been analyzed. Incorporation of shear.

- 12) **G.S. Hiremath, Md. Saddam Hussain (2014)** – They carried out a study and observed that optimum location of shear wall having uniform thickness throughout the building and to study the performance of the building with shear wall having varying thickness at certain levels of building for different locations. It is concluded that the displacement is of interest with regard to structural stability, strength and human comfort. Displacement is lowest in bottom stories, very high at upper stories.
- 13) **J.V. Sunil Ganesh, Mallikarjun S. Bhadiwad (2014)** - In this paper, the authors have discussed the significance of shear wall in a building. Shear wall acts as a major earthquake resisting member and simultaneously resists the gravity loads. In this study a 20 story a regular building in zone 5 is presented. In which same shear wall with same cross section area is considered which is analysed by changing the various locations to find the optimum position of shear wall. The parameters like story drift, story displacement, spectral acceleration, etc are compared. The use of standard FM softwares like ETABS has been done for the comparison.
- 14) **M.S. Ainawala, Dr. P.S. Pajgade (2014)**- In this paper, a comparative study is been then for analysing the seismic effect on multi storey buildings in seismic zone 2 3 4 and 5 with and without shear walls. ETABS was used as the software for analysis of the buildings. It was found that building with shear wall is more economical than the buildings without it.
- 15) **Mohamed A. Danish, Ahmet Tuken, Nadeem A. Siddiqui (2014)**- In this paper, a parametric study of shear wall in a building is done. For the study, shear walls of various thickness are considered, analysed and compared. The building was having a dual system and also various positions of shear wall. This always being compared and optimum position and thickness were decided.
- 16) **K. L. Lovaraju & K. V.G. D Balaji (2015)** - In this paper the focus is to identify effective location of shear wall in multi storey building. An earthquake load is applied to a building of

eight storey is located in zone-2, zone-3, zone-4, and zone-5 with different location of shear wall as per code provision IS 1893-2002. The analysis has been carried out using ETABS software. It was concluded that provision of shear wall influences the seismic performance of the structure with reference to strength and lateral displacement. Shear wall in position-3 performs better with reference to lateral displacement and it reduces 26.7% when compared to the frame without shear wall. The provision of shear wall position and appropriate location is advantageous and the structure performs better for an existing and new structure.

17) **M. R. Suresh, Ananth Shayana Yadav (2015)**. In this paper the main aim is to find the effective, efficient and optimum location of shear wall in high rise irregular R.C. building. Optimum location of shear wall has been investigated with the help of three different models (+20) storey R.C. buildings in zone 2 and zone5 are considered. It is concluded that the plan without shear wall gives more displacement and more drift compare to plan with shear wall along four edges providing shear wall along four edges is formed to be optimum position of shear wall.

18) **S K Hirde, N K Shelar (2015)** – In this paper, a G+6 story building is considered. The building is a regular shaped and comparison is made for the effective position of shear wall in building which is located at plain ground and at sloping ground. The paper clearly elaborates about the Dynamic Analysis of the building. The comparison was done for Base Shear, Torsion, Floor Displacement, etc. It was found that the base shear and torsion were increased at the sloping ground. For the analysis by Response Spectrum Method, SAP 2000 was used.

19) **Gourav Sachdeva, Rajesh Jain, Rajeev Chandak (2015)** – In this paper, a G+5 storey building is considered for studying the effectiveness of position of shear wall in the building. STADD Pro was used as a software package for the calculation of following – Reinforcement percentage, Storey Drift, Maximum Shear Force and Bending Moment, etc. The shear wall configuration which most effective was the one which distributed both the mass and stiffness in a uniform manner. This was compared by the results of the analysis.

- 20) **S Sangeetha, G C Shivanand (2016)** - In this paper, an attempt is made to study the dynamic behavior of the structure with vertical irregularity i.e. soft story effect. To eliminate the soft stories, masonry infill walls are used and also been tried to investigate the behavior of this system by considering the wall opening in the infill masonry unit. The paper deals with analytical study of the Stiffness Irregularity. For the analysis, a G+34 storey building is considered for the analysis purpose. Dynamic Analysis is carried out by Response Spectrum Method by using ETABS version 15.2. It was found that, the model with open ground floor is having more displacement as compared the soft stories placed at other levels. Thus, the failure of open ground floor buildings is more during earth's shaking.
- 21) **D Vivek Varam, C.H. Vinodh Kumar, K V Vijaya Kumarraju (2017)** - In this paper, a G+10 storey building is considered and determination of suitable position of shear wall is carried out by checking parameters like – nodal displacement, base shear, steel quantities, etc. The paper also describes about the cause of earthquake and apart from that, it clearly explains the Response Spectrum Method in analysis of building subjected to seismic loads.
- 22) **Abhija Mohan, Arathi S (2017)** – In this paper, a comparison is carried out for determining the effectiveness of shear wall with vertical and staggered opening. For this, both regular and irregular shaped buildings are considered. The effectiveness is defined from analyzing the results of base shear and storey displacement from various configurations of the shear wall. It was found that shear wall with staggered opening was more effective as compared to the walls with vertical opening.
- 23) **Poornima D, Sanjay S J, Yajnodbhavi H M (2017)** – This paper explains about various lateral load resisting systems as per Indian Standards. An L-Shaped Buildings is considered for comparison with a regular building. Various configuration of shear wall is considered for both regular and irregular shaped buildings and best configuration is defined by storey drift, storey displacement and base shear.
- 24) **Lakshmi K O, Prof. Jayasree Ramanujan, Mrs. Bindu Sunil, Dr. Laju Kottallil, Prof. Mercy Josphe Poweth (2017)** – This is a well described paper which deals with the determination of behavior of a building with respect to the position of shear wall. In this

paper, the authors have described the following topics - seismic resistant of buildings, equivalent static method, non linear pushover analysis, capacity – demand curve, methods of dynamic analysis. Eight models of multi-storey buildings are considered with various configurations of shear wall. These models are checked for the following behaviors – Storey Drift, Base Shear, Lateral Displacement, Reinforcement Demands in Columns, Plastic Hinge Locations. On a conclude note, it was found that the steel requirement was reduced to 44.6% when shear wall is provided at the core and 34.7% when shear wall is provided at the corner of the structure. Apart from that, it was also found that Push-Over Analysis provides an insight into the performance of the structure in post elastic range which thereby helps in assessing the weakness and possible failure mechanism of structure which is not possible when using equivalent static and response spectrum method of analysis.

25) **Mahdi Hosseini, N.V. Ramana Rao (2017)** – In this paper, the authors have represented the results of dynamic analysis of C shaped shear wall at the centre of the building. They have beautifully represented the comparison of the test models at the three soil conditions i.e. soft, medium and stiff.

26) **Ozem Cavdar, Ahmet Cavdar and Ender Bayraktar (2018)** – In this paper, performance based structural design is used to determine the expected performance level of structures under earthquake effect. In performance based design, it is expected that more than one damage level can emerge under one earthquake effect. In this study, the seismic behavior of shear wall building that collapsed during the 2003 Bingol Earthquake was investigated by non linear static and dynamic analysis. The performance goals of reinforced concrete shear wall were evaluated by applying Pushover Analysis. In the study, the building which is considered wall collapsed in the earthquake and the analysis was done as per Turkish Code. From the analysis, it was that the buildings was far from satisfying the performance level and apart from that, the results of pushover analysis show lower damage ration of upper storey beams than those from non linear dynamic analysis.

27) **Rama Krishna Kolli, Lingeshwaran Nagarathinam (2019)** – In this paper, the authors discusses the points like load vs. deflection curve, crack pattern, mode of failure of shear

wall. They have casted three model specimens and have beautifully represented the comparison.

28) **Richa Gupta, Alifa Bano (2019)** - In this paper, the authors have tested various shapes of shear walls in various test models. The models are having different story heights and shapes. The analysis is done by Response Spectrum Analysis.

29) **Ravikanth Chitraprolu, Ramchandra Pradeep Kumar** - In this paper, the usefulness of shear walls in structural planning of multi storey buildings is discussed. When wall are situated in advantages positions in a building, they can be very efficient in resisting lateral loads originating from wind or earthquakes. Reinforced concrete frame buildings adequate for adjusting both vertical and horizontal loads acting on them. In this paper, a comparative study has been done between a building with shear wall and without share wall. From the result it is inferred that share was more resistant to lateral loads in an irregular structure.

30) **O. Esmaili, S. Epakachi, M. Samdzad and S. R. Mirghaderi** – In this paper, structural aspect of a tall building of 56 stories located in high seismic zone is performed. The plan of the buildings is Y in shape. The use of coupled shear wall is also there along with main shear wall. The purpose of the paper is to study the behavior of the building in an earthquake and also to determine the factors which control the design of the earthquake resistant building. It was concluded that, the designer should consider the presence of time dependent effects because structural elements with different longitudinal stiffness makes the tower to be more sensitive to different displacements due to concrete time dependency. A level of ductility for seismic bracing system conceptually should be provide for energy absorption but at the same time axial loads have an adverse effect on their acceptable performance and this fact should be considered exactly.

Inference - After going through the above literatures, it is found that position of shear wall plays an important role in defining the behavior of building against lateral loads. To be more specific, the secret lies in the distribution of stiffness and mass of the structure which is governed by the location of shear wall. Thus, the entire optimum configuration which was obtained in the above papers was providing the best distribution of stiffness and mass. If this is done, the various

consequences like storey drift, displacement, base shear, etc. can be controlled at a greater extent.

Conclusion – After reading the above research paper related to our topic, it is found that lot of work is done in determining the position of shear wall in regular buildings. But, the input data or the test models for the comparison are very less and the calculations are very simple. In this manner, we are far away from the real challenges. In order to find the optimum position of shear wall, sufficient input data is required in form of test models. Apart from that, the surrounding condition should also be varied to obtain a relevant result. Thus, it is concluded that, optimum location of shear wall in such buildings can be more precisely determined by considering more no. of combination of configuration and surrounding data.

Chapter-3

Identification of Thesis Topic

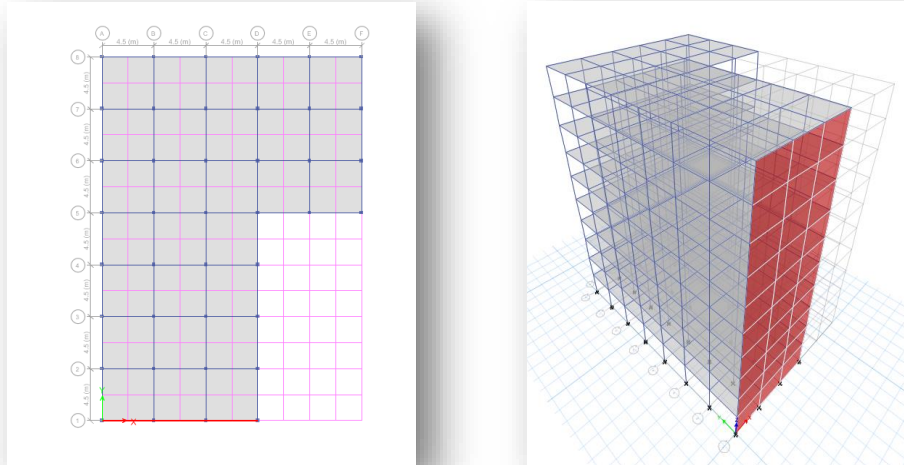


Fig. 3.1 Irregularity in Geometry (Image Caption from ETABS)

From the previous sections in this article, we have seen the importance of shear wall in the multi-storey building. The position of shear wall has dominance in defining the lateral stiffness of the building. We have also observed that, the lateral deformation reduces to about 26.7% (**ref. K. L. Lovaraju & K.V.G.D Balaji (2015)**) only due to the positioning of shear wall.

But, majority of studies is done for the buildings which have no irregularities and the input data for comparative analysis is also very less. Irregularities cannot be skipped in practical circumstances. This will give a better approach for construction when practical circumstances are considered.

I will determine the optimum location of shear wall in a multistory building with reinterant corner.

Chapter-4

Objective and Scope of Work

Objective –

The determination of optimum location of shear wall will consist of following objectives -

- 1) To study the comparison of storey drift and storey displacement of bare frame models and other test models due to application of extreme response as per Response Spectrum Method.
- 2) To study the comparison of Storey Shear of bare frame model and other test models due to application of extreme response as per Response Spectrum Method.
- 3) To study the comparison of Base Force, Joint Displacement of bare frame model and other test models due to application of extreme response as per Time History Method.
- 4) To study the torsional forces due to eccentricity between centre of mass and centre of stiffness

Scope -

In order to maintain the simplicity in complex calculation of dynamic analysis of test models and also in order to determine the optimum location, we need to set some boundaries in the study in order to obtain some relevant results –

- 1) The study of test models will be carried out by considering an Importance Factor of '1' i.e. as per IS 1893:2016 (Table – 6).
- 2) The study is to be done for seismic zone – V for Response Spectrum Analysis.
- 3) The study of the models will be such that, the loading will be similar throughout the models.

Chapter-5

Prerequisite Knowledge

5.1 Irregularities of a building- Many buildings in the present scenario have irregular configurations both in plan and elevation. This in future may subject to devastating earthquakes. In case, it is necessary to identify the performance of the structures to withstand against disaster for both new and existing one. Structures experience lateral deflections under earthquake loads. Magnitude of these lateral deflections is related to many variables such as structural system, mass of the structure and mechanical properties of the structural materials. Reinforced concrete multi-storied buildings are very complex to model as structural systems for analysis. The current version of the IS: 1893 (part I) -2002 requires that practically all multistoried buildings be analyzed as three-dimensional systems. This is due to the irregularities in plan or elevation or in both. The paper discusses the performance evaluation of RC (Reinforced Concrete) Buildings with irregularity. Structural irregularities are important factors which decrease the seismic performance of the structures.

5.1.2 Types of irregularities-

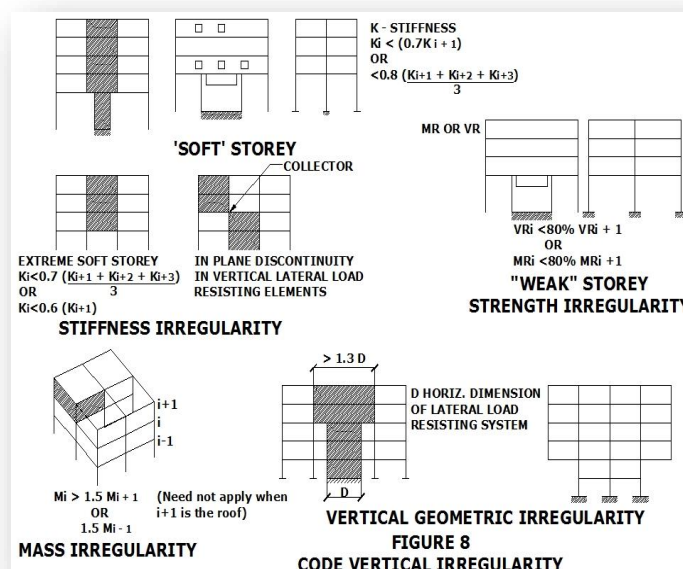


Fig. 5.1 Vertical Irregularities (Source: www.smadaconsultants.com)

A. Vertical Irregularity- It is in the direction of the gravity.

1) **Stiffness irregularity-**

a. Soft Storey: A soft storey is one, in which the lateral stiffness is less than 70% of that in the storey above or less than 80% of the average lateral stiffness of the three storeys above it.

b. Extreme Soft Storey: An extreme soft storey is one, in which the lateral stiffness is less than 60% of that in the storey above or less than 70% of the average stiffness of the three storeys above it. E.g. – Buildings on stilts.

2) **Mass irregularity-** They are considered to exist where the effective mass of any storey is more than 150% of the effective mass of the adjacent storey.

3) **Vertical Geometric irregularity-** When the horizontal dimension of the lateral force resisting system in any storey is more than 150% of that in an adjacent storey

4) **Discontinuity in capacity (Weak Storey)-** A weak storey is one in which, the storey lateral strength is less than 80% of that in the storey above, the storey lateral strength is the total strength of all seismic force resisting elements sharing the storey shear in the considered direction.

5) **In-Plane Discontinuity in vertical elements resisting lateral forces** – An in plane offset of the lateral force resisting elements greater than the length of those elements.

B. Plan Irregularities-

1) **Torsional Irregularity-** It exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis more than 1.2 times the average of the storey drifts at the two ends of the structure.

2) **Re-entrant Corners** – Plan configuration of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond the re-entrant corner are greater than 15% of its plan dimension in the given direction.

3) **Diaphragm Discontinuity** – Diaphragms with abrupt discontinuities or variations in stiffness, including those having cut-out or open areas greater than 50% of the gross enclosed diaphragm area or changes in effective diaphragm stiffness of more than 50percent from one storey to next.

- 4) **Out of plane offsets** – Discontinuities in lateral force resistance path, such as out of plane offsets of vertical elements
- 5) **Non-parallel systems** – The vertical elements resisting the lateral force are not parallel to or symmetric about the major orthogonal axes or the lateral force resisting elements.

5.2 Seismic Zones in India-

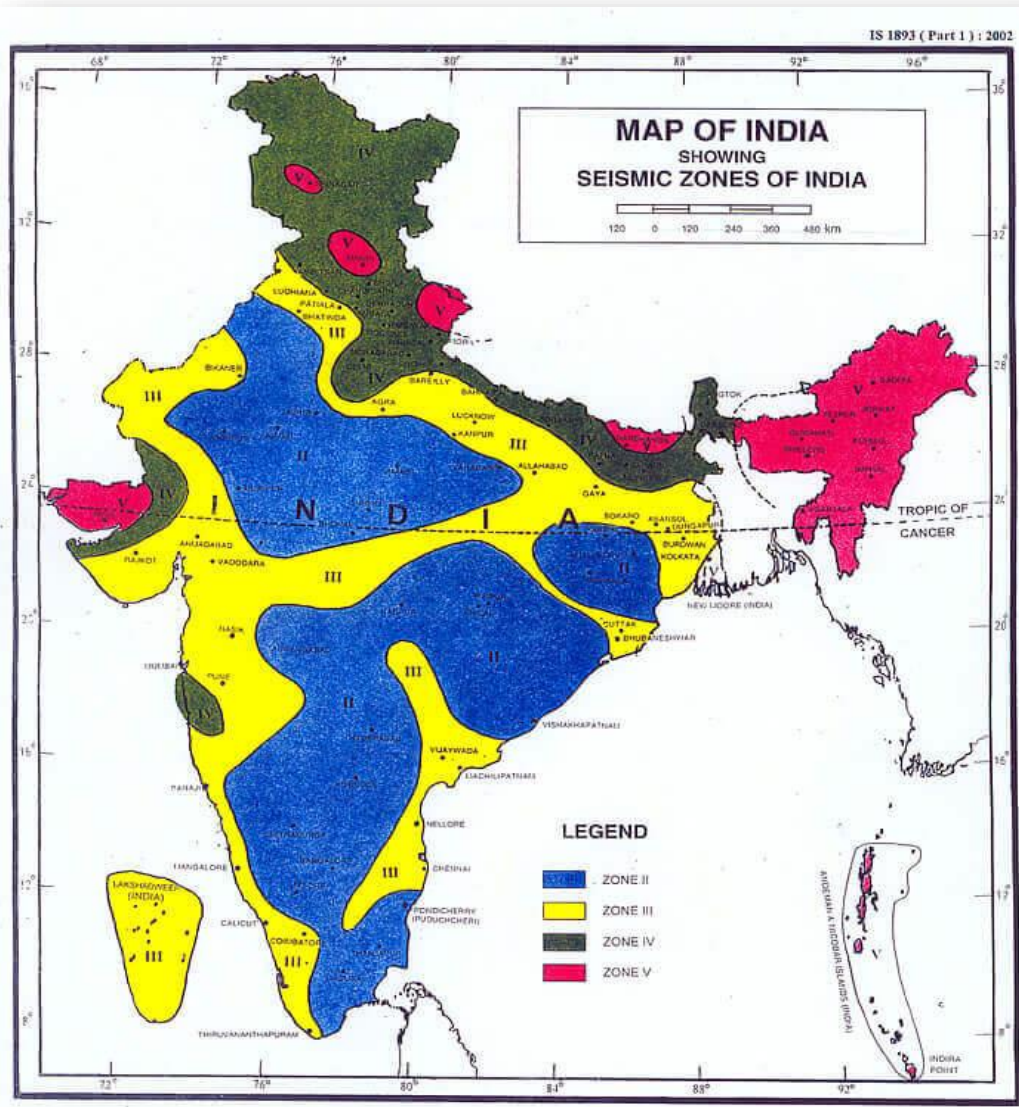


Fig. 5.2 Division of seismic zone in India as per IS 1893 (Part-1):2016

The Indian subcontinent has a history of devastating earthquakes. The major reason for the high frequency and intensity of the earthquakes is that the Indian plate is driving into Asia at a rate of approximately 47 mm/year. Geographical statistics of India show that almost 54% of the land is vulnerable to earthquakes. A World Bank and United Nations report shows estimates that around 200 million city dwellers in India will be exposed to storms and earthquakes by 2050. The latest version of seismic zoning map of India given in the earthquake resistant design code of India [IS 1893 (Part 1) 2016] assigns four levels of seismicity for India in terms of zone factors. In other words, the earthquake zoning map of India divides India into 4 seismic zones (Zone 2, 3, 4 and 5) unlike its previous version, which consisted of five or six zones for the country. According to the present zoning map, Zone 5 expects the highest level of seismicity whereas Zone 2 is associated with the lowest level of seismicity.

Broadly, **Zone - V** comprises entire northeastern India, parts of Jammu and Kashmir, Himachal Pradesh, Uttaranchal, Rann of Kutch in Gujarat, part of North Bihar and Andaman & Nicobar Islands. **Zone - IV** covers remaining parts of Jammu and Kashmir and Himachal Pradesh, National Capital Territory (NCT) of Delhi, Sikkim, Northern Parts of Uttar Pradesh, Bihar and West Bengal, parts of Gujarat and small portions of Maharashtra near the west coast and Rajasthan. **Zone - III** comprises Kerala, Goa, Lakshadweep islands, remaining parts of Uttar Pradesh, Gujarat and West Bengal, Parts of Punjab, Rajasthan, Madhya Pradesh, Bihar, Jharkhand, Chhattisgarh, Maharashtra, Orissa, Andhra Pradesh, Tamil Nadu and Karnataka. **Zone - II** covers remaining parts of country.

5.3 Analysis & Design of structures – Each and every body undergoes stress and strain when subjected to a certain amount of pressure. This also happens in the building, and by analysis of these stresses and strains, the design of building is done. However, the analysis also goes on for the constructed building in order to check the behavior in the near future.

In the current scenario, various design philosophies suggest a conservative side of design i.e. the building is designed by considering the linear variation of forces. Although, the upcoming design philosophies allow the designers to move further into non-linear behavior

of the buildings. Switching to the non linear analysis gives us a better understanding of the behavior of the building in the extreme scenarios. Due, to advent of the latest design and analysis software, it has become easy to calculate the complex sums for the non linear behavior. Apart from that, the calculation for dynamic behavior is also getting easy.

When a building is subjected to lateral loads like seismic and wind forces, the analysis of the building is done under the following sections.

TABLE 1: Types of Analysis of Buildings subjected to lateral loads

ANALYSIS TYPE	LINEAR	NON-LINEAR
STATIC	STRENGTH BASED	STATIC PUSHOVER
DYNAMIC	RESPONSE SPECTRUM	TIME HISTORY

STATIC ANALYSIS

This analysis is used to define a set of forces acting on a building to stimulate an earthquake ground motion effect which is usually defined by a seismic design response spectrum.

- 1) **Strength based analysis** – In this analysis, the structural components are specified based on their elastic limits exceed the demand of loading conditions. This is static – linear in nature.

- 2) **Static-Pushover Analysis** – The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out upto failure, thus it enables determination of collapse load and ductility capacity. On a building frame, and plastic rotation is monitored, and lateral inelastic forces versus displacement response for the complete structure is analytically computed. This type of analysis enables weakness in the structure to be identified. The decision to retrofit can be taken in such studies.

DYNAMIC ANALYSIS

This analysis is used to analyze the dynamic definitions such as natural frequency, acceleration and damping behavior of the structure.

- 1) **Response-Spectrum** – In this analysis, maximum structural response is plotted as a function of structural period for a given time history record and a level of damping.
- 2) **Time-History Analysis** - In this analysis, the structural response is computed at a number of subsequent time instants. In other words, time histories of the structural response to a given input are obtained as a result.

5.4 Consideration of Torsional Effects –

An irregular shaped building is always subjected to torsional forces because of the fact that centre of mass and centre of rigidity do not coincide at a single point. This causes eccentricity and thus results in torsional forces. Thus placement of shear wall in building should be such that it should introduce more torsion in the buildings.

Centre of Mass - It is an assumed point in a building which has equal distribution of mass around itself in all direction. In other words, the point where the whole mass of the building is assumed to be concentrated is called centre of mass.

Centre of Stiffness/Rigidity - Like the centre of mass, centre of stiffness is also an assumed point in a building where only lateral forces will be action.

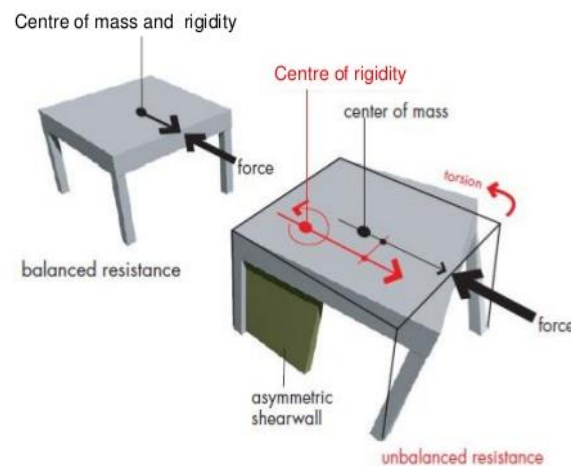


Fig. 5.3 Centre of Rigidity/Stiffness & Centre of Mass (Source: www.slideshare.net)

Thus, the consideration of torsional effects due to eccentricity between centre of mass and centre of rigidity should be of utmost importance.

5.5 Introduction to ETABS – Extended Three Dimensional Analysis of Building systems is engineering software widely used for design and analysis of multistory buildings. It is used to evaluate basic and advanced systems under static or dynamic conditions. For a refined assessment of seismic performance, modal and direct integration time-history analysis, may couple with p-delta and large displacement effects. The modeling of various regular and building is very easy in ETABS. The same is with the application various load patterns. Because of the user friendly interface, this is the choice of various consultancy firms around the globe.

Workflow of ETABS-

- Set up grid lines & storey levels
- Define section properties
- Draw structural objects.
- Assign properties.
- Define load patterns.
- Assign loads.
- Define load cases.
- Analyze the model.
- Check for results.
- Design model.
- Generate detailing document.
- Report generation.

Chapter-6

Methodology

The determination of optimum location of shear wall in an L-shaped building will be conducted on the basis of the following headings-

6.1 Preparation of test models in ETABS ver. 16 –

The proposed properties of the structural members of the test models are as follows-

TABLE 2: Details of test models

Sr. No.	ITEM	DESCRIPTION
01	BEAM	300 X 450 (in mm)
02	COLUMN	300 X 600 (in mm)
03	THICKNESS OF SHEAR WALL	230 mm
04	THICKNESS OF SLAB	150 mm
05	MASONARY	115 mm
06	NO OF STORIES	15
07	FLOOR TO FLOOR HIEGHT	3 m
08	MAXIMUM PANNELS OF SHEAR WALL	20

The modeling of the members like Beam, Column and Slab will be done as per the standard procedure by adopting following properties –

- 1) Beams, Column will be designed by M25 grade of concrete and Fe415 grade of steel.
- 2) The masonry wall will be having a standard density of 20kN/m^3 and will be considered as diaphragm in ETABS. The Diaphragm property in ETABS for masonry indicates that the masonry will not bear any load but it will only transfer its load to the other members.
- 3) The slab will be defined as thin shell in ETABS. This will ensure that the bending moments will be dominant compared to shear forces.

Modeling of Shear Wall –

Shear Wall can be modeled in two ways in ETABS, one way is to manually apply properties to the manually placed walls in the structure and the other way is select the shear wall properties from a given stack and apply them to manually placed wall. I have adopted the second method i.e. modeling the shear wall from the given wall stack. The materials of shear wall shear will be similar to other R.C.C. members.

6.2 Loading Pattern Details –

As the test models are generated in ETABS version 16. In order to model and analyze them, various methods can be used. But I have used a certain method in order to maintain simplicity in calculation. The following points will elaborate –

- 1) As the test models will undergo dynamic analysis (ref. section 4.3) for determination of optimum position of shear wall, similar loading patterns are used throughout the model, the following points will elaborate –
 - a. The live loads and dead loads will be similar in all the models as well at various levels in the structure.
 - b. The values of seismic zone, soil type, response reduction factor, time history record, importance factor, etc. will be similar throughout all the models.
- 2) As per the adopted method, the earthquake loads will be automatically generated by ETABS as per the configurations given in software. We have considered Indian Standard (i.e. IS 1893-2002) for automatically generating seismic loads. **Please note that ETABS will only consider this standard for Response Spectrum Analysis.**
- 3) The **Time History Method** will be carried out by adopting the most severe time history record (i.e. **Array Recording Station, El Centro, USA**) in the software package.

TABLE 3: Loading details of structural members

Sr. No.	LOAD PATTERN	DESCRIPTION	UNIT WEIGHT AS PER INDIAN STANDARD	CACLULATION	LOAD VALUE (in Pa)
01	DEAD	The loads are calculated as per IS : 875 (Part 1) – 1987			
		<p>a. Uniform Floor Load for 150 mm thick slab of M25 grade of concrete and Fe 415 of steel.</p> <p>b. Floor Finishing by Clay tiles</p>	<p>The unit wt. of reinforced concrete is 25 kN/mm³</p> <p>Ref. Page 30 of IS 875 (Part 1) - 1987</p>	<p>Thickness of Slab times the unit wt. of reinforced cement concrete (25 X .150)</p> <p>Refer the given load.</p>	<p>3.75</p> <p>0.2</p>
02	LIVE	The loads are calculated as per IS : 875 (Part 2) – 1987			
		a. Uniform Floor Load for commercial building.	Ref. Page 10 of IS 875 (Part 2) - 1987	Considered an average for the given set for Office Building in order to maintain simplicity in calculation.	3

TABLE 4: Loading details for Dynamic Analysis

Sr. No.	LOAD CASE	DESCRIPTION	REFERENCE
01	SEISMIC FOR RESPONSE SPECTRUM ANALYSIS	Generation by ETABS for zone – V for medium stiff and 5 % damping ratio of 5%.	ETABS consider Fig. 2 of IS 1893:2002 for Response Spectrum Analysis
02	SEISMIC FOR TIME HISTORY ANALYSIS	Generation by ETABS as Time History Record of Array Recording Station, El Centro, USA.	ETABS considers the recorded data of Array Recording Station which is of a certain earthquake. The data is a plot between ground acceleration vs. time at an interval of .01 sec.

6.3 Analysis of Model-

For the generated model, dynamic behavior of the building will be analyzed under linear and non linear extent. This will give the points of comparison for the optimum position of shear wall. The dynamic analysis will be carried out as per the given properties in the previous sections. The following points will indicate the other details to be considered while analysis –

- 1) For Response Spectrum Method, 30 modes will be considered at a time for analysis.
- 2) In order to obtain the extreme response from Response Spectrum Method, Complete Quadratic Combination Method (CQC) will be used.

The test models will be analyzed for obtaining the following results in form of graphs –

- 1) Plots for Base Shear, Storey Drift and Storey Displacement due to extreme response from Response Spectrum Curve.
- 2) Base Forces and Joint Displacement due to extreme Time History Record.

6.4 Determination of the optimum location-

After obtaining the plots for various cases as per 5.3, all the test models will be compared and the model with most effective response as compared to bare frame model will be considered as the model with best configuration of shear wall. Apart from that the model will also be tested for torsional effects on the basis of eccentricity in the building.

Chapter-7

Comparative Study

1. Layout of Test Models-

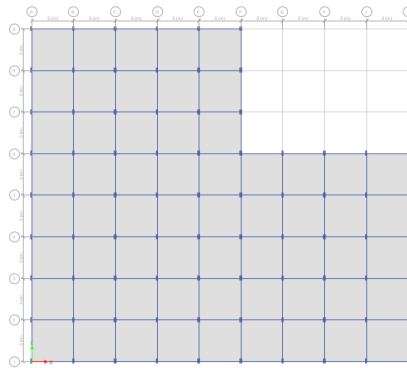


Fig. 7.1 Bare Frame Model

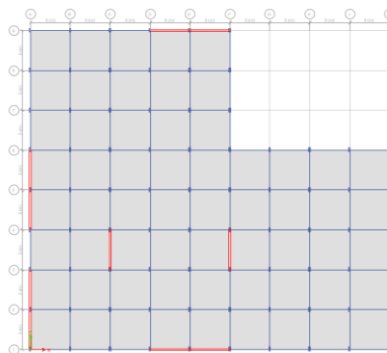


Fig. 7.2 MODEL 01

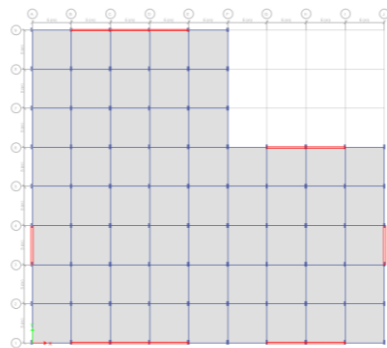


Fig. 7.3 MODEL 02

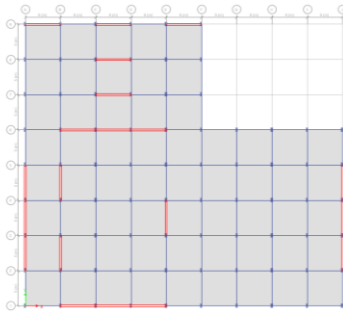


Fig. 7.4 MODEL 03

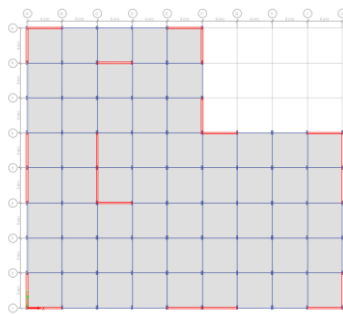


Fig. 7.5 MODEL 04

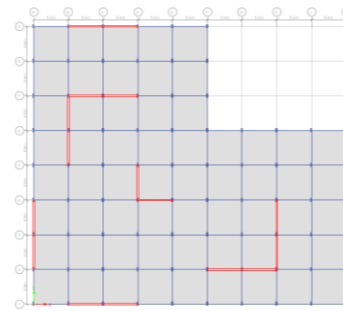


Fig. 7.6 MODEL 05

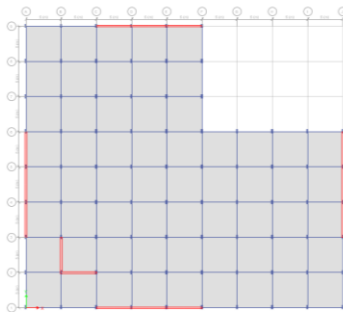


Fig. 7.7 MODEL 06

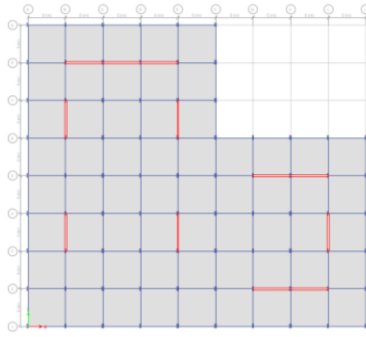


Fig. 7.8 MODEL 07

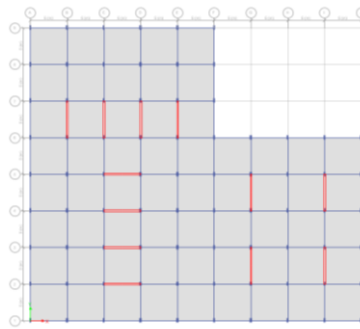


Fig. 7.9 MODEL 08

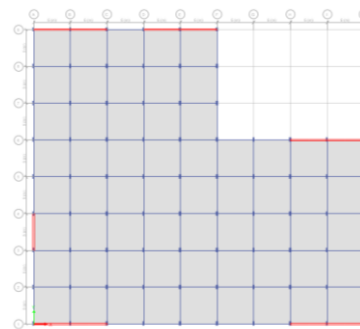


Fig. 7.10 MODEL 09

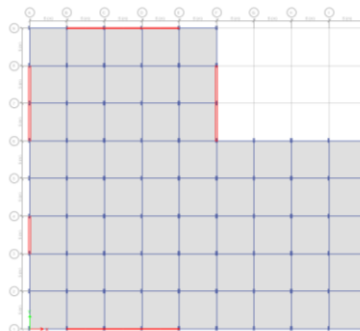


Fig. 7.11 MODEL 10

2. Result collection of test models

1) Storey Displacement by Linear Response Spectrum Method at ZONE V –

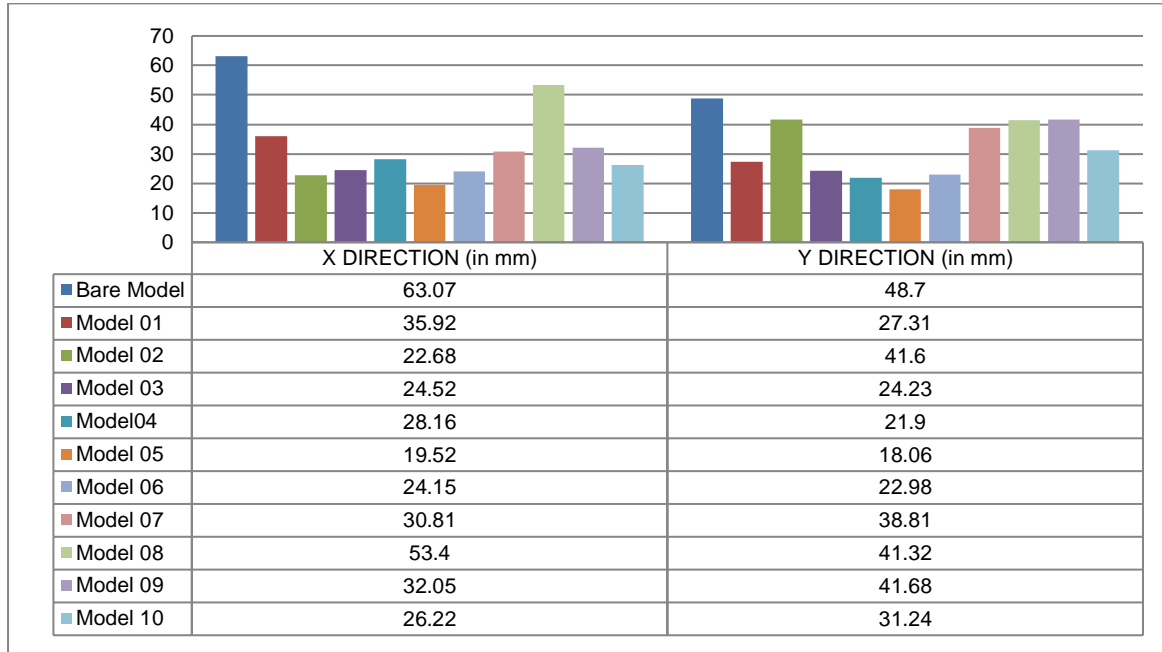


Fig. 7.12 Comparison of Storey Displacement from Response Spectrum Method

2) Storey Drift by Linear Response Spectrum Method at ZONE V –

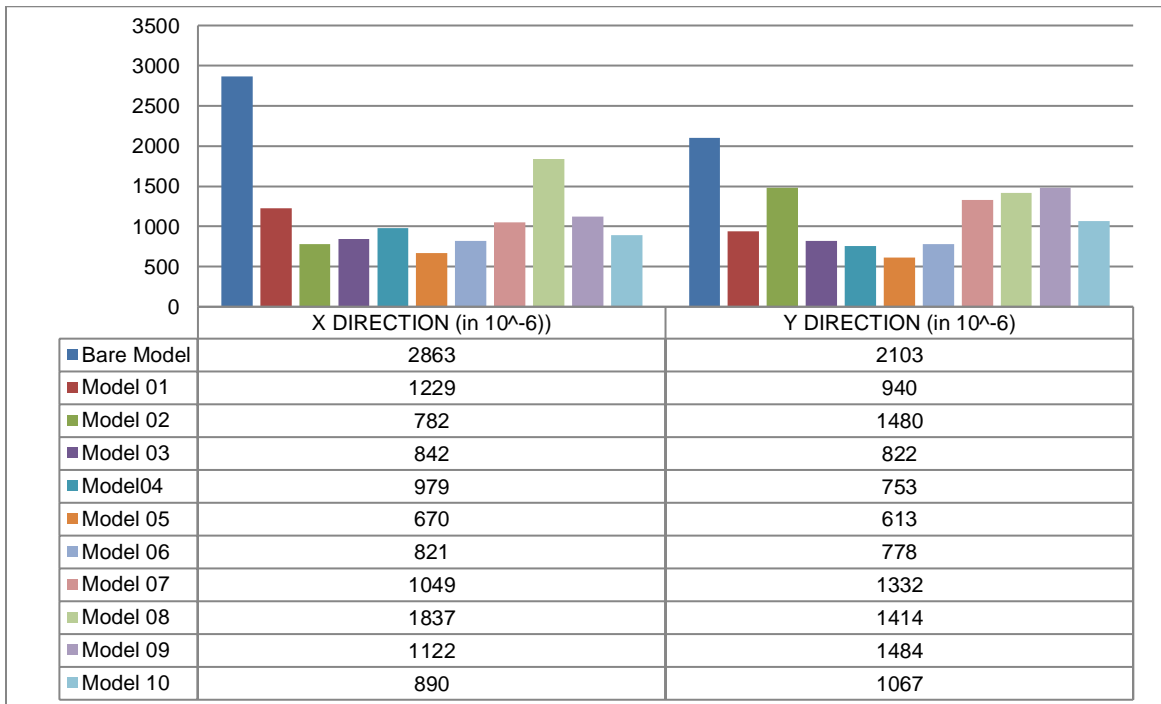


Fig. 7.13 Comparison of Storey Drift from Response Spectrum Method

3) Storey Shear by Linear Response Spectrum Method at ZONE V -

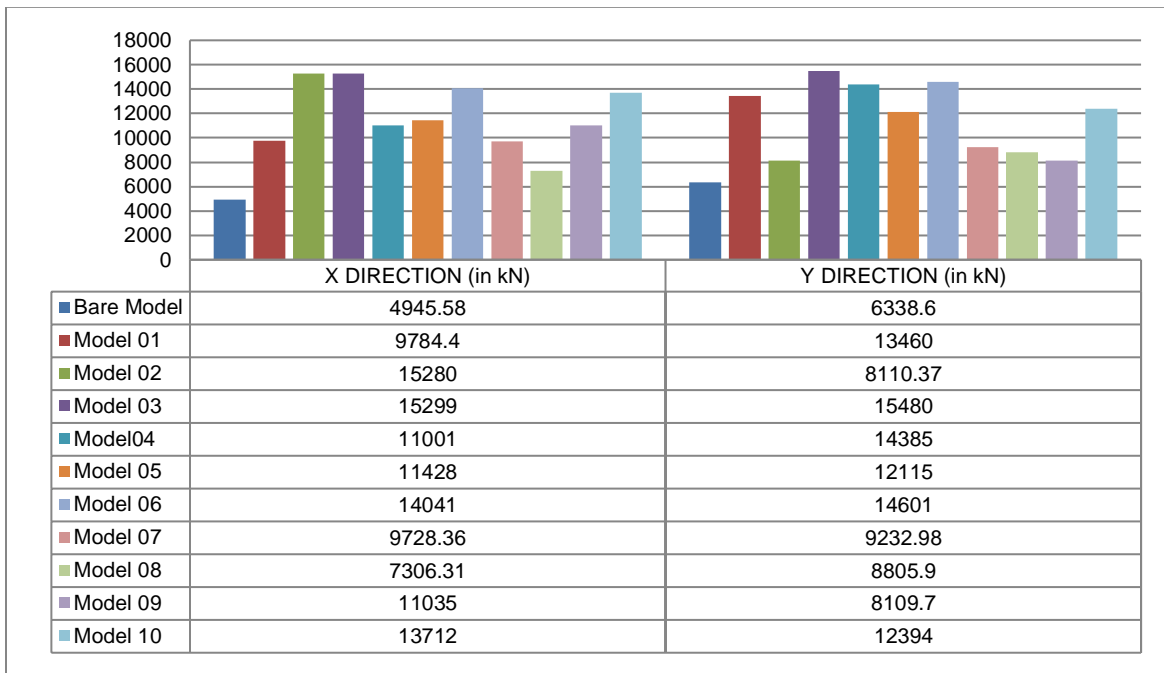


Fig. 7.14 Comparison of Storey Shear from Response Spectrum Method

4) Joint Displacement by Time History Record –

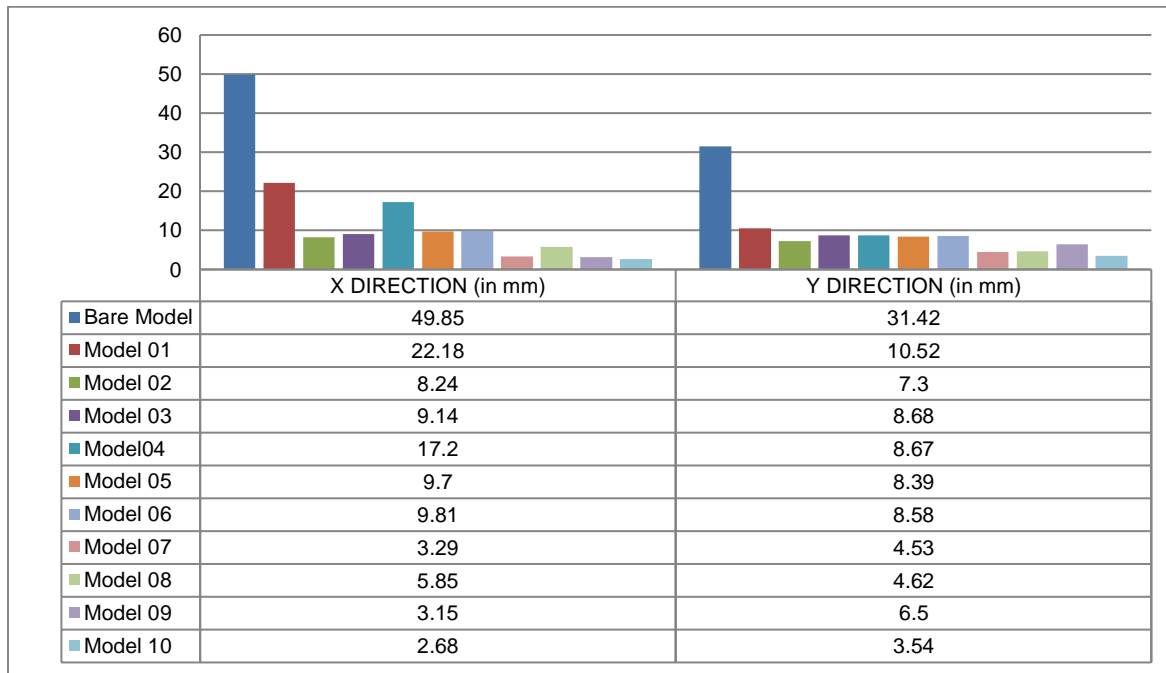


Fig. 7.15 Comparison of Joint Displacement by Time History Method

5) Base Force by Time History Record –

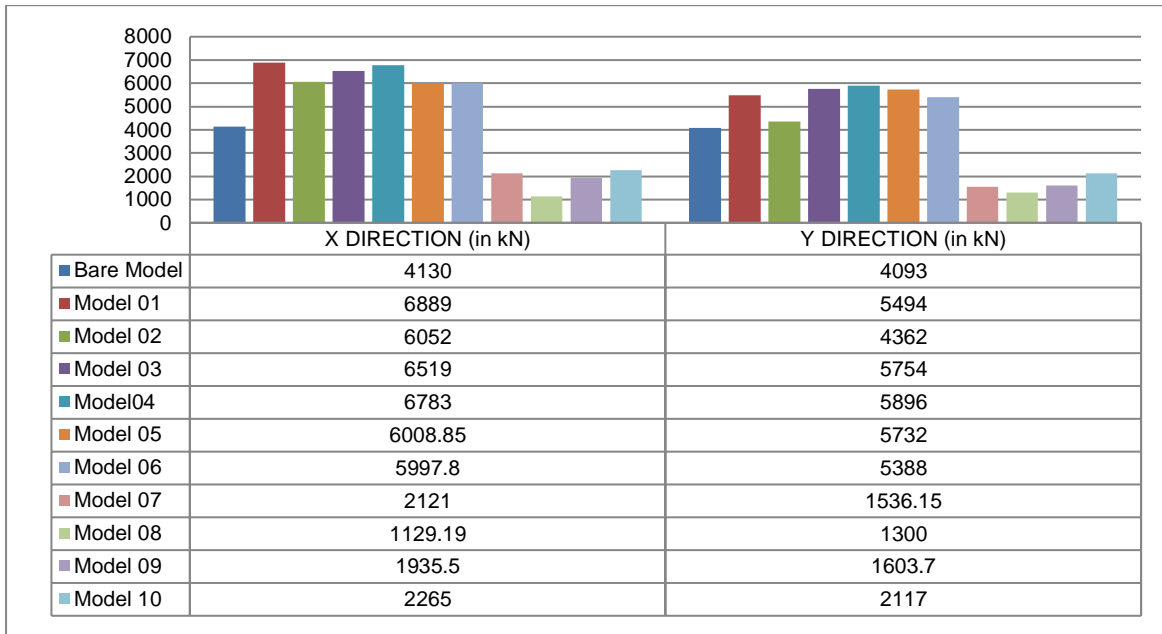


Fig. 7.16 Comparison of Base Force by Time History Method

6) Eccentricity between Centre of Mass and Centre of Rigidity –

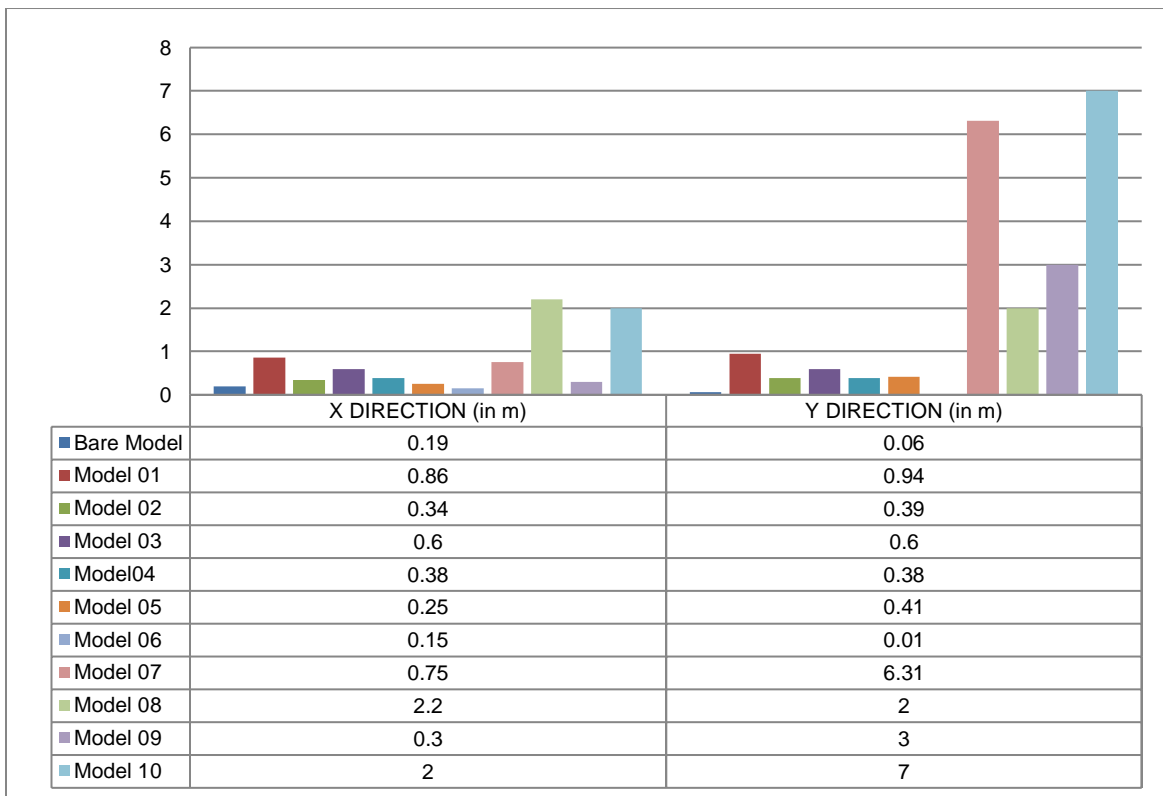


Fig. 7.17 Comparison of Eccentricity

Chapter-8

Result & Inference

From the comparative study of the tested models it was found that MODEL 06 was the model having optimum position of shear wall. The following bar graphs will elaborate the comparison –

1. Storey Displacement

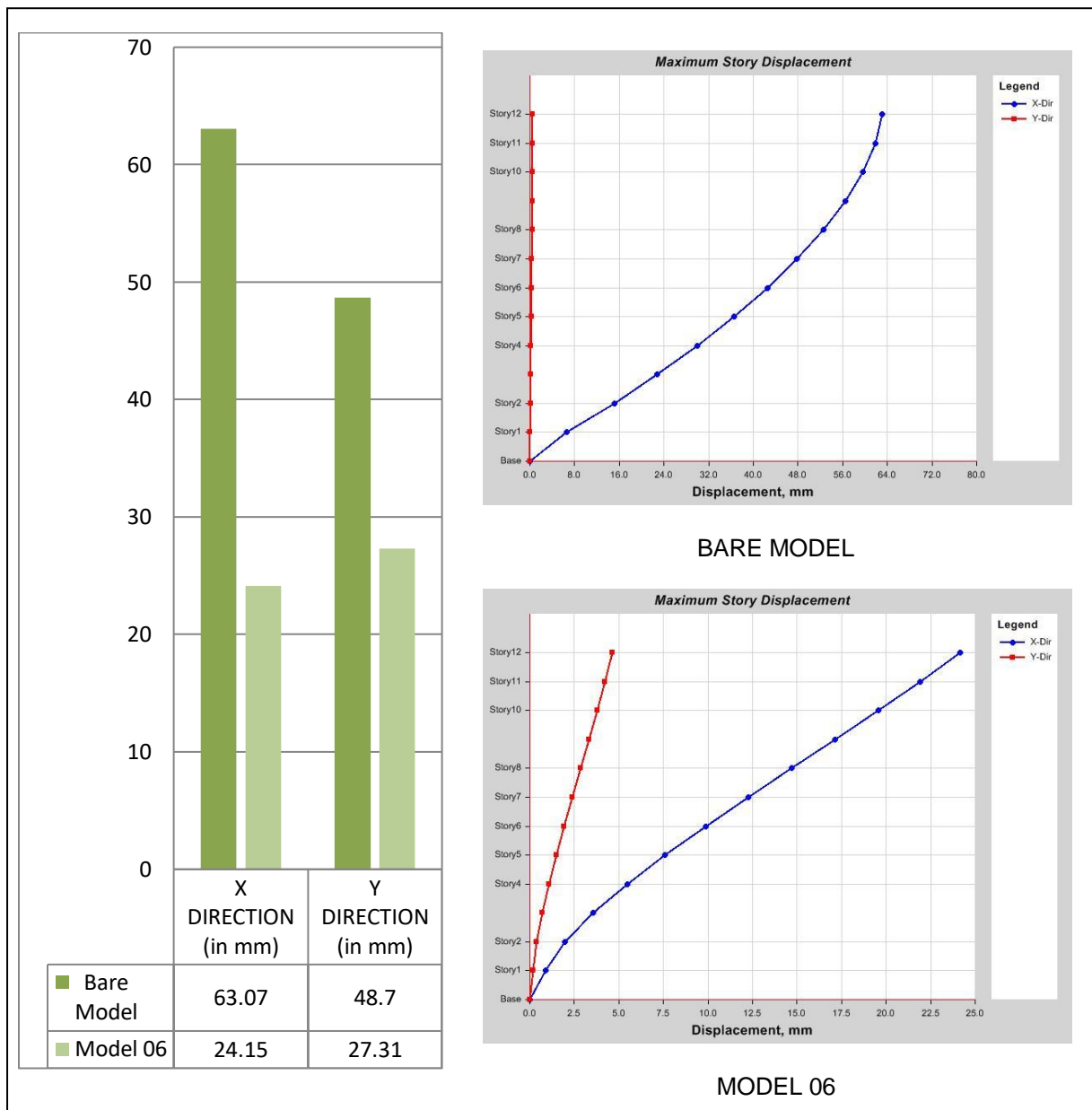


Fig. 8.1 Comparison of Storey Displacement

2. Storey Drift

Story Drift in a building is defined as the ratio of relative displacement between two adjacent stories and the distance between them. As per **Clause 7.11.1 of IS 1893 – 2016 (Part 1)**, the maximum storey drift of structure subjected to lateral force with a load factor ‘1’ is 0.004 time the storey height. For this case, **allowable drift** is **0.012** and that of **MODEL 06** is **0.00821**. Thus the test model is safe.

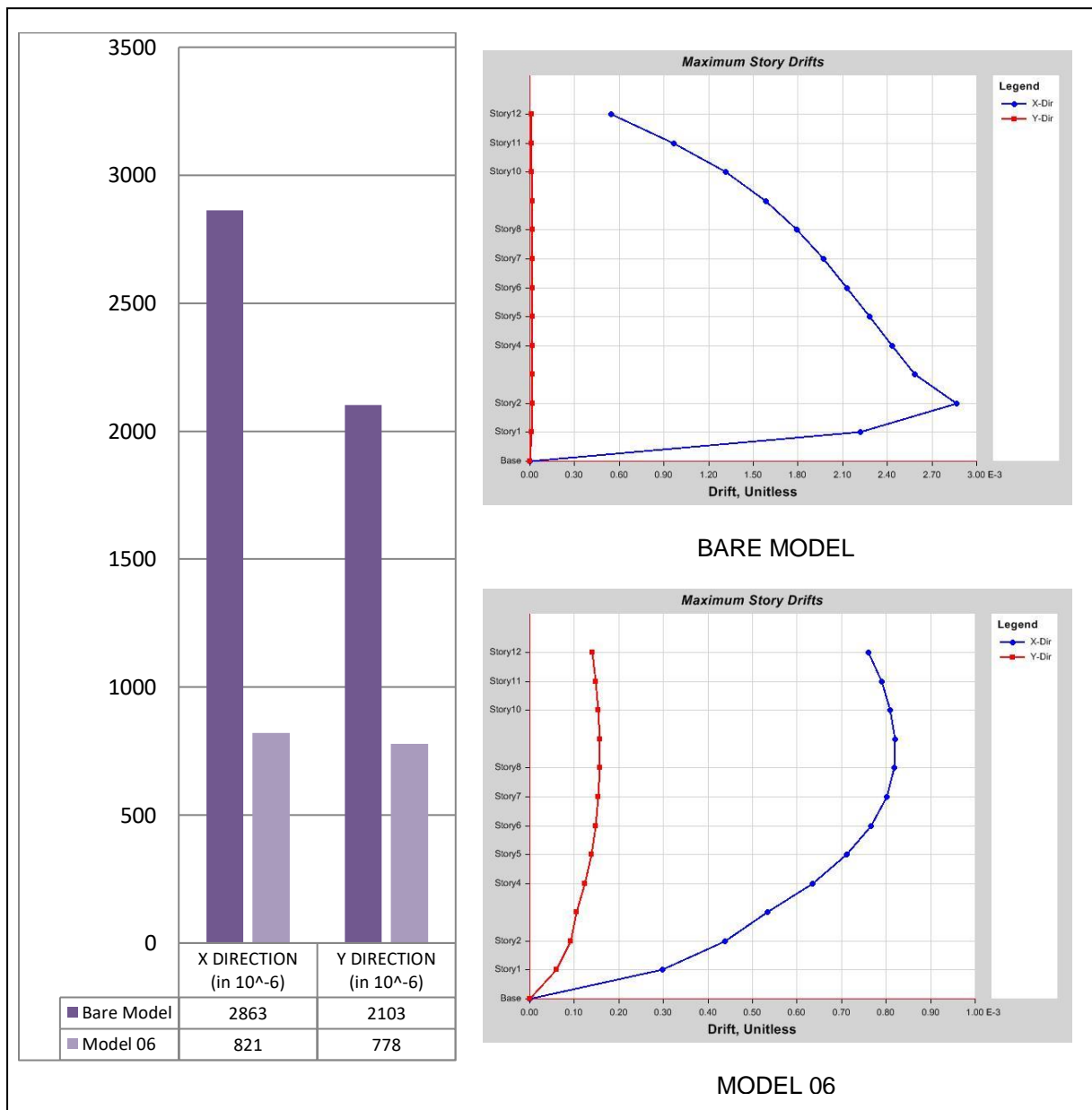


Fig. 8.2 Comparison of Storey Drift

3. Storey Shear

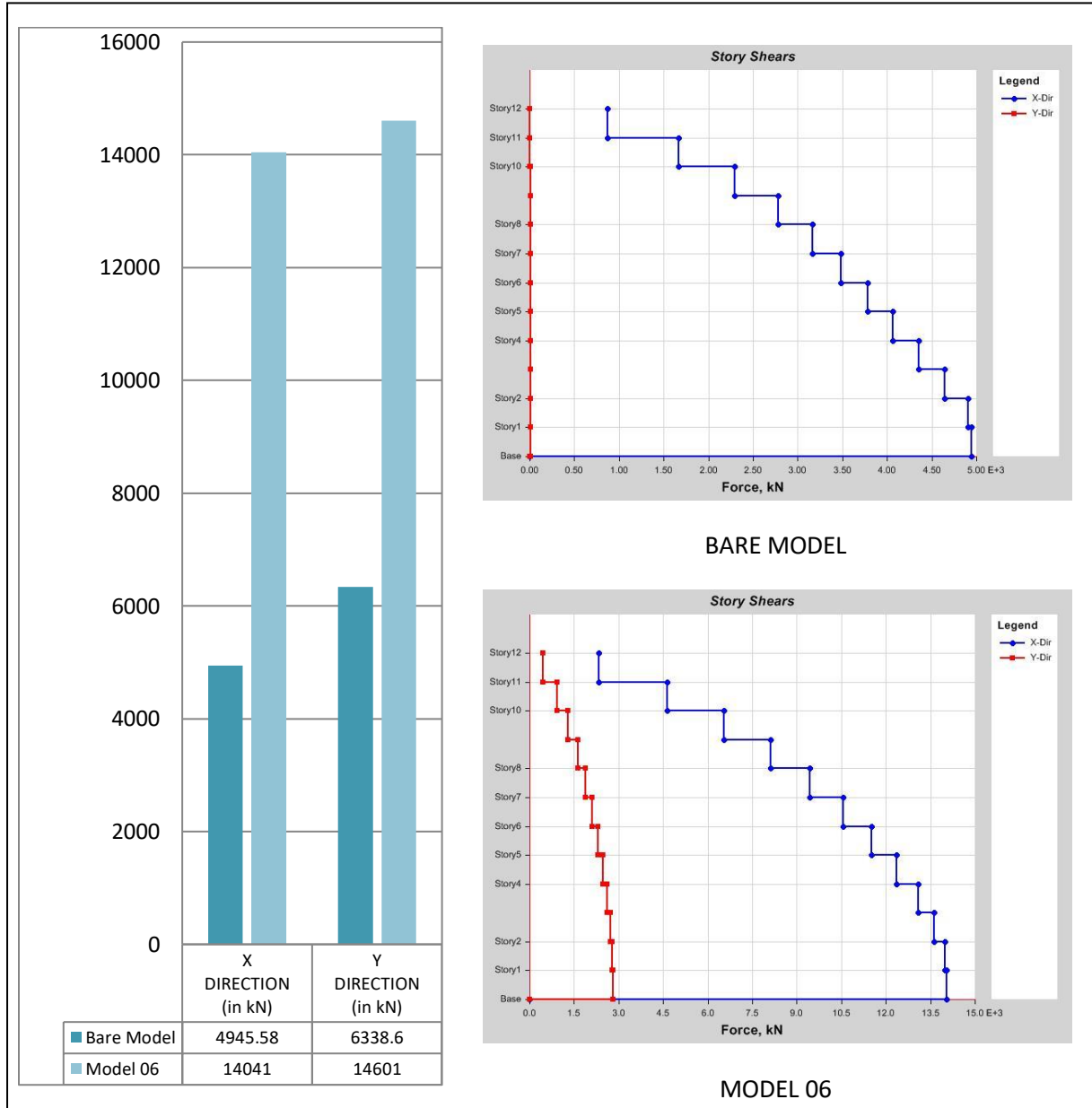


Fig. 8.3 Comparison of Storey Shear

4. Joint Displacement due to Time History Data

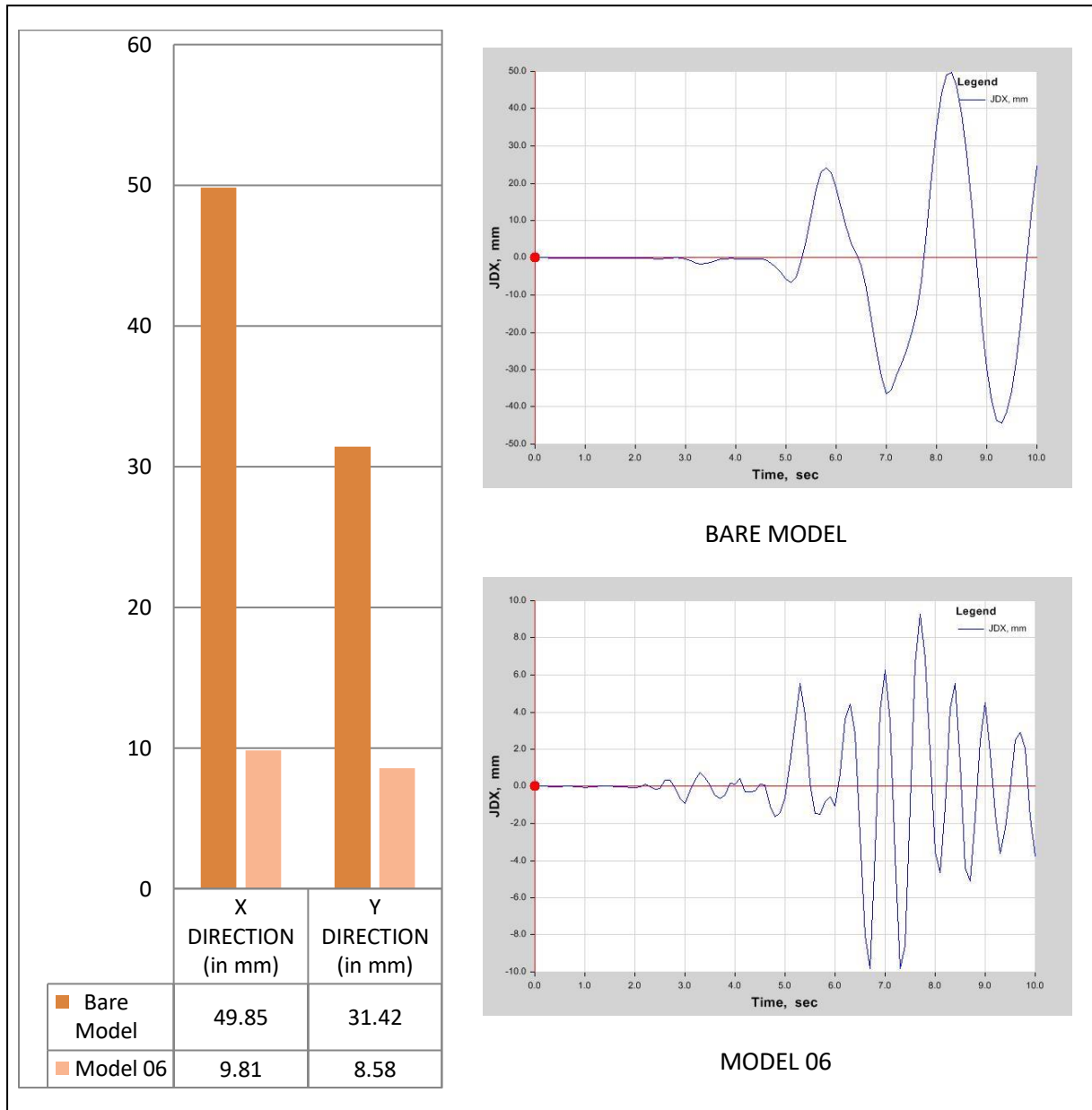


Fig. 8.4 Comparison of Joint Displacement

5. Base Force due to Time History Data

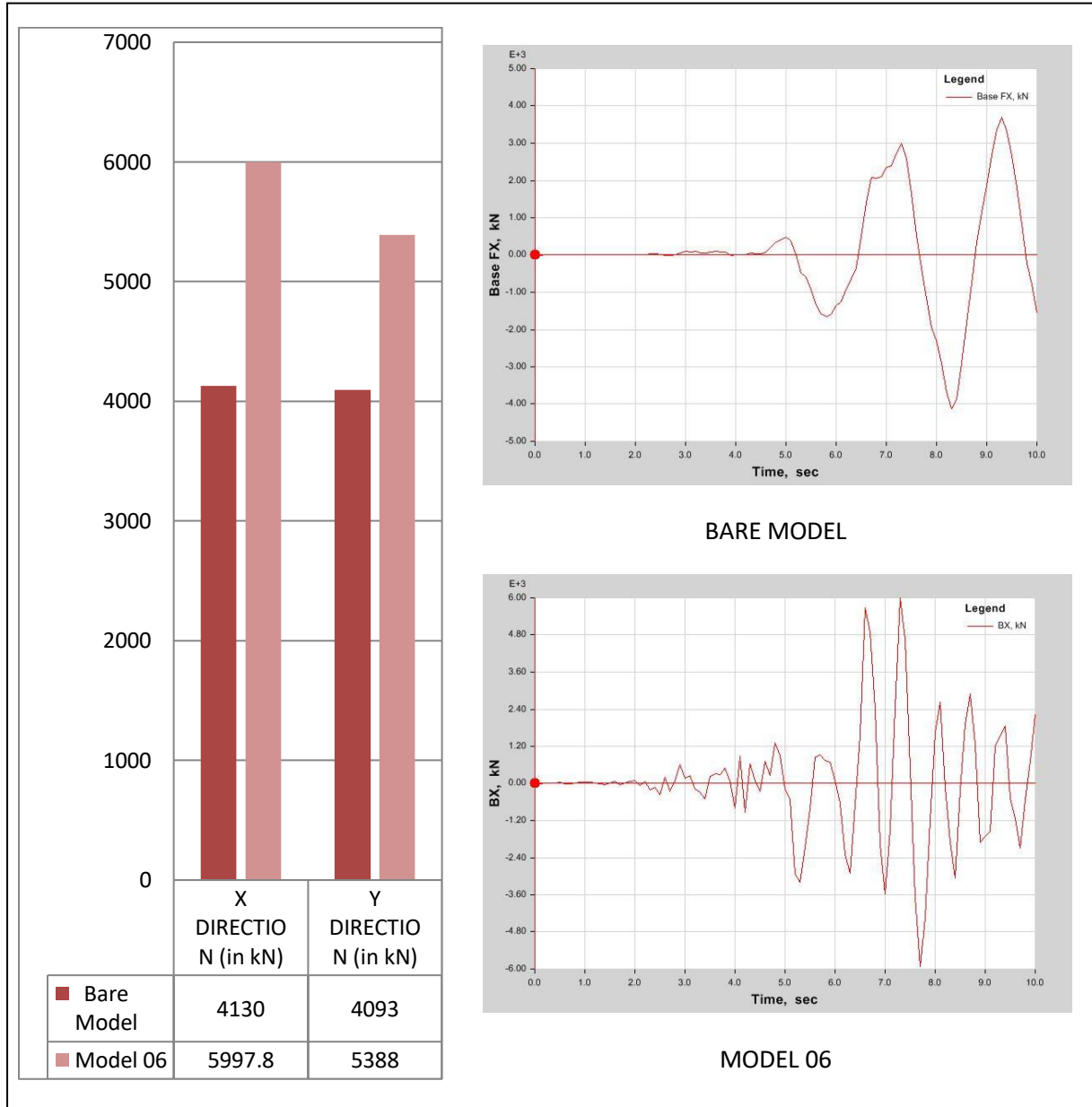


Fig. 8.5 Comparison of Base Force

6. Eccentricity between Centre of Mass and Centre of Stiffness -

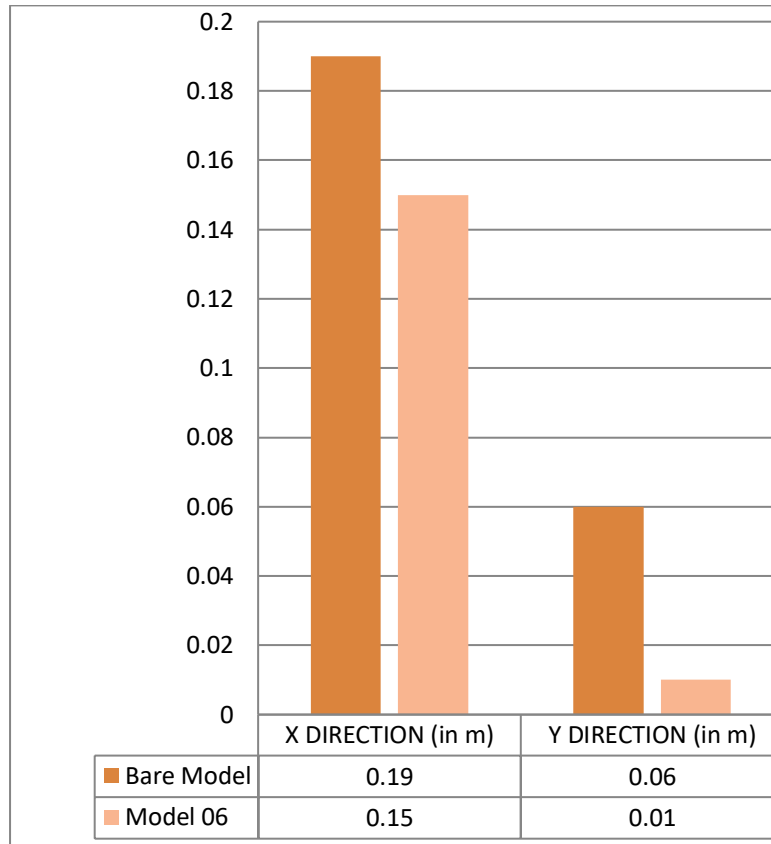


Fig. 8.6 Comparison of Eccentricity

Inference

The above data is sufficient to justify that MODEL 06 is having optimum position of shear wall. As stated earlier, position of shear wall is very crucial in generating torsional forces in the structure. Although on one hand the shear wall helps in reducing lateral displacement but on the other hand, if they are not placed in a optimum manner they can cause massive instability in the structure.

From the group of test models, some of the models were very good in resisting lateral displacement but they were also generating huge amount of eccentricity. Thus, it is observed that optimum position should not be defined on the basis of lateral displacement only. The eccentricity between centre of mass and centre of stiffness should be of utmost importance. Thus it should be considered very seriously.

Chapter-8

Conclusion

With this thorough analysis of the test models, the importance of shear wall can be easily understood. The point which are noted from the study are listed below -

- The shear wall is very effective in reducing Lateral Displacement. But if we observe the set of model with randomly placed shear wall (M 07 – M 10), we obtained poor results. Thus location of shear wall is the determining factor in its action against lateral forces.
- We observed huge amount of inborn eccentricity in the ‘L’ shaped building without shear wall. Shear Wall Configuration helped in reducing the torsion due to eccentricity in the building.
- The irregular shaped model experiences biaxial lateral displacement. This was effectively controlled by the effective position of shear wall.
- The moment of inertia of shear wall also plays an important role in reducing lateral displacement of the building. In a certain concerned direction, if the shear wall panels are placed along the direction of force, they will exhibit more resistance towards lateral forces. It is clearly observed in the test models.

From the test models, M 06 was considered as the model with optimum position of shear wall.

The optimum position of shear wall is based on following grounds –

- The shear wall configuration should effectively reduce the lateral displacement.
- The lateral displacement should be reduced on the basis of the fact that, minimum eccentricity should be generated between centre of mass and centre of stiffness. This will result in minimal amount of torsion.
- In irregular structures, the configuration should not promote any kind of additional forces in the structure; rather it should tackle the unwanted elements. Like the ‘L’ shaped models were having inborn eccentricity, but the optimum location of shear wall reduced the inborn eccentricity in the structure.

References

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