

# **Study of Shear Wall Locations in RC Building**

## **Thesis**

**Submitted to the**



**G. B. Pant University of Agriculture & Technology  
Pantnagar- 263145, Uttarakhand, India**

**By**

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**B. Tech. (Civil Engineering)**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF**

**Master of Technology**

**in**

**Civil Engineering  
(Structural Engineering)**

**February, 2021**

# ACKNOWLEDGEMENT

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*Words are very poor substitute to express one's emotions and feelings, there are no other alternative to give vent to one's sentiments, particularly on an occasion like this, when one sits in acknowledging the debts of others.*

*I must offer my profound gratitude to my thesis advisor **Dr. Vaneeta Devi** Assistant Professor, Civil Engineering and Chairperson of Advisory Committee for helping me in improving the draft, providing me sufficient time for discussions as and when desired by me. Since the beginning and until the completion of this work she has been kind enough to motivate and encourage me. I would also like to thank her for encouraging and helping to shape my interests and ideas.*

*I feel extremely privileged to express my veneration for the eminent member of my advisory committee, **Mr. Sunil Kumar**, Assistant Professor, Department of Civil Engineering and **Dr. V.K. Verma** Assistant Professor, Department of Civil Engineering for their authentic technical guidance, keen interest and valuable suggestion at every stage of my work.*

*I would like to give my special thanks to **Dr. P. S. Mahar**, Professor and Head of Department, Civil Engineering, **Dr. Kiran P. Raverkar**, Dean, College of Post Graduate Studies, **Dr. Alaknanda Ashok**, Dean, College of Technology, G. B. Pant University of Agriculture and Technology, Pantnagar for providing guidance, moral support and timely suggestions during entire period of my study.*

*Financial assistance through GATE provided by the MHRD, Government of India is duly acknowledged. I feel the limitation of my diction to truly reflect my feelings of gratitude. Hence, I have chosen this simple way of acknowledging the help received. I wish to thank all well-wishers whose blessing propelled me to achieve my dreams and could not find separate mention due to lack of space.*

Pantnagar  
February, 2021

  
(Neeraj Kumar Tiwari)  
Author

## **CERTIFICATE-I**

This is to certify that the thesis entitled “**Study of Shear Wall Locations in RC Building**” submitted in partial fulfillment of the requirements for the degree of **Master of Technology in Civil Engineering** with major in **Structural Engineering**, of the College of Post-Graduate Studies, G. B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. Neeraj Kumar Tiwari, Id. No. 53889** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

Pantnagar  
February, 2021

  
(Vaneeta Devi)  
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## **CERTIFICATE-II**

We, the undersigned, members of the Advisory Committee of **Mr. Neeraj Kumar Tiwari, Id. No. 53889**, a candidate for the degree of **Master of Technology in Civil Engineering** with major in **Structural Engineering**, agree that the thesis entitled **“Study of Shear Wall Locations in RC Building”** may be submitted in partial fulfillment of the requirements for the degree.



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**(V.K. Verma)**  
Member

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## **LIST OF ABBREVIATIONS AND SYMBOLS**

|                   |                                                           |
|-------------------|-----------------------------------------------------------|
| 2D                | 2 Dimension                                               |
| 3D                | 3 Dimension                                               |
| ATC               | Applied technology council                                |
| BM                | Bending Moment                                            |
| Cl                | Clause                                                    |
| CQC               | Complete quadratic combination                            |
| DL                | Dead Load                                                 |
| DOF               | Degree of freedom                                         |
| EL                | Earthquake Load                                           |
| ESA               | Equivalent static analysis                                |
| ETAB              | Extended to Three-Dimensional Analysis of Building System |
| FEMA              | Finite element method analysis                            |
| Fig.              | Figure                                                    |
| G                 | Ground                                                    |
| I                 | Importance Factor                                         |
| IL                | Imposed Load                                              |
| IS                | Indian standard                                           |
| kN/m <sup>2</sup> | Kilo Newton/meter square                                  |
| LDA               | Linear dynamic analysis                                   |
| LL                | Live Load                                                 |
| LLRS              | Lateral load resisting system                             |
| LSA               | Linear static analysis                                    |
| m                 | Meter                                                     |
| m/sec             | Meter/Second                                              |
| MDOF              | Multi-degree-of-freedom                                   |

|                  |                                        |
|------------------|----------------------------------------|
| mm               | Millimeter                             |
| MPF              | Mass participation factor              |
| N/m <sup>2</sup> | Newton/meter square                    |
| OMRF             | Ordinary moment resisting frame        |
| R                | Response Reduction factor              |
| RC               | Reinforced concrete                    |
| RCC              | Reinforced cement concrete             |
| RSA              | Response spectrum analysis             |
| RSM              | Response-spectrum method               |
| Sa/g             | Design acceleration spectrum           |
| SAP              | Systems, applications and products     |
| SDOF             | Single-degree-of-freedom               |
| SF               | Shear Force                            |
| SMRF             | Special moment Resisting frame         |
| SRSS             | Square root of sum of squares          |
| STAAD PRO        | Structural Analysis and Design Program |
| SW               | Shear Wall                             |
| Ta               | Natural time period                    |
| THA              | Time history analysis                  |
| UBC              | Uniform building code                  |
| WL               | Wind Load                              |
| Z                | Zone Factor                            |



# *Introduction*

**1.1 General**

Although reinforced concrete buildings are adequate to withstand vertical and lateral loads, but in the prevailing situation and necessity of high-rise tall buildings, both residential and commercial, these simple framed buildings have been found to be inadequate under extreme lateral loading to sustain design requirements of strength, serviceability, stability and human comfort. The excessive sizes of the beams and columns are very heavy and hence the joints are very congested, resulting in poor workability and compactness and thus less stable structure. The lateral loads also decrease the structure's stability by creating a moment of sway and causing high stresses. In such a situation, the structure's stiffness is more important than the structure's strength to resist the lateral load.

Disturbance at some depth below the earth surface causes the vibration of the ground surface and these vibrations are absolutely uncertain and happen in all direction. Earthquake causes ground to shake and support of the structure is subjected to vibration. Because of the earthquake, some part of the world face high financial and human losses every year. These losses are mainly accounted by the harm of the structure or fall of the buildings.

India has experienced a number of earthquakes in the last decades that have caused considerable damage to the structure. According to Indian seismic code [IS 1893 (Part 1):2016], more than 60% of India's land territories are situated in higher three seismic zones III, IV and V but only about 3 percent of the built environment is engineered correctly. India has the potential for powerful seismic shaking with an immense supply of powerless structures. Thus it is important to understand the effect of earthquake loading or lateral loading on buildings and to plan the structure to protect against a rigorous earthquake. As the tall buildings become a requirement in terms of engineering and architecture, shear walls prove to be a better choice for designers to create a safe and stable structure.

## 1.2 Moment Resisting Frames

The frames obtain their lateral load resistance by the rigidity of the relations between beams and columns, as shown in Fig. 1.1, i.e. by the bending moment and shear force developments at the joints and in the frame members. Frame's action is straight forward and their computer modelling is also not complicated. For partitioning reasons the frames are infilled with masonry plates. These partitions are typically overlooked for their lateral load resistance as these are considered non-structural component. These panels behave in a complex way. These non-structural components act as diagonal bracing components until they collapse and fall apart from the frame. In several cases these fail under severe shaking and fall apart before the frame is subjected to ultimate load, which is why their contribution to lateral load resistance is not calculated.

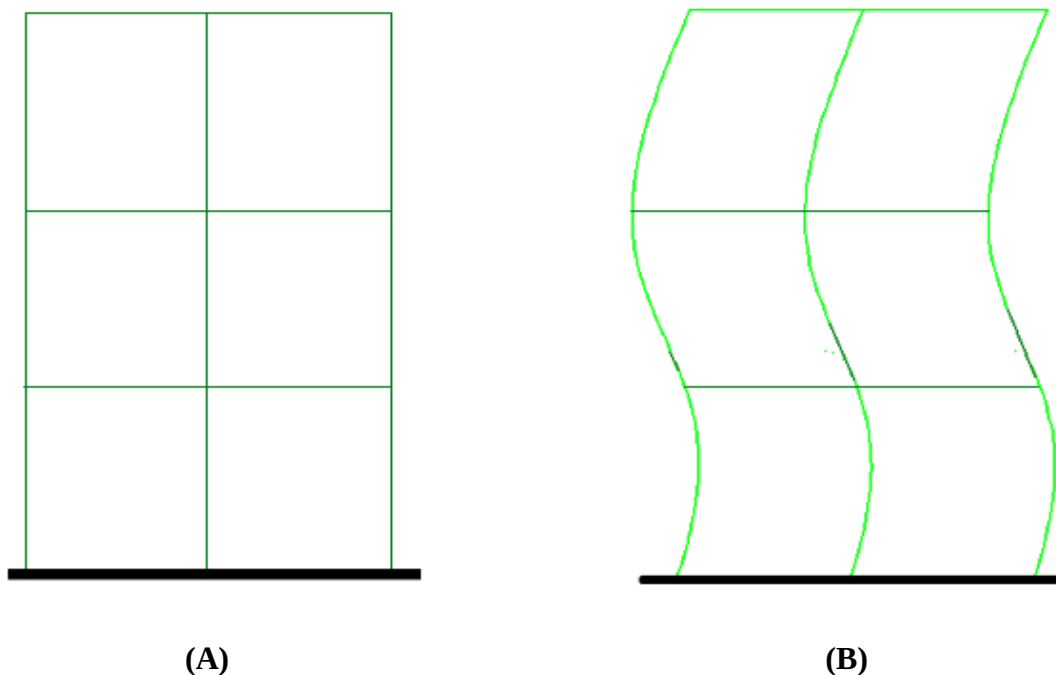


**Fig. 1.1 Behaviour of Moment Resisting Frames (A) without sway (B) with sway**

### 1.2.1 Types of Moment-Resisting Frames

#### 1. Ordinary Moment-Resisting Frame:-

It is a moment-resistant frame designed and detailed as per IS 456, but not meeting special detailing requirements for ductile behaviour as per IS 13920.

## 2. Special Moment-Resisting Frame:-

It is a clearly comprehensive frame resisting moment to provide ductile conduct and comply with the requirements provided in IS 13920 and IS 4326, respectively.

### 1.3 Shear Wall Concept

Lateral load resistance systems are used to withstand lateral loads caused by wind or seismic activity. Nowadays, various systems are available that are being used for the same purpose. Moment resisting frames, bracing systems, tubular systems, shear-wall system and hybrid system (consisting more than one of the types) are some of the techniques, as shown in figure 1.2, that are in business to be used against lateral loads

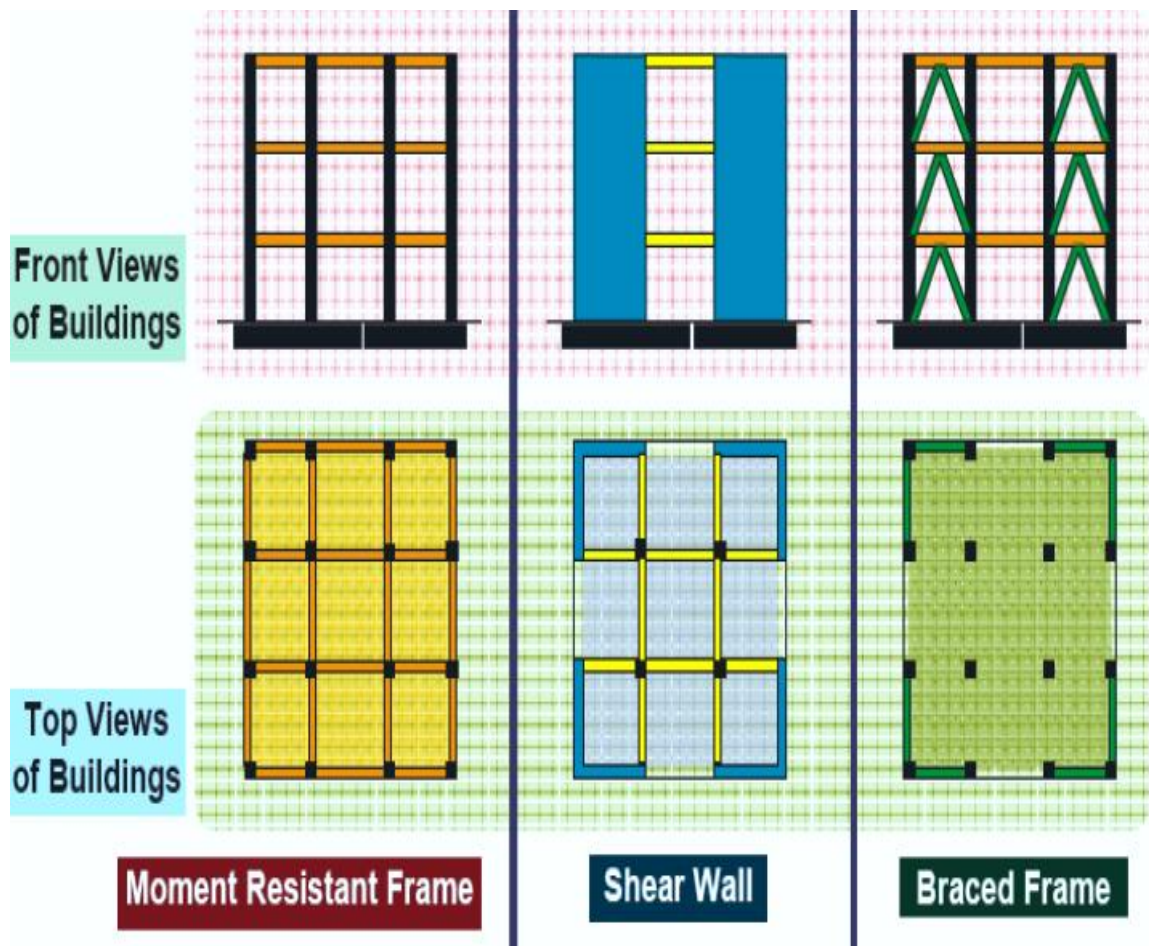


Fig. 1.2 Lateral Load Resisting System

In the ongoing work, focus is only on shear wall techniques. The following contents discuss the shear wall system in details.

A shear wall is a wall built to withstand the shear force and lateral caused by the earthquake. Several building codes recommend to use shear walls to make buildings safer and secure, and learning about shear walls is an integral part of structural education. Engineers are required to integrate shear walls and other protection measures when constructing a structure so that they can fit the walls and also make the structure sound and aesthetically attractive. The shear wall can be made to serve the following functions;

1. Act as a Partition Wall
2. Serves as load bearing walls thereby eliminating several columns
3. To carry or resist a substantial portion of Lateral force caused by earthquake or wind forces by virtue of the large stiffness of the walls in their own planes.

An effective shear wall is both stiff and strong and resist the lateral force while providing support. Shear wall in general covers the elevator shaft, stairwell or central core unit. The shear wall in building becomes economical as soon as the lateral force governs the design of structural components like beam and column. Shear walls are critical in RC multi-story structures, because they also support the numerous floors of the building in order to avoid the failure of external walls, helping to ensure that they do not just collapse as a result of lateral movement in an earthquake. Without the aid of shear wall, many frame structures can not be effectively designed to satisfy lateral load provision. In such structures, the primary objective of the shear wall is to enhance the lateral rigidity of the structure.

In multi-story structures, shear walls are crucial because besides of preventing the malfunction of exterior walls, they also support the numerous floors of the building, ensuring that they do not collapse because of the lateral movement/sway during an earthquake. It is termed as a soft-storey whenever a building is constructed having a storey either without shear wall, or with improperly placed shear walls, referring to the idea that in a crisis the storey having no reinforcement will be susceptible. The shear walls can not be removed/cut open since they are structural in nature. When building a structure from the ground up, it is an essential matter to consider how space uses might

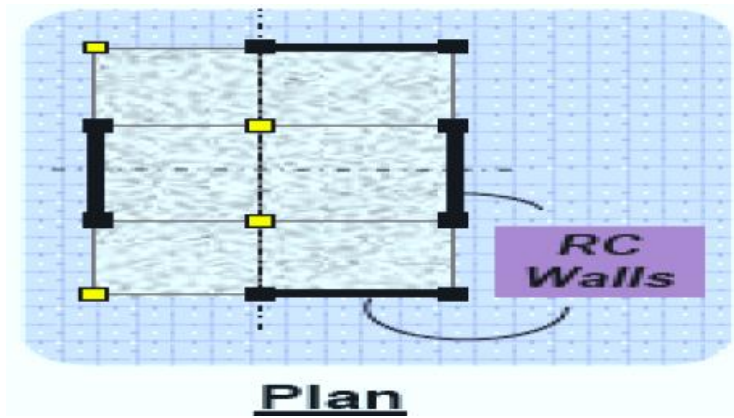
change to make certain that a shear wall does not turn out to be a nuisance later.

**Function of Shear Wall:** In order to resist horizontal or lateral forces, shear wall transfers these forces to the following element of the building in the load path below them. They also provide roof or floor lateral firmness in addition to this, preventing them from unwarranted side swaying. The shear wall force transfer phenomenon is shown in Fig 1.3 (C).

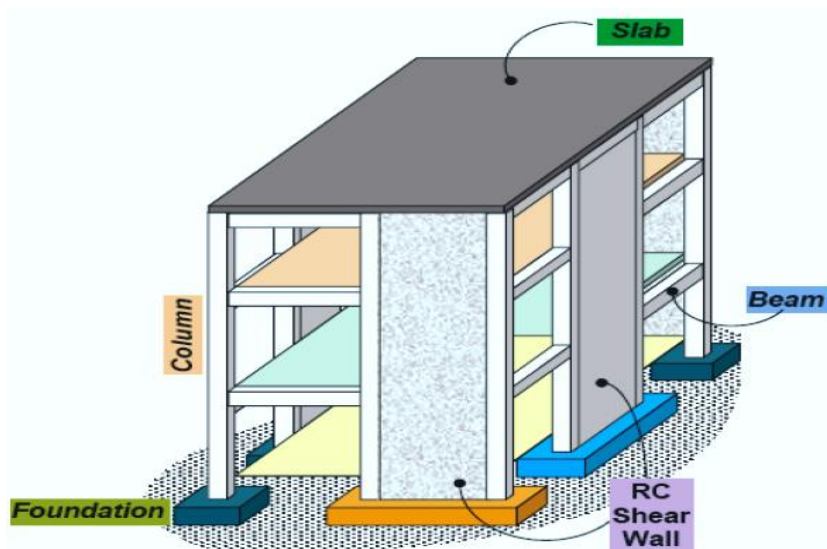
These vertical plate-like reinforced concrete walls usually start at base/foundation level and are incessant all through the building elevation. Various thickness of shear walls that can be provided in a RC building range from 150mm (minimum) to 400mm (maximum). Shear walls are typically provided along both length and width of buildings. Shear walls are like large vertically oriented beams bringing earthquake loads down to the foundation or base.

Reinforced concrete walls, including lift walls or shear walls, are characteristic requirements for multistory or high-rise buildings of reinforced concrete. It will be efficient to build the shear wall in high, medium and even short buildings and in turn strengthen the structure to make it significantly more economical than the bending frames. The side bending of the structure can be controlled by the shear much better than other elements such as closed frames and certainly the shear walls are more flexible than them. However, the design has to be based on the location of the lift and stair case walls in relation to the centre of mass in many instances.

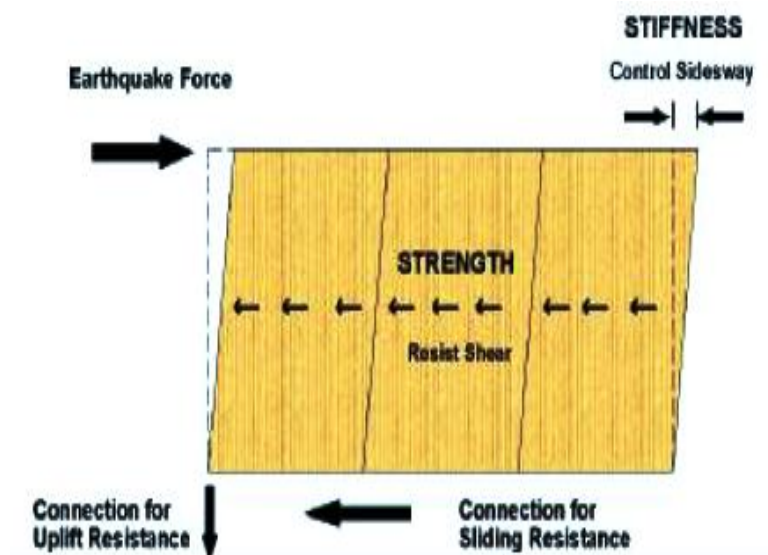
Most RC frame structures with shear walls also do have columns and these columns principally carry gravity loads (i.e., loads due to self-weight and elements of building). Shear walls provide buildings with great strength and stiffness along the axis of their orientation, which significantly decreases the building's lateral sway and thus reduces damage to the property and its contents. Since large fraction of the horizontal earthquake forces are carried by shear walls, the overturning effects on the walls are huge. Therefore, the design of their foundations requires special care. Shear walls should ideally be provided along the length and width of the building plan, as shown in Fig 1.3 (A) and (B).



(A)



(B)



(C)

Fig. 1.3 (A) Plan view of Building with Shear Wall (B) View of Shear Wall Running Full Height of Building (C) Functioning of Shear Wall

### 1.3.1 Shear Wall-Frame Interaction

This system has a grouping of shear wall and RC frame that provides a resistance to lateral loading. The potential of wall-frame structure totally depends on the RC frames, the shear walls and the height of the building. The taller the structure and stiffer the RC frames, the larger the interaction. The RC frame is deflected in shear mode while the shear wall is responded in bending as similar to a cantilever. The structural conformance of lateral deflection builds up the interaction between them.

In combination with the shear wall deflected in the parabolic sway, the lateral sway of the RC frame results in significantly enhanced rigidity of this system because the shear wall is efficiently restrained by the moment frame at the top levels, while the moment frame is restrained by that of the shear wall at the lower levels. Therefore, the combined action of structural elements is truly based on the relative rigidity of the both and their respective modes of deflection. The horizontal deflections of a RC shear wall are much more identical to a cantilever column. At the bottom, the shear wall acts relatively stiff and hence, the floor to floor deformations would be less than half the values at the top. Resulting from the combined effect of shear wall rotation, the lateral deflection increases rather readily on the top floors. The shear mode of deflection was adopted by RC frames on the other side. Comparative floor deflections are basically based on the shear force value claimed to the floors at all storey levels. Nevertheless, the lateral deflection is greater at the lower storey level and lesser at the top levels of storey as compared to the shear wall, the floor to floor deformations may be considered nearly uniform in distribution following the height of the building. When the current system i.e the shear wall-frame system is connected by applying rigid diaphragm action then a non-uniform storey shear force generates between them. Consequently, the typical interaction results in a much more economical structural system.

### 1.3.2 Overall Geometry of Shear Walls

Shear walls are oblong in cross-section, i.e. one dimension of the cross-section is much larger than the other. While most common cross-section is rectangular, other shapes like L-shape and C-shape sections are also used. Geometry of some of the shear walls are shown in figure 1.5. Thin-walled hollow RC shafts, also known as box-shape shear walls, provided at the elevator core of the buildings serve as shear walls and are used to resist earthquake forces.

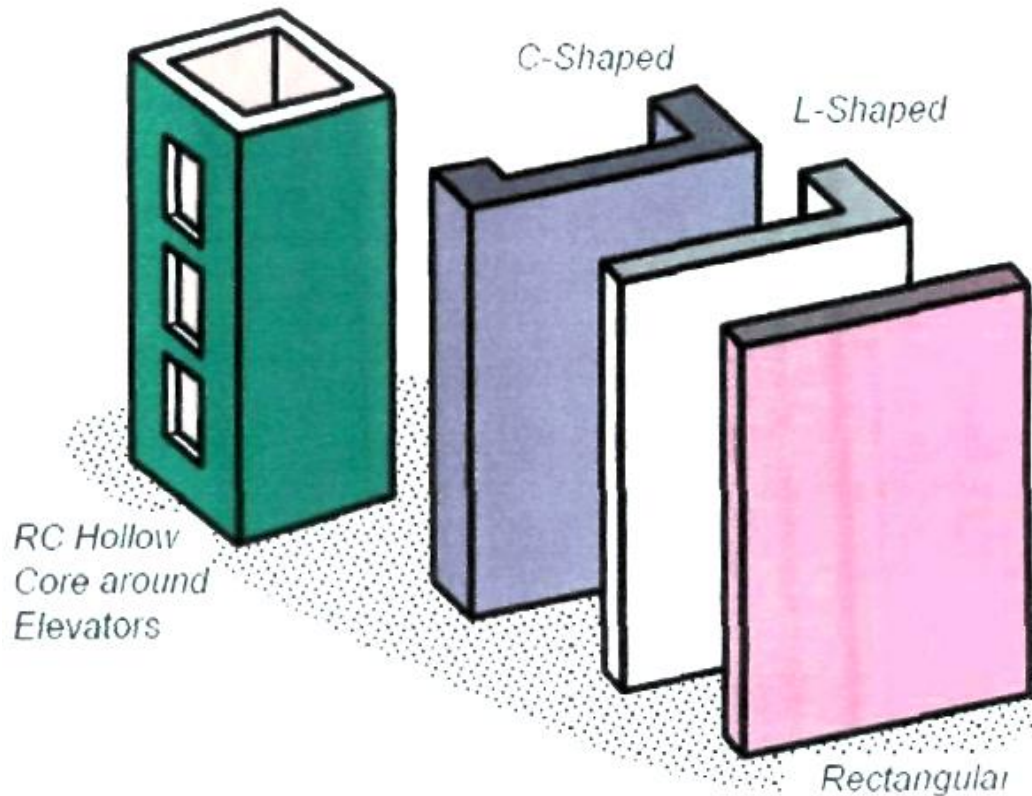


**Fig. 1.4 Different Geometries of Shear Walls**

Although a detailed discussion on shear walls has been done, but for the current work shear walls having symmetry about structure's plan axes is chosen, hence neglecting any torzional effect. Also interaction effect of soil-foundation is also negeted in this study.

#### **1.4 Inspiration Urging This Work**

Natural disasters are an unfortunate fact of life on Earth. Earthquakes are no exception, especially in areas of the world that are more susceptible to them. While we are only 20 years into the 21st century, more than 657,000 people have already been killed by earthquakes. Many more have been injured and made homeless. The countries like Haiti (a poorest country in the western hemisphere) which lacked in adequate building codes, affected one third of its population in 2010 eatrhquake, while the country like china also suffered the damage of 80% of the structures in Sichuan in 2008 earthquake. Nepal earthquake in 2015 distroyed more than 600,000 structures in the small country with around 9,000 human loss.

To avoid this huge destruction and to minimize the construction cost, preplanned seismic evaluation and strengthening of the structure show a better option rather than the replacement of buildings. Mark Fintel, in 1994 published his research that studied the performance of the buildings with shear walls in earthquakes from 1960 to 1990. He observed that the structures damaged were mainly unengineered structures. Research also mentioned that not a single structure with shear wall even needed any repairing in 1988 Armenia earthquake which suffered the complete loss of 263 major buildings with six to fifteen storeys. So, in order to meet the primary requirement of the tall buildings i.e. safety and minimum damage, shear wall frame provide one of the better options.

Figure 1.5 and 1.6 shows damaged non-shear wall structures and safe shear wall structures in Spitak city of Armenia and in Mexico city of Mexico, respectively.



(A)



(B)

**Fig.1.5 (A) Damaged city (B)Undamaged Shear Wall structure  
Spitak,Armenia,December, 1988.**



(A)



(B)

**Fig. 1.6 (A) Damaged Nuevo Leon Building (B) Un-damaged Shear Walled structure Mexico City, Mexico, September, 1985**

## 1.5 Objectives

1. To learn and understand the STAAD. Pro V8i software.
2. To study the influence of shear walls and its orientation in RC Framed Buildings.
3. Comparative study of storey drift and lateral displacement of simple framed building and Shear Wall- frame buildings in seismic zone IV.
4. Comparative study of base shear, maximum bending moment and time period of shear wall-Frame building with different positions of shear wall.
5. To study the most efficient orientation/ position of Shear Wall-Frame System in RC frame building model located in seismic zone IV.

## 1.6 Thesis Organization

The work in this thesis has been presented in six chapters. These chapters are briefly described here

- Chapter 1** This chapter provides a brief information about the study work, objectives of the present study and organisation of thesis.
- Chapter 2** This chapter contains previous research carried out by various authors in the this field to identify what has been done and what still needs to be done for a more comprehensive understanding of the seismic performance of the multistorey RC buildings.
- Chapter 3** The detailed discussion on the selected method for the present study has been described in this chapter. Moreover, various terminology and parameters used in the present study analysis are also given in this chapter. The model configurations, geometrical dimensions of building and various parameters of the proposed models viz., seismic zone, soil condition, size of structural element of the building, orientation of shear wall in selected models etc. are discussed in detail.
- Chapter 4** Results obtained from the present study analysis are presented in this chapter which includes tables, graphs of the selected study parameters, namely base shear, bending Moments, storey drift, maximum displacement with and without shear wall and all are discussed in detail.
- Chapter 5** This chapter summarizes all the work carried out in the present study. The important conclusions drawn from the present investigation and suggestion for future work are given in this chapter.



*Review  
of  
Literature*



**2.1 Introduction**

Shear walls can form a very efficient lateral load resisting system when placed in a building in an advantageous position and configuration. The study was investigated by many authors on various parameters, such as displacement, storey drift and member forces, in order to find out the ideal location and configuration of shear walls in the building. This present chapter focuses on the studies carried out by different authors and the conclusions that they drew out of their studies.

**2.2 Review of Research Works**

The Research work carried out by various researchers and their results are explained in the following paragraphs.

**Lopes (2001)** identified a detailed test in order to study the seismic performance of reinforced concrete walls subjected to extreme conditions and a shear failure was observed. A test setup was designed to enforce beam behaviour in order to perform this experiment and a low shear ratio was maintained during the test mentioned in this work. Finally, observations were made and some special characteristics identified that were based on failure mode.

**Rana et al. (2004)** had performed a pushover analysis on a nineteenth storey slender concrete tower building situated in San Francisco to verify the 1997 Uniform Building Code's primary intention of life safety performance under design earthquake. Building was of 240 feet tall with a gross area of 430,000 square feet in seismic zone of IV and on southeast side two of the parameter columns were discontinued at the 6<sup>th</sup> storey and six new columns were introduced that slope for lowest six stories at an angle of twenty degrees. Shear walls were 15inch thick at the 15<sup>th</sup> storey and above and 24inch thick at 14<sup>th</sup> storey and below, except for transverse walls in eastern half where walls were 36inch thick at 6<sup>th</sup> storey and below. Time period range of 2-2.5sec was considered relevant for the building. Eight separate pushover analysis were performed, where SAP2000 was used to perform pushover with shear wall modeled as equivalent frame element and wall at 1<sup>st</sup> storey as shell element and ETABS was used to calculate

hinge properties of shear wall and elastic analysis. Result showed that shear hinges were formed at few walls and spandrel locations, however, their plastic rotations were within limits suggested by FEMA and ATC guidelines and average story drift values were also within FEMA guidelines. The research concluded that even for tall and slender building design as per 1997 UBC may result in shear wall failing in shear rather than in flexure.

**Pujol *et al.* (2008)** tested a full scale three-storey structure having infill brick walls under displacement reversals. The outcomes of this test were compared with the slab-column junction, and a punching shear failure was seen in the structure. Infill walls avoided the collapse of the slab and improved the structure's strength and stiffness efficiently. In order to match the numerical model of the test structure, the experimental results were calibrated. Numerical simulations indicated that even during strong motion, the measured drift ability was not reached.

**Kaltakci *et al.* (2010)** via the use of shear walls, for which the position of the shear wall was chosen as the basic parameter of the research, performed an experimental study dealing with a commonly used strengthening process in Turkey. They concluded that shear walls and frame columns operated monolithically in both applications in the light of the scaled experimental elements and the data obtained from the experiments, and any anchorage de-bonding was not seen at the column-shear joint. Although the external shear wall type was predicted to exhibit a higher horizontal load bearing capacity than the partially in-filled shear wall type, during the tests, the partially in-filled type exhibited higher horizontal load bearing and lower horizontal displacement compared to the external shear wall type.

**Anshuman *et al.* (2011)** had carried out the investigation to establish the solution for shear wall position in multi-storey buildings based on the both its Elastic and Elasto-plastic behaviour. For this a building of fifteen stories located in seismic zone-IV was analysed using both STAAD Pro.2004 and SAP2000 by computing shear force, bending moment and storey drift. Model had a plan view with 11 bays in longer direction and three bays in shorter direction with shear wall thickness of 300mm. Analysis of building without shear wall showed that in case of earthquake load in shorter direction, the top deflection was 235.725mm which exceeds the permissible

deflection limit of 203.6mm as specified by IS1893:2002(part-1) when analysed using STAAD Pro also, the maximum moment and shear were at ground level in 1<sup>st</sup> and 12<sup>th</sup> frame. After providing shear wall in 1<sup>st</sup> and 12<sup>th</sup> frame the top deflection was reduced to 154.49mm when analysed by STAAD Pro. and it reduced from 198.4mm to 114.29mm when analysed using SAP and bending moment and shear force were also increased in 1<sup>st</sup> and 12<sup>th</sup> frame. Also when shear walls were applied in 6<sup>th</sup> and 7<sup>th</sup> interior frames, maximum top deflection recorded were 135.47mm and 105.91mm when analysed using STAAD Pro. and SAP respectively. It was observed from the analysis that the inelastic analysis performance point was small and within elastic limit.

**Kaplan *et al.* (2011)**, summed up, that vulnerable buildings and their restoration are critical problems for regions impacted by earthquakes. In this research, under reversed cyclic loading, a new reinforcing alternative for RC structures, namely exterior shear walls, has been experimentally investigated. It is possible to reinforce buildings using the proposed technique without disrupting their users or vacating the building during renovation. In this method, shear walls are built in parallel to the exterior sides of the house, it has been found that the use of external shear walls greatly increases RC structures' ability and sway stiffness.

**Hidalgo *et al.* (2011)** presented both flexure and shear failure modes in order to predict the inelastic seismic response of RCC shear-wall buildings by developing a computer model. The SINA hysteresis model implemented in LARZ computer program was adopted in this study to model the non-linear flexure behavior and moment hysteretic for wall elements and the result was compared with two actual buildings during 1985 Chilean earthquake. One of the two buildings was a 10-storey plus basement Villa Real building, designed in 1981, and the other was a 7-storey plus a basement Sermena building, designed in 1971. The typical shear wall ratio was .027% along X-direction and .033% along Y-direction. Original design base shear for villa real building was 2390kN while the result showed the predicted values of 5520kN and 7020kN along X and Y directions, respectively. For Sermena building original design value was 2830kN, whereas, result gave the predicted maximum values of 8370kN and 7310kN along X and Y directions, respectively. Result also predicted the maximum inter-story drift ratios of .0073 and .0051 along two directions for Villa Real building and .0048 and .0044 for Sermena building. Result showed some difference between

actual effect and predicted effect of model which could have occurred due to non inclusion of the elevator shaft, presence of cracks in original buildings prior to earthquake and some other unknown facts about the structure construction.

**Venkatesh and Sharada Bai (2011)** studied the effect of internal and external shear wall on performance of building frame subjected to earthquake loads. In the study the attempt was made to find the difference in structural behaviour of three-dimensional single-bay three-bays ten-storeyed basic moment resisting RC frame building and two different types of shear wall as LLRS. The detailed investigations were carried out for seismic zone V by considering 15 models which consist of one bare frame with three different sizes/orientations of columns and other two include bare frame with internal shear wall and external shear wall with two different thickness of 200mm and 300mm. Among all the models the least maximum deflection was found in case of 300mm thick shear wall with column orientation as 300X750mm. When external shear wall was compared with internal shear wall the maximum deflection was found to be 2.74 time to 3.25 time in one direction and 1.15 to 1.2 times in other. Similarly values of maximum column forces were much higher, ranging from 21% to 200%, in case of external shear wall as compared to internal shear wall. In case of beams moments were higher by 11-44% in case of external walls than internal walls where as shear walls were higher by 11-14% in case of internal shear wall. The complete analysis showed that internal shear walls were more suitable than the external shear walls.

**Romy Mohan and Prabha (2011)** used six different types of shear wall with its variations in shape on two buildings of seven and eleven storey for studying their effectiveness in resisting lateral forces using SAP 2000 software. They also studied the effect of variation of building height on structural response of shear wall and highlighted the accuracy and exactness of time history analysis (THA) in comparison with most commonly adopted response spectrum analysis (RSA) and equivalent static analysis (ESA). Their study on 400mm thick shear wall showed a percentage variation of 2.69%, 6% and 4.9% in story drift between ESA and RSA which even reached to 24.47% in U shaped shear frame type model. Percentage variation in storey-drift between RSA and THA for some models were about 30%. The result showed that ESA was effective for symmetric buildings up to 25m height and for higher and un-symmetrical buildings RSA was but more effective, but for structures of most importance THA was most suitable.

**Burac *et al.* (2013)** performed an analytical study to evaluate the effect of the ratio of shear wall area to floor area on a midrise RCC Building under a seismic activity. 24 building models with five to eight stories were studied within a range of 0.51% and 2.17% shear wall area to floor area ratio. A non-linear time history analysis was carried out on models under earthquake loading with main parameters as roof and inter-story drifts and base shear response. PERFORM-3D was used to analyse the RCC framed building models. 24 model's study indicated that at least 1.0% shear wall ratio should be provided in design of midrise building to control the drift. Study also showed that there was no significant improvement in the seismic behavior of building when shear wall ratio was increased beyond 1.5%. There was no clear trend between first yield and shear wall ratio, however, the total number of members that yielded varied in different models depending on shear wall ratio. Buildings with 1.0% shear wall ratio showed that 80% of base shear was carried by ground floor shear wall which was found more than 90% in buildings with 1.5% to 2.0% shear wall ratio.

**Oni and Vanakudre (2013)** investigated a three storey and a six storey building with plus shaped shear wall of 400mm thickness for seismic performance by equivalent static method and by response spectrum method as per IS1893:2002(part-1) using finite element analysis software ETABS and also assessed the seismic performance by Pushover analysis as per ATC-40 guidelines for seismic zone-V. Apart from highlighting the accuracy of pushover analysis, the paper also dealt with the effect of variation of building height on structural response of shear wall. PMM hinges with axial force-moment interaction were assigned at the wall ends near floor level and shear hinges were assigned at mid height level of walls. Storey drift variation was found to be 3.4% and 7.1% in three storey and six storey building models respectively between equivalent static method and response spectrum method, while between response spectrum and pushover variation was 10.39% and 43.76% respectively. This paper concluded that plus shaped shear wall can be effectively used in resisting lateral loads and pushover analysis being most accurate and to be used in case of all important structures.

**Chandurkar *et al.* (2013)** in their study focused on solution for the shear wall location in multi-storey building with the help of four different 10-storey building models. First model was a bare frame structural system, second was of dual system with

shear wall one on each side, third was of dual system with shear wall of 4.5m length on corners and fourth was a dual system with shear wall of length 2m on corners. The buildings were modelled using software ETAB Nonlinear V 9.5.0. They studied all the models in all four seismic zones and parameters like lateral displacement, storey drift and total cost required for ground floor were calculated. In their study they found that the displacement of all four models in zone II, III and IV was reduced upto 40% as compared to zone V. Result also showed that story drift was maximum for first model and minimum for third in all zones. First model was found to be most costlier than the others and fourth model was most economical among all. They also observed that the position of shear wall affected the attraction of forces and their proper positioning is important to reduce the displacement.

**Shahzad et al. (2013)** in their study of 25 storey building in zone-V by changing various locations of shear wall determined the parameters like storey drift, storey shear and displacement using ETAB. Five models were created; model-1 without shear wall, model-2 with shear wall at centre, model-3 with shear wall at centre and at four outer edges parallel to Y direction, model-4 with shear wall at centre and at four outer edges parallel to X direction and model-5 with shear wall at centre and at four outer edges parallel to both X and Y directions. Result showed that model-1, model-2, model-3 and model-4 had 5.82%, 3.06%, 2.62% and 3.37% respectively lesser seismic base shear as compared to the model-5 in both longitudinal and transverse directions. In their study they found that model-5 had better location of shear wall as lateral displacement and inter-storey were lesser compared to the other models.

**Chaudhary and Pandian (2014)** had studied the effectiveness of RCC shear walled eight-storey building located in different seismic zones subjected to earthquake load with four different models by finite element method using SAP2000. Model-1 was bare framed structure while model-2 was a core type with rectangular type shear wall at lift well. Model-3 was a coupled type with openings and core type shear walls at lift wells and model-4 included shear walls at four corners as well as at lift. In their study it was observed that in seismic zone-V the lateral displacements were maximum in model-1 while these were reduced by 50% in model-2 and by 15% in model-3. In seismic zone-IV model-3 had 25% reduced lateral displacements with respect to model-1. The final result presented model-2 as the best suited model for seismic zone-V and IV, while model-4 was suitable in zone-II and model-3 in seismic zone-III.

**Todut et al. (2014)** presented the findings of an experimental programme designed to research the seismic output with and without openings of precast reinforced concrete wall panels. Due to the constraints imposed by the laboratory facilities, the specimen features and reinforcement configuration were taken from a standard Romanian project commonly used since 1981 and scaled 1:1.2. This form of precast wall panels was mainly used from 1981 to 1989 for residential buildings with multiple flats constructed. The output and failure mode of all the tested panels revealed a type of shear failure that is caused by the opening type, and in some regions, critical areas and lack of reinforcement were observed. A numerical analysis was conducted to produce a model that could predict the behaviour of different parameters of the precast reinforced concrete shear walls.

**Harne (2014)** did the seismic analysis, as per IS 1893(part-I):2002, on a six storey rcc building, placed in Nagpur, to determine the solution regarding shear wall position in buildings. Four different models, which included one without shear wall and three with shear wall at corners, at outer periphery and at centre, were created and analysed by STAAD Pro. software. Three different load combinations were studied as per IS code guidelines and among all the load combination of 1.5DL+1.5EQX was found to be most critical one. Result showed that the lateral deflection in building with shear wall along outer periphery got reduced up to 33.33% and 32.06% as compared to other two cases of L type and cross type shear wall.

**Baral and Yajdani (2015)** used both equivalent static and response spectrum method to study the response of a G+9 storey building, with five bays in both lateral directions, with different positions of shear wall. Five models in seismic zone V were analysed using ETABS 2103 as per IS1893 (part-I):2002. They observed that building with shear wall at corners extending 3m on each side had the least fundamental period of vibration among all models. Also lateral displacement was also found to be the least in this model in both static and response spectrum method. The storey drift was also found least in the same model, while for all models drift was higher in static method than in response spectrum method. The complete study showed that among all models, building with shear wall along the four corners displayed better result than the other models.

**Rao et al. (2015)** had compared the earthquake behavior of buildings with and without shear wall. For their study they chose four different models with different shear wall positioning in all seismic zones. Models were of 50 storey with shear wall thickness of 450mm. Dead loads and imposed loads on the buildings were assessed from IS875:1987 (part-1&2) and seismic parameters were used as per IS1893:2002. The analysis done by STAAD Pro. software showed that the top storey displacement was reduced in all zones in case when shear wall was used. Displacement was least in core-type shear wall position, which showed 24%, 17.5%, 18% and 19% less deflection compared to bare framed building model.

**Madan et al. (2015)** performed dynamic analysis on three buildings of 10, 15 and 20 storey with different combinations of shear walls and r.c. braces using STAAD Pro. software for seismic evaluation of buildings. Earthquake load was applied as per IS1893:2002(part-1) for zone IV and floor was assumed to act as rigid diaphragm and for distribution of earthquake forces, the contribution of six interior frames with shear wall or braces was grouped together and remaining forces were assumed to be taken by two exterior frames with shear walls or braces. All the braces were of 350mmX600mm and shear wall thickness was of minimum capacity, 250mm. Analysis showed that fundamental time period was not much affected by change in configurations. Introduction of shear walls in exterior frame showed that share of two exterior frames in storey shear was around 24% which increased to around 45% in conventional shear walls. Similarly with conventional X-braces share went up to 43% and in combination case it went up to 77% in 20 storey building. Combination configuration also reduced the maximum lateral displacement by 73-80 percent in different buildings, while shear walls alone reduced it by 27%-58% and braces by 24%-49%. They found that combination configuration with shear walls in middle bays and braces in outer bays was most effective arrangement among all.

**Kumar and Venkat (2016)** had carried out the study to observe the effect of lateral forces on pre-cast shear wall of a G+11 storey building using ETABS software. Effect of lateral load on out of plane moments, axial forces, shear forces, base shear, maximum storey drift and tensile forces in shear wall were plotted for all four seismic zones and for all wind zones. Model considered the shear wall thickness as 150mm. Result showed that the parameters had a non-linear behavior along height of building.

Difference in maximum out of plane moment between zone II and zone V was 29.25% and that in shear force was 27.77%, while maximum storey shear in storey one was found to be 907.77kN for zone II and 1958.46kN for zone V.

**Md. Samdani *et al.* (2016)** adopted a numerical approach to show dissimilarity between shear wall system and steel bracing system by considering East Malaysia as the corresponding region. Analysis was done on six different models by Etabs9.7 software. Model-1 and model-2 included only shear wall at mid portion and at side portion of building, respectively, model-3 and model-4 included only bracing at mid portion and at side portion of building, respectively and model-5 and model-6 included both bracings and shear wall at mid portion and at side portion of building. Method adopted was response spectrum analysis and UBC97 was used to implement the analytical parameters. The result of analysis showed that model-1 was the safest among six models as it showed the minimum deflection and drift along both the lateral directions, which again highlighted the dominant point regarding positioning of shear wall in buildings.

**Haque *et al.* (2018)** had studied the impact of the bracing system on the structural performance of steel building. In this research, a steel building of ten storied building has been designed and analyzed under seismic (lateral) loading. The performance of structure has carried out using various types of the bracing system these are X bracing, diagonal bracing and eccentric bracing. The different parameter has been selected for a comparative study these are storey displacement, storey drift, moment on beam at a different level between braced and un-braced system. ETAB software has been used for the comparative study of 10 storied steel building. From the study it was found out that, X bracing reduced the lateral displacement of the structure by 41% and provide greater structural stiffness to the structure. The researcher concluded that X bracing gives better performance than another type of bracing under similar circumstances.

**Hosseini and Rao (2018)** had studied the effect of earthquake load on column forces in concrete frame structure with different types of shear wall under different soil conditions. The soil types considered were: hard soil, Medium soil and Soft soil. For study thirty-storey buildings with C-shape, Box-shape, E-shape, I-shape and Plus shape

RC shear wall for earthquake zone-V were analysed using software ETABS. Column axial force, column moment, column shear force, column torsion, time period and frequency and modal load participation ratios were estimated by response spectrum analysis as per IS1893:2002(part-1). Five models, one-five, considered were of dual frame system with shear wall of: plus, box, C, E and I shape respectively. Result showed that maximum time period was for model-3, 6.415sec and minimum for model-2, 5.785sec. Similarly frequency was maximum in case of model-2, 0.176cyc/sec, and least for model-3, 0.156cyc/sec. All these values were found to be same in all soil types. Study reported that shear wall position had significant influence on time period and Box-shape wall was most efficient with least time period. It was also reported that column moment and torsion were influenced by type of soil and positioning of shear wall and maximum model mass was 94.7% for model-2 and minimum 86.71% for model-1. Result recommended that uniformly distributed vertical reinforcement should not be less than horizontal reinforcement, particularly when height-width ratio is about 1.0.

**Reddy and Kumar (2018)** modelled a G+9 RCC framed building in three parts; model without steel bracing and shear wall, model with different bracing system and model with shear walls, to study the effectiveness of steel bracing systems in resisting earthquake load. These models were analysed for seismic forces at different zones using ETAB software and the performance was studied by considering lateral displacement, storey shear and storey drift as parameters. Result showed that chevron type bracing with shear wall was more efficient in zone II and III while X type with shear wall was more efficient in zone IV and V. It also showed that steel bracings with shear wall were more efficient than only shear wall and the performance was enhanced by 15%-20% when compared to bare framed structure.

**Khan et al. (2019)** performed a comparative analysis of earthquake resisting techniques on a G+10 story building. The comparison is done between an un-Resisting structure, X-shaped bracings, diagonal bracings, parallel shear walls, L-shaped shear walls and V-shaped bracings for seismic zone III as per IS1893:2002(part-1) using STAAD Pro. Software. The analysis result showed that maximum deflection got reduced significantly in both shear wall and bracing cases compared to bare structure, while deflection was least in X-bracing type structure. Similarly in case of storey shear and axial force X type bracing was found to be most efficient comparatively.

### 2.3 Summary

The following descriptions present a brief overview of the literature by reviewing the different literature on different types of shear wall system for the multistoried RC frame in a high seismic area.

- All the studies have supported the fact of providing shear wall symmetrically with respect to all the axis.
- The performance of structure has been carried out using various types of the shear wall system, which include L-shape, C-shape, E-shape, I-shape among various types, to study the best suited one. In most of the case L-shaped external shear wall and box shaped core shear wall are most efficient.
- Concrete bracing and steel bracing have been used as an alternative to the other for strengthening. It was found that X type of concrete bracing for reducing storey displacement and V types of steel bracing is most efficient for reducing storey displacement. In concrete X bracing system and steel frame, V bracing system on all the side of the building as well as on any two sides of the building increases base shear by 60 to 65%.
- There was a significant increment in base shear of the braced frame compared to the bare frame structure.
- For different types of bracing system weight of the structure are more when compared to the unbraced structure with the same configuration of the structure.



*Materials  
and  
Methods*



**3.1 General**

The response of the structure to earthquakes is a dynamic phenomenon that relies on structural dynamic attributes and the intensity, duration, and frequency of exciting ground shaking. Because the action of the earthquake is dynamic in nature, it is used in practise to carry out dynamic studies of high buildings and of asymmetrical/irregular structures due to its superiority in more precisely reflecting earthquake response when used properly. These studies often include a large number of analyses under different ground motion record and different structural parameters to provide insight into the structural behaviour. In the present study linear dynamic analysis of the models is carried out by Response Spectrum Method. Shear walls are provide at two exterior locations (L-shape and flat-rectangular shape) and at three interior locations (Box, I and + shape) to observe the performance of the building by studying different parameters, namely, Time Period, Base Shear, Lateral Deflection, Storey Drift and Maximum Bending Moment.

**3.1.1 Time Period**

It is the time taken by building in one complete oscillation. Time period of a building is its inherent property whose value gets affected by any change in following; the mass of the building, building's stiffness, building's height, column orientation in structure, infill walls with masonry only (i.e. without reinforcement) etc. Increased stiffness reduces the natural time period while increased mass increases it.

**3.1.2 Base Shear**

It is the estimated value of the maximum force that would occur at the base of the building in the lateral direction due to ground motion effect of earthquake. Here, the base is the level at which inertia forces generated in the building are considered to be transferred to the ground through the foundation.

**3.1.3 Bending Moment**

As the transverse external force is applied to the columns, causing the element to bend from its original axis, then the induced incident is called bending moment.

When a shear force is zero at that section or switches the symbol, the highest bending moment occurs at that section in the column.

### 3.1.4 Top Storey Displacement

Storey displacement is measure of the deflection or deviation of the structural element from its original/un-deflected position at each floor/roof level.  $\Delta_1$  and  $\Delta_2$  are displacements at two stories sown in figure 3.1

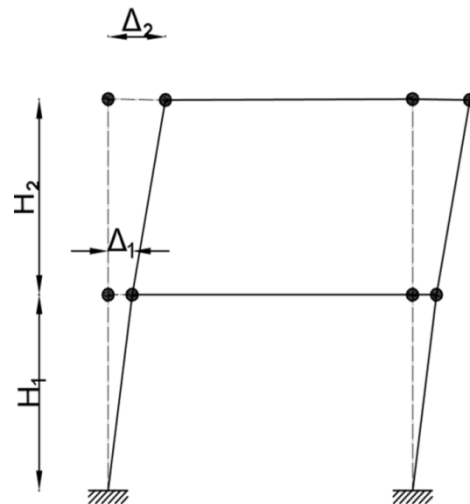


**Fig. 3.1 Storey Displacement in Frame**

### 3.1.5 Storey Drift

Drift value for a storey is the relative displacement between the floors above and/or below the storey under consideration.

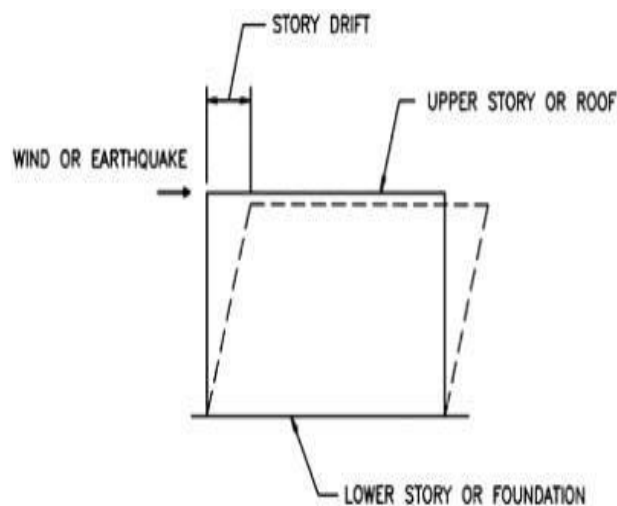
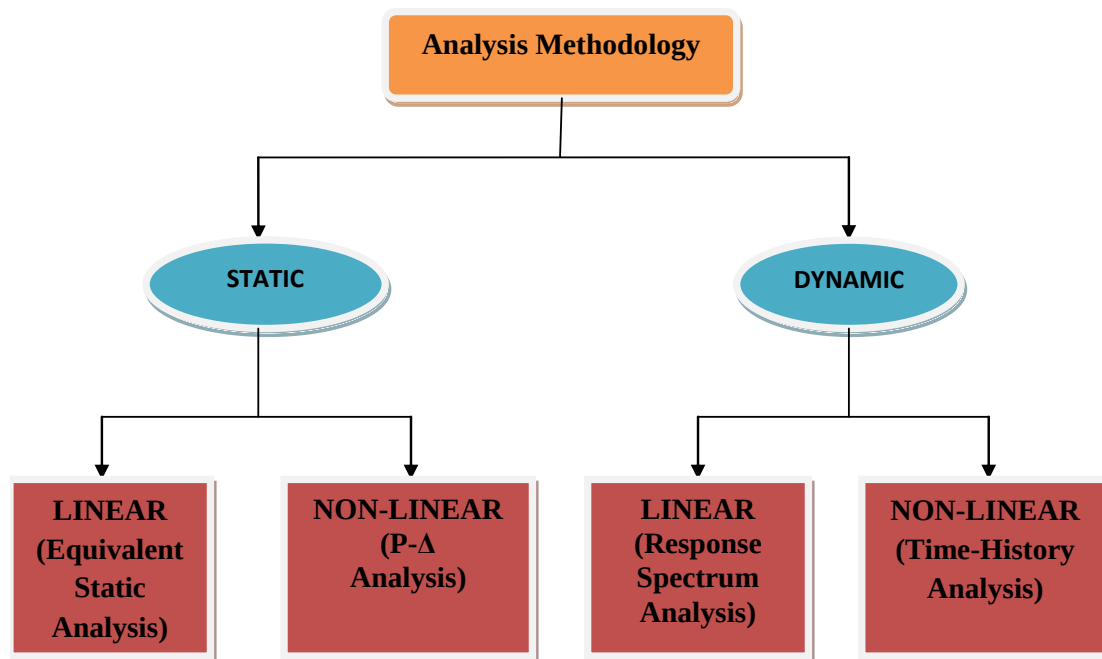


**Fig. 3.2 Storey Drift of the Frame**

### 3.1.6 Mass Participation Factor (MPF)

Modal mass, in a particular mode 'k', is a part of the total seismic mass of the structure that is effective in natural mode 'k' of oscillation during horizontal or vertical ground motion and the amount by which natural mode k contributes to overall oscillation of the structure during horizontal and vertical ground motion is called modal participation factor. So, basically mass participation factor represents the percentage of the system mass that participates in a particular mode. It provides a measure of the energy contained within each resonant mode. A mode with a large MPF is usually a significant contributor to the dynamic response of a system.

### 3.2 Methods for Seismic Analysis



IS 1893 (Part 1):2016 is the principle code that gives an outline for computing earthquake design forces on buildings. Depending on the buildings height and earthquake zone to which it belongs, different analysis methodology (static and dynamic) can be taken for earthquake analysis of RCC frames.

#### 3.2.1 Linear Static Analysis

**Seismic Coefficient Method/Equivalent Static Analysis (ESA):** For an earthquake, the equivalent lateral force (static force) is a unique concept used in earthquake engineering. The concept looks attractive as it converts a dynamic analysis into a

partially dynamic analysis and then evaluates the maximum displacement/movement and/or stresses caused by the earthquake in the structure. The earthquake's equivalent horizontal/lateral force is known as a collection of lateral static forces that will produce the same structure's peak response as the structure's dynamic analysis during same earthquake. This equivalence is strictly restricted to a single mode of structure vibration. As this method does not demonstrate the correct response of the earthquake, it uses the following assumptions while performing the analysis;

- It assumes complete rigidity for the structure.
- Perfect fixity between structure or super structure and foundation is assumed.
- It is assumed that each point on the structure experiences the same accelerations during ground motion.
- An earthquake's dominant effect is similar to the horizontal force with varying magnitude along the height of the structure.
- Determined total Base Shear on the structure is an approximated value.

#### **Advantages of ESA:**

1. Calculations are very simple and handy.
2. This is less time consuming.

Static analysis approach should only be used for regular, symmetrical buildings up to around 25m height and where the primary mode of the structure governs the structural dynamics. This is not suitable for other buildings which are having irregularities in their plan and elevation. Apart from these limitations, this method has following Disadvantages;

1. This method does not represent the correct picture of earthquake load distribution, which is more logical in RSM.
2. First, the design value of the base shear is computed for the entire building. It is then allocated along with the building's height.

#### **3.2.2 Linear Dynamic Analysis (LDA):**

The dynamic procedure is necessary for tall buildings, for buildings having torsion irregularities or for non-orthogonal structures. The building is simulated as a

multi-degree-of-freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix in the linear dynamic method.

The earthquake data is modelled whether using modal spectral analysis or time history analysis, but linear elastic analysis determines the associated internal forces and lateral displacements in both cases. With respect to linear static (ESA) procedures, the additional benefit of these linear dynamic methodologies is that higher modes can be considered. They are, however, based on linear elastic response, and therefore the usefulness decreases with increasing non-linear performance, which is quantified by factors of global force reduction.

The response of the structure to wave propagation is assessed in the time domain in linear dynamic analysis (LDA), and all phase information is therefore retained. There are only linear characteristics presumed. The method of analysis can use modal decomposition as a means of dipping the degree of freedom in the analysis.

### **Response Spectrum Analysis:**

Response-spectrum analysis (RSA) is a method of linear-dynamic statistical analysis that assesses the contribution of every natural vibration mode to indicate the probable maximum earthquake response of a structure that is essentially elastic. In this response spectrum analysis (RSA) the spectral values are obtained from the design spectrum that are multiplied with the modal load vector and the LS-Analysis is carried out to determine the respective modal peak responses. This method is referred as classical modal analysis.

In this present method, the multi-degree-of-freedom (MDOF) system response is expressed as the modal response superposition, determining each modal response from the single-degree-of-freedom (SDOF) system spectral analysis, which is then integrated to calculate the total response.

Given its natural oscillation frequency, the response spectrum can then be used to pick-off any linear system's response. One such use is to evaluate the peak earthquake response of buildings. Dynamic analysis of the system gives the mode shapes and frequencies of the structure and has to solve an Eigen value problem. The provisions of codes per IS: 1893 (Part-1)-2016 for response spectrum analysis of the multi-storey building.

To minimize some of the disadvantages of RSM, it is necessary to combine the model responses. Out of the several ways to carry out this, two popular ways are SRSS and CQC methods;

**SRSS (Square Root of Sum of Squares):** This is one of the most frequently used modal combination methods. According to this rule the maximum response in terms of a given parameter (displacements, velocities, accelerations or even internal forces) may be estimated through the square root of the sum of the modal response squares, contributing to the global response.

$$\lambda = \sqrt{\sum_{k=1}^r \lambda_k^2}$$

Where,

$\lambda_k$  = absolute value of quantity in mode k

r = number of modes being considered

This method usually gives good results if the modal frequencies of the modes contributing for the global response are sufficiently separated to each other. Otherwise another method, such as the one following, will be more adequate.

**CQC (Complete Quadratic Combination):** The reason why this method is more effective in evaluating the maximum response when the modal frequencies are close to each other is due to the fact that it considers the correlation between modal responses, whereas the SRSS method considers these to be independent. In fact if two vibration modes have close frequencies their contribution to the global response is not independent.

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

Where,

$\lambda_i$  = response quantity in mode i

$\lambda_j$  = response quantity in mode j

$\rho_{ij}$  = cross-modal coefficient

$$\rho_{ij} = \frac{8\zeta^2(1+\beta)\beta^{1.5}}{(1+\beta^2)+4\zeta^2\beta(1+\beta)^2}$$

Where,

$\zeta$  = modal damping ratio

$\beta$  = frequency ratio = ( $\omega_j / \omega_i$ )

$\omega_i$  = circular frequency in  $i^{\text{th}}$  mode

$\omega_j$  = circular frequency in  $j^{\text{th}}$  mode

### Procedure for Response spectrum method:-

#### Step 1: Zone factor (Z) determination

With the help of IS 1893 (Part 1):2016 select zone factor (Z) is by identifying the earthquake zone depending on the location of the building.

**Table 3.1 Zone Factor, Z**

| Earthquake Zone | II   | III  | IV          | V    |
|-----------------|------|------|-------------|------|
| Zone Factor     | 0.10 | 0.16 | <b>0.24</b> | 0.36 |

#### Step 2: Seismic Weight (W) calculation

Seismic weight (W), to be calculated, includes complete dead load and IS code recommended percentage of imposed/live load. IS 1893:2016 recommends 25% of live load if it is up-to  $3\text{kN/m}^2$ , and 50% for imposed load being higher than  $3\text{kN/m}^2$ .

In general, seismic weight of entire building is the total of seismic weights with all floors where seismic weight of single floor is the total of D.L. of the floor, specific contributions of weights of vertical beams, walls and all other fixed/permanent items from the storeys above and below, finishes and services, and relevant quantities of designated L.L. on the floor.

#### Step 3: Determination of Fundamental Natural Time Period ( $T_a$ )

In clause number 7.6.2 IS code 1893:2016 gives fundamental time period for RC Frame building for two cases;

$$T_a = 0.075h^{0.75} \text{ (Without brick infill panel), and}$$

$$T_a = 0.09h/\sqrt{d} \text{ (With brick infill panel)}$$

Where,

h= height of building (meter).

d = Building's Base dimension at the plinth level (meter) along lateral force direction.

#### Step 4: Design horizontal Seismic Coefficient ( $A_h$ )

$$A_h = \left[ \frac{S_a}{g} \times \frac{Z}{2} \right] / \left[ \frac{R}{I} \right]$$

Where,

Z = Zone factor as obtained in step1

I = Importance factor

R = Response reduction factor

$S_a/g$  = Average response acceleration coefficient

**Table 3.2 Importance Factor, I**

| Structure                                                                                                                                                                                                                 | Importance Factor |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
| Important community and service structures, lifeline and emergency buildings (television and radio stations), railway stations, airports, food storage buildings, fuel and power station buildings, large community halls | 1.5               |
| All other buildings                                                                                                                                                                                                       | 1                 |

**Table 3.3 Response Reduction factor (R)**

| Building Type                                                   | R        |
|-----------------------------------------------------------------|----------|
| Ordinary Reinforce Concrete moment-resisting frame (OMRF)       | 3        |
| <b>Special Reinforce Concrete moment-resisting frame (SMRF)</b> | <b>5</b> |

**Table 3.4 Response Acceleration Coefficient ( $S_a/g$ )**

| Nature of soil Sites | ( $S_a / g$ )                         |
|----------------------|---------------------------------------|
| Rocky or Hard Soil   | $1+15T; \quad 0.00 \leq T \leq 0.10$  |
|                      | $2.5; \quad 0.10 \leq T \leq 0.40$    |
|                      | $1.00/T; \quad 0.40 \leq T \leq 4.00$ |
| Medium Soil          | $1+15T; \quad 0.00 \leq T \leq 0.10$  |
|                      | $2.5; \quad 0.10 \leq T \leq 0.55$    |
|                      | $1.36/T; \quad 0.55 \leq T \leq 4.00$ |
| Soft Soil            | $1+15T; \quad 0.00 \leq T \leq 0.10$  |
|                      | $2.5; \quad 0.10 \leq T \leq 0.67$    |
|                      | $1.67/T; \quad 0.67 \leq T \leq 4.00$ |

**Step 5: Calculation of design Base Shear ( $V_b$ )**

Base Shear is obtained from the product of seismic weight of the building and horizontal seismic coefficient.

$$V_b = A_h \times W$$

**Step 6:** The design base shear ( $V_b$ ) computed in step 5, will be allocated along the height of the buildings as per the following equation as suggested by IS 1893:2016 Clause 7.6.3

$$Q_i = V_b \{ (W_i h_i^2) / (\sum W_j h_j^2) \}$$

**Step 7:** Establish the structure's mass [M] and stiffness [K] matrices using a system of masses lumped at floor level with SDOF for each mass.

**Step 8:** Using step 4 and operation of the principles of dynamics calculate the modal frequency  $\{\omega\}$  and corresponding mode shape  $\{\phi\}$ .

**Step 9:** we can find the modal mass  $M_K$  of mode k using the following relationship where n is the number of modes.

$$M_K = \frac{[\sum_{i=1}^n W_i \phi_{ik}]^2}{[g \sum_{i=1}^n W_i \phi_{ik}^2]} \quad \text{as per clause 7.7.5.4a of IS 1893 (Part 1):2016}$$

Where,

$g$  = acceleration due to gravity

$\phi_{ik}$  = Mode shape coefficient at  $i^{\text{th}}$  floor in mode  $k$ .

$W_i$  = Seismic weight of  $i^{\text{th}}$  floor of the structure.

**Step 10:** Calculate modal participation factor  $P_k$  of mode  $k$  using the following relation where  $n$  is a number of modes considered,

$$P_K = \frac{\sum_{i=1}^n W_i \phi_{ik}}{\sum_{i=1}^n W_i \phi_{ik}^2} \quad \text{as per clause 7.7.5.4b of IS 1893 (Part 1):2016}$$

**Step 11:** Compute design lateral force ( $Q_{ik}$ ) at each floor in each mode (i.e. for the  $i^{\text{th}}$  floor in mode  $k$ ) using the following relationship.

$$Q_{ik} = A_{h(K)} \phi_{ik} P_k W_i \quad \text{as per clause 7.7.5.4c of IS 1893 (Part 1):2016}$$

**Step 12:** Calculate storey shear forces due to all modes considered,  $V_i$  in the storey  $i$ , by combining shear forces due to each mode in accordance with clause 7.7.5.3 of IS 1893:2016 i.e. either CQC or SRSS modal combination method are used.

While, peak storey shear force ( $V_{ik}$ ) in storey  $i$  in mode  $k$  is given by;

$$V_{ik} = \sum_{j=i+1}^n Q_{ik}$$

**Step 13:** Finally compute design lateral forces at each storey as

$$F_{roof} = V_{roof}$$

and

$$F_i = V_i - V_{i+1}$$

This method represents the correct picture of earthquake load distribution up to an elastic limit, which is more logical in Response spectrum method. This method can be applied for high rise buildings with irregular plans.

**Time History Analysis (Response History Analysis):** Dynamic analysis using the time history analysis calculates the building responses at discrete time steps using discrete record of synthetic time history as base motion. If three or more time history

analyses are performed, only the maximum responses of the parameter of interest are selected.

### 3.2.3 Non-Linear Static Analysis (P- $\Delta$ Analysis)

Non-linear static analysis of frame shear wall (non-staggered) and staggered shear wall panel emphasizes on lateral stiffness, ductility, strength and drift control to prevent possible damages followed by complete collapse. As structures become increasingly slender and less resistant to deformation, then there is a need to consider second order analysis and to be more precise need of P- $\Delta$  effects arises. As a result, multi-country codes of practise refer engineers to use the second order analysis more and more in order to account for P- $\Delta$  effect and stress stiffening impacts when acceptable in design.

In every structure where elements are subjected to axial load, a non-linear P- $\Delta$  effect occurs. It is a legitimate effect linked to the intensity of the axial load applied and the displacement. The degree of the P- $\Delta$  effect is associated to the

- (i) magnitude of the axial load,
- (ii) slenderness of the structure as a whole,
- (iii) slenderness of the individual elements.

In linear analysis of structures, the equations of equilibrium are based on the undeformed geometry existing before load application. This is sufficiently accurate for many practical cases. However, the frames with slender members may have large deformations, so that it is necessary to consider equilibrium in the real deformed configurations. This requires non-linear analysis involving iteration, which can be done using Newton-Raphson technique. The equilibrium equations are based on trial displacement values, whose accuracy is improved by iterations, so as to satisfy the equilibrium of the nodes or the members in their displaced positions or their deformed shapes. Non-linearity caused by large deformations is referred to as geometric non-linearity. A member subjected to large axial force combined with transverse loads or to transverse end translation or rotation represents a geometric non-linear problem, frequently referred to as a beam-column problem or casually, a P-  $\Delta$  problem.

### **3.2.4 Non-Linear Dynamic Analysis**

This is the most efficient method for determining structures' earthquake responses. The structure is subjected to actual ground movement in this method, which is the portrayal of the acceleration vs. time of the ground. To provide the ground motion record, the ground acceleration is evaluated at a small time stage. Then, at every moment, the structural response is calculated to assess its time history and the maximum value from this time history is selected as the design demand. Therefore, a Mathematical model explicitly integrating the non-linear characteristic of each and every component and element of the building shall be put-through the earthquake shaking portrayed by ground by ground motion time history to obtain the forces and the displacement (FEMA 356). Since the effect of material nonlinearity is directly accounted for by the numerical model, inelastic responses and calculated internal forces are reasonably close to those anticipated during the earthquake design. Following are two different methods by which the THA (time history analysis) is carried out:

A. Non-linear Modal Time History Analysis

B. Non-linear Direct Integration Time History Analysis.

## **3.3 Load Description**

The structure should always be designed in such a way that it should be sufficiently strong to tolerate any kind of load at any time which is likely to occur in its lifespan. Different types of loads can cause stress, displacement and displacement on a structure which causes a problem in the structure and may increase the chances of failure of the structure. So, the estimation of the total load that likely to occur in structure is calculated accurately and structural elements should be designed properly. The types of load that occur in the structure are Dead Load (DL), Live Load/ imposed load (LL/IL), Wind Load (WL) and Earthquake Load (EL). Indian Standard (IS) codes provide the information of all types of loads for the design of structures and discussed in the subsequent section.

### **3.3.1 Dead Load**

Dead load also called as permanent load are mainly associated with the weight of the structure and are always at rest and always constant with time. Dead loads

include the self-weight of any structural element i.e. partition wall, beam column, slab, etc. and any types of floor/ roof finishing. It is calculated by finding the quantity of each material and then multiplied it with the unit weight of that specific material. The unit weight of Reinforced concrete is  $25\text{kN/m}^3$ . Dead loads for various materials being considered in analysis and design to have taken from the IS 875:1987 (part1). In the present analysis, a dead load of  $3\text{ kN/m}^2$  on floor/ roof is used.

### **3.3.2 Live Load**

Live load is also called as imposed loads are usually temporary and changeable. Its intensity depends on the time of the day at one time room may be empty that time the live load is zero. Another example of an office building which experience increased live load during the weak hour and less live load during the weekend. These include loads such as furniture; occupants and other equipment. Live loads may be concentrated or distributed.

In the present analysis live load used as  $4\text{kN/m}^2$ . The codal provision which has been used for live load is given in IS 875(part 2) 1987. Imposed floor loads for different occupancies have been given in table 1(clauses 3.1, 3.1.1 and 4.1.1) of IS 875(part 2) 1987. Live load to be considered in the calculation of the earthquake weight of building as per IS 1893:2016 load up to and including  $3\text{kN/m}^2$  percentage of imposed load is 25% and above  $3\text{kN/m}^2$  percentage of imposed load 50%.

### **3.3.3 Earthquake Load**

Earthquake force comprises both vertical and horizontal forces in the building. The total vibration brought by an earthquake is recorded into three mutually perpendicular directions normally taken as vertical and two horizontal directions viz., N-S and E-W as shown in Fig.3.2. The vertical direction earthquake forces do not cause any significant damages to structures while the effect of horizontal earthquake forces on structures is devastating if not considered in the analysis of structures. The structural stability due to ground vibration depends on the nature of foundation soil, size of the foundation, mode of construction and intensity of ground motion. IS 1893 (Part 1):2016 has been used for calculation of earthquake forces.

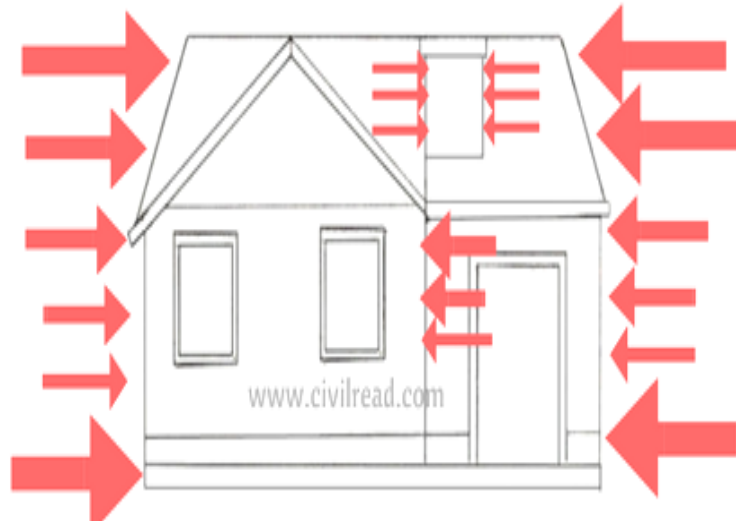


**Fig. 3.3 Earthquake Load on the Structure**

### 3.3.4 Load Combination

A load combination is provided when more than one load types act on the structure. Building codes usually indicate a variety of load combination together with load factors for each load types in order to ensure the safety of the structure under different maximum loading situation. The combination of different loads which produce an adverse effect in the structure may be adopted for the analysis.

As per IS 1893(part 1):2016 clause no. 6.3.2.2 the following load cases have to be considered for analysis.

$$1.5(DL+IL)$$

$$1.2(DL+IL+EL)$$

$$1.2(DL+IL-EL)$$

$$1.5(DL+ EL)$$

$$1.5(DL- EL)$$

$$0.9DL+ 1.5EL$$

$$0.9DL- 1.5EL$$

DL = Dead load, IL = Imposed load / Live load, & EL = Earthquake load

### 3.4 Model Description

In the following contents details of the bare RC frame model and models with shear wall have been described by explaining the geometry of the structures and showing various figures of plan view and 3-d view of the models. Orientation of the different models is taken same for all cases and is selected in a pattern where both the lateral/horizontal directions are represented by X and Z axis while vertical direction is represented by Y direction, as shown in figure 3.4.

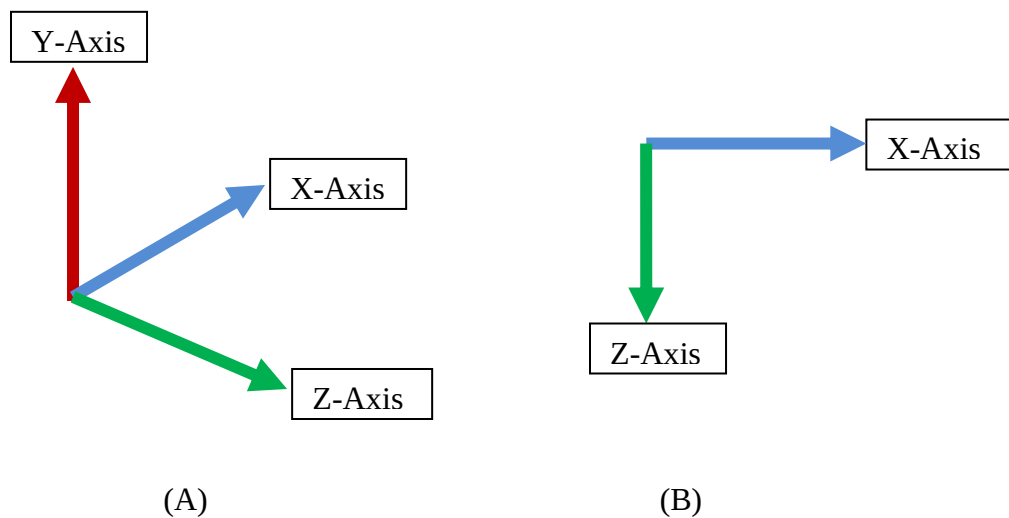


**Fig. 3.4 Axes orientation for different models (A) isometric view (B) plan view**

#### 3.4.1 Model-1

##### **Bare RC Frame Building:**

A G+14 storey RC frame has been selected as a basic structural model and behaviour of this model under lateral loading is then taken as a basis for comparison with other models having shear walls. The Plan and elevation of the bare RC frame building are shown in Fig. 3.5 and Fig. 3.6 respectively. There are total 5 grid lines in both X and Z direction in the structural plan of the RC frame model of the structure and have 4-bays in both X and Z direction at a spacing of 3 m, i.e. it is a square plan building with plan size 12 m x 12 m. The total height of the building chosen is 45 m and 3 m being the height of each storey. The basic data/details of the selected building frame for analysis are listed in Table 3.5.

**Table 3.5 RC Frame Model Details Considered for the Analysis**

| <b>Geometry of the structure</b>         | <b>Detail/ value</b> |
|------------------------------------------|----------------------|
| Number of Grid in X & Z direction        | 5                    |
| Spacing of Grid lines in X & Z direction | 3m                   |
| Number of Storey                         | G+14                 |
| Typical Storey height                    | 3m                   |
| Ground Floor height                      | 3m                   |
| Size of Beams                            | 450 x 450mm          |
| Size of Columns                          | 600 x 600mm          |
| Shear Wall Thickness                     | 150mm                |
| Types of Soil                            | Medium               |
| Types of support                         | Fixed                |
| Seismic Zone                             | IV                   |
| Dead Load                                | 3kN/m <sup>2</sup>   |
| Impose Load                              | 4kN/m <sup>2</sup>   |
| Combination Method                       | CQC                  |
| Response Reduction Factor                | 5                    |
| Importance Factor(I)                     | 1                    |
| Damping Ratio                            | 5%                   |

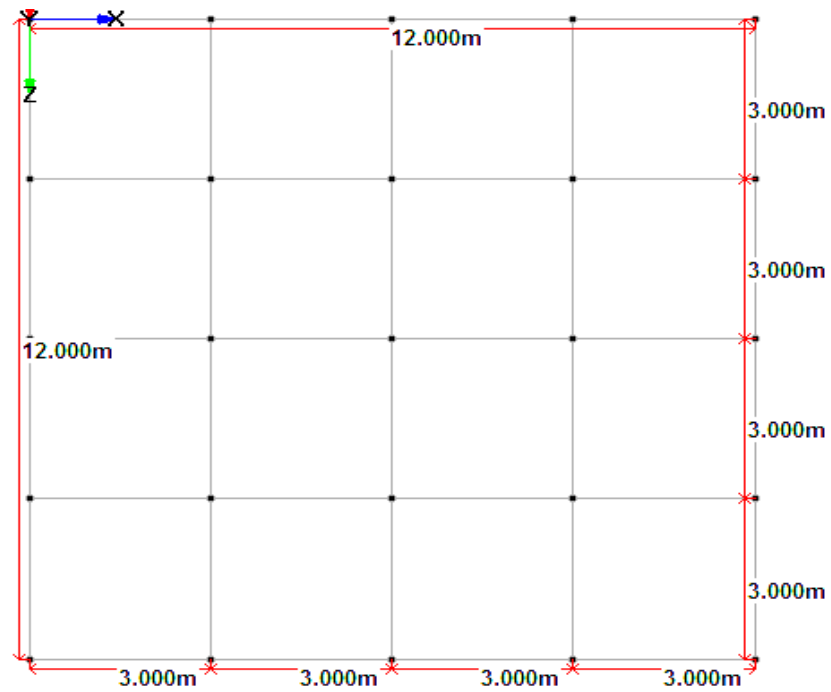


**Fig. 3.5 Structural Plan/Layout of RC Frame Model**

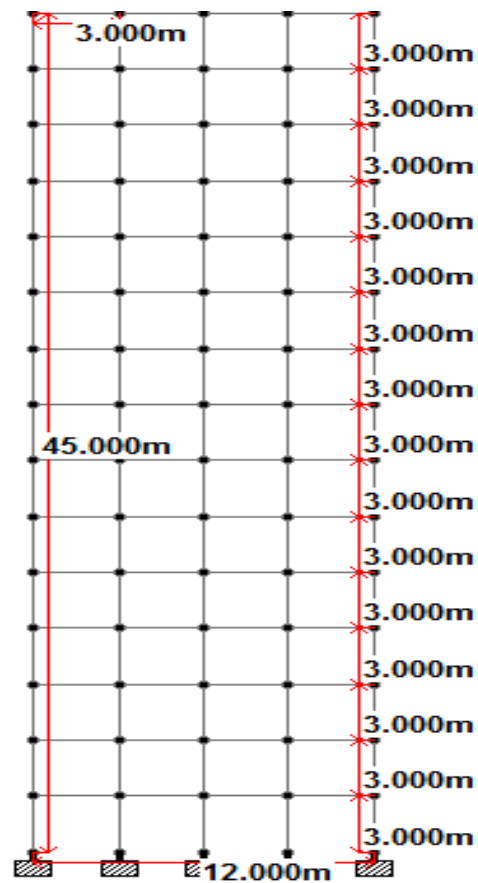


**Fig. 3.6 Structural Elevation of RC Frame Model**

### 3.4.2 Model-2

#### L-shape Shear Wall Building:

In this case the 45 meter tall bare frame building has been modified by providing shear walls at the all four corners of the building. The walls are applied in L-shape accompanying one bay along each X and Z direction at each corner. Thickness of the walls is taken 150mm and they run throughout the height of the building starting at the base level. Fig. 3.7 shows the top/plan view of the shear wall building while fig. 3.8(A) and fig. 3.8(B) shows 3-D isometric and rendered view of the building, respectively.

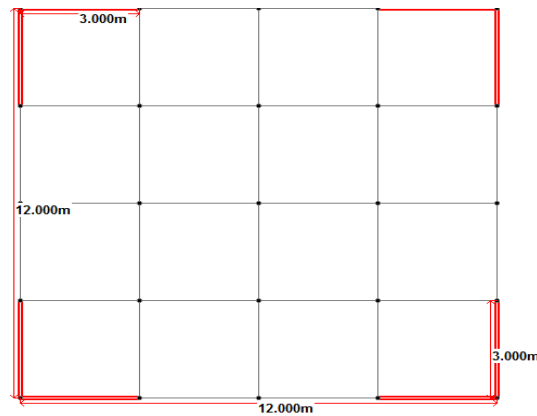


**Fig. 3.7 Top/plan view of L-shape shear wall building**

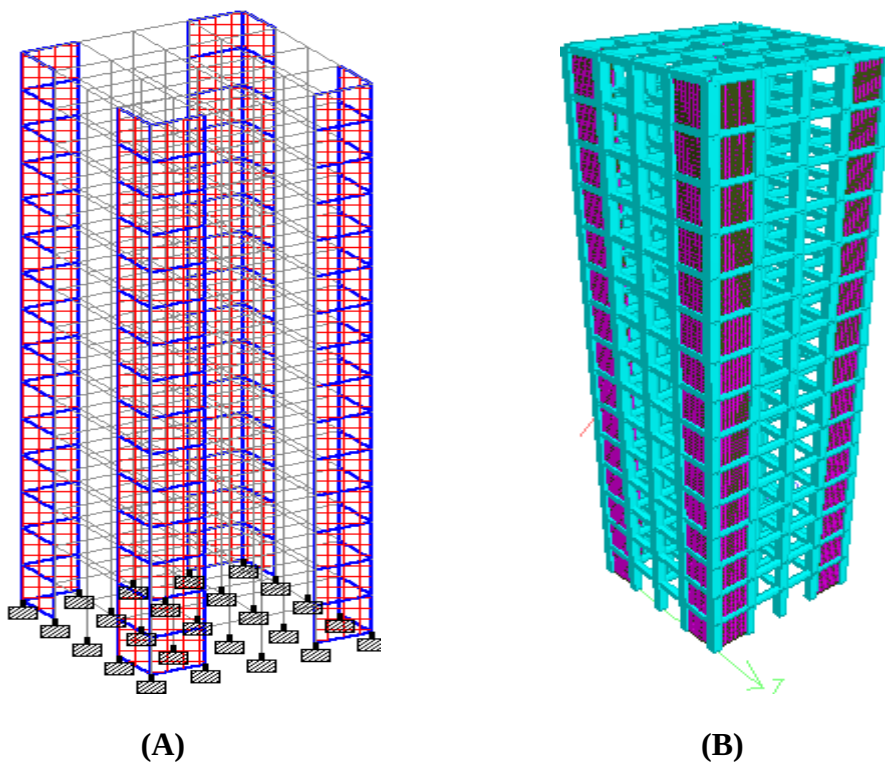


**Fig. 3.8 3-D view of L-shape shear wall building (A) isometric (B) rendered**

### 3.4.3 Model-3

#### Rectangular shape Shear Wall Building:

This model contains the shear walls at two central bays on the outer periphery of the frame at all four faces (X and Z faces) that looks like a flat plate at each face and rectangular shape is obtained when combined together. Shear walls thickness are taken same as 150mm. Fig. 3.9 shows the top/plan view of the shear wall building. 3-D isometric and 3-D rendered view of the building have been shown in fig. 3.10(A) and fig. 3.10(B), respectively.

Since the shear walls are provided on the outer bays of the building in the model-2 and model-3, these models are also termed as external shear wall buildings. Behaviour of these models will be compared separately with both model-1 and model-4, model-5 and model-6.

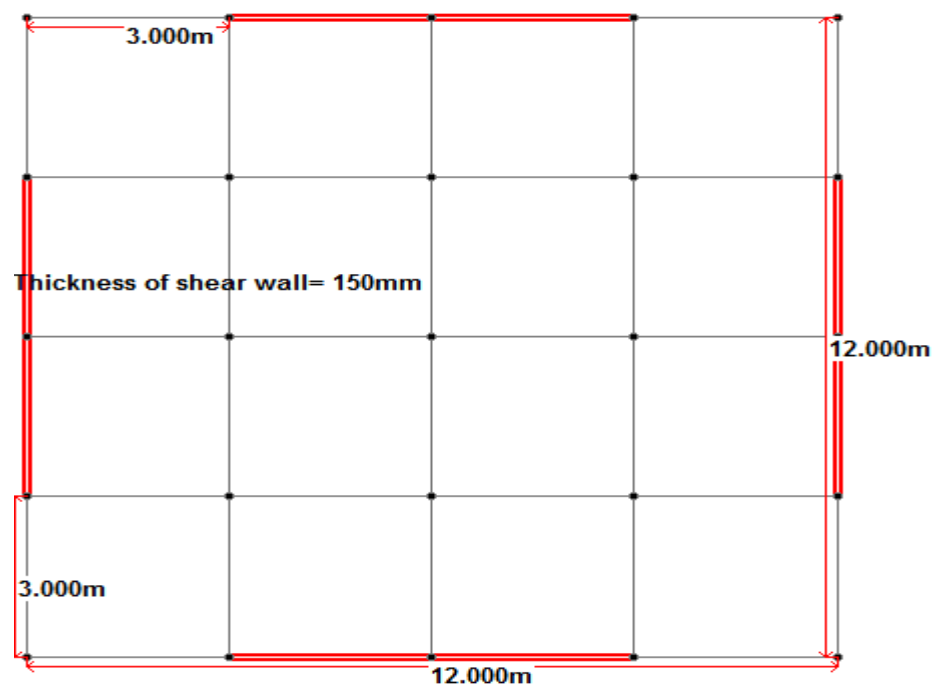


Fig. 3.9 Top/plan view of Rectangular shape shear wall building

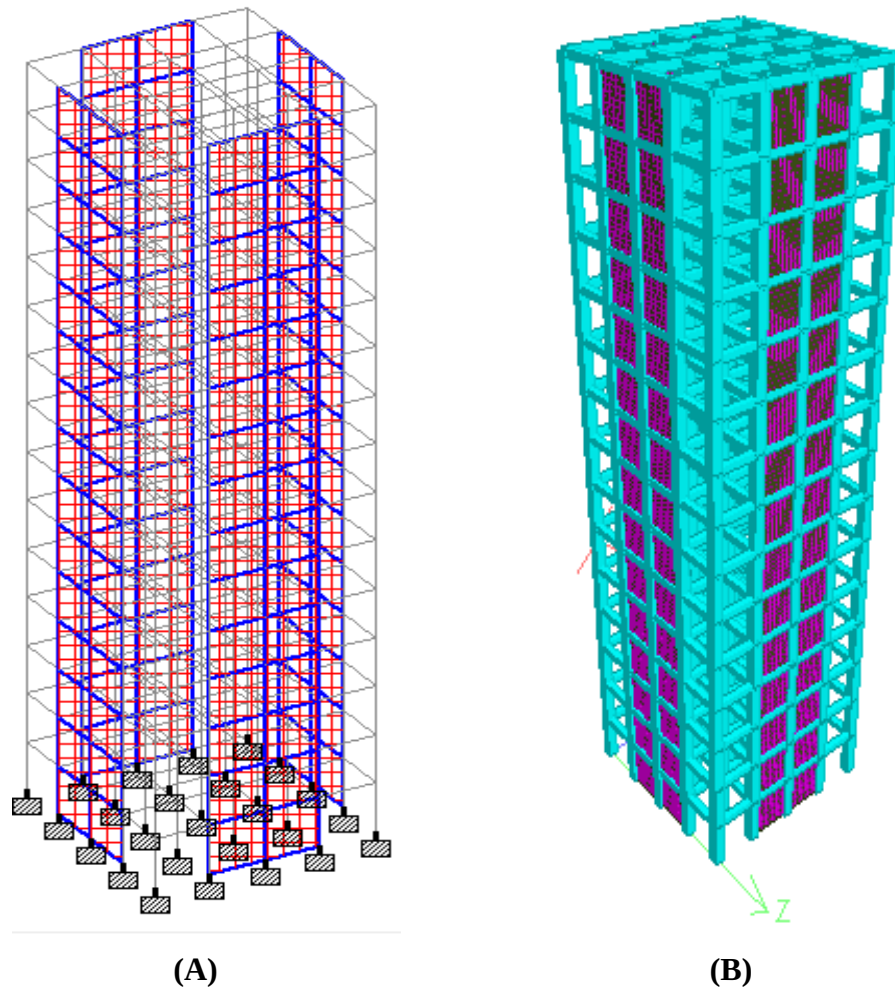
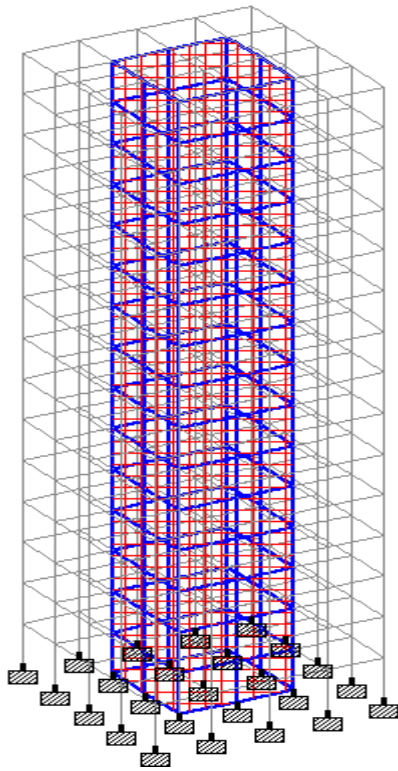


**Fig. 3.10 3-D view of Rectangular shear wall building (A) isometric (B) rendered**

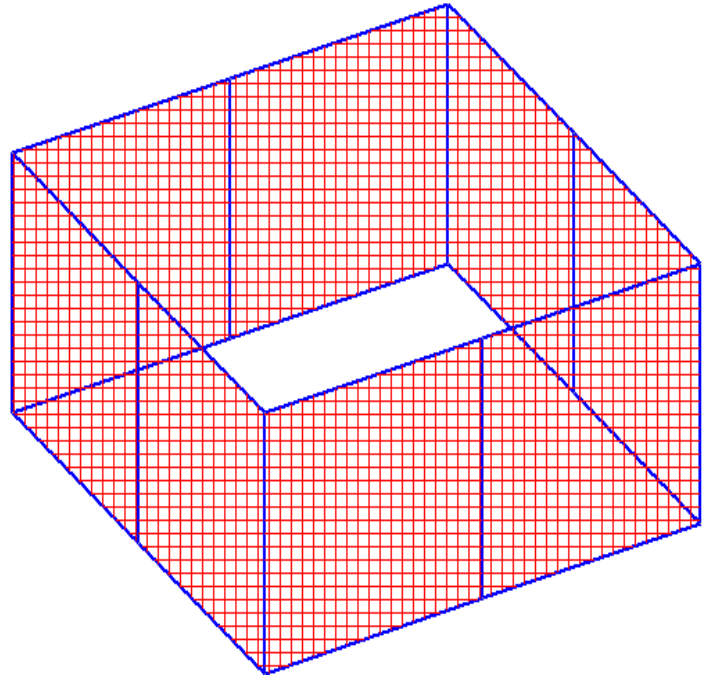
#### **3.4.4 Model-4**

##### **Box-shape Shear Wall Building:**

Shear walls are provided at the core of the building taking two bays on four faces along X and Z direction. The shape of the shear wall system looks like an open casing or a box and hence termed as box-shape shear wall building. Thickness of the walls is same as in external shear wall system i.e. 150mm. A 3-D isometric view of the complete structure with shear wall been shown in fig. 3.11(A) and a 3-D view of the shear wall shape has been show in fig. 3.11(B). Fig. 3.12 shows the top/plan view of the shear wall building.



(A)



(B)

**Fig. 3.11 Box-shape SW building with 3-D isometric view (A) whole structure (B) Shear Wall**

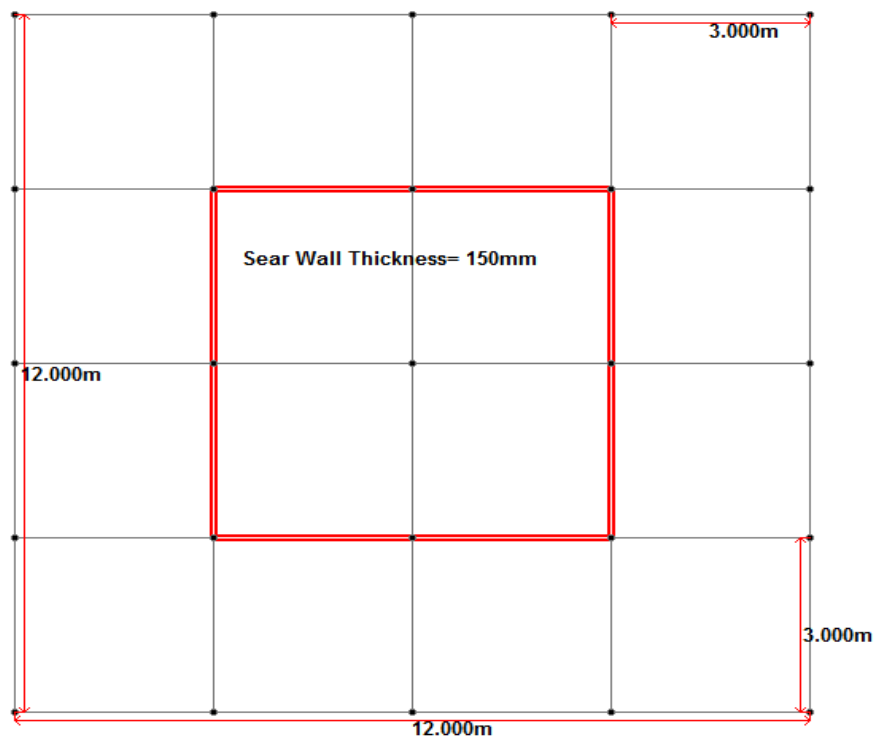


**Fig. 3.12 Top/plan view of Box-shape shear wall building**

### 3.4.5 Model-5

#### Plus-shape Shear Wall Building:

In this case bare frame building has been stiffened by providing shear wall at the very central core of the building. The walls are applied in plus-shape using three grids each along X and Z direction with one common grid at the very core of the building. Figure 3.13(A) and 3.13(B) shows 3-D isometric view of the whole structure with shear wall running from base to the top floor of building. Fig. 3.14 shows the top/plan view of the shear wall building.

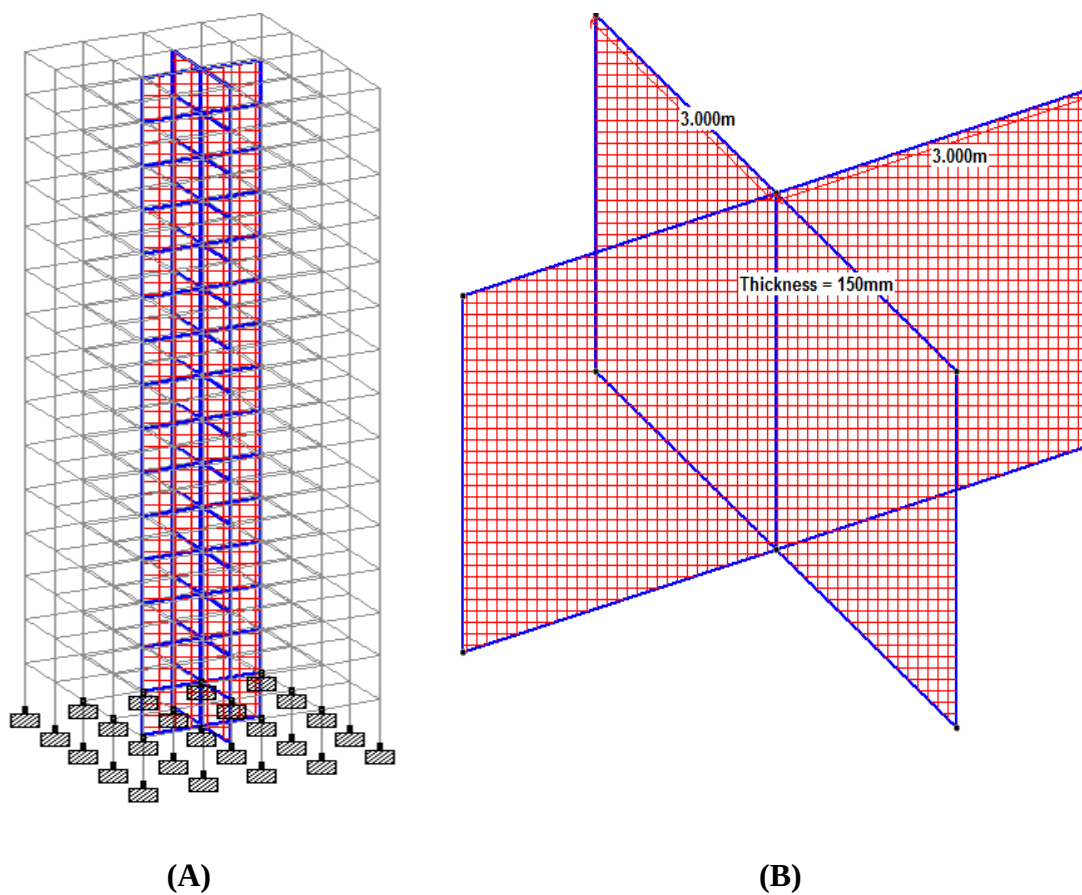


**Fig. 3.13 Plus-shape SW building with 3-D isometric view (A) whole structure  
(B) Shear Wall**

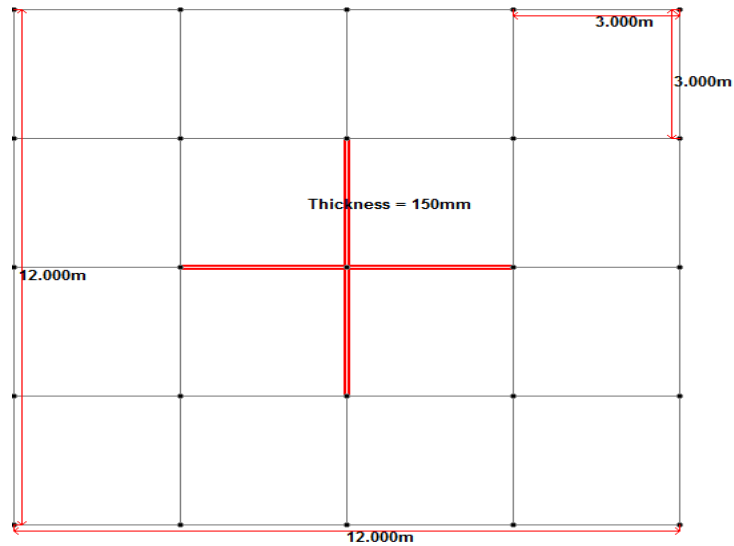


**Fig. 3.14 Top/plan view of Plus-shape shear wall building**

### 3.4.6 Model-6

#### I-shape Shear Wall Building:

Figure 3.15 shows the plan view of the building strengthened with I-shape shear wall. It can be seen from the figure that walls are provided on four bays, two bays each on opposite faces, along one lateral direction (X-direction) and on two bays along other lateral direction (Z-direction). In this case stiffness along X direction is more than that along Z direction. 3-D isometric view of the whole structure and the shape of shear wall has been shown in Fig. 3.16(A) and fig. 3.16(B), respectively.

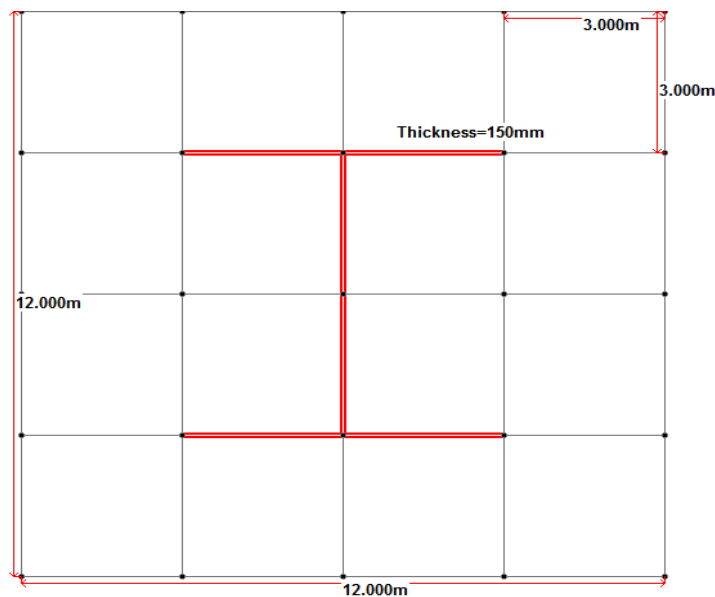


**Fig. 3.15 Top/plan view of I-shape shear wall building**

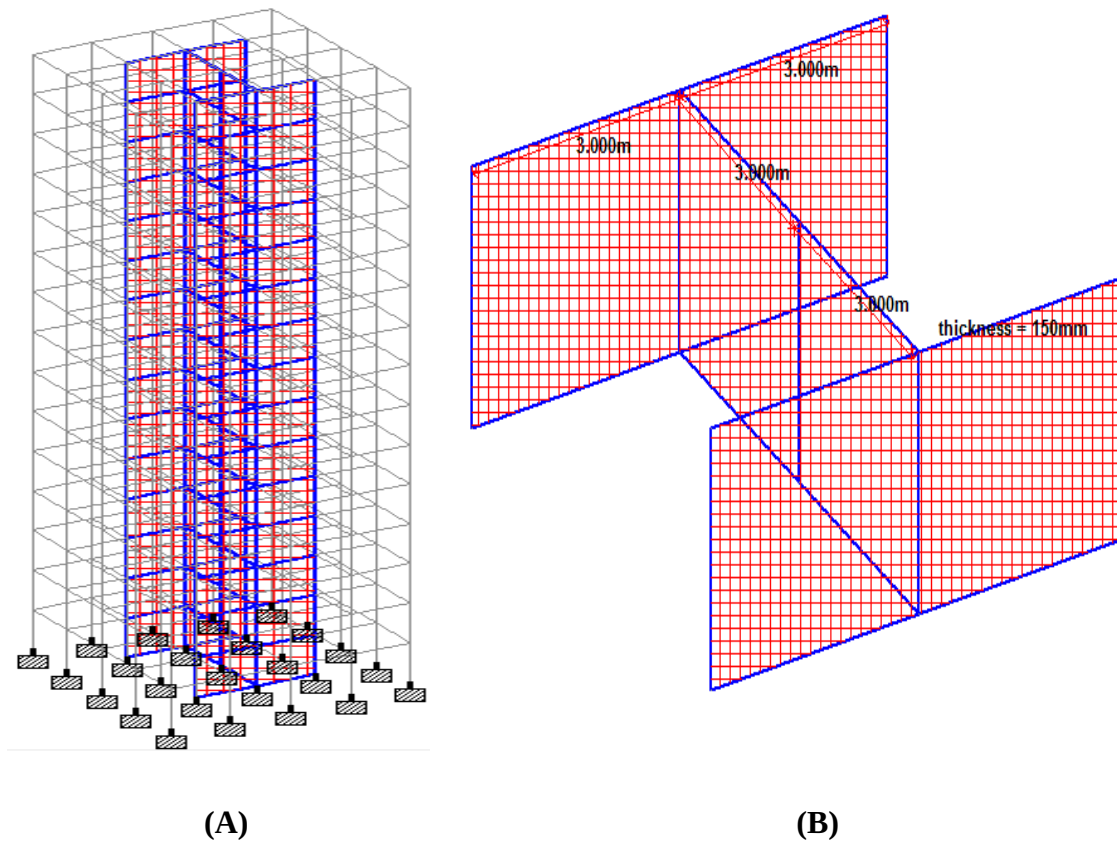


**Fig. 3.16 I-shape SW building with 3-D isometric view (A) whole structure (B) Shear Wall**

In these three models, i.e. model-4, model-5 and model-6, location of the shear walls is at the interior of the building frame and hence these are categorized as interior shear wall buildings.

### 3.5 Procedure of Analysis in STAAD. PRO

For analyzing and to study the effect of shear wall location on RC frame building under lateral forces occurred due to the effect of earthquake in earthquake zone IV, the following procedure is adopted.

#### Step 1: Select the structure type

- a) Select the space structure (3D framed structure) under a new project
- b) Give the file name and its location.
- c) SI units are chosen for the analysis i.e. meter for Length and kilo Newton for forces.

- d) Click next and select the add beam option.
- e) Click finish.

### **Step 2: Geometrical Modelling**

- a) Click on geometry option on the tool and select run structure wizard.
- b) Select the model type as frame models.
- c) Double click on the bay frame.
- d) Describe the length, width and height of frames and respectively provide bay along the length, width and height.
- e) Click apply and transfer this frame into the STAAD Pro and click yes.
- f) Give coordinate 0, 0, and 0 in X, Y and Z-direction and select ok.
- g) In snap node/beam in right hand side unselect the default grid.

Continue the step until the frame profile is obtained.

### **Step 3: Assigning section properties and material type**

- a) Go to general tab and define section from the property.
- b) Select the define option from the property and select the rectangular option and specify the value of beam and column.
- c) For shear wall select thickness database and in that select surface option and specify the thickness to be provided.
- d) Go to select beam and click on beam parallel to and select the respective direction.
- e) Click on assign to edit the list and click on assign.

### **Step 4: Assign of supports conditions**

- a) In general tab select support option.
- b) Click creates an option in the dialogue box.
- c) From all the support select fixed support and then add.
- d) Select the fixed support from the dialogue box and now select the node where fixed support has to provide.
- e) Click on assign to the selected node and click on apply.

### **Step 5: Assign different loads and load combinations**

- a) In general tab select load and definition.
- b) Click on the definition and select earthquake definition.
- c) Select code IS 1893-2002/2005 and give the parameter like zone, response reduction factor (R), importance factor (I), nature of soil and damping ratio.
- d) Assign the self-weight and floor weight and then close it.
- e) Then select load case detail and assign earthquake load, dead load and live load.
- f) In earthquake load give self-weight, floor weight in all direction (X, Y and Z)
- g) Select the earthquake load and click the add option after that one dialogue box will open in that select code and nature of soil.
- h) After that give the load combination by selecting add option in load case detail, a dialogue box will open select auto load combination after that select auto load combination.
- i) Generate the loads and click on add.

### **Step 6: Analysis of the frame**

- a) Click on the analysis/Print tab
- b) In analysis/print command select print option all and select add.
- c) Select the post print option.
- d) Click defines command.
- e) Select storey drifts value and click add.
- f) Click analysis in the task bar.
- g) Click save then click done.

### **Step 7: Exploration of analyzed results**

- a) To view the output results, choose view output file.
- b) Member forces due to different load combinations for each and every member can be seen through member forces all option.

- c) Click on Results option and view results by selecting Eigen solution, Mass Participation Factors, Analysis Results and Storey Drift option in STAAD Output Viewer.
- d) Mode shape, time v/s acceleration graph, time v/s velocity graph and time v/s displacement graph can be seen through a dynamic tab.
- e) To determine the deflection, bending, shear and axial force in any beam. Select the beam then go to the post processing section.
- f) Select the load case and then click ok.
- g) Go to result on the task bar, and then click view value and then select beam result after that annotate the value.

### **3.6 Summary**

This chapter briefly describes the various methods of seismic analysis viz. static and dynamic (linear and non-linear) and in detail step by step procedure of RSM analysis. The parameters that will be studied were talked over in the current chapter. Detail description of the load that occurs in the structure along with the load combinations were given in this chapter. Geometry of bare frame building and shear wall buildings were tabulated and shown by various diagrams that included dimensions of the different members of the RC frame buildings. Shapes and locations of five different types of shear walls were depicted through 3-dimensional isometric view of the models. Analysis procedure that is to be followed in STAAD. Pro.V8i software was also described step-wise.



# *Results and Discussion*



**4.1 General**

Results obtained from the analysis of various RC building models with various positioning of shear walls, as described in chapter 3, are being presented in this chapter. The results obtained from analysis for various parameters of study (detail in chapter 3) are listed in the form of tables and represented by graphs respectively. The plotted graphs indicate the trend and pattern of variables/parameters being considered in the present study work. Furthermore, these results will be studied to obtain the best building model depending on the comparative study of six parameters namely storey displacement, storey drift, time period, base shear, maximum bending moment and modal mass participation factor. The behaviour/performance of the building frameworks, with and without shear walls, in seismic zone IV is assessed by comparing the setup of shear wall in various locations in the plan of building.

Arrangements of shear wall provided in the building plan in five locations are in L-shape, rectangular shape, box-shape, plus-shape and I-shape. Thus, there are six number of model (including bare frame) that have been considered in this present study and explained in detail in chapter 3.

Interpretation of results to study the behaviour and performance of the models are being discussed in two forms as follows;

- A. Comparison of bare frame building structure with shear wall building structures.
- B. Comparison of external shear wall building model with internal shear wall building model.

STAAD. Pro V8i software is being used to obtain the results and the graphs are drawn with the help of micro-soft excel software.

**4.2 Storey Displacement**

This parameter represents the displacement of one storey level with respect to the ground storey. Lateral displacement increases with the increase in height of the building, because with the increase in the height the lateral stiffness of the building

decreases. For lateral displacement in the seismic region IV, an RC building frame with and without shear wall has been analyzed and examined for various parameters used in the study. An example of the maximum lateral displacement for the chosen building frame with and without shear wall for demonstration is shown in Fig.4.1 (a) and Fig. 4.1(b) respectively.

Table 4.1 lists the maximum lateral displacement values obtained from analysis at each storey level. These listed values of maximum lateral displacement are mapped against the storey height to understand the effectiveness of various shear wall system and best suited position for shear wall in the building plan. The maximum Storey displacement without and with Shear Wall (SW) is represented in Figure 4.2. The deviation of peak storey displacement for various arrangements of shear wall system in building plan are shown in figure 4.3.

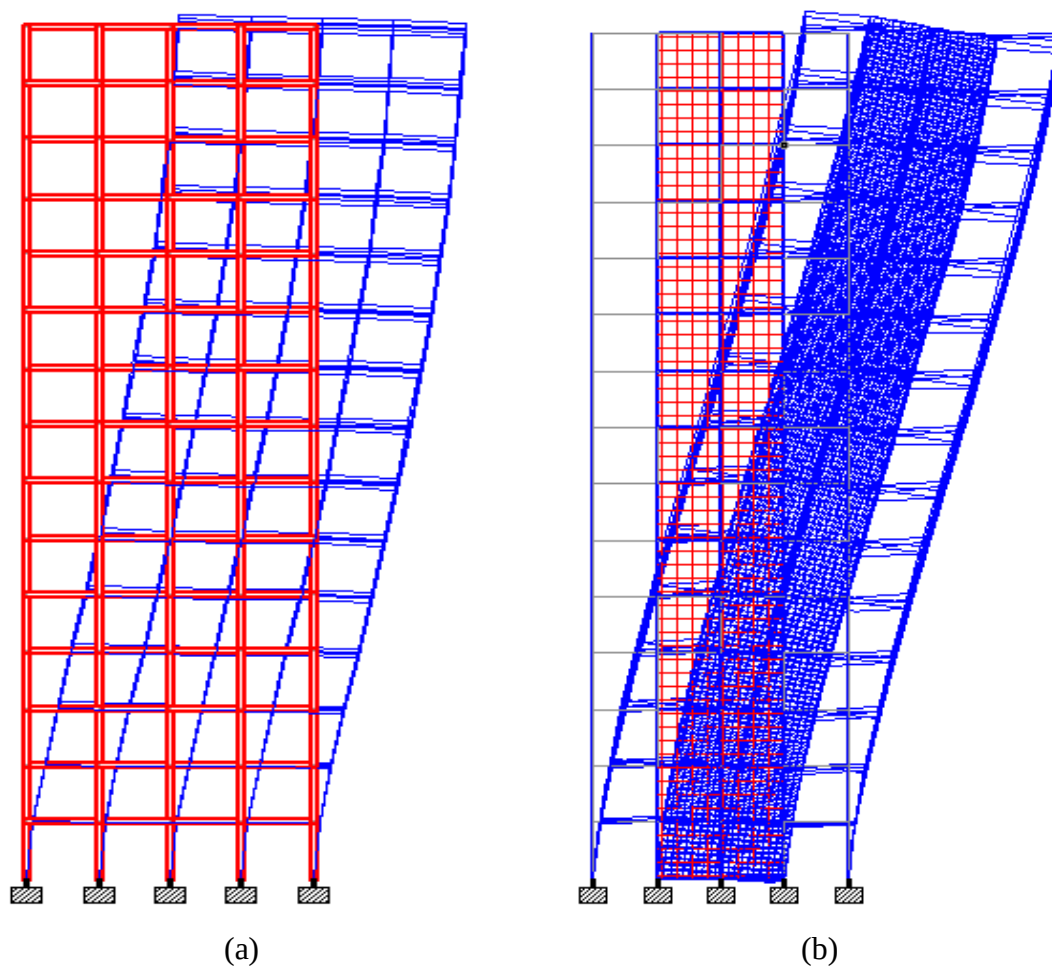


**Fig. 4.1 Lateral Displacement of Building (a) without Shear wall  
(b) with Shear Wall**

**Table 4.1 Maximum Lateral Displacement (mm) for Different Building Models in Zone IV**

| Storey No. | Storey Height(m) | Maximum Lateral Displacement (mm) |                      |        |                      |        |        |
|------------|------------------|-----------------------------------|----------------------|--------|----------------------|--------|--------|
|            |                  | Bare Frame                        | With Shear Wall      |        |                      |        |        |
|            |                  |                                   | External SW Location |        | Internal SW Location |        |        |
|            |                  |                                   | L                    | RECT   | BOX                  | PLUS   | I      |
| Ground     | 3                | 0.807                             | 0.385                | 0.316  | 0.259                | 0.420  | 0.296  |
| 1          | 6                | 2.248                             | 1.096                | 0.891  | 0.864                | 1.185  | 0.815  |
| 2          | 9                | 3.863                             | 1.941                | 1.562  | 1.172                | 2.070  | 1.43   |
| 3          | 12               | 5.547                             | 2.882                | 2.303  | 1.1725               | 3.032  | 2.124  |
| 4          | 15               | 7.261                             | 3.905                | 3.106  | 2.341                | 4.061  | 2.887  |
| 5          | 18               | 8.984                             | 4.993                | 3.965  | 3.007                | 5.142  | 3.706  |
| 6          | 21               | 10.695                            | 6.125                | 4.864  | 3.711                | 6.26   | 4.564  |
| 7          | 24               | 12.372                            | 7.28                 | 5.791  | 4.44                 | 7.398  | 5.447  |
| 8          | 27               | 13.990                            | 8.439                | 6.728  | 5.182                | 8.535  | 6.338  |
| 9          | 30               | 15.523                            | 9.581                | 7.66   | 5.928                | 9.652  | 7.223  |
| 10         | 33               | 16.942                            | 10.868               | 8.571  | 6.668                | 10.729 | 8.091  |
| 11         | 36               | 18.218                            | 11.732               | 9.438  | 7.394                | 11.742 | 8.927  |
| 12         | 39               | 19.321                            | 12.868               | 10.232 | 8.100                | 12.660 | 9.715  |
| 13         | 42               | 20.221                            | 13.505               | 10.905 | 8.767                | 13.442 | 10.449 |
| 14         | 45               | 20.920                            | 14.175               | 11.415 | 9.35                 | 14.188 | 11.096 |

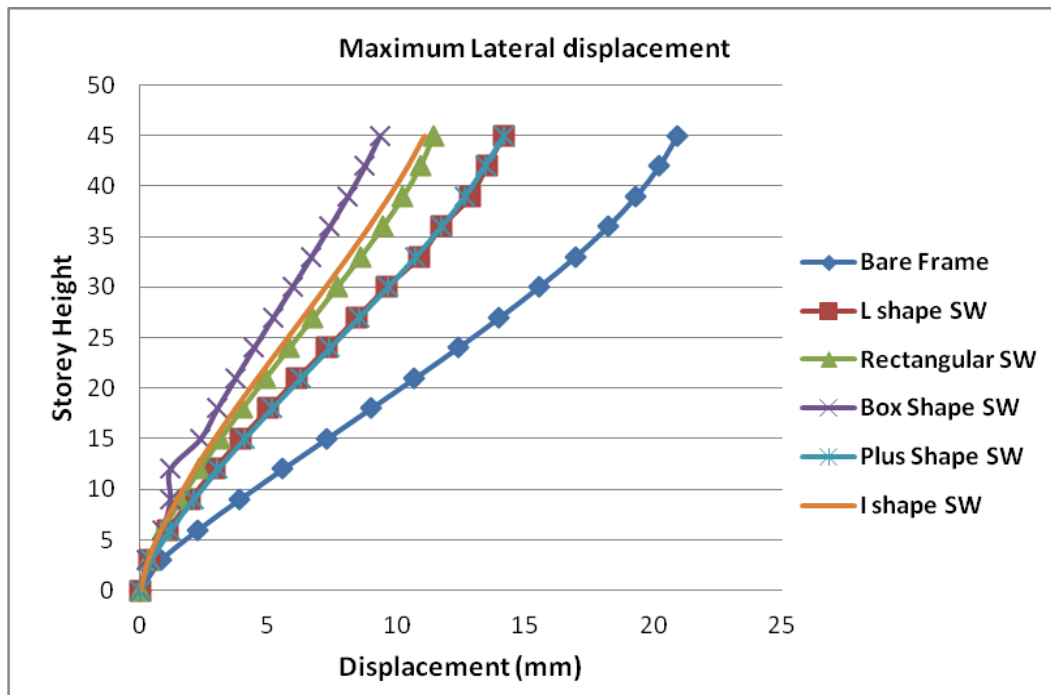


**Fig. 4.2 Maximum Lateral Displacement (mm) for buildings with and without shear wall**

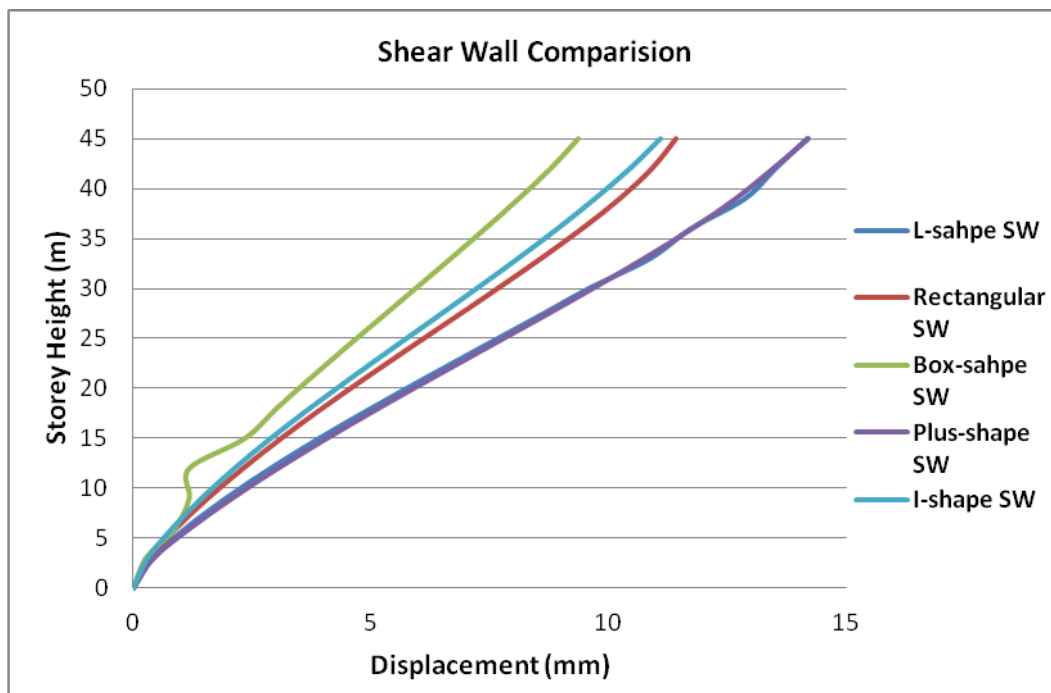


**Fig. 4.3 Maximum Lateral Displacement (mm) for various arrangement of Shear Wall in buildings plan**

It can be clearly observed from the lateral deflection plots that deflection along the height of the building got decreased in shear wall system with respect to the bare frame building. Moreover, when different arrangement of shear wall systems is compared among themselves, a deviation in behaviour of lateral deflection is observed. Although all the shear wall system performed better than the bare frame building but it is observed from the graph that in case of the box shape shear wall system (provided at the interior of the building frame), the reduction in lateral displacement is very high as compared to other systems. To study the effect of the position of shear wall provided in the building on the lateral displacement of the building, percentage reduction in the displacement of different shear wall system with respect to bare frame is observed. Table 4.2 gives the relative percentage drop in maximum lateral displacement of the shear wall building with respect to bare frame building.

**Table 4.2 Percentage Reduction (%) in the Lateral Displacement**

| Storey No. | Type of Shear Wall System |                |                 |                 |            |
|------------|---------------------------|----------------|-----------------|-----------------|------------|
|            | L-shape SW                | Rectangular SW | Box-shape SW    | Plus-shape SW   | I-shape SW |
| Ground     | 52.29244                  | 60.84263       | 67.90582        | 47.95539        | 63.32094   |
| 1          | 51.24555                  | 60.36477       | 61.56584        | 47.28648        | 63.74555   |
| 2          | 49.75408                  | 59.5651        | 69.66089        | 46.4147         | 62.98214   |
| 3          | 48.04399                  | 58.48206       | 78.86245        | 45.33982        | 61.70903   |
| 4          | 46.21953                  | 57.22352       | 67.75926        | 44.07106        | 60.23964   |
| 5          | 44.42342                  | 55.86598       | 66.52939        | 42.76492        | 58.74889   |
| 6          | 42.73025                  | 54.5208        | 65.30154        | 41.46798        | 57.32585   |
| 7          | 41.15745                  | 53.19269       | 64.11251        | 40.20369        | 55.97317   |
| 8          | 39.67834                  | 51.90851       | 62.95926        | 38.99214        | 54.69621   |
| 9          | 38.27868                  | 50.65387       | 61.81151        | 37.8213         | 53.46905   |
| 10         | 35.85173                  | 49.40975       | 60.64219        | 36.67218        | 52.24295   |
| 11         | 35.60215                  | 48.19409       | 59.41377        | 35.54726        | 50.99901   |
| 12         | 33.39889                  | 47.04208       | 58.0767         | 34.47544        | 49.71792   |
| 13         | 33.213                    | 46.07092       | 56.64408        | 33.52455        | 48.326     |
| 14         | 32.24187                  | 45.43499       | <b>55.30593</b> | <b>32.17973</b> | 46.95985   |

From the observation of the table 4.2 it is found that rectangular shear wall building performed better than the building with shear wall provided at its four corners in case of the shear walls provided at the exterior of the building. While in case of the interior positioned shear wall systems, best performance is observed in box-shape shear wall building. Though, the best performance is observed in internal shear wall system rather than the external shear wall system, but the least performance is also found in internal shear wall system provided in plus-shape.

### 4.3 Base Shear

An RC building frame is generally fixed at the foundation level, where maximum lateral force (Base Shear) gets generated under the action of earthquake force.

Base shear values for the RC frame building with and without shear walls are obtained from the dynamic analysis of the different models. These value are tabulated in Table 4.3 and are arranged in the form of bar chart for comparative study of the bare frame structure and shear wall frame structure. These bar chart are shown in fig 4.4.

**Table 4.3 Base Shear (kN) for Different Shear Wall System in Zone IV**

| Structure Type | Base Shear(kN)  |
|----------------|-----------------|
| Bare Frame     | 723.267         |
| L              | 818.6917        |
| RECT           | <b>818.6917</b> |
| BOX            | <b>818.692</b>  |
| PLUS           | 770.9795        |
| I              | 794.8358        |

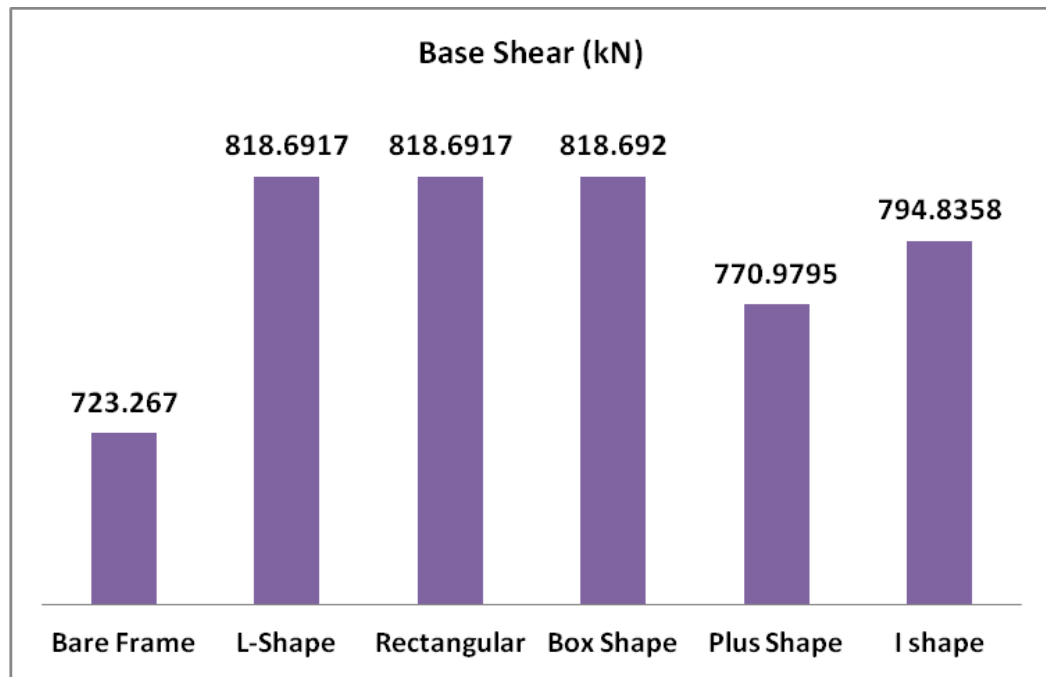


**Fig. 4.4 Base Shear (kN) for Different Shear Wall System in Zone IV**

Significant increase in the value of the base shear has been observed in shear wall RC building frames in compare to bare frame. Graph depicts that base shear in L-shape, rectangular and box-shape shear wall buildings is same. The variation in base shear for other shear wall buildings also has been found in-significant. Percentage increase in base shear value in shear wall buildings from bare RC frame building has been 6.60% to 13.19%.

#### **4.4 Storey Drift**

Storey drift also known as inter storey displacement is the relative displacement between the floors above or below the storey under consideration. The RC building frame models with shear wall system and without shear walls situated in seismic zone IV have been analyzed and obtained values have been listed in Table 4.4. To study the effect of shear walls provided in RC buildings, these values of inter storey displacement have been plotted against the building height and is shown in fig. 4.5. These values are again plotted for shear wall buildings only to compare the different positioned shear walls and to obtain the best location for shear walls, shown in fig 4.6.

**Table 4.4 Maximum Storey Drift for Different Types of Shear Wall System in Zone IV**

| Storey Number | Maximum Storey Drift |                 |       |              |              |       |
|---------------|----------------------|-----------------|-------|--------------|--------------|-------|
|               | Without Shear Wall   | With Shear Wall |       |              |              |       |
|               |                      | L               | RECT  | BOX          | PLUS         | I     |
| 0             | 0                    | 0               | 0     | 0            | 0            | 0     |
| 1             | 1.213                | 0.069           | 0.057 | 0.038        | 0.059        | 0.044 |
| 2             | 2.158                | 0.114           | 0.086 | 0.064        | 0.127        | 0.081 |
| 3             | 2.442                | 0.142           | 0.102 | 0.08         | 0.168        | 0.102 |
| 4             | 2.522                | 0.161           | 0.115 | 0.092        | 0.191        | 0.118 |
| 5             | 2.569                | 0.173           | 0.125 | 0.101        | 0.202        | 0.131 |
| 6             | 2.581                | 0.181           | 0.132 | 0.108        | 0.208        | 0.141 |
| 7             | 2.563                | 0.186           | 0.137 | 0.113        | 0.211        | 0.15  |
| 8             | 2.511                | 0.189           | 0.14  | 0.116        | 0.214        | 0.157 |
| 9             | 2.422                | 0.19            | 0.141 | 0.119        | 0.216        | 0.164 |
| 10            | 2.294                | 0.189           | 0.14  | 0.12         | 0.218        | 0.17  |
| 11            | 2.123                | 0.186           | 0.137 | 0.12         | 0.219        | 0.173 |
| 12            | 1.908                | 0.18            | 0.131 | 0.119        | 0.214        | 0.174 |
| 13            | 1.647                | 0.17            | 0.122 | 0.115        | 0.197        | 0.167 |
| 14            | 1.345                | 0.149           | 0.108 | <b>0.104</b> | <b>0.156</b> | 0.147 |
| 15            | 1.04                 | 0.113           | 0.085 | 0.079        | <b>0.074</b> | 0.109 |

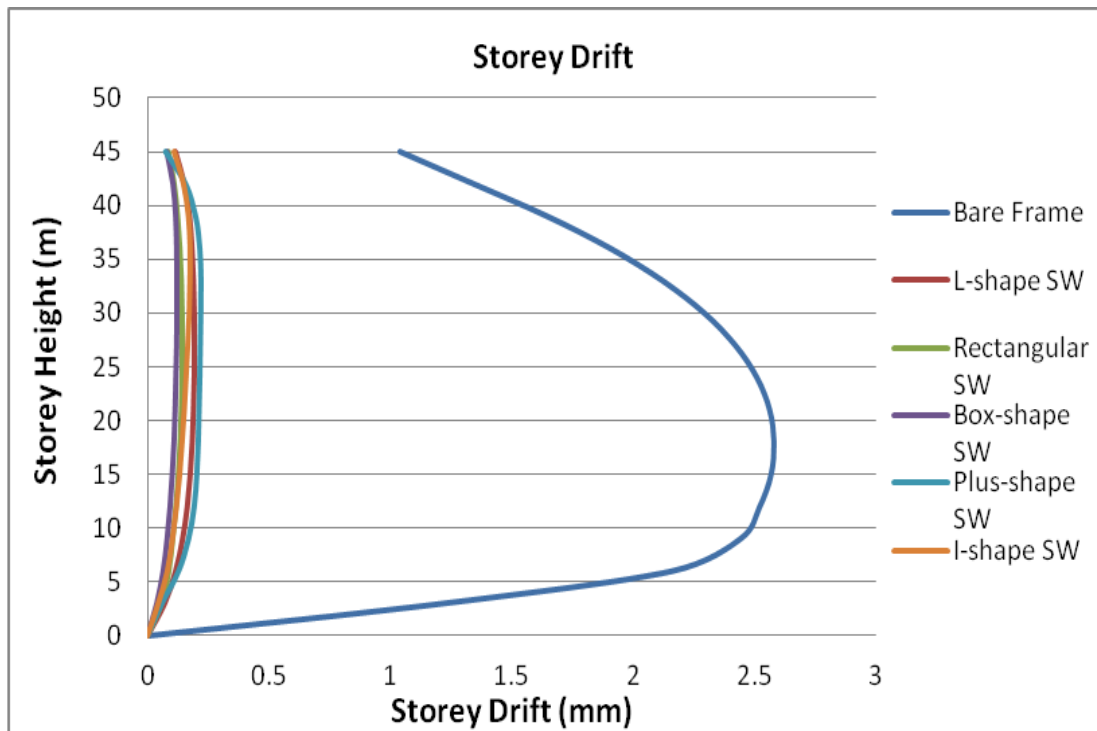


**Fig. 4.5 Maximum Storey Drift for Buildings with and without Shear Wall**

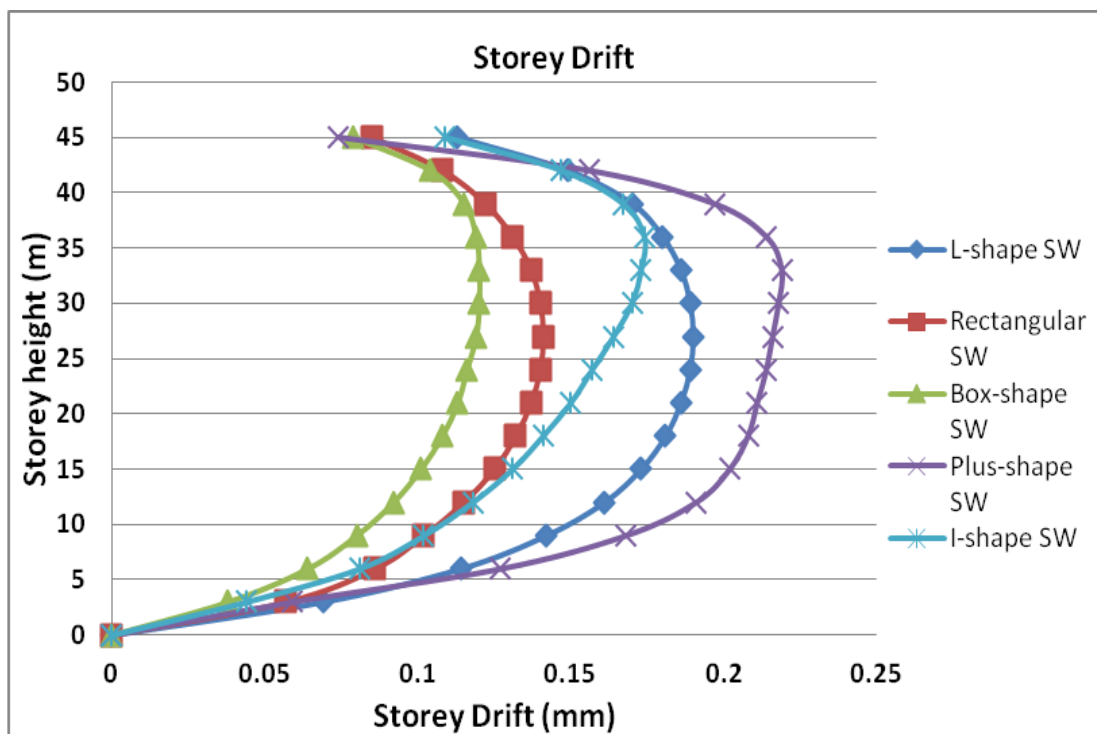


**Fig. 4.6 Maximum Storey Drift for Shear Wall Buildings**

Although all graphs show the similar pattern for the reduction in the storey drift value along building height for all models, but there has been large reduction in storey drift values in shear wall buildings when compared to bare building frame. In case of bare frame structure, it has been observed that the storey drift increases up to 6<sup>th</sup> storey and then decreases along the building height. While for shear wall buildings, plot shows increment up to 9<sup>th</sup> storey and the reduction starts for L-shape, rectangular and box-shape shear wall, but for plus-shape and I-shape increment has been observed up to 11<sup>th</sup> storey. However, different Shear wall systems provided different maximum storey drift value at different storey height level, the maximum reduction has been observed in case of box-shape shear wall in comparison to other model structures. The observed percentage reduction in storey drift values for shear wall structure while compared to bare frame structure are 92.99%, 94.88%, 95.82%, 92.17% and 94.53% in L-shape, rectangular, Box-shape, Plus-shape and I-shape shear wall systems respectively, with maximum reduction by 95.82% in box-shape shear wall.

#### 4.5 Bending Moment

The analysis has been carried out to study the occurrence of maximum bending moment in columns of bare RC frame building and in buildings with shear wall provided in different five locations. The bending moment values obtained for vertical members of the structure are given in Table 4.5. To compare shear walled buildings with bare frame building and among themselves, the results are plotted in the form of bar charts as shown in fig 4.7.

**Table 4.5 Maximum Bending Moment for Different Shear Wall System**

| Structure Type | Bending Moment (kN.m) |
|----------------|-----------------------|
| Bare Frame     | 72.772                |
| L              | 58.619                |
| RECT           | 43.566                |
| BOX            | <b>31.897</b>         |
| PLUS           | 55.096                |
| I              | 40.793                |

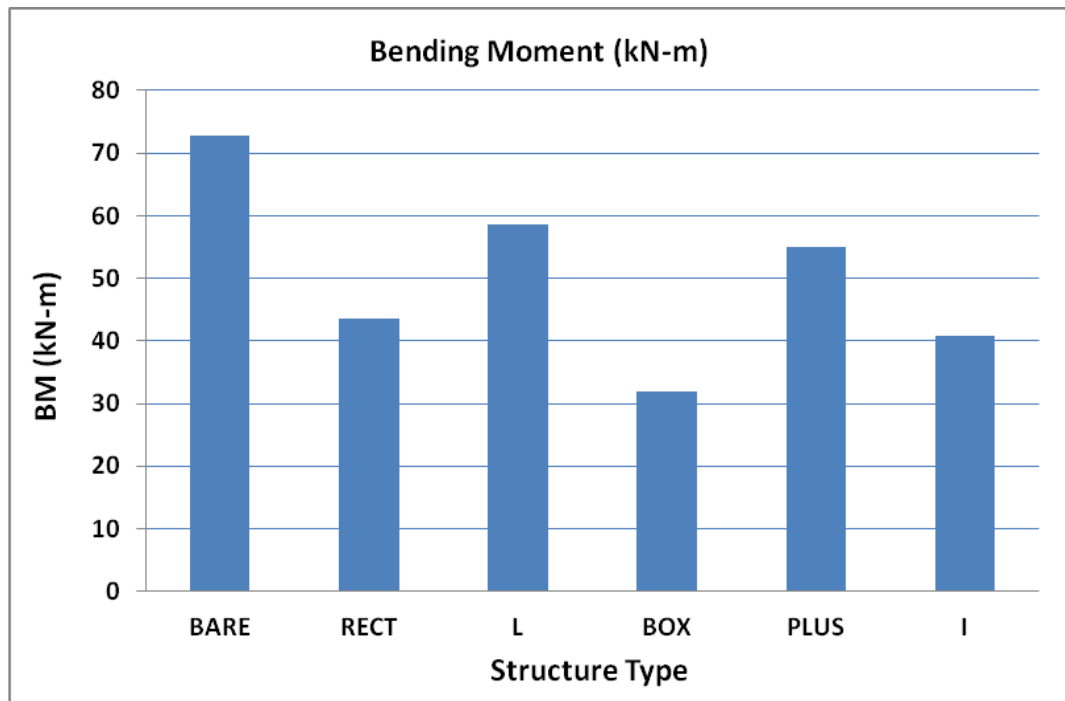


**Fig. 4.7 Maximum Bending Moment for Different Shear wall System**

It has been observed that bending moment gets reduced when the shear wall system is added to the RC frame building. Least value of bending moment has been observed in the box-shape shear wall with 56.17% reduction in the value when compared to bare frame structure. While in case of external shear wall system, the maximum reduction was found to be 40.13% in rectangular shear wall system. For shear wall systems, maximum value of bending moment has been observed in L-shaped shear wall structure.

#### **4.6 Fundamental Time Period**

Fundamental time period (in seconds) has been obtained for all six models and the values are presented in Table 4.6. These values of time period are then plotted as column bar chart, fig. 4.8, to understand the effectiveness of the different building models with and without shear wall.

It can be observed from the plotted chart that the time period values for shear wall buildings has been decreased significantly with respect to the bare frame building. Maximum reduction is observed in box-shape shear wall structure, while maximum value among shear wall system is obtained for plus-shape shear wall.

**Table 4.6 Time Period (seconds) for Different Shear Wall Systems**

| Structure Type | Time Period    |
|----------------|----------------|
| Bare Frame     | 1.3939         |
| L              | 1.0848         |
| RECT           | 0.97007        |
| BOX            | <b>0.86604</b> |
| PLUS           | 1.13106        |
| I              | 0.97868        |

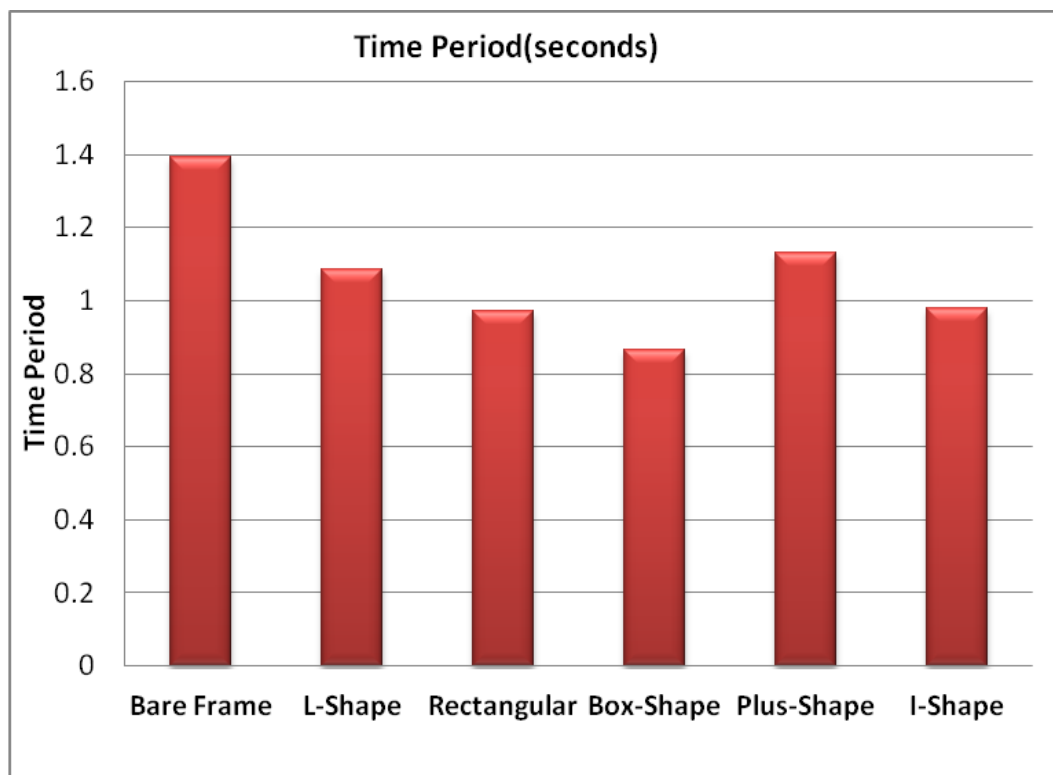


**Fig. 4.8 Time Period for Different Shear wall System**

#### 4.7 Peak Storey Shear

Storey shear is the lateral load acting at that storey level and can also be termed as shear force at that particular storey. This value decreases along the height of the building, with maximum value being at the base of the structure and minimum at the top storey level. The peak values of storey shear resulted at different storey height for different models have been tabulated in Table 4.7. A graph showing how much lateral load is acting per storey has been plotted and has been shown in fig. 4.9. The graph is plotted for storey shear values given in table 4.7 against storey height to give an understanding of how shear force has developed in the buildings with and without shear wall under the action of lateral earthquake forces.

It can be observed from the plotted graph that the increment in storey shear value in shear wall buildings compared to bare frame building is very large. Maximum shear value for each store was observed in a building with a box-shaped shear wall. Among the external shear wall buildings, larger store values were obtained in the rectangular shear wall building. Among the inner shear wall structures, the least shear production was found in the case of a plus-shaped shear wall construction.

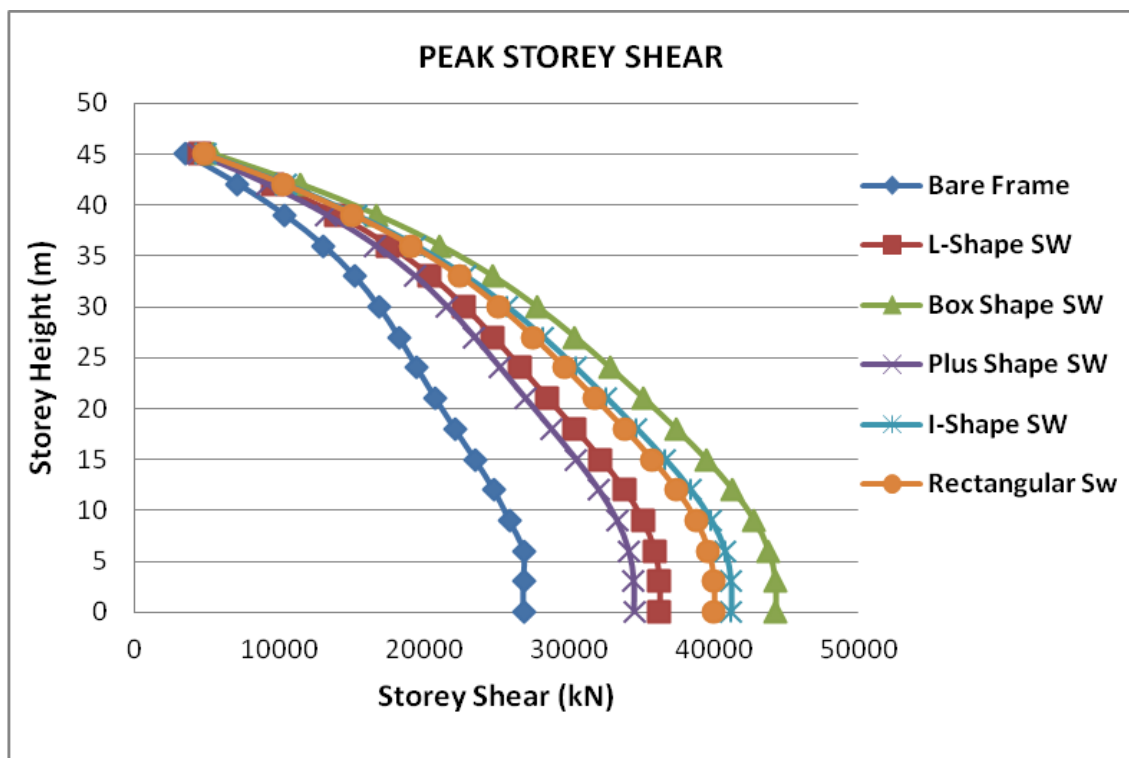


**Fig. 4.9 Peak Storey Shear for Different Buildings with and without Shear Wall**

**Table 4.7 Maximum Storey Shear (kN) for Different Types of Shear Wall System**

| Storey Number | Maximum Storey Shear (kN) |                 |          |                |         |         |
|---------------|---------------------------|-----------------|----------|----------------|---------|---------|
|               | Without Shear Wall        | With Shear Wall |          |                |         |         |
|               |                           | L               | RECT     | BOX            | PLUS    | I       |
| 0             | 26858.4                   | 36251.59        | 40011.31 | 44292          | 34487   | 41199.1 |
| 3             | 26858.4                   | 36238.47        | 39996.09 | 44268.9        | 34478.5 | 41182.2 |
| 6             | 26858.6                   | 35901.64        | 39626.4  | 43804.8        | 34138.2 | 40769.2 |
| 9             | 25881.2                   | 35084.22        | 38750.46 | 42801.5        | 33316.2 | 39818.8 |
| 12            | 24800                     | 33813.96        | 37409.05 | 41322.2        | 32061.3 | 38399.3 |
| 15            | 23483.7                   | 32197.96        | 35710.44 | 39472.7        | 30492.9 | 36637   |
| 18            | 22091.1                   | 30381.48        | 33787.99 | 37377.1        | 28757.4 | 34667.3 |
| 21            | 20743.8                   | 28501.09        | 31757.73 | 35144          | 26982   | 32593.8 |
| 24            | 19478.1                   | 26633.09        | 29675.58 | 32827.2        | 25229.3 | 30453.6 |
| 27            | 18226.4                   | 24755.01        | 27508.88 | 30398.9        | 23465.5 | 28199.9 |
| 30            | 16840.4                   | 22740.96        | 25136.81 | 27746.5        | 21563.3 | 25710.7 |
| 33            | 15145.8                   | 20396.32        | 22382.28 | 24698.1        | 19338.6 | 22821.9 |
| 36            | 12997.2                   | 17515.16        | 19062.08 | 21063.6        | 16604.8 | 19371.9 |
| 39            | 10316                     | 13935.38        | 15036.17 | 16678.9        | 13221.5 | 15243.1 |
| 42            | 7103.66                   | 9576.49         | 10244.15 | 11439.1        | 9125.57 | 10389.4 |
| 45            | 3434.72                   | 4456.26         | 4723.68  | <b>5322.53</b> | 4344.3  | 4847.86 |

#### 4.8 Mass Participation

The style of oscillation associated with the natural era of the building is the deformed shape of the building when shook during the natural cycles/period. Thus, the building has as many mode shapes as it has active DOFs considered in the analysis. The vibration of different modes depend upon the natural frequencies and a structure has as many natural frequencies as it has the DOFs. The deformed shape of the building associated with oscillation at fundamental natural period is termed its first mode shape. Fig. 4.10 gives an example of mode shape for a particular mode in bare frame model and in a shear wall frame model.

The mass participation factor represents the percentage of the system mass that participates in a particular mode of vibration. A mode with a large mass participation is usually a significant contributor to the dynamic response of a system, as per the IS code 1893:2016.

Table 4.8 and table 4.9 gives the mass participation factor values that has been obtained from the analysis of six different models in six modes along X and Z directions respectively.

**Table 4.8 Mass Participation in X-direction for Different Shear Wall system**

| Mode | Bare frame | L-shape SW | Rectangular SW | Box-shape SW | Plus-shape SW | I-shape SW |
|------|------------|------------|----------------|--------------|---------------|------------|
| 1    | 22.701     | 6.243      | 52.098         | 9.126        | 0             | 0          |
| 2    | 55.453     | 66.461     | 20.331         | 62.018       | 68.703        | 71.721     |
| 3    | 0          | 0          | 0              | 0            | 5.045         | 0          |
| 4    | 8.067      | 11.472     | 0.113          | 7.888        | 0             | 0          |
| 5    | 3.507      | 3.623      | 15.604         | 10.201       | 2.769         | 0          |
| 6    | 0          | 0          | 0              | 0            | 12.309        | 16.755     |

**Table 4.9 Mass Participation in Z-direction for Different Shear Wall system**

| Mode | Bare frame | L-shape SW | Rectangular SW | Box-shape SW | Plus-shape SW | I-shape SW |
|------|------------|------------|----------------|--------------|---------------|------------|
| 1    | 55.452     | 66.46      | 20.331         | 62.019       | 0             | 0          |
| 2    | 22.7       | 6.243      | 52.098         | 9.126        | 5.045         | 0          |
| 3    | 0          | 0          | 0              | 0            | 68.703        | 73.458     |
| 4    | 3.506      | 3.623      | 15.603         | 10.201       | 0             | 0          |
| 5    | 8.067      | 11.471     | 0.113          | 7.889        | 12.309        | 16.07      |
| 6    | 0          | 0          | 0              | 0            | 2.77          | 0          |

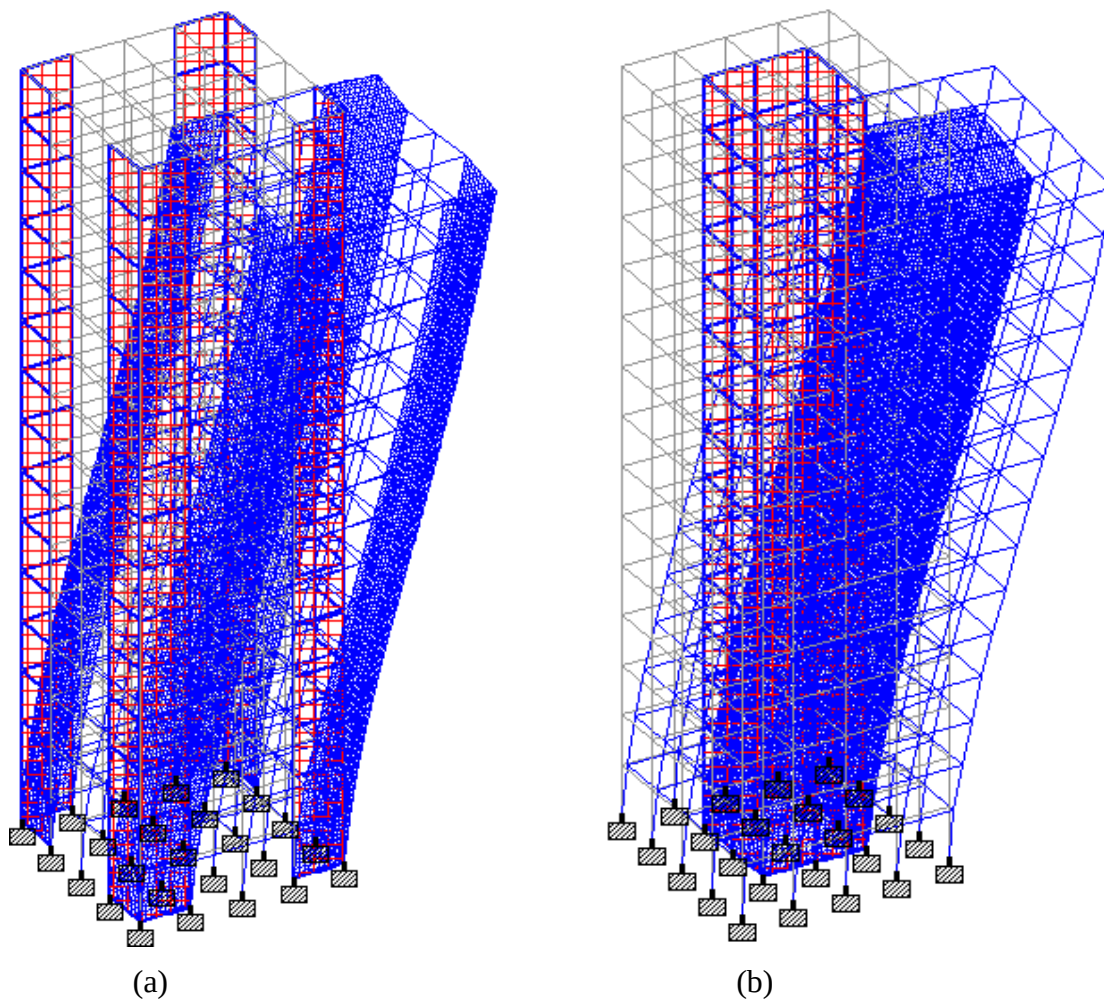


**Fig. 4.10 Mode Shape for (a) L-shape Shear wall (b) Box-shape Shear Wall**

It has been found from the table values that mass participation values along two mutually perpendicular lateral directions is same for all the building models, except I-shape shear wall model. Symmetry of the different models, except I-shape shear wall model, about X and Z direction has been the reasons for such observation. For internal shear wall, models maximum participation has been observed in I-shape shear wall and for external shear wall system maximum participation has been given by L-shape shear wall.

#### 4.9 Validation of Results

Results discussed in this chapter shows similarity with the results of many other research works that had been cited. Results of two such research works and their similarity with current work are presented as follows;

**Table 4.10 Details of the Validating Research Work**

| <b>Research Work</b> | <b>A</b>                                      | <b>B</b>                            |
|----------------------|-----------------------------------------------|-------------------------------------|
| Authors              | S.V. Sumanth Chaudhary and Senthil Pandian M. | S.K. Madan, R.S. Malik, V.K. Sehgal |
| No. Of Stories       | G+7                                           | G+9, G+14, G+19                     |
| Size of Beams        | 300 X 450mm                                   | 350 X 600mm                         |
| Column Size          | 450 X 600mm                                   | Varying                             |
| Seismic Zone         | II, III, IV, V                                | IV                                  |
| Method of Analysis   | LDA( RSA)                                     | LDA( RSA)                           |
| Shear wall thickness | 250mm                                         | 250mm                               |

- Research work ‘A’ shows 50% reduction in lateral displacement for building with rectangular shear wall along with core lift shear walls in seismic zone IV, which is close to current work’s results having 45% reduction in rectangular shear wall and 55% reduction in box-shape shear wall. While research work ‘B’ shows 40% reduction in lateral displacement with rectangular shear wall in 15-storey building.

- Reduction in bending moment and increment in base shear has been observed 47% and 12%, respectively, in research work 'A' which is closely related to the 40% and 13%, respectively, values of this work.
- Reduction of fundamental time period observed in research work 'B' for rectangular shear wall building with respect to base structure is 0.25second (from 2.27sec to 2.02 sec), while in present work the reduction is 0.309 seconds in case of rectangular shear wall building and 0.528 seconds in box-shape shear wall building.
- Reduction in the maximum inter storey drift over base structure in 15-storey building in research work 'B' was from 5.91mm to 3.52mm, whereas in ongoing research maximum reduction over base structure has been observed from 2.581mm to 0.131mm.

Some variation in the results had been accounted due the difference in the beam and column sizes and variation in storey height and shear wall thickness.

#### **4.9 Summary**

Results obtained for seismic zone IV for all six models had been presented and discussed with the help of tables and graphs. Obtained values for all parameters were tabulated and graphs showing their variation were drawn in this chapter. Finally results were verified from two other research works.



# *Summary and Conclusions*



**5.1 General**

Comparing performance of RC frame buildings having shear wall with moment resisting bare frame RC building and study of effectiveness of various locations of shear walls in RC building have been the main objectives of the present study. For this, an analytical study was performed using STAAD.Pro.V8i software on a variety of configurations of the building with and without shear wall by creating models for each configuration. Linear-dynamic study was performed using response spectrum method (RSM) on bare RC frame model, L-shape shear wall model, rectangular-shape shear wall model, box-shape shear wall model, plus-shape shear wall model and I-shape shear wall model situated in seismic zone IV and the results were obtained for maximum storey displacement, storey drift, peak storey shear, base shear, maximum bending moment in columns and for fundamental time period, as already discussed in chapter 3.

This chapter provides the overall conclusion procured from the results discussed in the previous chapter. Scope for future work that can be done on the same study area is also presented in this chapter.

**5.2 Concluding Remarks**

All the shear wall frame models are compared with bare frame model based on the variables/parameters chosen. External shear wall frame models are also compared with internal shear wall models to obtain an optimum solution for shear wall position in RC frame buildings. Although the results of the discussions have already shown that all shear wall buildings respond much better to lateral loads than bare frame buildings, but the conclusive report on the relative performance of shear wall frame buildings is presented in the following paragraph.;

1. Large reduction in lateral storey displacement takes place in case of all shear wall systems with respect to the bare frame building. Box-shape shear wall system gives maximum reduction in tope storey displacement (55.31%) while plus-shape system shows least reduction with 32.18%. Comparison of external shear wall models and

internal shear wall models indicates that internal position of shear walls is superior to external position because rectangular shear wall performed better among external shear wall models with decrease in top storey displacement by 45.43%, which is less than box-shape shear wall model.

2. Although, base shear values increases for the buildings with shear walls compared to bare RC frame building, but not much variation is there among shear wall buildings themselves. For instance, percentage increase in base shear value from bare frame structure for box-shape, l-shape and rectangular shear wall structures is same (13.10%). In this case also, plus-shape shear wall gives least increment of 6.59% in base shear values.
3. The Story drift values obtained for shear wall models are reduced by large percentage in comparison to the bare RC frame model. For overall performance, box shape shear wall gives less storey drift as compared to other shear wall building models, but for top storey drift least value is in case of plus-shape shear wall building model. Again, shear walls positioned at the interior of the building frame gives better results as compared to shear walls positioned at the exterior location in building frame. For externally located shear walls, rectangular shear wall shows a reduction in top storey drift of 91.83% while in case of internally positioned shear wall the reduction is 92.88%.
4. Maximum bending moment values in columns of shear walled structures gets reduced vastly as compared to bare frame structure. Model-4 i.e. box-shape shear wall model has the least value of maximum moment among all the representations of shear wall. Except for model-5, all other internal shear wall frameworks give lesser value of bending moment in comparison with the external shear wall models.
5. Fundamental time period decreases in models having shear wall (model-2 to model-6) as compared to model without shear wall (model-1). Lesser time period values are obtained for internal shear wall framework as compared to external shear wall framework with least value observed in model-4 (box-shape shear wall model) and maximum in model-5 (plus shape model).
6. Significant increase in peak storey shear values is there in case of all five shear wall building models in comparison to bare frame building model. While maximum

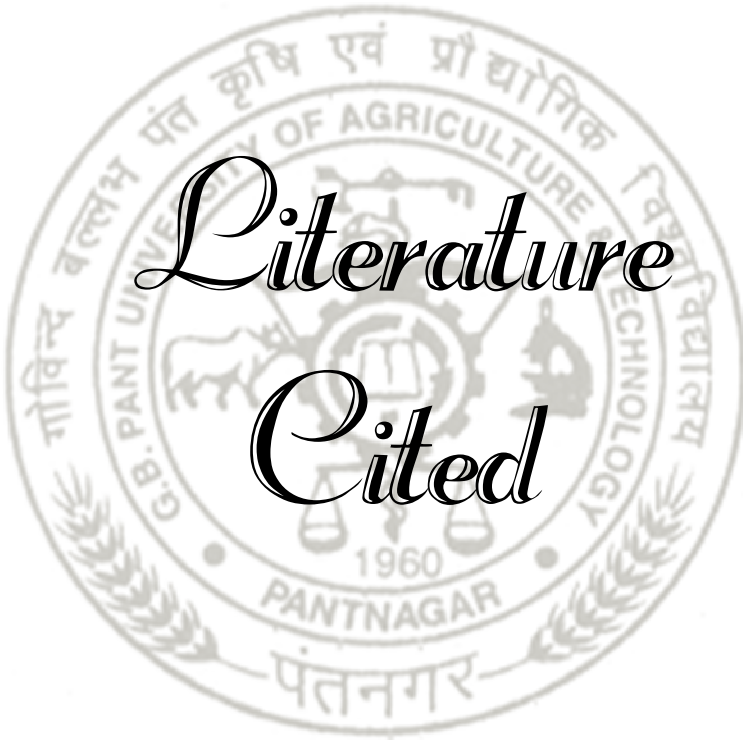
increment is of 54.96% in model-4 with box-shape shear wall system, the minimum increment is also in case of internal shear wall building with 26.48% increased value in model-5 having plus-shape shear wall.

It is clear from the concluding points that box- shape of shear wall positioned at the core of the building frame gives the best result among all five types of shear walls having different shapes and different locations. In case of external shear wall, best performance is given by rectangular shear wall.

### **5.3 Future Scope**

In a developing country like India, present work provides a vast area for research works and can be extended to many more future studies. Some of the possible options are given in the following points;

1. The present work has been carried out on symmetrical building to study the effect of shear wall's location that can be further studied for asymmetrical buildings also.
2. A thesis work on effect of shear wall on varying height of building and storey can also be done. This work can be extended to seismic zone III and V also.
3. Comparative study of LSA and LDA as well as of linear and non-linear analysis can also be done on the same working model.
4. Present research work can be extended to use steel plates as shear wall so that a comparative study of the two can be carried out.



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## VITA

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## **ABSTRACT**

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| Sem. & Year of Addition | : 1 <sup>st</sup> , 2018-19                    | Degree     | : M. Tech.          |
| Major                   | : Structural Engineering                       | Department | : Civil Engineering |
| Thesis Title            | : Study of Shear Wall locations in RC Building |            |                     |
| Advisor                 | : Dr. Vaneeta Devi                             |            |                     |

Due to devastating effect of earthquake in the past decade, it is now important to consider the effect of earthquake while constructing medium to high rise buildings. Due to scarcity of space and shifting of people from rural to urban areas, it is now essential to construct high rise buildings. To counter the large size of beams and columns an alternative has been found for high rise buildings and is termed as shear wall. It has very high in plane stiffness and when situated in advantageous positions in a building, they can be very efficient in resisting lateral loads originating from earthquakes. However, we cannot provide shear walls at all the locations due to economic considerations. So it is very necessary to determine effective, efficient and ideal location of shear walls. Therefore, an attempt has been made to find the ideal location of shear walls in symmetrical structures. A 3-D analysis of G+14 storey shear wall structures has been carried out using the STAAD. Pro V8i software. Different models have been drawn by adopting different locations of shear walls. A comparative study has been done on six parameters, namely, storey displacement, storey drift, storey shear, base shear, bending moment, peak storey shear and time period of the structure between bare frame RC model and shear wall RC frame model. Linear dynamic method of analysis (response spectrum analysis) has been used following IS 1893 (Part 1):2016. From the study, it has been observed that the lateral displacement, storey drift, bending moment and time period of the shear wall system decreases as compared to the bare frame. Base shear and storey shear value in the shear wall structure increases as compared to bare frame structure. It is concluded that Box-shape shear wall system (located at the core of the building) significantly contribute to structure stiffness as compared to the other shear wall systems.



**(Vaneeta Devi)**  
Advisor



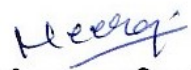
**(Neeraj Kumar Tiwari)**  
Author

## सारांश

|                       |                                                   |         |                        |
|-----------------------|---------------------------------------------------|---------|------------------------|
| नाम                   | : नीरज कुमार तिवारी                               | परिचायक | : ५३८८९                |
| सेमेस्टर, प्रवेश वर्ष | : प्रथम, २०१८-१९                                  | डिग्री  | : प्रौद्योगिकी निष्णात |
| प्रमुख                | : संरचनात्मक अभियांत्रिकी                         | विभाग   | : जनपद अभियांत्रिकी    |
| शोध का शीर्षक         | : आरसी इमारत में कतरनी दीवार के स्थानों का अध्ययन |         |                        |
| सलाहकार               | : डॉ. वनीता देवी                                  |         |                        |

पिछले एक दशक में भूकंप के विनाशकारी प्रभाव के कारण, मध्यम से ऊँची इमारतों का निर्माण करते समय भूकंप के प्रभाव पर विचार करना महत्वपूर्ण है। जगह की कमी और लोगों के ग्रामीण से शहरी क्षेत्रों में स्थानांतरित होने के कारण, ऊँची इमारतों का निर्माण करना आवश्यक हो गया है। ऊँची इमारतों में बीम और स्तंभों के बड़े आकार की समस्या का मुकाबला करने के लिए एक विकल्प पाया गया है और इसे कतरनी दीवार कहा जाता है। इनकी स्व-सतह कठोरता बहुत अधिक होती है और जब किसी इमारत में उपयोगी स्थान पर स्थित हों, तो वे भूकंप से उत्पन्न पार्श्व भार का विरोध करने में बहुत कुशल हो सकते हैं। हालाँकि, हम आर्थिक विचारों के कारण सभी स्थानों पर कतरनी दीवारें प्रदान नहीं कर सकते हैं। इसलिए कतरनी दीवारों के प्रभावी, कुशल और आदर्श स्थान को निर्धारित करना बहुत आवश्यक है। इसलिए, सममित संरचनाओं में कतरनी दीवारों का आदर्श स्थान खोजने का प्रयास किया गया है। STAAD. Pro V8i सॉफ्टवेयर का उपयोग करके G+14 मंजिला कतरनी दीवार संरचनाओं का त्रि-आयामी विश्लेषण किया गया है। कतरनी दीवारों के लिए विभिन्न स्थानों को अपनाकर विभिन्न आदर्श तैयार किए गए हैं। अनावृत फ्रेम आरसी आदर्श और कतरनी दीवार सहित आरसी फ्रेम आदर्श के बीच विभिन्न मापदंडों, नामतः मंजिल विस्थापन, मंजिल बहाव, मंजिला कतरनी, आधार कतरनी, झुकने का क्षण, शिखर मंजिला कतरनी और समय अवधि पर एक तुलनात्मक अध्ययन किया गया है। आईएस 1893 (पार्ट 1): 2016 का अनुपालन करते हुए रैखिक गतिशील विधि (प्रतिक्रिया विस्तार विश्लेषण) का उपयोग विश्लेषण के लिए किया गया है। अध्ययन से, यह देखा गया है कि कतरनी दीवार प्रणाली में पार्श्व विस्थापन, मंजिल का बहाव, झुकने का क्षण और समय अवधि अनावृत फ्रेम की तुलना में घट जाती है। कतरनी दीवार संरचना में आधार कतरनी, शिखर मंजिला कतरनी और मंजिला कतरनी मान अनावृत फ्रेम संरचना की तुलना में बढ़ जाते हैं। यह निष्कर्ष निकाला गया है कि बॉक्स-आकार की कतरनी दीवार (भवन के मूल में स्थित) प्रणाली अन्य कतरनी दीवार प्रणालियों की तुलना में संरचना की कठोरता में सार्थक योगदान देती है।

  
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