Analysis of RC Multistorey Building with Steel Bracings

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

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 ***Mr. Sunil Kumar*** *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 he has been kind enough to motivate and encourage me. I would also like to thank him 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, ***Dr. Vaneeta Devi****, 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

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Author

CERTIFICATE-I

This is to certify that the thesis entitled **“Analysis of RC Multistorey Building with Steel Bracings”** 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. Deepak Chauhan, Id. No. 54045** 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.

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CERTIFICATE-II

We, the undersigned, members of the Advisory Committee of **Mr. Deepak Chauhan, Id. No. 54045,** a candidate for the degree of **Master of Technology in Civil Engineering** with major in **Structural Engineering**, agree that the thesis entitled **“Analysis of RC Multistorey Building with Steel Bracings”** may be submitted in partial fulfillment of the requirements for the degree.

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LIST OF ABBREVATIONS AND SYMBOLS

ASM	Absolute Sum Method
BM	Bending Moment
CBF	concentric braced frame
Cl	clause
CQC	Complete Quadratic Combination
DL	Dead Load
EBF	Eccentric braced frame
EL	Earthquake Load
ETABS	Extended to Three-Dimensional Analysis of Building System
Fig.	Figure
FRP	Fiber Reinforced Polymer
G	Ground
I	Importance Factor
IL	Imposed Load
IS	Indian standard
ISA	Indian Standard Equal/Unequal Angle
ISMB	Indian Standard Medium Weight Beam
ISMC	Indian Standard Medium Weight Channel
kN/m^2	Kilo Newton/meter square
LL	Live Load
m	Meter
m/sec	Meter/Second
M_K	Modal Mass
MDOF	Multi-degree-of-freedom
MRF	Moment Resisting frame

N/m^2	Newton/meter square
R	Response reduction factor
RC	Reinforced concrete
RCC	Reinforced cement concrete
RSA	Response-spectrum analysis
Sa/g	Design acceleration spectrum
SDOF	Single-degree-of-freedom
SF	Shear Force
SMRF	Special Moment Resisting frame
SRSS	Square Root of the Sum of the Squares
STAAD.Pro	Structural Analysis and Design Program
T_a	Natural time period
WL	Wind Load
Z	Zone Factor
2D	2 Dimension
3D	3 Dimension

Introduction

Chapter 1 INTRODUCTION

1.1 General

The term **earthquake** is used to describe any form of seismic event generating seismic waves that may be either natural or human-initiated. Earthquakes are typically triggered by ruptures in geological fault, but they may also be caused by volcanic activities, mine blasts, landslides and nuclear explosions. Seismic waves are generated because of the earthquake and the developed waves are further referred to as seismic force or lateral loads. The lateral loads thus minimize the structure's stability by creating a moment of sway and developing stresses in the structure. In such a situation, the structure's stiffness is more important than the structure's strength to resist the lateral load.

A number of earthquakes have occurred in India, causing significant and serious damage to residential, commercial and human infrastructure. According to the Indian seismic code IS 1893 (Part-1):2016, more than 60% of Indian land areas are clustered in the upper three seismic zones III, IV and V and only about 3% of the building area is properly engineered. With the increase in seismic activity around the world in recent years, seismic forces have drawn increased interest and have shown their effects to be more devastating. Structures located in areas at seismic risk can experience serious damage during a major earthquake. Because of the ground motion, deformations take place through the elements of the load-bearing system of buildings. A building has a limit to resist displacement so, there is a need to increase the strength of the building. Strengthening techniques are then used to ensure that a building's displacement demand is maintained below its displacement capacity. This can primarily be accomplished by the enhancement of the structure's displacement capacity. In general, there is smaller horizontal displacement requirements for buildings with greater stiffness and lower density.

Multi-storey reinforced concrete structures are vulnerable to extreme deformation, which allows special precautions to be placed in order to counteract this deformation. One of the lateral load opposing systems in multi-storey buildings is the steel braced structure. The steel bracing system increases the structure's resistance to horizontal forces and also increases its stiffness.

1.2 Moment Resisting Frame

A rectangular assembly of beams and columns is a moment-resistanting frame, with the beams and columns rigidly linked. Such frames can be built from steel or concrete. For the purpose of partitioning, the frames are provided with masonry panels in the form of infills. These partitions are regarded as non-structural elements and are usually ignored because of their lateral load resistance and the panel's action is complex. These act as diagonal bracing members before failing and thus falling separately from the frame. In many cases, under brutal shaking these fail and fall away from each other before the frame is subjected to ultimate load and that is why their contribution to lateral load resistance is not measured.

Resistance to lateral forces is mostly given by rigid frame action, i.e. the development of the bending moment and shear force in the members and joints of the frame. A moment frame does not displace laterally without bending the beams or columns, it is dependent on the geometry of the connection and owing to the rigid beam-column connections. Therefore, the bending rigidity and strength of the components of the frame is the key factor of lateral stiffness and strength for the whole frame. The moment resisting frame is shown in the figure.1.1.

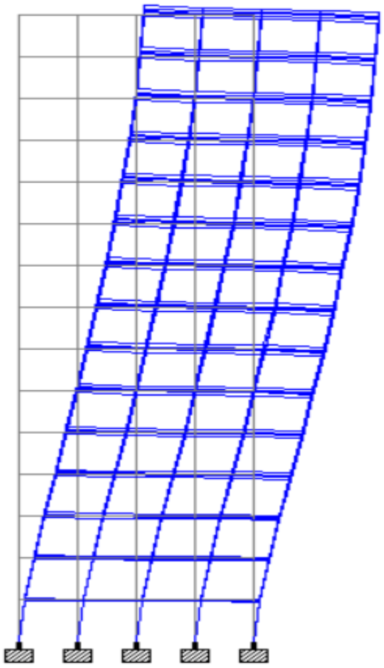


Fig. 1.1 Moment Resisting Frame

1.3 Strengthening of RC Structures for Earthquake Resistance

All around the world, earthquakes have been occurring frequently and the intensity, location, and time of occurrence of earthquakes are very difficult to forecast. Structures correctly built for regular loads such as dead, live, wind, etc. can not necessarily be protected from the lateral loads occurring due to earthquakes. The figure 1.2 shows undamaged and damaged building during an earthquake. Therefore, as the earthquakes are frequent nowadays, so the safety measures should be taken into consideration and these can be done by increasing the lateral load resisting capacity of a building. Thus, earthquake resistant techniques should be deployed on the structure most frequently for increasing the stability of the structures. Some methods for giving the building some appropriate strength to withstand lateral load are described below.

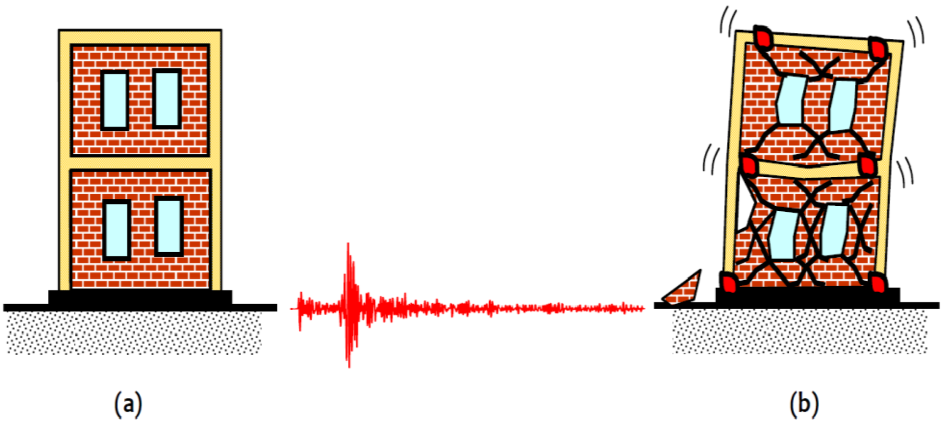


Fig 1.2. An earthquake in normal constructions (a) undamaged building, and (b) damaged building.

1.4 Methods of Strengthening

Seismic strengthening is generally carried out in the following ways.

i. Structure level methods

ii. Member level methods

1.4.1 Structure Level Methods

Two methods are used in the Structure Level Methods to increase the strength at the structure level-

i. Conventional methods based on increasing the seismic resistance of the buildings.

ii. Non-conventional methods based on reduction of seismic demands.

1.4.1.1 Conventional Method

In order to improve the seismic resistance of the structures by removing or minimizing the detrimental effects of design or construction, conventional methods are used and thus it maximize the strength of buildings. The techniques include solutions such as shear wall addition, infill walls or steel braces. Some techniques used in conventional methods is shown in the figure. 1.3.

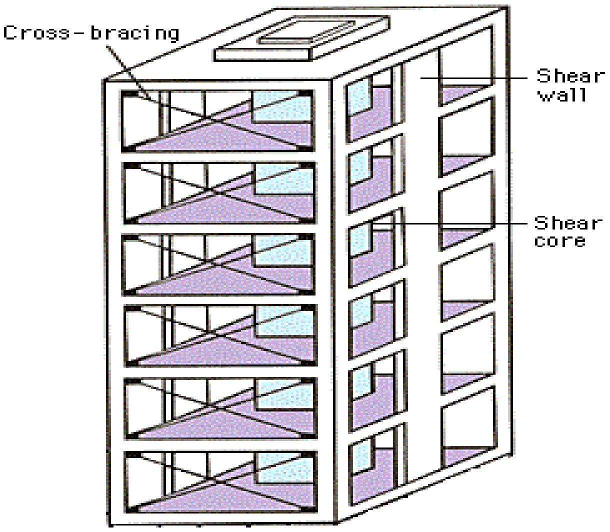


Fig. 1.3 Building with bracing and shear wall

1.4.1.2 Non-Conventional Method

For non-conventional methods, the most common are the seismic base isolation and the addition of supplemented device techniques. These approaches continue with very distinct ideologies in the context that the horizontal seismic forces are essentially conceived to be decreased. The figure 1.4 shows a non-conventional method named base isolation.

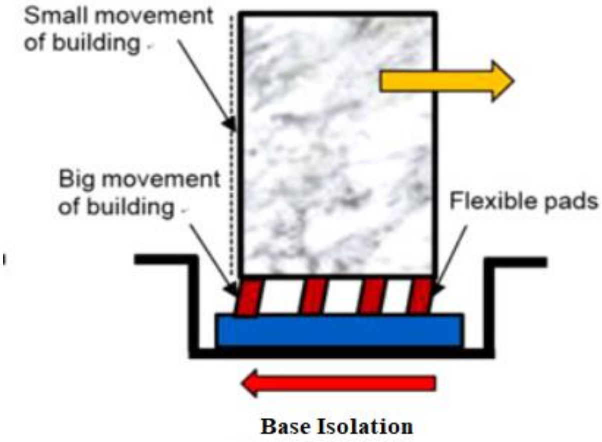


Fig. 1.4 Isolated base of a buiding

1.4.2 Member Level Methods

The strengthening approach at the member level is to upgrade the strength of the seismically deficient members. Compared to the solution at the structure level, this approach is more cost efficient. Jacketing is the most common way to increase the strength of each member in this method. It includes adding jackets of concrete, steel or fiber reinforced polymer (FRP) for use in confining columns, beams, joints and foundations of reinforced concrete. In figure 1.5 column has been jacketed with steel to increase its member level strength.

Fig. 1.5 Column Jacketing

1.5 Strengthening of RC structures with Steel Bracing

Steel bracing applied on framed structures is an earthquake resisting technique which is most commonly used in recent times. It is an economical way to strengthen the structure and also to resist the lateral forces to which the structures are subjected. Buildings with greater heights are provided with the bracings systems. In order to provide stiffness and strength against horizontal shear, bracing is effective since the diagonals operate in axial stress and thus require minimum member sizes. A number of researchers have studied different methods to increase the resilience and ductility of structures. Study by the researchers included the use of steel bracings, infill walls, encasing the existing columns, etc. Seismic performance of a building is increased with the use of steel bracing in the structures and it thus increases the stiffness and the strength of the structure. In addition of the bracing system, load could be transferred from the frame and into the braces, bypassing the weak columns thus increasing strength of the structure.

A structural system which is much effective to resist the lateral loads (earthquake and wind loads) is the frames provided with steel bracings. It is one the most productive and practical way to improve seismic resistance, since it increases the ability of structures to withstand the energy dissipated by the earthquake and integrating bracing components in the frame. A greater degree of pressure exerted by earthquakes can be sustained by the braced structure. Thus, the use of steel bracing systems to improve the stability of reinforced concrete frames with inadequate lateral resistance is also attractive, figure 1.6 shows a steel braced structure.

Fig. 1.6 Building with steel bracings

1.6 Behaviour of Steel Bracing under Lateral And Gravity Loadings

Under lateral and gravity loads, the different bracing system works differently. Braced frames are regarded as the most powerful way to oppose these lateral forces in any directions. Opposing horizontal shear caused due to lateral forces is the key function of the brace. Therefore, the horizontal web member will experience axial stress in the lateral direction for equilibrium while the diagonal member is forced into compression. Forces and deformation can be induced in each braced member when the system is subjected to lateral loading in the opposite direction.

As the gravity load acts on a column, because of the compression it gets shortened axially. As a consequence, because of the tying action, the diagonal members are subjected to compression and the beam will experience axial stress. Figure.1.7 shows the transfer of the external forces to the ground. In the case where diagonal members are not connected at the ends of the beams, no force can be conveyed by the diagonal members and thus no restraint is given by the beams to develop force. In this manner, such bracing does not play any role in countering the loads of gravity.

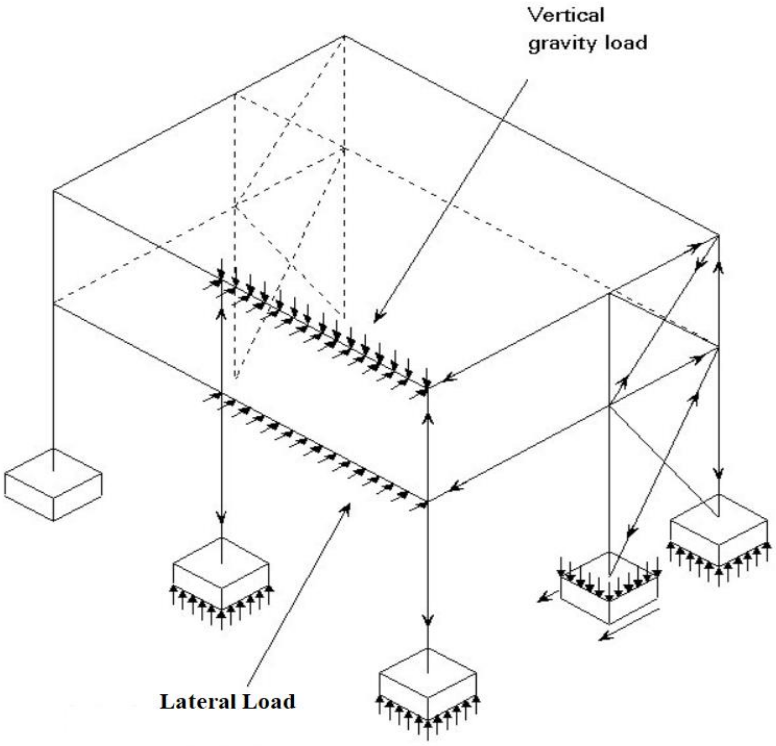


Fig. 1.7 Transfer of external action to foundation

1.7 Research Significance

An earthquake triggers unexpected seismic motion to numerous structures of various degrees and lives, i.e. either complete or partial, causing extensive damage and destruction. In essence, this harm to infrastructure causes irreparable loss of life with a significant number of casualties, therefore strengthening a building proves to be a safer choice. Two methods are mostly implemented for strengthening of the building against earthquakes or seismic activities i.e., global or local. Further it consist of two ways either conventional or non-conventional method. For increasing the seismic resistance, conventional method is used in the buildings and for reduction in seismic demands non-conventional methods are used in the buildings. This research work involves the use of the conventional method i.e. the use of steel bracings to increase the seismic resistance of the structure.

The response and intensity of damage depends on the magnitude of the earthquake, as when it is subjected to ground motion, it affects the efficiency of the building structure. The earthquake classification on the bases of its magnitude is given in table.1.1. Analytical study on the reinforced concrete multi-storey building for different configurations is carried out in this study.

Table 1.1: Earthquake classification based on Magnitude

Class	**Magnitude**
Minor	3-3.9
Light	4-4.9
Moderate	5-5.9
Strong	6-6.9
Major	7-7.9
Severe	8 or more

1.8 About STAAD.Pro

STAAD.Pro V8i is a software for structural analysis and design that is commonly used to study and design the bridges, tower, house, transportation, industrial and utility structure systems. It is a computer aided structural analysis and design program originally established in 1997 by Research Engineers International in Yorba Linda, CA and lately in 2005, Bentley Systems purchased Research Engineers International. It ensures the completion of our steel, concrete, timber, aluminium and cold-formed steel projects on schedule and on budget, regardless of difficulty. Using this program, we can use about 90 international codes to confidently design structures anywhere in the world, eliminating the need for our team to learn many software applications.

From conventional static analysis to more modern computational approaches such as p-delta analysis, geometric non-linear analysis, pushover analysis (Static-Non Linear Analysis) or buckling analysis, multiple types of analysis can be performed with this software. Different types of dynamic analysis techniques may also be used such as time history analysis to response spectrum analysis. STAAD.Pro.V8i software is used for the modeling and analysis of the multi-storey RCC building in the present study.

1.9 Objective of Present Study

1. To learn and understand STAAD.Pro V8i software.
2. To analyse the building model with a different arrangement of steel bracing system namely Concentric Braced Frame (CBF's) by Response spectrum method.
3. Comparative study of the parameters i.e., Storey Drift, Storey Displacement and Time period of different models in seismic zone IV.
4. Study of the parameters i.e., Maximum bending moment, Peak Storey Shear and Base Shear of the different models and compare the results.
5. To study the most efficient bracing system with the best location in the RC framed structure for the considered seismic zone.

1.10 Thesis Organization

This thesis is organised in six chapters.

Chapter 1	This chapter contains a brief introduction, the scope and thesis objectives, as well as the thesis organization.
Chapter 2	This chapter summaries the literature review related to past studies, 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 building.
Chapter 3	In this chapter, the theory of different loading systems with their IS codes and various load combiantion have been provided. This chapter also includes model configuration, dimension, the detail information of the method used for the study and various parameter of the proposed model. Analysis of G+14 RC multistoried framed building with and without bracing systems is carried out using STAAD Pro Software.
Chapter 4	In this chapter, obtained result values from the present study analysis are tabulated in the form of table for various study parameters i.e., lateral displacement, storey drift, time period, bending moment of the column, base shear and peak storey shear presented in the form of graphs. The comparetive study of result with and without bacing is also included here.
Chapter 5	General conclusions from the present investigation and suggestion for future work are presented in the this chapter.

Review of Literature

Chapter 2 REVIEW OF LITERATURE

2.1 General

The past and a recent studies performed by various researchers on seismic analysis of braced frames are reviewed in this chapter. Considering the growth of seismic activities all over the world, earthquake has caused a major loss to mankind and thousands of people have lost their lives. Therefore efforts has been made to develop and improve the structural stability and to reduce seismic impact in buildings and bridges. The buildings are subjected to the vertical loads in addition to the lateral loads induced by earthquakes or seismic activities and wind as well. Lateral stability of the structure has been increased by increasing the stiffness of the structure and increasing the ability to resist the lateral loads to which the building is subjected. Therefore researchers has considered bracing a highly efficient and economical method to laterally stiffen the framed structures against earthquake and wind loads. This chapter comprises the review of literature and various types of bracing systems with their basic characteristics viz., strength, stability and ductility and bracing mechanism involved.

2.2 Review of Research Works

Following paragraphs describing the research works and its finding carried by various researchers.

Viswanath *et al.* (2010) studied that for enhancing the earthquake resistance, increasing the strength and for retrofitting the concrete frames the use of steel braces is a very good solution. A 4-storey RC buildings with concentric steel bracing on peripheral columns were analysed for the seismic analysis. A computer based software named STAAD Pro was used for analysis and zone IV was considered. The performance of various steel bracing (X, K and Diagonal) were studied and the bracings were provided along the height for the building. Evaluation of the building was done by getting the storey drifts. The results when compared with the base frame and different steel braced frames, it was found that there was a reduction in the lateral displacement of the building when bracing system was introduced in it. Shear forces were reduced and bending moments were also reduced and in the columns due to the use of bracings. Study found that structural stiffness was increased due to the use of X (cross) type of steel bracing and it was the most effective when compared with different cases. The study was further extended to more storied building in which percentage reduction in lateral displacement was studied and the steel bracing which reduced the inter-storey drift was the X type bracing system when used in the frames.

Takey and Vidhale (2012) studied the behaviour of a linear bracing system of steel building under seismic response using software approach. As associated with Reinforced cement concrete the steel has got some important physical properties like the high strength per unit weight and ductility. The analysis of unsymmetrical building with the bracing system to resist the seismic lateral load using SAP and also compared the braced and unbraced building which were subject to seismic load. Response spectrum analysis was carried out in G+9 stories in zone III using the steel bracings. The bracing which used for the analysis were the X-type and inverted V-type bracing system. The parameter considered in the study to compare the seismic performance of the building were bending moment, shear force, storey drift, and axial force. The conclusion which has come out that storey drift and displacement of braced building when compared to unbraced building was decreased, therefore it was concluded that X bracing performance was better than another different type of bracings.

Bajoria *et al.* (2012) examined the steel structure with or without bracing for the seismic analysis. The study was carried out in the steel building (G+40) to verify the behavior of an alternative form of bracing (X bracing, Diagonal bracing and k bracing) in the steel building, bracing throughout the building extended the building's lateral resistance potential during an earthquake. The method used in this paper to describe seismic analysis, i.e. dynamic investigation was the time history method and was executed according to IS 1893 (part1). In x and y-axis, the building was symmetrical with a length of 40 m and a width of 22 m with a floor height of 3.5 m. Normal frequency, base shear, inter-storey drift, and mode shapes were taken into consideration for the seismic study. Conclusion after the study was made that the displacement of the top roof was decreased by up to 65 percent with the inclusion of different bracing systems and base shear was increased by up to 38 percent. The final conclusion that arose was that the diagonal brace style has highly efficient and economical nature.

Kulkarni *et al.* (2013) studied that braces widen the resistance to lateral forces of inclined members and minimizes the forces which are in the columns and beams. It acts like a truss and are subjected to mostly axial stresses. This results in less moments when compared to moment resisting frames and we can get smaller sizes of beam and column. The study deals with the seismic analysis of RCC frames which were provided with RC braced member in V – braced pattern. A 12-storey building with five bay in each direction is analysed numerically. The V-bracing system was arranged as; i) bare and fully braced frames ii) baywise and levelwise braced frames iii) outrigger i.e. partially braced frames (combination (i)and (ii)). After these possibilities were developed to arrange bracing at different positions in the buildings to form different pattern and to make the building partially braced. This pattern would produce smaller forces in buildings for the worst load combinations. This arrangement was called as optimum frame. Lateral displacement was calculated for bare frame and braced frames and comparison was made. It was concluded from the result that optimally braced frames were more stiffer and more stronger. This structural system was also considered more economical when compared to fully braced frames. Optimally braced were also said to induce less forces in the structure and produced less displacement which were within the limit.

Kevadkar and Kodag (2013) studied that severe damage was experienced by the structures in high seismic areas, so the structure should be able to resist the lateral loads which can develop considerable stresses. Therefore use of steel bracings and shear wall in steel structure were considered in resisting lateral load due to seismic activities. In this study, G+12 storey building with three different kind of models were considered- I) Bare frame II) Frame which consisted of different bracing types III) Frame which consisted of different shear wall system. Further the shear wall and bracings were also of different types. For 3D modelling and to carry out the analysis a computer based software E-TABS was used. Zone III was considered for the study purpose and codal provisions used for analysis were IS-456:2000, IS-1893:2002 and IS-875:1987. Parameters considered for the evaluation and comparison of the building were the base shear, storey drift, storey shear and lateral displacement. It was found that steel bracings reduced the bending moment and shear force in columns and beams and thus these lateral loads were transferred through axial load mechanism. Therefore it was concluded that X bracing type was better as it increased the strength of the structure and reduced the storey drift and also the lateral displacement of the structure. Steel bracing was considered more safer against the collapse when compared with shear wall.

Mohammed and Nazrul (2013) investigated the multi-storey RCC braced structures to get the performance of the structures. Bracing system is a retrofitting technique provided for stiffening and strengthening the building to resist the lateral forces. Study consisted of a G+14 storey SMRF (Resisting frame) is situated in zone IV and then analysed using STAAD V8i software. Analysis of the RCC frame with and without bracings system is done with the software. Bracings of different kinds were used such as Cross (X), V, Diagonal and K type bracings. Comparison is done between fully braced and unbraced framed structure and different parameters such as storey shear, bending moments in buildings, shear forces were computed. Conclusion made after the result was that there was decrease in the displacement of the structure due to the bracing provided in the structure. Cross bracing helped in reducing the lateral displacements and also the shear forces and bending moments in the columns. Cross bracing system was considered best among all the bracing systems as it gave better results when compared to other bracing systems.

Tafheem and Khusru (2013) studied that there is a need of retrofication in many existing steel buildings to resist the lateral loading. Modelling and then linear static analysis of a six storied steel building was performed using ETABS software. Analysis performed was done by considering the lateral loading and live and dead load for the building. The concentric and the eccentric bracing system were used to check performance of steel buildings or models. Concentric bracing used was the X- type and the eccentric bracing used was the V-type. Parameters evaluated after the analysis were the storey drift and lateral displacement at different levels of the building. Computation of the axial force and bending moment was also done for the study purpose. Comparison was made between braced and unbraced frames and different bracings were used for the same building parameters. Results obtained after the study was that the lateral stiffness of the building was increased due to application of concentric bracing than the eccentric V-type bracing and concentric X-type bracing reduced the lateral displacement in the building. It was also found that the column at the exterior face and at the corner of the braced building were induced with the maximum axial forces when compared with the unbraced frames and the columns on the exterior face of the unbraced structure were experienced with the maximum moments when compared with the braced structure. Therefore, the concentric X-type bracing was found the best bracing system after the study.

Yadav and Khuswaha (2015) studied that the using steel bracing in the buildings which are prone to seismic activities is a good solution for resisting the lateral forces in multi storey RC building. A G+7 storey building was considered with 4-bays in both the direction. Three bracing systems were considered for the seismic analysis i.e., X-type Bracing, K-type Bracing and V-type Bracing. These bracings were provided at different locations i.e., at core and outer in the frame. Modelling and analysis was done of the different frames with the help of STAAD.Pro software for all the seismic zones. Models so formed were divided into two parts i.e., frame with and without bracing system and a total of nine cases were formed. Various parameters evaluated during the analysis were the maximum moments generated in beams, shear force, maximum lateral displacements and storey displacement. After the comparison between two efficient bracing patterns i.e., core and outer, core was considered the better option and amongoust the various bracing system, X bracing was more stable and gave good results in all seismic zones. So, it was found that X bracing which was provided at core of the building was the most efficient one.

Chadhar and Sharma (2015) studied that for resisting the horizontal forces in a RCC building, steel bracing system is very effective as they are subjected to tension and compression. Use of steel bracing helped in increasing the stiffness and stability of the buildings and are favorable to resist horizontal forces induced in the structure. Seismic analysis was performed in a G+15 storey RCC building for studying the effect of inverted V type and V type bracings. These bracings were arranged at various positions in the building. Analysis work and modelling work was conducted with the use of computer software StaadproV8i. Seismic zone IV as per the seismic zone map of India was considered for the study. Influence of the different steel cross-sections but same cross-sectional area was also the part of the study. Three different steel profiles i.e., ISMC, ISA and ISMB were used as the bracing members. After the analysis it was revealed that the inverted V-type bracing gave better result compared to V bracing as it reduced the shear force, bending moment, storey drift and node displacement significantly. It also concluded that arrangement of bracing systems also plays a vital role on seismic performance of the building frame and the steel profile ISA gave better result than the other two.

Bhosle and Shaikh (2015) studied about the structural systems i.e., Concrete and steel bracings were used for resisting seismic loads in multi-storeyed RCC buildings and analysed that lateral loads developed due to the seismic activities such as earthquake can develop considerable stresses and thus theses loads cause vibration and produce sway in the structures which leads to failures for the structure. So, the structure should have adequate strength and stiffness to resist the vertical loads together with the lateral forces.

In this seismic study different bracings types were used such as X, Diagonal, Inverted V type, V type and combination of V, K and X type and compared for the safety of reinforced concrete buildings. The bracings were provided on the parallel sides of the building and on its column periphery. Analysis was done using ETAB software of a 13- storey building and seismic zone III was taken for the study considering the codal provisions as per IS 1893: 2002. The reduction in the displacement was found for the top floor, it was upto 60 to 65% and base shear was also a parameter for the study. After the comparison of the different bracings the most efficient one was the X type bracing which gave the maximum reduction in the drift of the multi storey building and was found that it is the best option in terms of storey overturning moment.

Kalra (2016) studied that earthquake forces affects the lateral stability of multistoreyed buildings. Therefore use of steel bracing was a good solution to overcome the problem and meet the required stiffness and strength of the building. In this study four bracing types were used i.e., Cross, K-type, V and inverted-V type, which were provided in six storeyed building at three different locations. First location was at the corners of the exterior frame, second was in the middle-bay of the exterior frame and third was provided in the middle-bay in interior and exterior frames both. A total of 12 cases were considered which consisted of RCC frames which were steel braced and were analyzed and comparison was made with the unbraced RCC framed structure. The analysis was performed with the help of Staad Pro-2007 using the Response Spectrum method. Various parameters computed from the study were time period, lateral displacements, bending moment, base shear, shear force, storey shear and axial force in the members of the building. It was found that X bracing showed the best results and the location recommended was the second one i.e., the X bracing in the middle bays of the exterior frame. The K type bracings were the least preferred type bracing.

Khan *et al.* (2016) studied the effectiveness of the various bracing systems on RC structures for enhancing and retrofitting the seismically ineffective on reinforced concrete building frame. Different bracing were used in a G+15 building frame and analysis were carried out on different seismic zones III, IV, V, which were used as per IS code 1893, and thus was taken into account in their study. For the study, ETAB Software was used, and both equivalent static and response spectrum approaches were used. In this research, researcher discovered that in order to monitor storey drift, lateral displacement and member forces in the structure, various forms of bracing had to be used. Compared to the bare frame, bracing lowers storey drift and lateral displacement, and X bracing adds less lateral displacement compared to other bracing.

Anes Babu *et al.* (2017) studied the effects of steel braced RCC framed structures. Modelling and analysis were carried out using a computer aided E tabs 2015 software and a G+9 RCC framed building was considered for analysis of seismic forces at different seismic zones. Models were divided into three parts 1) Bare Frame 2) Frame with bracings of different types (i.e., diagonal, X, K, V, Inverted V or chevron) 3) Frame with the shear wall. The shear walls and bracings were provided on the middle bays to find out seismic performance of RCC framed building. Parameters considered for the evaluation purpose and analysis were the storey drift, lateral displacement, and storey shear in the building. Conclusion made after the study was that for Zones IV & V, X type bracing gave better results and for zones II & III, chevron type of steel bracing gave more efficient results. After the comparison it was also found that 15 to 20% difference came in the parameters of the braced building and shear wall building. Further steel braced building gave more efficient results and it significantly reduced the lateral drift which was less than the shear wall building.

Nassani *et al.* (2017) have researched that strength is less important than stiffness in high building. In steel frame construction, the braced and moment resistant frame was used as lateral load resisting structural elements. In this paper, under seismic effect, the researcher reveals a comparison of the seismic response of different bracing in steel frames. X, V, inverted V, knee, and zipper braced frame are the multiple bracing systems that have been used. The structure consists of a steel brace that is inserted in the middle bay of a 3 bays structure. With the help of dynamic analysis and nonlinear static analysis, the system was modeled and analyzed at four different storey levels. Drift ratio, base shear, storey displacement, roof displacement are the distinct constraints used to determine the structure stiffness. The results showed a decent increase in seismic resistance with distinct bracing. The study found that the bracing components were remarkably effective in decreasing drift as a 58 percent decrease was found in inter-storey drift when compared with the unbraced frames thus these systems contain strength and stiffness.

Mapari and Ghugal (2017) analysed the seismic evaluation of the multi storeyed steel structure with bracings and without bracing. Dynamic analysis was done for the evaluation purpose. ETAB 2013 software was used for modelling and analysis of the high rise steel building of 25-storey. Different shapes of the bracings were used and the types were the Cross, K-type, V and inverted-V type. The method used was the response spectrum and the dynamic analysis was performed as per IS 1893 (Part 1): 2002 and was carried out for 5 different models. Different parameters considered for evaluation were base shear, displacement in the building and modal time period and were used for comparison for the models.

After obtaining the results, it was observed that use of bracing system can increase base shear due to increase in lateral stiffness. For different bracing systems base shear varies in both directions depending upon geometry of bracing. It also showed that bracing shows a good effect on structural behavior of structure and after applying bracing system in both directions, base shear of structure increased, modal time period reduced and the displacement of roof level of building decreased. X bracing was highly effective bracing system in comparison to other bracing system.

Swetha and Ujith (2017) studied that providing bracing to the structure increased the stiffness and thus the strength to the building against lateral forces, so is a good retrofitting technique. The study concentrates on the seismic behaviour of reinforced concrete building with different bracing system i.e., diagonal, X, V, Inverted V. The response spectrum method was used for the analysis and use of Etabs 2016 software was done to get the results such as the storey drift of the building, time period, displacement and base shear of the different models. The were 5 models considered for the study, such as (a)Frame Without bracing (b)Frame with X-type bracing (c) Frame which consisted of V-type bracing (d) Frame with inverted V-type bracing (e) Frame with inclined bracing and all these models were used for the comparison to get different parameters. It was found that X bracing is more effective bracing system because it has 2-elements which can take both tension and compression, thus it shows better seismic performance. When X-bracing was added to the structure, then model showed 54% reduction in displacement, time period and drift reduced by 90%.

Qureshi *et al.* (2018) studied that shear wall system were commonly used for resisting the lateral forces which were induced by the seismic load, wind loads etc. and thus it provided stability to structure due to its high strength and stiffness. The work was performed to get the seismic responses of multi storied building. Buildings with G+15, G+25, G+45 storey, with and without shear wall were considered for the seismic anlysis. The different cases of shear wall positions were taken for 4 models and a comparative study was performed for the different parameters such as lateral displacement and storey drift. Model-1 was the framed structure, Model- 2 was the shear wall provided in the lift area, Model-3 was the shear walls provided on the corners of the frame and Model-4 was the shear walls provided inside. Earthquake behaviour of models was checked using STAAD Pro software. Zone considered for the analysis purpose was the seismic zone III.

After the analysis, the result so obtained was that the displacement was less in model-4 as compared to others in both X and Z direction and storey drift was also less in model-4 in comparison to other models. So the conclusion was that the shear walls inside the buildings make the building much safer for seismic design.

Reddy and Kumar (2018) studied the effect of the bracings on the RCC framed structures. Analysis and modelling was done of the reinforced concrete framed building with G+9 storey. Three models were considered for the purpose i.e 1) Bare frame 2) Framed structure with different kind of bracing systems 3) Framed structure with shear wall. Bracings used were also of 2 different types namely X and Chevoron type. Mid- bays of the structure were provided with the bracings and shear walls and thus analysis was done using E tabs 2015 software for different seismic zones. To check the suitability of the seismic analysis, different parameters such as lateral displacement, storey shear and storey drift were studied. After the work was done it cleared that both the bracings were appropriate and suitable but for Zones II & III, the better bracing type was the chevron steel type and for Zones IV&V, the better one was X type of steel bracing as it gave better results for those particular zones. When steel braced building and shear wall building were compared, steel braced buildings reduced the lateral drift as it was a bit more for the shear wall building.

Kanungo and Bedi (2018) studied that multi-storey structures are mostly influenced by the seismic activities so it should have enough ability to resist the horizontal forces and keep the structure stable. Strengthened steel framework which consist of solid edges are considered suitable for opposing the lateral forces that the buildings are subjected to. In this examination a G+19 storey structure with 3m height of each storey with exposed casing and edges having X-type bracings at the corners was considered. The bracings were provided on the fringe sections of the building. The analysis was performed with the help of Staad.pro software. There were eight cases with and without bracing for 4 different zones (II, III, IV and V). As a result, when steel X-bracing were provided at the two parallel of the structure then there was a reduction in the lateral displacement and storey drift of the structure. Due to bracing the base shearing capacity of the building was increased which indicated that the building’s stiffness has increased and the overturning moment of base of RC frame was also increased.

Khan *et al.* (2019) presented a analysis on the different techniques for resisting the earthquake for a G+10 multi-storyed building. Techniques used were the use of shear walls & bracings on the multi-storey building, using a computer aided software. These techniques were used for strengthening the structure and to make the structure more strong to oppose the earthquake. As per IS 1893:2002 codal provisions, a G+10 storey building with 4-bays in both the direction for seismic zone III was analysed using STAAD-PRO V8i 3.1. Shear wall and bracings were used as the seismic resistance techniques in the analysis. Five structures were considered for analysis- (i) Base structure without any resistance (ii) Structure with parallel shear walls in the mid bays (iii) Structure with Corner Shear Walls (iv) Structure with diagonal bracings (v) Structure with cross bracing. Different parameters such as maximum deflection, storey drift, storey shear and maximum axial force were calculated and compared for all the five structures. Conclusion made after the study was that maximum deflection and storey drift was reduced by the use bracing and shear wall. Location best preferred for the shear wall was the parallel shear wall and the best bracing type which can be used for better results was the cross bracing. Therefore after the overall study, the cross bracings were the best for maximum earthquake resistance.

Katte and Kulkarni (2019) carried out the seismic analysis for the steeled structure which consisted of the steel bracings at different location of the structure. Bracing were used in the structural system to increase resisting capacity of the building against the lateral loads. Study deals with the X type bracing system on steel building at different locations and thus forming six different models and loadings were considered as per IS: 1893-2016. Modelling and analysis of a G+15 storey was done by the use of ETABS software and response spectrum method respectively. The building had 4-bays in both the direction of the G+15 storey. Comparison of different seismic parameters like displacement and storey drift was carried out between the models. Six different models were analysed in which five models were X-braced frame model with bracings at different locations and one was unbraced frame model. It was found that model which consisted of the bracing at second and third bay in one-direction and second and third bay in other-direction at core gave the best result. The displacement and drift of the structure was reduced with the use of X- bracing.

2.3 Introduction to Bracing

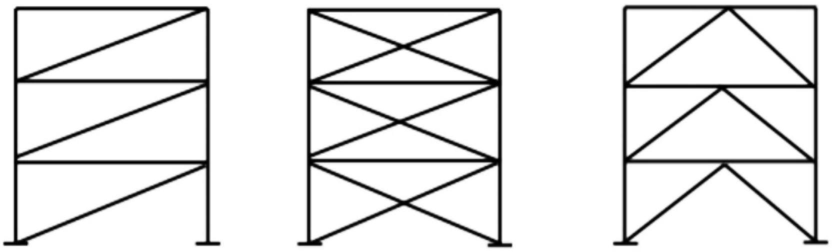
In a frame structure, bracing is a highly effective and economical means for resisting horizontal forces. For most of the world's tallest buildings, bracing are used to support the structure laterally. In order to provide stiffness and strength to the structure against horizontal shear, bracing are provided in the structure in which the diagonals are very effective as they work both in tension and compression which helps in reducing the member size. Performance of the structure against seismic activities is also increased. Addition of the bracing system helps in load transfer by bypassing the weaker columns and increasing the strength of the building.

2.4 Types of Bracing Systems

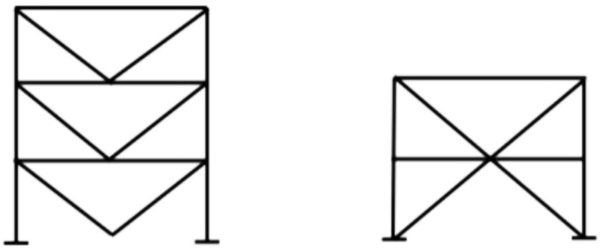
There are two types of bracing system, namely concentrically braced system, and Eccentrically braced system. These are explianed in the following sections:

2.4.1 Concentric Bracings

This are composed primarily of diagonal braces positioned in the frame plane. In order to form a truss, all the braces in the framing members joins at the ends, thus making a structure stiff. Concentric bracing strengthens the frame's lateral stiffness, which in turn increases the natural frequency and thus reduces the drift at different storey level. Moreover, by reducing the bending moments and shear forces in the column, the axial stresses in the columns are increased due to bracings. Concentric bracing can be arranged in some unique arrangements such as cross, V, diagonal bracing, etc. as shown in fig.2.1 and these members can be subjected to both the stress.



a. Diagonal bracing b. X bracing c. Inverted V bracing



d. V bracing e. Two-story X bracing

Fig 2.1 Different concentric bracing

2.4.2 Eccentric bracing

These bracings consists of the braces in the diagonal form and located in the frame plane, where one or both ends of the brace do not join the end points of other framing members, fig 2.2 shows eccentric bracings. Diagonal braces two in number are connecting the column at the mid-span of the beam with a small portion of the beam are prepared for these braced frames, in order to increase the lateral load resistance in terms of seismic efficiency. It improves the capacity of energy absorption during ground motion and reduces the system's lateral stiffness. The vertical portion of the bracing force induces concentrated load at the point of attachment of eccentric bracings on the beams due to the earthquake. Basically, this assembly includes both the moment frame and concentrically braced frame. The eccentric connection in the frame means that a bracing which has eccentricity transfers lateral forces either to a further brace or to a vertical column through shear. In addition, the lateral movement resistance in the eccentric braces is throughout the column and beam.

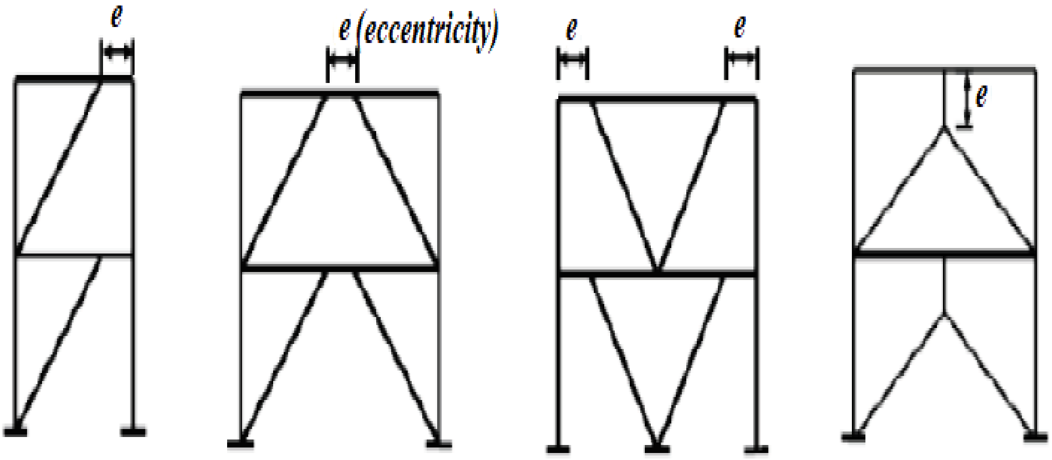


Fig 2.2 Eccentric bracing systems

2.5 Summary

By studying the various literature regarding different types of bracing system for the multistoried steel frame and RC frame in a high seismic area. The following details present a brief summary of the literature.

- As per the researchers, the bracing provided in the buildings has the capability of controlling the lateral displacement also reduces the inter-storey drift.

- The performance of the buildings has been checked using different bracing types, these are mainly X bracing, diagonal bracing, Chevron bracing and eccentric bracing and further the positions of the bracings were also changed in the buildings.
- From the study, it was found out that, X bracing reduced the lateral displacement of the structure by about 30 to 45% and thus it gives a greater structural stiffness to the structure.
- The bracing used as an alternative for strengthening the structure are either of concrete or steel.
- It was found that X type and Chevron type bracing is most efficient for reducing storey displacement and storey drift in Zone IV. The bending moment in the columns has been minimum in the X-type and Chevron bracings.
- The time period was minimum for the X-type of bracing compared to other bracing types.
- There was a significant increment in base shear of the braced frame when compared with the bare frame structure.
- Bracing system applied at the core and mid bays are more efficient compared to other locations in the buildings.

Materials and Methods

Chapter 3 MATERIALS AND METHODS

3.1 General

A Braced Frame is a structural system that is mainly designed to withstand the forces induced by the earthquakes. Through bracing action of inclined members, bracings resist the lateral load. In the associated beams and columns, they stimulate forces such that the entire work is subjected to axial stress like a truss. This axial stress thus reduces the moment and which in turn results in the reduced sections of the columns. The bracing components are structured in several configurations that bears tension only or tension and compression alternatively. When it is designed to resist only tension, the bracing consists of crossed diagonals. One diagonal takes all of the tension based on the wind direction, while the other diagonal is assumed to remain inactive. Cross bracing is one of the most common arrangements. By transferring the loads sideways down to the ground, bracings keep the structure stable and are used to resist lateral loads, thus preventing the structure from swaying.

In the previous chapters, the objective and literature review of the study are mentioned. The present study is to compare the seismic effect on high rise multistorey RC building by using different types of bracing systems in different positions of the building. Thus this chapter illustrates the various load and their combinations as per IS codes, the detailed description of the building, as it consist of the un-braced and braced RC frame models. In this, the geometry is shown through the plan, elevation, the location of the bracing systems in the building and 3D view of RC frame with and without bracing system. The methodology used in the study is also included in this chapter.

3.2 Loading Description

The structure should be constructed in such a manner that the load system applied to the structure over its lifetime will withstand it. The load application leads to the development of stress and also leads to displacement of a structure, leading to the structure's collapse. Gravity loads and seismic loads are the types of loads used in the methodology.

The codes of the Indian Standard (IS) provide information on all types of loads for structural design. For the study of the building, the following loads were considered:

3.2.1 Gravity Loads

The intensity of dead load and live load at various floor levels considered in the study are listed below.

3.2.1.1 Dead Load (DL)

Permanent loads are dead loads and act vertically downwards. Dead loads are basically due to the structure's self-weight as well as the floor slab weight, beams, columns, walls and floor finish. It is possible to calculate the death load of buildings by calculating and adding the self-weight of each structural element. The formula used for calculating self-weight of each structural element in kN/m is:

$$DL = \gamma_m \times d \times b$$

where, γ_m =unit weight of material (kN/m^3)

d=depth of element

b=width of element

The unit weights taken for plain concrete and reinforced concrete are 24 kN/m^3 and 25 kN/m^3 respectively. Dead loads for various materials being considered in analysis and design to have taken from the IS 875 (part1). In the present analysis, a dead load of 3 kN/m^2 on floor and roof is used.

3.2.1.2 Live Load /Imposed Load (IL)

Live loads are those which may change in position and magnitude. In order to cover not only the physical contribution due to persons, but also due to the nature of occupancy, the furniture and other equipment that are part of the character of the occupancy, the use of the term live load was changed to "imposed load". The imposed load presumed to be produced by a building's intended use or occupancy, including the weight of movable partitions, distributed, concentrated loads, impact and vibration loads, and dust loads, but excluding wind, seismic, snow and other loads due to changes in temperature, creep, shrinkage, differential settlement, etc. Imposed loads for residential buildings are taken as per IS 875 Part 2 as described below.

Live load is used as 4kN/m^2 in the present study. The codal provision which has been used for live load is given in IS 875(part 2). Live load to be considered in the calculation of the seismic weight of building as per IS 1893-2016 load up to and including 3kN/m^2 is 25% of the imposed load is and above 3kN/m^2 percentage of imposed load used is 50%.

3.2.2. Earthquake Load

There are large scales of hilly terrain in the north and northeast parts of India, which comes under seismic zones IV and V. Buildings are particularly vulnerable to earthquakes in such areas. Due to collision of tectonic plates, earthquake occurs and thus the epicenter of earthquakes is normally located at fault lines.

The intensity of earthquakes involves both vertical and horizontal forces in the structure. The cumulative vibration induced by an earthquake is registered in three mutually perpendicular directions, one in vertical and two in horizontal directions. Earthquake forces in the vertical direction do not cause any major damage to buildings, whereas the impact of horizontal earthquake forces on structures is catastrophic thus is taken into consideration for the seismic analysis. The structural stability due to ground vibration depends on the quality of the soil of the foundation, the size of the foundation, the design mode and the speed of the ground motion. The calculation of earthquake forces is based on IS 1893:2016.

3.3 Load Combination

When more than one form of load acts on the structure, a load combination is given. In order to ensure the safety of the structure under various maximum load conditions, building codes generally indicate a number of load combinations along with load factors for each load type. For the study, a combination of various loads that produce a detrimental effect on the structure are used.

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

i. 1.5(Dead load + Impose load)

ii. 1.2(Dead load + Imposed load ± Earthquake load)

iii. 1.5(Dead load ± Earthquake load)

iv. 0.9Dead load ± 1.5 Earthquake load

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

3.4 Detail of the Model

A G+14 storey RC frame building is selected for the seismic study and its performance is being checked when exposed to the seismic forces. It has been compared with the different bracing systems with the same configuration. A G+14 storey building is modeled and analyzed using a computer aided software STAAD.Pro V8i. The Plan and elevation of the bare (un-braced) RC frame of a building are shown in Fig. 3.2 and Fig. 3.3(a) respectively. In the structural plan of RC frame model of the structure, there are total 5 grid lines in both X and Z direction and having 4 bays each in both X and Z direction at a spacing of 3m i.e. it is a square plan building having plan dimension 12 m x 12m. The total height of the building is 45 m and the height of each floor is 3m.

The structural models of RC frames with different bracing systems and different location of the bracings and the plan and elevation of the building is shown in the figures 3.2 to 3.9(b). Plan consists of the position of the bracings in the building and the elevation consists of the 3D rendered view of that particular plan. The RC frame models used for the analysis with detailed description are-

Model 1- Shows the elevation and 3D view of RC frame structure without bracing (Bare frame) as shown in fig. 3.3(b)

Model 2- Shows the elevation and 3D view of RC frame structure with X Bracing in the mid 2-bays as shown in fig. 3.4(b)

Model 3- Shows the elevation and 3D view of RC frame structure with X Bracing on the side bays as shown in fig. 3.5(b)

Model 4- Shows the elevation and 3D view of RC frame structure with Inverted-V Bracing on the mid 2-bays as shown in fig. 3.6(b)

Model 5- Shows the elevation and 3D view of RC frame structure with Inverted-V Bracing on the side bays as shown in fig. 3.7(b)

Model 6- Shows the elevation and 3D view of RC frame structure with V Bracing on the mid 2-bays as shown in fig. 3.8(b)

Model 7- Shows the elevation and 3D view of RC frame structure with V Bracing on the side bays as shown in fig. 3.9(b)

The cartesian coordinates directions used in STAAD.Pro V8i for the analysis of the RC multi-storey building is shown in the fig.3.1. All the plans, elevations and 3D Rendered views are according to shown directions of the x, y and z portrayed in the fig. 3.1 of the three coordinates.

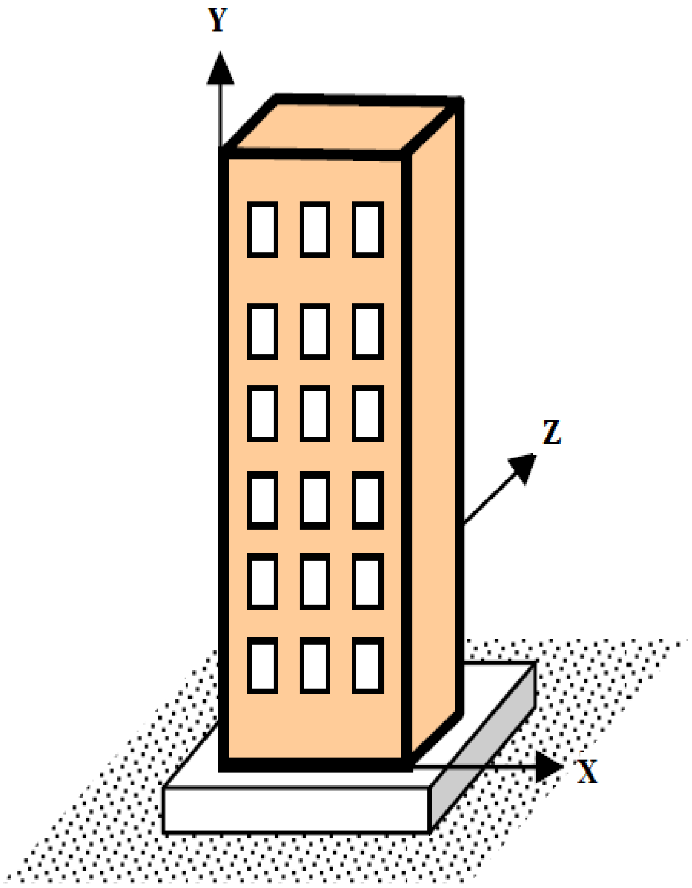


Fig 3.1 Cartesian coordinates directions in the building

The basic data details of the selected building frame for analysis are listed in Table 3.1. To study the seismic analysis of frames, the basic values are selected form IS 1893:2016 (part 1) to meet the basic requirement of the structure. Moreover, various IS code has been used to calculate the DL, LL, etc. and all are explained in detail.

Table 3.1 RC Frame Data Details Considered for the Analysis

The geometry of the structure	**Detail/ value**
Grids in the direction-X	5
Grids in the direction-Z	5
Grid line spacing line in X-direction	3m
Spacing of Grid line in Z-direction	3m
Number of Storey	G+14
Height of each storey	3m
Height of the ground-floor	3m
Beam's dimension	450 x 450mm
Column's dimensions	600 x 600mm
Steel bracing	ISMB 200
Soil Type	Medium
Support type	Fixed
Seismic Zone	IV
Dead Load	3kN/m^2
Live Load	4kN/m^2
Combination Method	CQC
Response Reduction Factor	5
Importance Factor(I)	1
Damping Ratio	5%

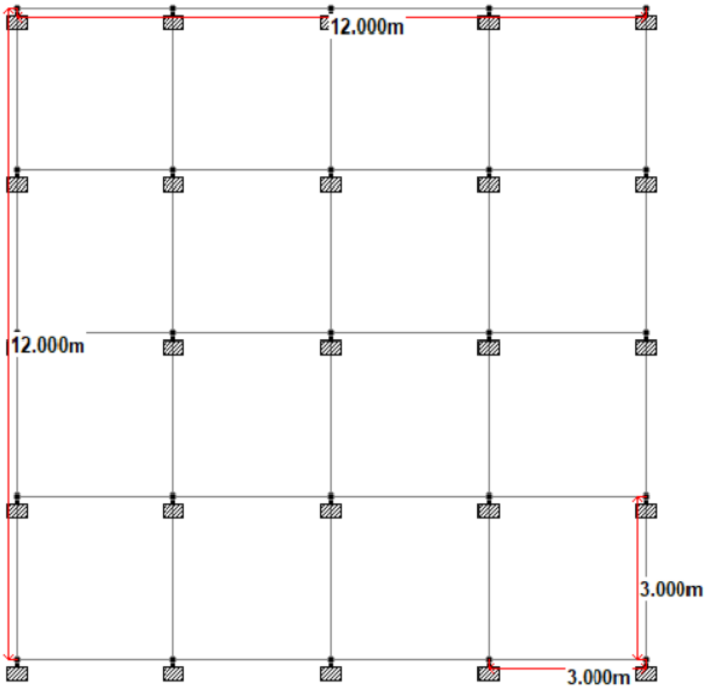


Fig.3.2 Structural Plan/Layout of RC Frame Model

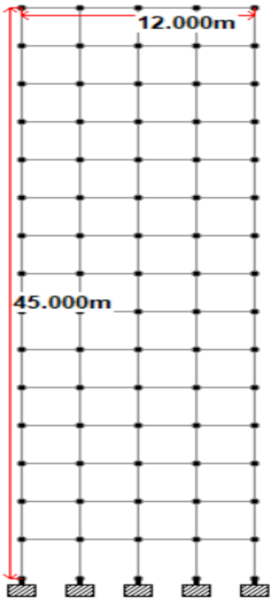


Fig.3.3(a) Structural Elevation of RC Frame Model

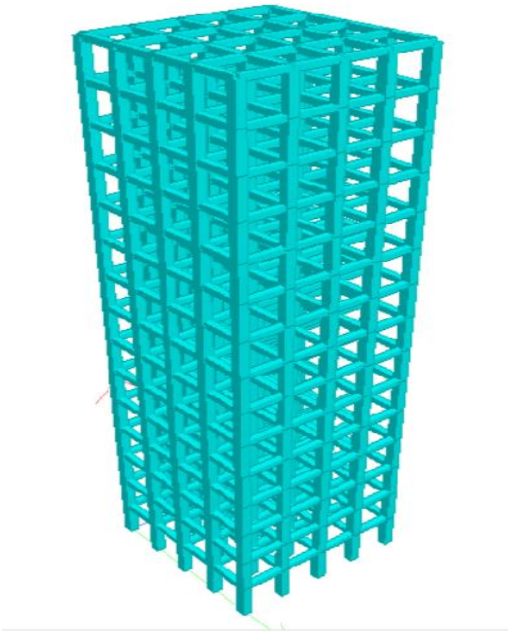


Fig.3.3(b) Rendered view of unbraced RC Frame (Model-1)

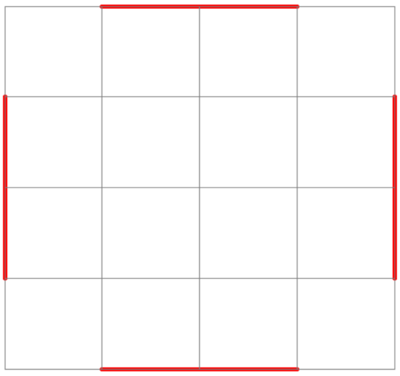


Fig.3.4(a) Structural Plan for X-braced RC Frame (Model-2)

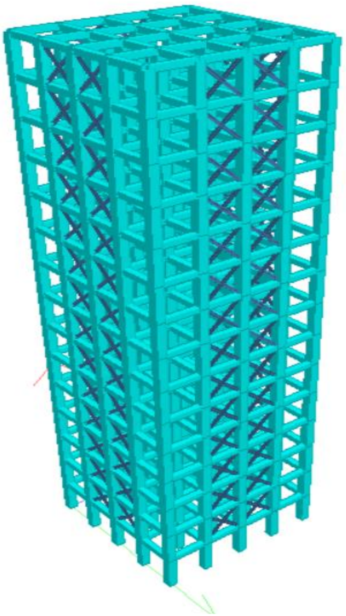


Fig.3.4(b) Rendered view for X-braced RC Frame (Model-2)

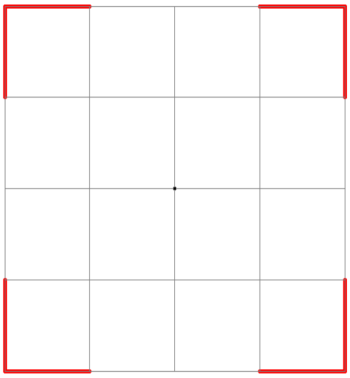


Fig.3.5(a) Structural Plan for X-braced RC Frame (Model-3)

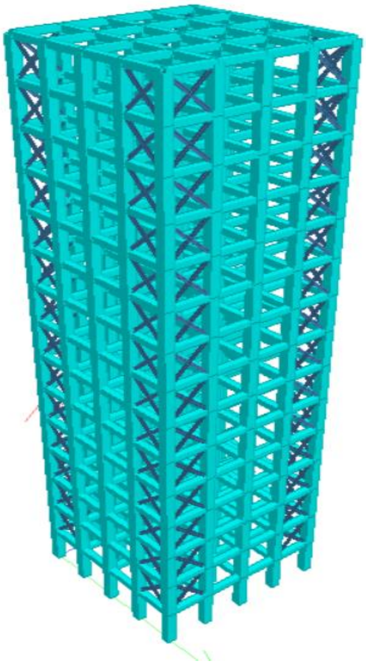


Fig.3.5(b) Rendered view for X-braced RC Frame (Model-3)

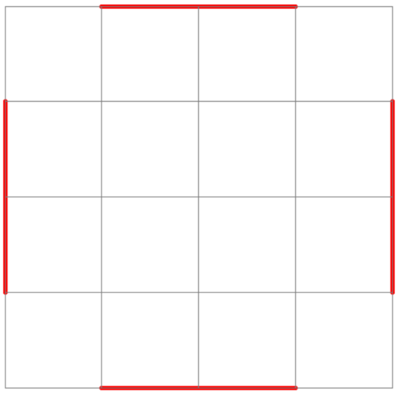


Fig.3.6(a) Structural Plan for Inverted V-braced RC Frame (Model-4)

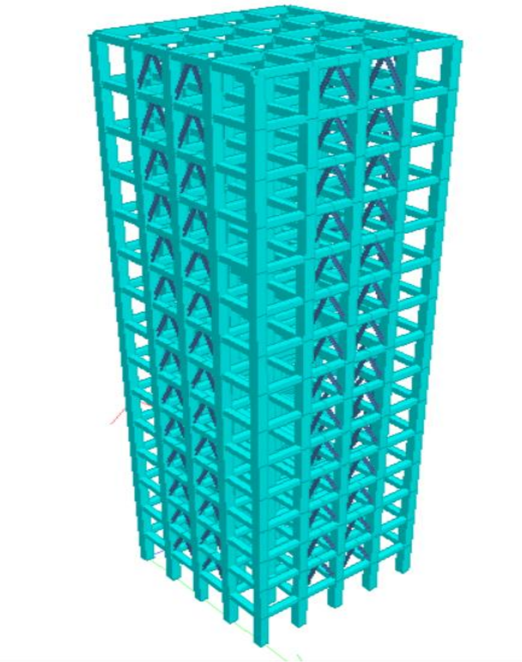


Fig.3.6(b) Rendered view for Inverted V-braced RC Frame (Model-4)

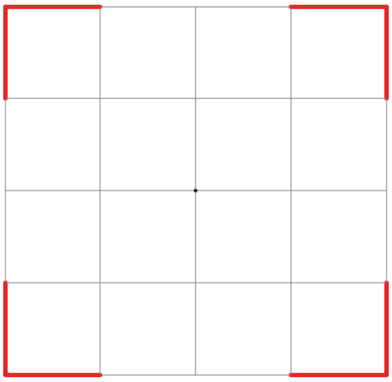


Fig.3.7(a) Structural Plan for Inverted V-braced RC Frame (Model-5)

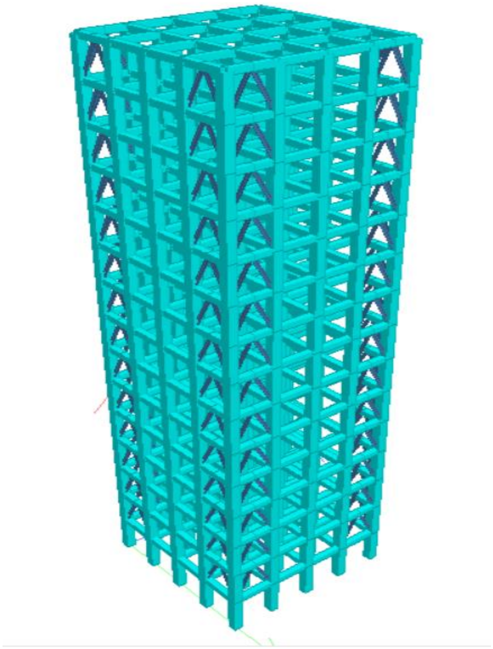


Fig.3.7(b) Rendered view for Inverted V-braced RC Frame (Model-5)

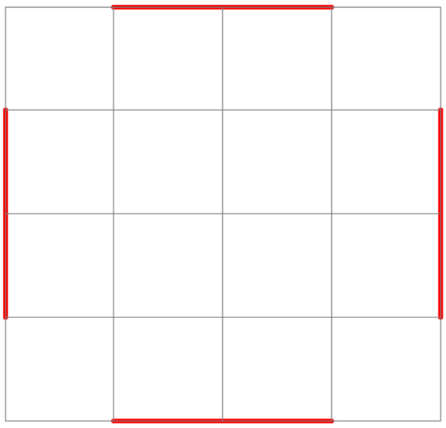


Fig.3.8(a) Structural Plan for V-braced RC Frame (Model-6)

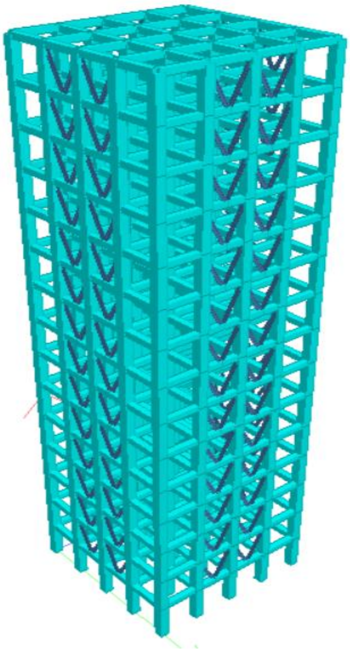


Fig.3.8(b) Rendered view for V-braced RC Frame (Model-6)

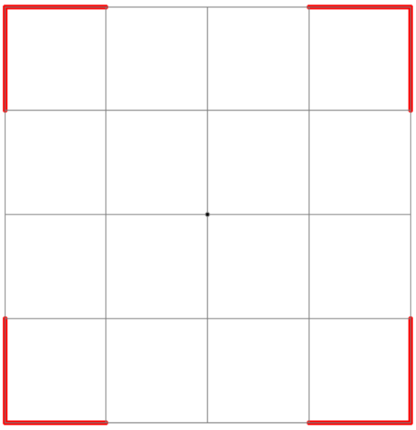


Fig.3.9(a) Structural Plan for V-braced RC Frame (Model-7)

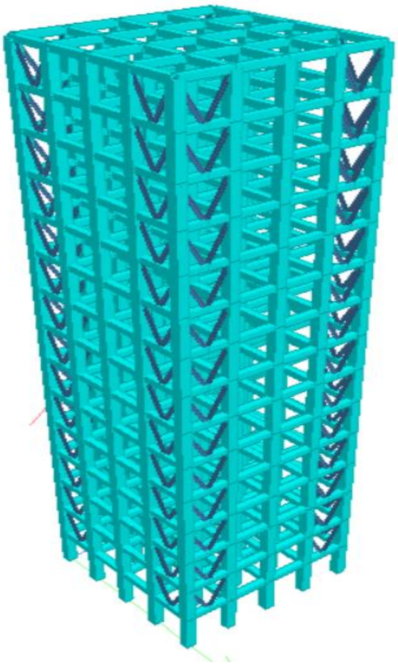


Fig.3.9(b) Rendered view for V-braced RC Frame (Model-7)

3.5 Parameters for Analysis

The main objective of the present study is to compare the seismic behavior of un-braced and braced RC frame in the seismic zone IV. To achieve the objectives, following parameters have been considered in the analysis.

1. Time Period
2. Base Shear
3. Storey Displacement
4. Storey drift
5. Maximum Bending Moment for Column
6. Peak Storey Shear

1. Time Period

A building's time period is the time it takes to undergo one full oscillation cycle. It is a building's inherent property, governed by its mass and stiffness. According to IS regulations, the time period formula relates to the building's total height and the building's base dimension. In the design of earthquake-resistant buildings, the time period plays an important part.

2. Base Shear

Base Shear is an estimation, due to seismic activity, of the overall projected lateral force on the base of the foundation.

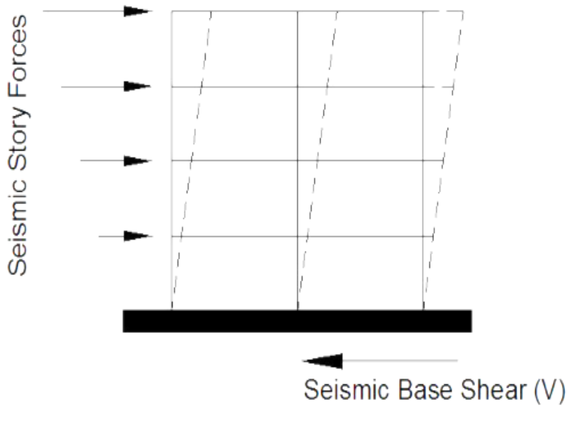


Fig.3.10 Base Shear at the foundation level

The framework has been set at the base, i.e. at the foundation level, for study purposes. Structures do not stay rigid during the earthquake, they deflect, and therefore base shear is spread along with the height of the structure. The base shear calculation relies on the site's soil quality. The cumulative base shear distribution is seen in Figure 3.10.

3. Storey Displacement

Storey displacement is known as the displacement of the building relative to the base. Storey displacement is important to keep in mind when seismic force affects the structure. It depends on the structure's height. Tall structures are more versatile for lateral loads than other structures. On the first floor, the displacement values are larger than on the bottom floor. The storey displacement at various storey heights is shown in Figure 3.11 by Δ_1 and Δ_2 at storey heights H_1 and H_2, respectively.

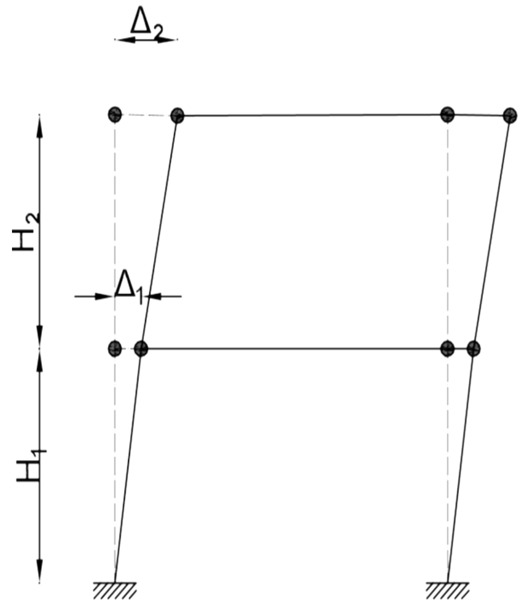


Fig.3.11 Lateral Displacement of the Frame

4. Storey Drift

Storey drift is the displacement in the lateral direction of the inter-storey above and below. Its maximum value should be 0.004 of height of the storey. Generally, its value is maximum at mid stories. Storey drift or inter storey displacement is as indicated in Fig 3.12.

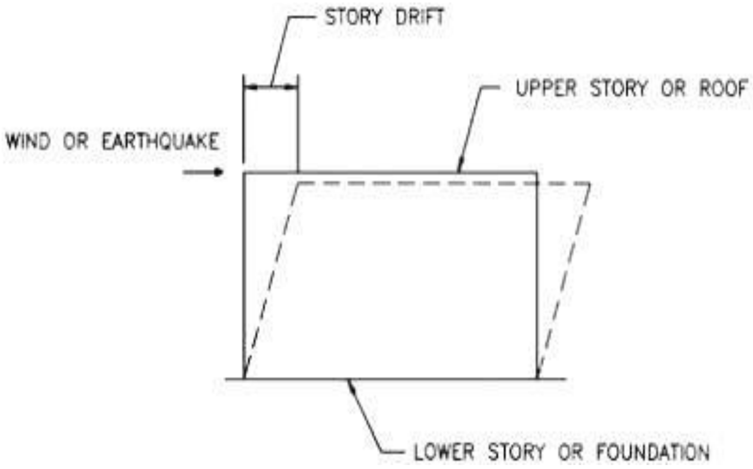


Fig. 3.12 Storey Drift of the Frame

5. Maximum Bending Moment

As the external force is applied to the beams or columns which bend the element from its original axis, producing the element's bending moment. In the beam, where a shear force is negative at the segment or changes the sign, the maximum bending moment occurs.

6. Peak Storey Shear

It is the lateral force acting on a storey due to the forces such as seismic and wind force or the design seismic force to be applied at each floor level is called storey shear. It is calculated for each storey, changes from minimum at the top to maximum at the bottom of the building i.e., the lower you go, the greater the shear becomes.

3.6 Seismic Analysis

Seismic analysis is connected to the assessment of a building or any other structure's response to earthquake. In territories where earthquakes are common, it is part of the structural design phase that includes earthquake engineering or structural evaluation.

3.6.1 Method of Seismic Analysis

In general, the methods of seismic analysis can be classified as

i. Static analysis

ii. Dynamic analysis.

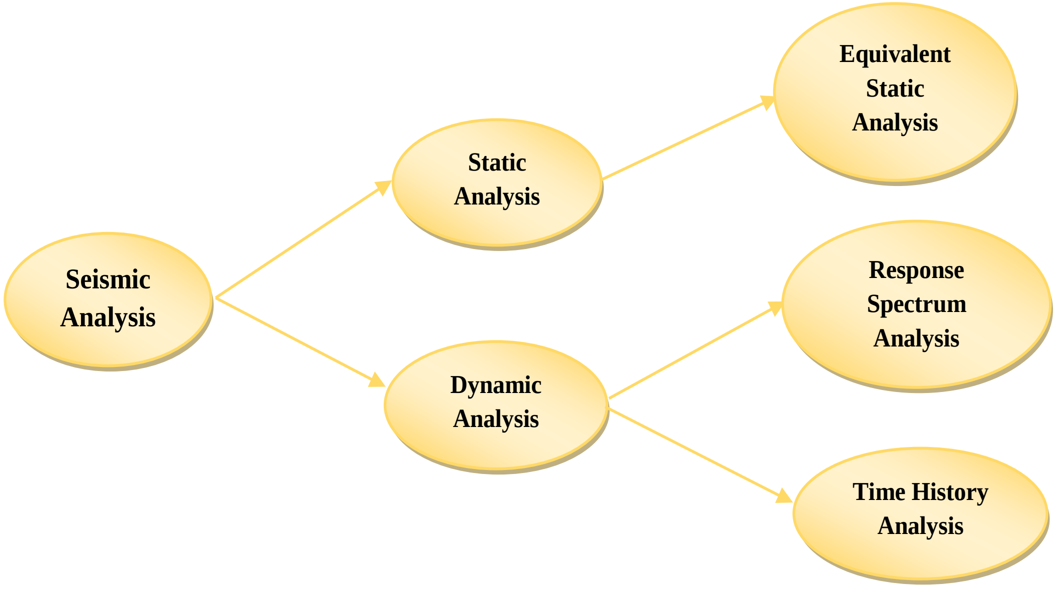


Fig. 3.13 Classification of seismic analysis

Equivalent static analysis is a part of static analysis, and Response spectrum and Time History analysis are part of dynamic analysis as shown in fig 3.13.

The principle code that provides an outline for computing seismic design forces on buildings is IS1893-2016(part 1). For seismic analysis of RCC frames, various analysis methodologies (static and dynamic) can be followed depending on the building height and seismic zone to which it belongs. In the following section, a short description of static analysis and dynamic methods of analysis is explained.

3.6.1.1. Equivalent Static Analysis

The simplest method of analysis is the equivalent static method. The method is attractive because it turns a dynamic analysis into a partially static and partially dynamic analysis to find the maximum stresses caused during the earthquake in the system. This method of study is limited to a single mode of structure vibration only.Assumptions based on the equivalent static method are as follows-

1) Structure is rigid.
2) Between foundation and structure there should be perfect fixity.
3) Same accelerations encountered by each point on the structure during ground motion.

4) The detrimental effect of an earthquake is equivalent to the horizontal force of varying magnitude over the height.
5) Approx. determination of the total horizontal force (Base shear) on the structure.

3.6.1.2. Response Spectrum Analysis

It representation of the maximum response of idealized single degree freedom systems having certain period and damping, during earthquake ground motion. The maximum response is plotted against the natural period and for various damping values, and can be expressed in terms of maximum absolute acceleration, maximum relative velocity, or maximum relative displacement.

This particular method enables the multiple modes of response of a structure/building that is to be taken into account. This is required in many building codes, except for very simple structures. A structure's response can be described as a combination of several special shapes (i.e. modes) which correspond to the "harmonics" in a vibrating string as shown in fig 3.14. It is feasible to use computer simulation to evaluate these modes for a structure. For every one of the mode, a response is interpreted from the design spectrum, depending upon the modal frequency and the modal mass, and then they collectively provide an estimate of the overall response of the structure. These combination methods are:

i. **Absolute Sum Method (ASM)** combines the modal results by taking the sum of their absolute values.
ii. **Square Root of the Sum of the Squares (SRSS)** combines the modal results by taking the square root of the sum of their squares.
iii. **Complete Quadratic Combination (CQC)** method takes into account the statistical coupling between closely spaced modes caused by modal damping and also it is a method that is an improvement on SRSS for closely spaced modes.

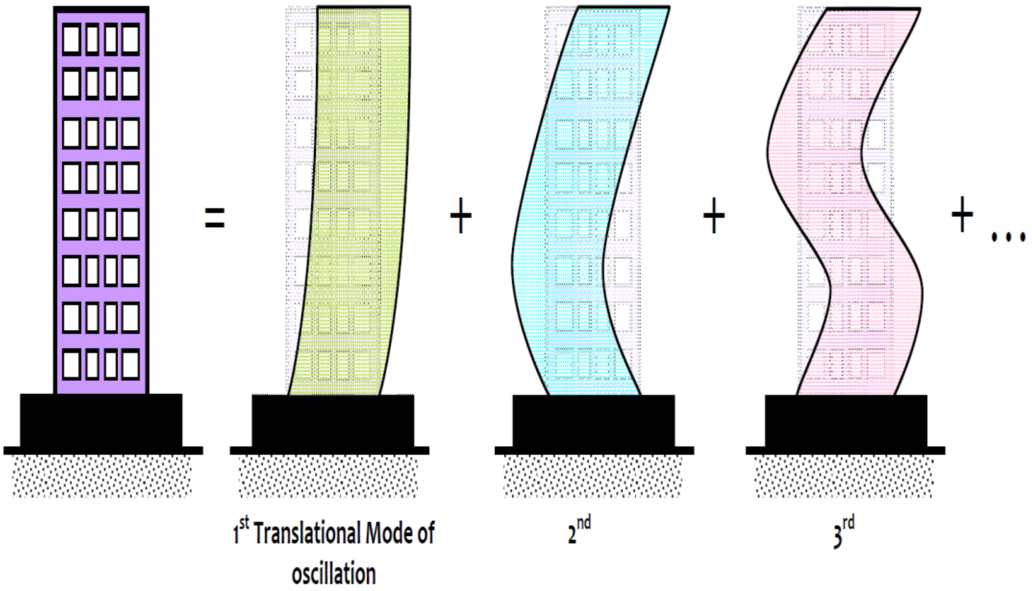


Fig. 3.14 Structures corresponding to each mode of oscillation of the building

The response-spectrum analysis (RSA) is also known as the mode superposition method or modal method, and it is a method of linear-dynamic statistical analysis It is based on the idea that a building's response is the superposition of the responses of individual modes of vibration, each mode reacting with its own unique deformed shape, its own frequency, and with its own modal damping. In this approach, the multi-degree-of-freedom (MDOF) system’s response is expressed as the superposition of the modal response, evaluating each modal response of the single-degree-of-freedom (SDOF) system from the spectral analysis, which is then combined to measure the total response. The provisions of codes per IS: 1893 (Part 1)-2016 for response spectrum analysis of the multi-storey building are given below:

3.7 Procedure for Response Spectrum Method

Step 1: Building location should be selected and thus identify the seismic zone and assign zone factor (Z) for that particular location as per IS-1893 (2016) Part I. For this particular work Zone IV and zone factor is taken as 0.24.

Step 2: As per IS1893:2016 seismic weight (W) of the structure will be calculated i.e., the sum of total dead load and appropriate amounts of the imposed (live) load as given in the table 3.2.

Table 3.2 Proportion of Live Load to be considered in the estimate of Seismic Weight of buildings

SI No.	**Imposed Uniformity Distributed Floor Loads (kN/m^2)**	**% age of LL (Imposed Load)**
1	Up to & including 3.0	25
2	Above 3.0	30

Step 3: Determination of the natural period of vibration (T_a) as per IS 1893(part 1) 2016

For with no brick infill panel, will be obtained by the given formula,

$$T_a = 0.075h^{0.75} \text{ (For moment resisting RC frame building)}$$

$$T_a = 0.080h^{0.75} \text{ (For RC-Steel composite MRF building)}$$

Where, h= height of building in metre.

Step 4: Depending on the soil type (i.e., soft, medium or hard) and the fundamental natural time period T_a, the design acceleration spectrum (Sa/g) will be estimated and this will be multiplied by the multiplying factor as per of IS: 1893:2016, for the damping coefficient 5 %.

Step 5: Determine the horizontal seismic coefficient A_h with the help of the formula

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

Where, Z = Zone factor considered as per the analysis

I = Importance factor as per recommended by the code IS 1893:2016

R = Response reduction factor as per IS1893:2016

S_a/g = Average response acceleration coefficient as shown in Fig. 3.16

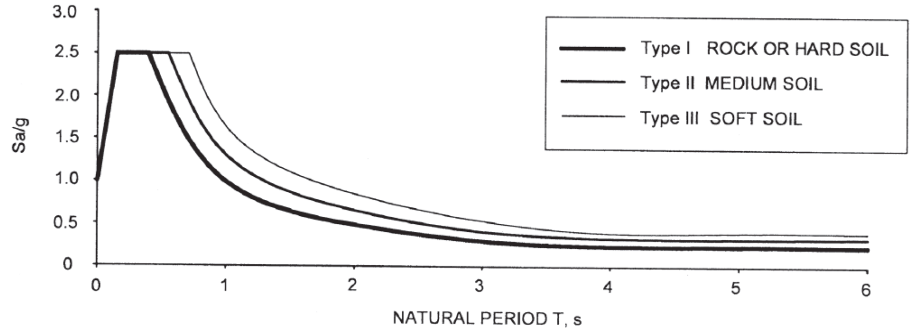


Fig. 3.15 Average response acceleration coefficient with natural period

$$\frac{S_a}{g}=\begin{cases}\text{For rocky or hard soil sites} & \begin{cases}1+15T & T<0.10\text{ s}\\ 2.5 & 0.10\text{ s}<T<0.40\text{ s}\\ \dfrac{1}{T} & 0.40\text{ s}<T<4.00\text{ s}\\ 0.25 & T>4.00\text{ s}\end{cases}\\ \text{For medium stiff soil sites} & \begin{cases}1+15T & T<0.10\text{ s}\\ 2.5 & 0.10\text{ s}<T<0.55\text{ s}\\ \dfrac{1.36}{T} & 0.55\text{ s}<T<4.00\text{ s}\\ 0.34 & T>4.00\text{ s}\end{cases}\\ \text{For soft soil sites} & \begin{cases}1+15T & T<0.10\text{ s}\\ 2.5 & 0.10\text{ s}<T<0.67\text{ s}\\ \dfrac{1.67}{T} & 0.67\text{ s}<T<4.00\text{ s}\\ 0.42 & T>4.00\text{ s}\end{cases}\end{cases}$$

Fig. 3.16 Design acceleration coefficient for the different soil types

Step 4: The design seismic base shear, V_b will be evaluated as follows;

$V_b = A_h \times W$, as per IS1893:2016 and Clause 7.6

Step 6: The base shear (V_b) computed will be as per IS: 1893:2016 Clause 7.6.3 and will be distributed throught the building's height as per the following expression

$$Q_i = V_b \times \left[\frac{W_i h_i^2}{\sum W_j h_j^2}\right]$$

Where,

Q_i= Design lateral force at floor i

W_i= Seismic weight of floor i

h_i= Height of floor i measured from the base, and

Step 5: Establish the mass [M] and the stiffness [K] matrices of the structure using system of masses lumped at the floor levels with each mass having single degree of freedom.

Step 6: Using step 3 and operate the principles of dynamics calculate the modal frequency $\{w\}$ and corresponding mode shape $\{\phi\}$.

Step 7: The modal mass M_K of mode k can be found using the expression given below and where number of modes is given by n.

$$M_k = \frac{[\sum_{i=1}^{n} W_i \, \Phi_{ik}]^2}{g \sum_{i=1}^{n} W_i \, \Phi_{ik}^2}$$

Where,

g = acceleration due to gravity

ϕ_{ik}= Mode shape coefficient at floor i in mode k.

W_i= Seismic weight of floor i of the structure.

n = Number of modes.

Step 8: Calculate modal participation factor P_k of mode k using the following relation

$$P_k = \frac{\sum_{i=1}^{n} W_i \Phi_{ik}}{\sum_{i=1}^{n} W_i \Phi_{ik}^2} \quad \text{Considered as per IS 1893:2016}$$

Step 9: Compute design lateral force (Q_{ik}) at each floor in each mode (i.e. for $i^{\,th}$the floor in mode k) using the following relationship.

Q_{ik}= $A_h \phi_{ik} P_k W_i$ as per IS 1893:2016

Step 10: 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 i.e. CQC modal combination method are used.

Step 11: Finally compute design lateral forces at each storey as

F_{roof}=V_{roof} and

F_i = V_i- V_{i+1}

3.8 Procedure to Analyze the Structure using STAAD.Pro

For analyzing and to study the behavior of RC frame with or without bracing system under the effect of seismic forces in the seismic zone IV, the following procedure is adopted.

Step 1: Choose the type of structure, name the file, then place of the file location and units to be taken.

a) Select the new project.

b) The space structure has to selected, which is a 3D framed structure.

c) The file is to be given a name and its location in the drive.

d) Units selected are meter and kilo Newton for length and force respectively.

e) After clicking next, select Open Structure Wizard.

f) Click finish.

Step 2: Generation of a geometrical model for the analysis

a) Select the model type as the frame models.

b) Give the length, width and height of frame corresponding to the three mutually perpendicular directions.

c) Give the number of bays required along the length, width and height.

d) Click apply and then select file and click on the Merge Model with STAAD.Pro Model.

e) Coordinate provided will be 0, 0, and 0 in all the mutually perpendicular directions(x,y,z) and then select ok.

Step 3: Selection of properties of various sections

a) Select to general tab and define the properties of the different sections.

b) Select the rectangular option and give the dimensions of beam and column.

c) For steel bracing, select section database, in that select the Indian code and then select the material and close it.

d) The material used for the beam and column will be concrete and for bracings it will be steel.

e) Select tools option from the toolbar and select create group name.

f) Now define group name as beam, column and bracing for the all the beams, columns and bracings.

g) The type to be selected for all the three will be beam.

h) Now go to Select option on the toolbar and associate all the beams, columns and bracings corresponding to the groups they belong to.

i) Select all the beams, columns and steel bracings from the group name respectively and assign the defined properties to the respective sections by clicking on Assign.

Step 4: Assigning of the supports conditions

a) Click on the tab named general on the left side and select support option.

b) Click on the create option and then a box appears with different support options in it.

c) Fixed support need to be selected and then click on add.

d) Click on the fixed support appearing in the box and then select all the nodes at the base or where the nodes where the supports are to be assigned.

e) Now select on assign to the selected node and click on apply.

Step 5: Assigning of the loads and their combinations

a) Click on the tab named general on the left side and click on the load and definitions.

b) First of all definition is given so select definitions and then click on seismic definition and then click on add.

c) Select the Indian code i.e., IS 1893-2016 and provide the parameters necessary such as the zone considered, response reduction factor, importance factor, the type of soil considered and damping ratio.

d) Select self-weight, with self-weight factor and floor weight and then close it.

e) Now click on the load case detail and add all the loads considered in the analysis.

f) Assign all the loads considered i.e., seismic load, dead load, live load and Response Spectra to the structure to be analysed.

g) In Response Spectra give self-weight, floor weight in all direction (X, Y and Z)

h) After all this load combination need to be generated by selecting add option in load case details and then further clicking on auto load combination and select all the combinations generated.

i) Click on add.

Step 6: Analysis of the considered frame

a) Click on the tab i.e. Analysis/Print tab on the left side.

b) A box appears named analysis/print command, select the option all and then click on add.

c) Now click on the tab named post print on the left side.

d) Click on the define commands on the right side.

e) Click on the story drift and joint displacement on the box appearing and click add.

f) Click on analysis on the task bar shown above.

g) Click save then click done.

Step 7: View results of analysis

a) To get the output results, click on 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, Storey Drift and Joint Displacement 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.

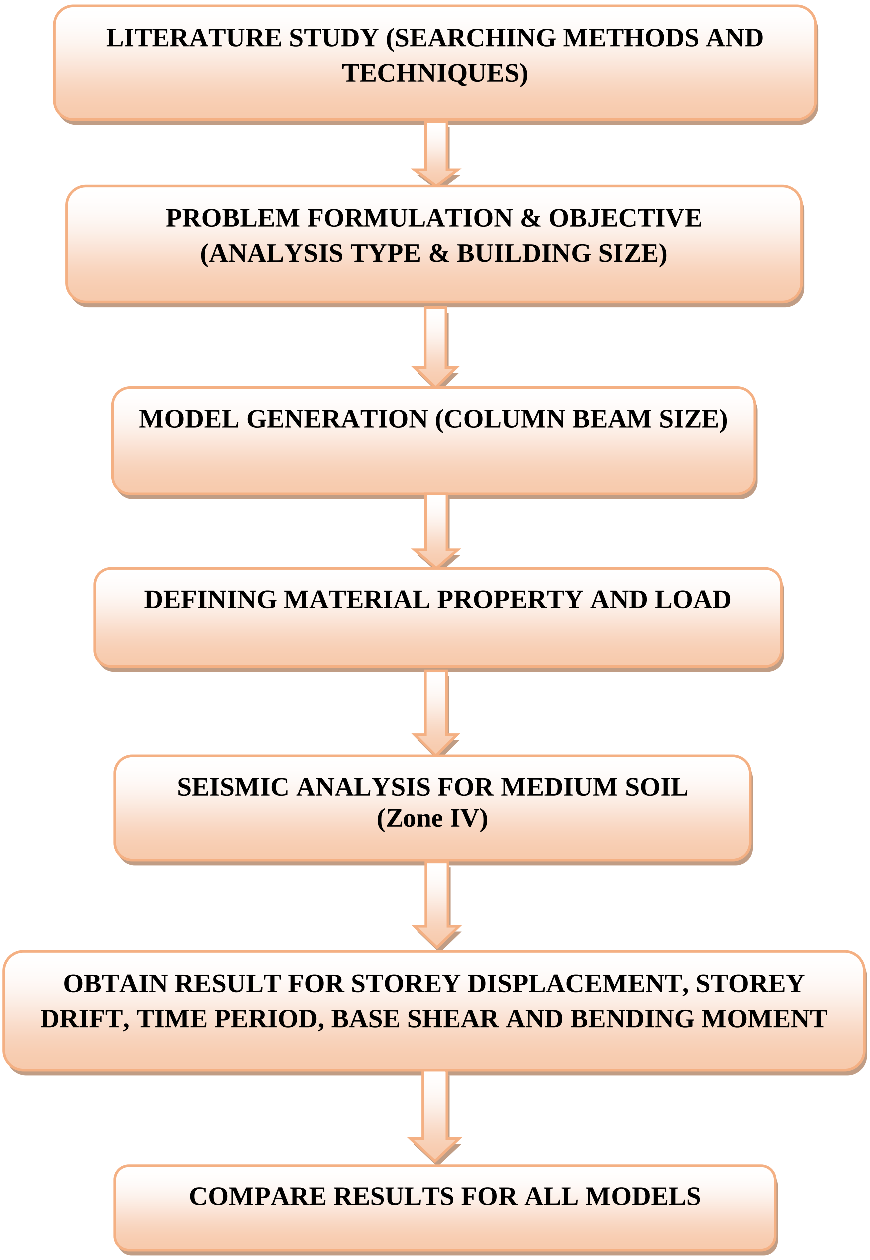


Fig. 3.17 Flow chart of the analysis procedure

3.9 Summary

This chapter comprises the methods used for analysis purpose for which the structure is subjected to seismic load. Detail description of the load that occurs in the structure and their load combination are given in this chapter. The detail of plan and elevation of unbraced RC frame and elevations with a 3D rendered view of the different braced system is included in this chapter. Total plane area of the building is 12m x 12m and the total height of the building is 45m.The description of various parameters used in the analysis of the building frames. And the step by step analysis of the RC structure with the help of STAAD.Pro V8i software has been explained in this chapter with details.

Results and Discussion

Chapter 4 RESULTS AND DISCUSSION

4.1 General

The present study is based on the seismic analysis of the multi-storey building of the various types of models and parameters considered in the analysis in Chapter 3. With the seismic method mentioned earlier, i.e. the response spectrum method, the performance of the un-braced and braced framework in the RC structure is tested. The results of the study of different models with and without the bracing are obtained in this chapter. For this purpose, three different types of bracing systems i.e., X-bracing, inverted-V bracing and V-bracing have been taken into consideration, and the bracing positions are also distinct. The seismic zone IV is taken and further the analysis is performed using STAAD.Pro V8i and their results are compared with un-braced frame.

The state of the soil strata is held the same in the structure study. To study the behavior and performance of the bracing system in the RC frame Structure, the parameters used were Time Period, Base Shear, Storey Displacement, Storey Drift, Maximum Bending Moment and Peak storey shear of the structure. Total seven numbers (Model-1 to Model-7) of RC models with and without bracings have been considered in the present study and all are described in detail in chapter 3.

The analysis results obtained are explained one by one in the subsequent sections of this chapter.

4.2 Mass Participation Factor

It is the amount by which mode contributes during horizontal or vertical earthquake ground motion to the total oscillation of the structure. The amount of the system's mass participating in that mode represents the mass participation associated with each mode. The total sum of modal masses of the modes to be used in the earthquake shaking study along the direction considered should be at least 90% of the total seismic mass (IS 1893 part 1:2016).

In order to judge the importance of vibration mode, the modal mass participation factor is important. Modes of greater mass participation should be the most effective forms to concentrate on. It is less likely that modes with a lower mass participation factor would get excited, so these modes may be overlooked. Therefore, a mode with a large effective mass is usually a significant contributor to the system's response. There are six number modes considered in the study. All the models have been analyzed and examined for all considered parameters. For demonstration, the mass participation factor in percentage for the seismic forces in z-direction for model-2 is given in table 4.1.

Table 4.1 Mass participation factor in z-direction for Model-2

Mode	**Mass Participation Factor (%)**						
	Model-1	**Model-2**	**Model-3**	**Model-4**	**Model-5**	**Model-6**	**Model-7**
1	55.45	70.65	1.94	39.73	70.17	74.93	20.76
2	22.70	6.76	74.53	38.34	7.03	3.07	56.47
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	3.51	5.96	3.05	1.68	0.38	6.36	8.60
5	8.07	7.70	10.94	10.96	12.74	6.31	4.42
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Mode shape of oscillation associated with a natural period of a building is the deformed shape of the building when shaken at the natural period. Hence, a building has as many mode shapes as the number of natural periods. The deformed shape of the building associated with oscillation at fundamental natural period is termed its first mode shape. Similarly, the deformed shapes associated with oscillations at second, third, and other higher natural periods are called second mode shape, third mode shape, and so on, respectively. The different mode shapes of the most bracing system i.e., X-bracing is show in the figures 4.1 to 4.6.

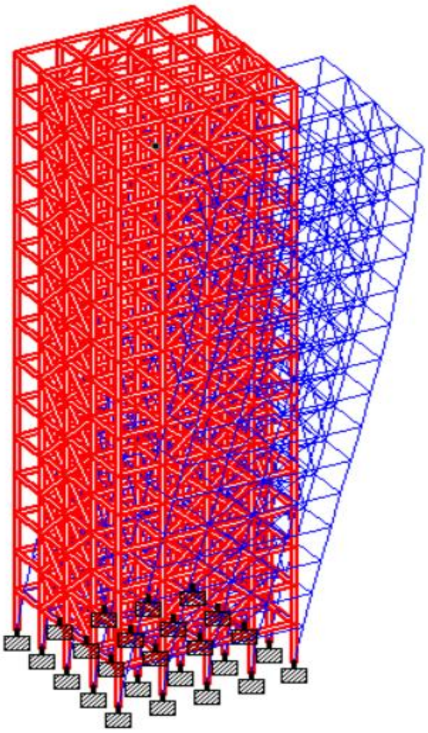


Fig.4.1 Mode Shape 1

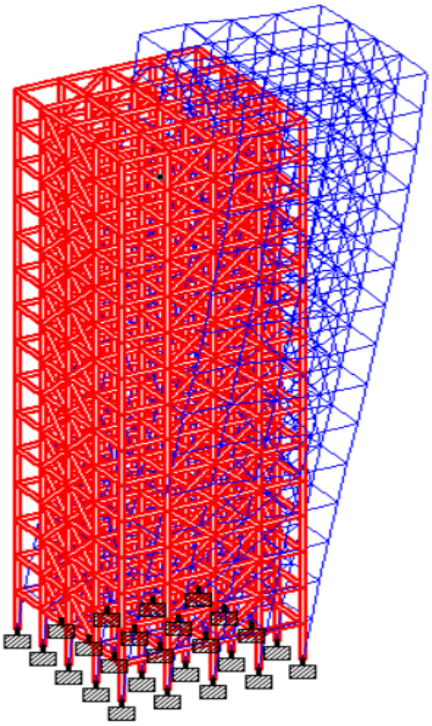


Fig.4.2 Mode Shape 2

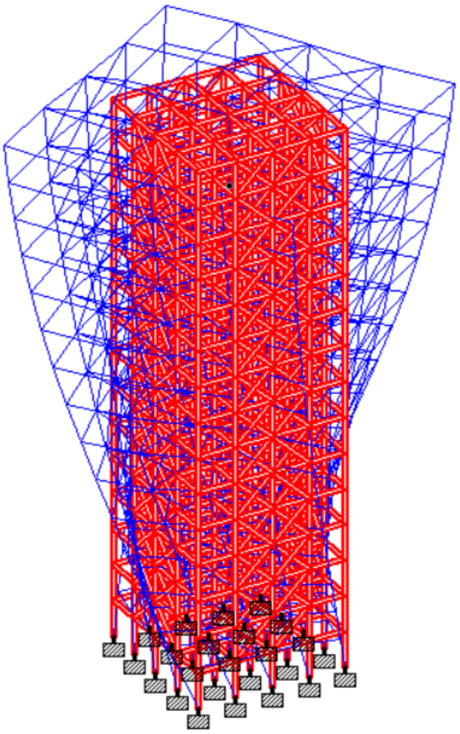


Fig.4.3 Mode Shape 3

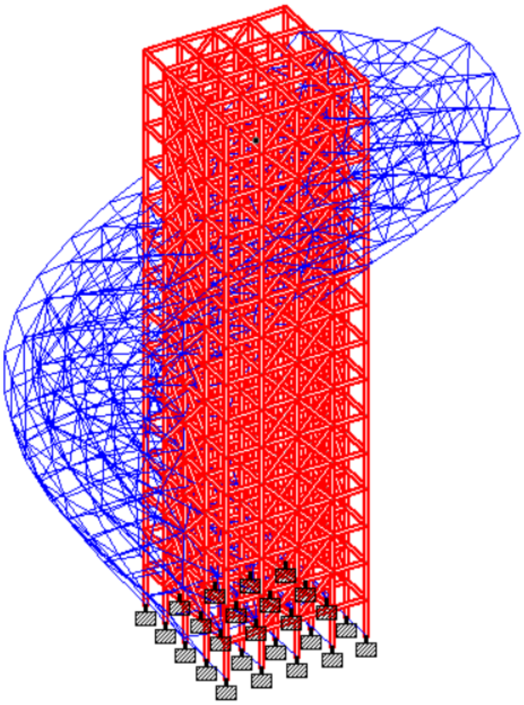


Fig.4.4 Mode Shape 4

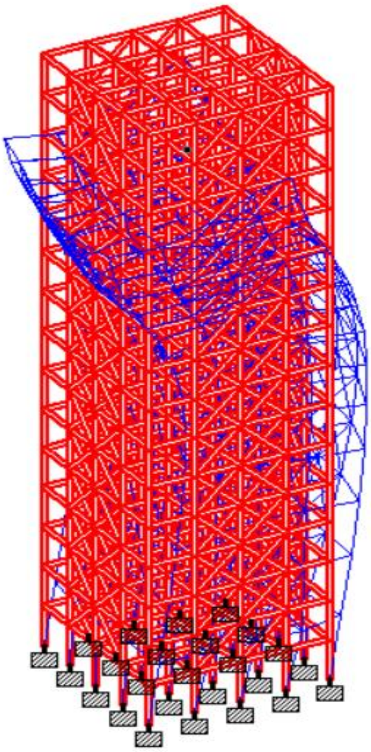


Fig.4.5 Mode Shape 5

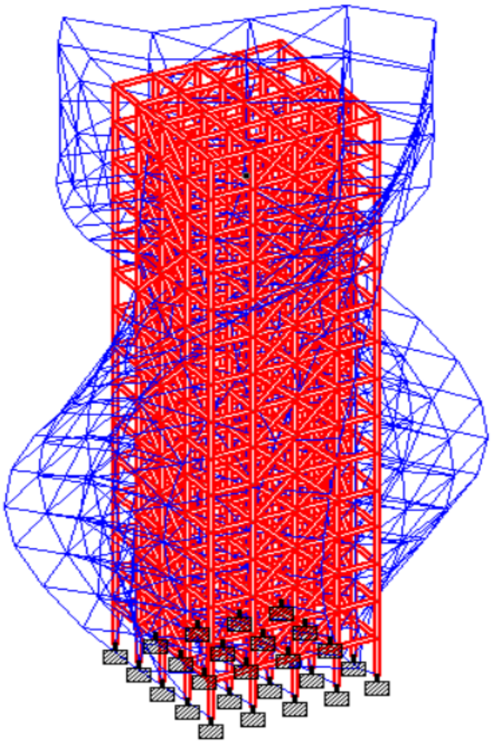


Fig.4.6 Mode Shape 6

4.3 Time Period

For the time period observation, a RCC framed structure with and without a bracing system in seismic zone IV is studied.

Table 4.2 Time period for Different Models

Model	**Time Period (sec)**
Model-1	1.393
Model-2	1.125
Model-3	1.213
Model-4	1.187
Model-5	1.251
Model-6	1.200
Model-7	1.266

Using STAAD.Pro.V8i, various models without and with braces at different locations were evaluated and the time period values were extracted from the results. The time period obtained for the various models considered for study is tabulated the table 4.2. The graph for the Time period for different bracing system is shown in Fig 4.7.

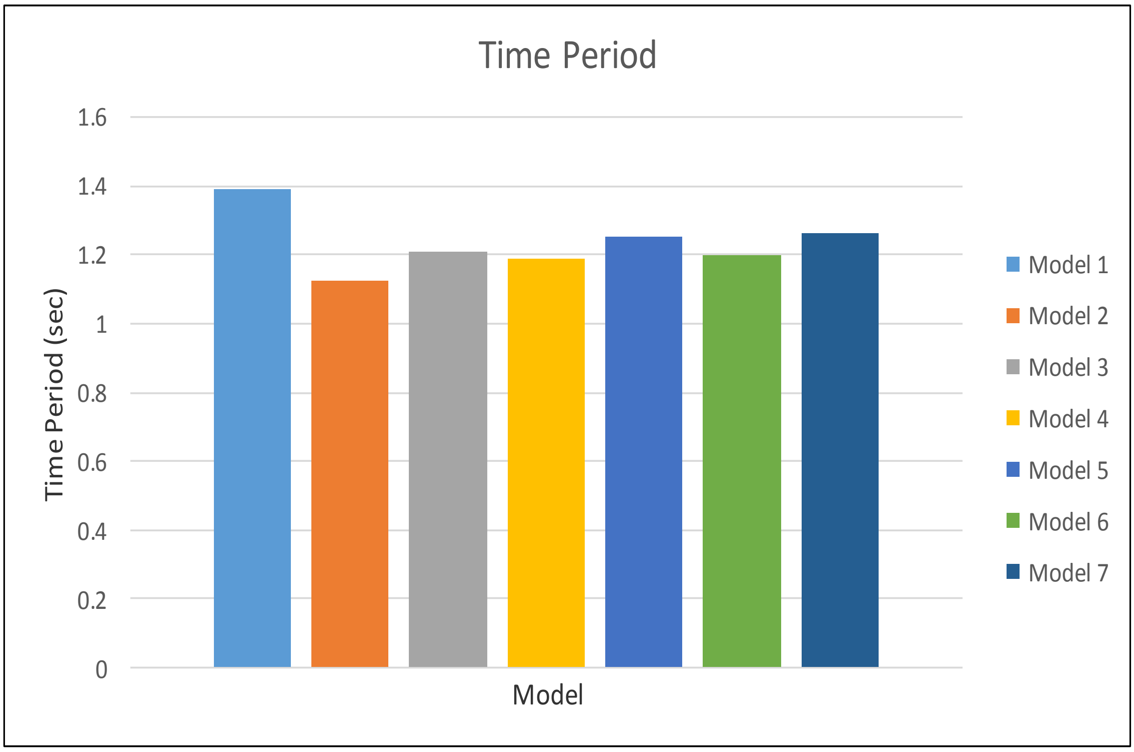


Fig. 4.7 Time Period for Different models

The values listed in the table 4.2 and graph 4.7 represent the time period values in seconds of the braced structure. The graph shows that, in relation to the bare frame, the time period reduces in the case of various bracing systems. The bar chart reveals that in the case of X bracing and Inverted-V, the value of the time period is low relative to other bracing and bare frame.

The percentage reduction in the time period of model-2 with respect to model-1(bare frame) is 19.24%. The X-bracing provided in the middle bays of the structure is the most efficient bracing from the data, i.e. Model-2 is the most effective.

4.4 Base Shear

The maximum lateral force produced at the base of the structure is base shear. The structure has been fixed at the base, which is at the foundation level, for analysis.

For the evaluation of the base shear, a RCC framed structure with and without a bracing system in seismic zone IV was studied. The base shear obtained for the various models considered for study is set out in the table 4.3. The graph for the base shear for different bracing system is shown in Fig. 4.8.

Table 4.3 Base Shear for Different Models

Model	Base Shear (kN)
Model-1	724.66
Model-2	730.30
Model-3	730.30
Model-4	729.12
Model-5	729.12
Model-6	729.12
Model-7	729.12

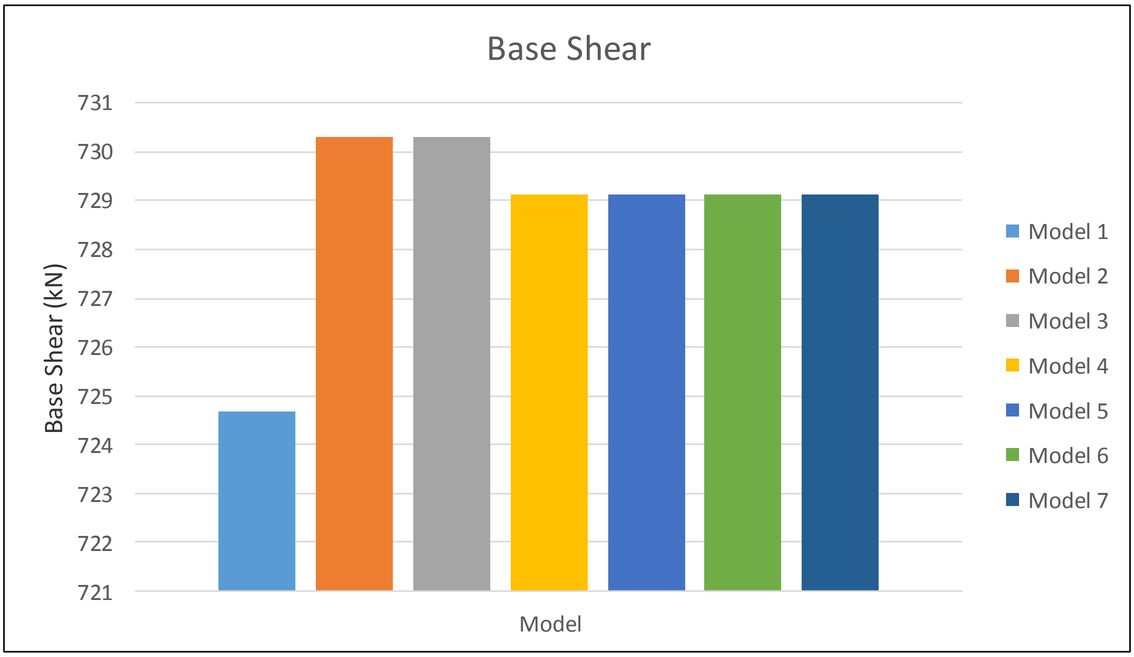


Fig.4.8 Base Shear for Different models

The values given in the table and the graph shows the magnitude of the base shear of the braced framework increase in the structure. The graph shows that, in the case of different bracing systems, the magnitude of base shear is almost the same. The base shear relation reveals that in the case of X bracing, the magnitude of the base shear is high relative to other bracing and bare frame.

4.5 Storey Displacement

Displacement refers to the movement of the whole structure from their original location when subjected to lateral forces. The overall displacement value of each storey has been taken through the study. The maximum displacement values obtained for the different models considered for analysis is given below in Table 4.4. The graph for the maximum lateral displacement for different bracing system is shown in Fig. 4.9.

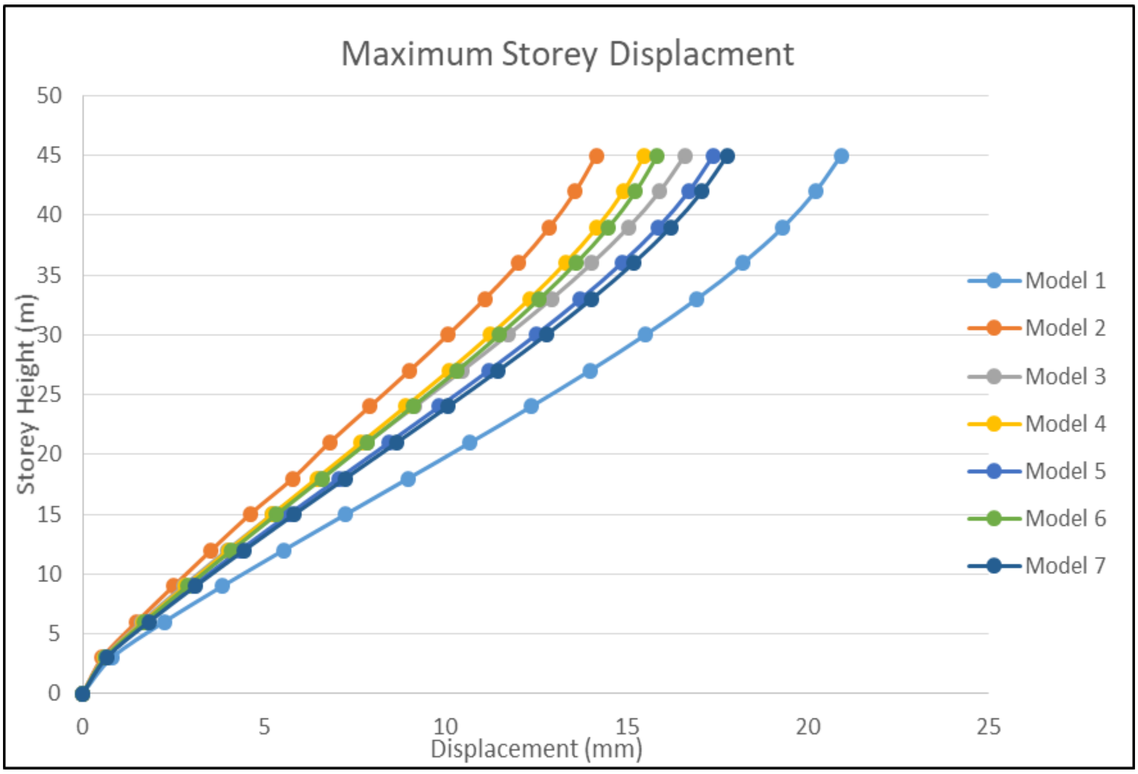


Fig. 4.9 Maximum storey displacement for different models for different storey

From the values given in the table and their plot, it was observed that the lateral displacement of the braced system decreases with an increase in building height. This decrease from the base to the top of the frame is incremental.

Table 4.4 Maximum storey displacement for different models for different storey

Storey Height (m)	Maximum Lateral Displacement (mm)						
	Model Without Bracing	Model With Bracing					
	Model 1	Model-2	Model-3	Model-4	Model-5	Model-6	Model 7
0	0	0	0	0	0	0	0
3	0.807	0.543	0.587	0.610	0.640	0.622	0.658
6	2.248	1.488	1.626	1.677	1.774	1.711	1.823
9	3.863	2.508	2.777	2.838	3.030	2.900	3.116
12	5.547	3.550	3.982	4.026	4.338	4.117	4.460
15	7.261	4.617	5.234	5.235	5.686	5.354	5.841
18	8.984	5.797	6.525	6.459	7.063	6.606	7.248
21	10.695	6.812	7.840	7.688	8.454	7.861	8.666
24	12.372	7.920	9.159	8.908	9.839	9.107	10.076
27	13.990	9.015	10.462	10.101	11.197	10.324	11.457
30	15.523	10.078	11.726	11.248	12.505	11.496	12.787
33	16.942	11.092	12.931	12.328	13.739	12.600	14.042
36	18.218	12.034	14.052	13.317	14.873	13.613	15.198
39	19.321	12.879	15.060	14.190	15.880	14.510	16.228
42	20.221	13.595	15.920	14.919	16.725	15.260	17.092
45	20.920	14.164	16.610	15.492	17.396	15.851	17.781

The graph shows that in the case of X bracing, the lateral displacement decreases very strongly compared to other bracing and bare frame. In the middle bays, the place of the X bracing is more effective than the other spot. The percentage reduction in lateral displacement at floor height of 24 m and 42 m for the different models with bracings in zone IV, compared to the unbraced model is given in Table 4.5, the soil medium is kept the same in the study.

Table 4.5 Percentage reduction in the storey displacement w.r.t Model-1

	Storey Height (m)	**Types of Models with Bracings**					
		Model-2	**Model-3**	**Model-4**	**Model-5**	**Model-6**	**Model-7**
Percentage Reduction	24	35.98	25.97	27.99	20.47	26.39	18.56
	45	32.29	20.60	25.94	16.84	24.23	15.00

Thus, the percentage decrease in displacement is very high in the case of the X bracing system. Because of the high shear rigidity, high ductility and high energy absorption power, this decrease in displacement in X bracing is high.

4.6 Storey Drift

The relative displacement between the floors above or below the storey under consideration is storey drift or inter storey displacement. Via STAAD.Pro, maximum storey drift values have been measured. The maximum values of storey drift obtained from the analysis at each storey level for the different models are given in the table below. Further, the storey drift values, which have been listed in Table 4.6, are plotted against the storey height to understand the effectiveness of different bracing system at different positions and the plot is shown in Fig.4.10.

The graph has been shown to display the comparable trend for the decrease in storey drift value per storey height. Initially, the storey drift reduction rate was found to be very low in all braced structures up to 2-3 storey level and then it has been observed that the decrease in storey drift values rises rapidly up to the level of 5-7th storey and there is a drop in storey drift values again after that.

Table 4.6 Maximum Storey Drift for Different models for different storey level

Storey Height (m)	Maximum Storey Drift (cm)						
	Model Without Bracing	Model With Bracings					
	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6	Model-7
0	0	0	0	0	0	0	0
3	0.1213	0.1007	0.1045	0.1062	0.1088	0.1078	0.1121
6	0.2158	0.1346	0.1477	0.1556	0.1653	0.1592	0.1694
9	0.2422	0.1430	0.1635	0.1664	0.1799	0.1711	0.1865
12	0.2522	0.1509	0.1764	0.1737	0.1920	0.1782	0.1977
15	0.2569	0.1573	0.1862	0.1789	0.2005	0.1832	0.2055
18	0.2581	0.1619	0.1929	0.1822	0.2058	0.1862	0.2102
21	0.2563	0.1645	0.1966	0.1831	0.2080	0.1870	0.2118
24	0.2511	0.1446	0.1969	0.1861	0.2068	0.1853	0.2104
27	0.2422	0.1623	0.1940	0.1774	0.2024	0.1810	0.2056
30	0.2294	0.1573	0.1876	0.1702	0.1945	0.1738	0.1976
33	0.2123	0.1497	0.1787	0.1600	0.1832	0.1638	0.1863
36	0.1908	0.1393	0.1664	0.1466	0.1685	0.1502	0.1717
39	0.1647	0.1260	0.1510	0.1298	0.1504	0.1335	0.1537
42	0.1345	0.1095	0.1324	0.1098	0.1291	0.1135	0.1325
45	0.1040	0.0903	0.1113	0.0881	0.1062	0.0917	0.1104

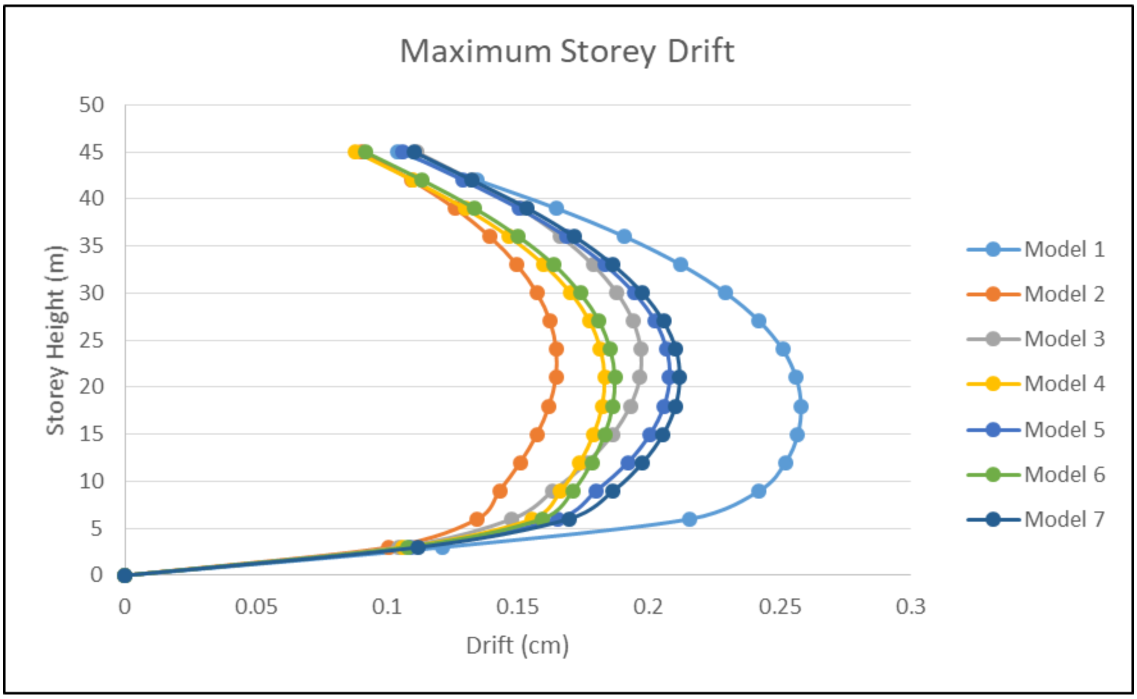


Fig. 4.10 Maximum Storey Drift for Different models for different storey level

However, the maximum storey drift value at various storey levels is displayed by different bracing systems provided at different locations. In the case of Model-2, relative to other braced and unbraced systems, the percentage decrease in storey drift is very high and is seen in the graph Fig.4.10.

Table 4.7 Percentage Reduction in the Storey Drift w.r.t Model-1

	Storey Height (m)	Types of Models with Bracings					
		Model-2	Model-3	Model-4	Model-5	Model-6	Model-7
Percentage Reduction	24	42.41	21.58	25.88	17.64	26.20	16.20
	45	13.17	7.02	15.28	2.11	11.82	6.15

Table.4.7. shows a percentage reduction in storey drift at floor height of 24 m and 42 m for the various models with braces in zone IV relative to the unbraced model.

4.7 Bending Moment

The purpose of the analysis was to study the occurrence of a maximum bending moment in the braced and unbraced frame structure column. From the analysis, the bending moment values are obtained for the columns at the centre of the frame and the values are shown in Table 4.8. The corresponding obtained result values of the bending moment are arranged in the form of the bar chart as shown in Fig.4.11.

Table 4.8 Maximum Bending Moment for Different Models

Model	Bending Moment (kNm)
Model-1	72.567
Model-2	54.560
Model-3	57.159
Model-4	59.283
Model-5	61.064
Model-6	60.092
Model-7	62.233

It has been found that when the bracing system is applied, the bending moment is decreased and it is good for the structure. Compared to other types of bracing system, the building construction with the X bracing system provided in the middle outer bays would have the least possible bending moment.

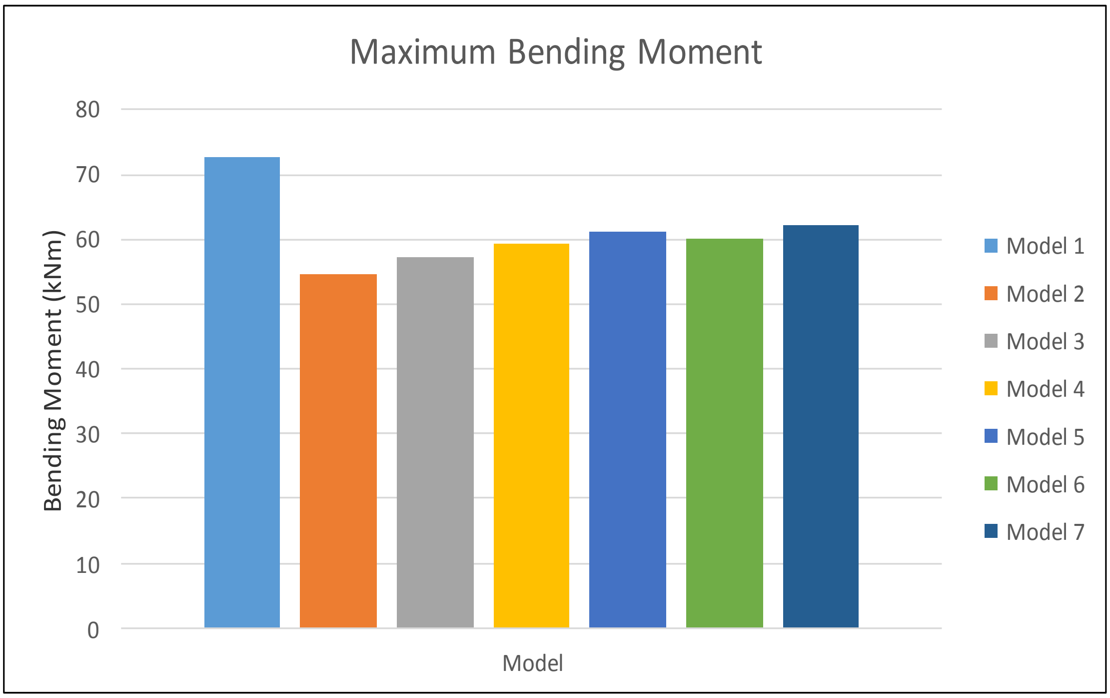


Fig. 4.11 Maximum Bending Moment for Different models

4.8 Peak Storey Shear

It is the design seismic force or wind force presumed to be applied at each floor level. It is calculated for each storey, changes from minimum at the top to maximum at the bottom of the building.A RC building frame with and without bracing has been studied for the peak storey shear in the seismic zone IV with the help of STAAD.Pro V8i. The values of the peak storey shear obtained from analysis of the structure are given in Table 4.9. The peak storey shear of different bracing system are represented by graph and have been shown in Fig 4.12.

Table 4.9 Peak Storey Shear for Different models

Storey Height (m)	**Peak Storey Shear(kN)**						
	Model Without Bracing	**Model with Different Bracings at different positions**					
	Model-1	**Model-2**	**Model-3**	**Model-4**	**Model-5**	**Model-6**	**Model-7**
45	3434.72	4083.67	3973.07	3859.87	3809.39	3841.21	3785.89
42	7103.66	8439.90	8153.14	7999.35	7876.46	7954.84	7795.29
39	10315.97	12269.50	11760.75	11655.73	11365.18	11580.25	11277.96
36	12997.13	15521.11	14752.92	14766.99	14300.26	14656.02	14179.01
33	15145.74	18213.98	17163.50	17340.66	16673.28	17191.09	16518.47
30	16840.44	20435.30	19100.15	19454.72	18578.39	19265.70	18391.86
27	18226.36	22321.92	20723.57	21241.30	20167.31	21014.95	19952.33
24	19478.06	24026.56	22208.30	22853.00	21611.48	22594.39	21372.53
21	20743.70	25674.69	23692.10	24417.41	23050.54	24133.82	22792.78
18	22091.00	27326.32	25232.64	25995.49	24546.11	25694.95	24274.65
15	23483.59	28959.11	26792.47	27562.40	26063.56	27252.08	25782.73
12	24799.96	30478.96	28258.55	29019.20	27489.86	28704.13	27202.55
9	25881.13	31750.91	29482.86	30226.96	28674.93	29909.60	28382.39
6	26586.51	32637.75	30327.11	31049.40	29478.88	30730.09	29181.06
3	26858.26	33037.60	30700.91	31400.18	29818.92	31078.84	29516.68
0	26858.26	33037.60	30100.91	31400.18	29818.92	31078.84	29516.68

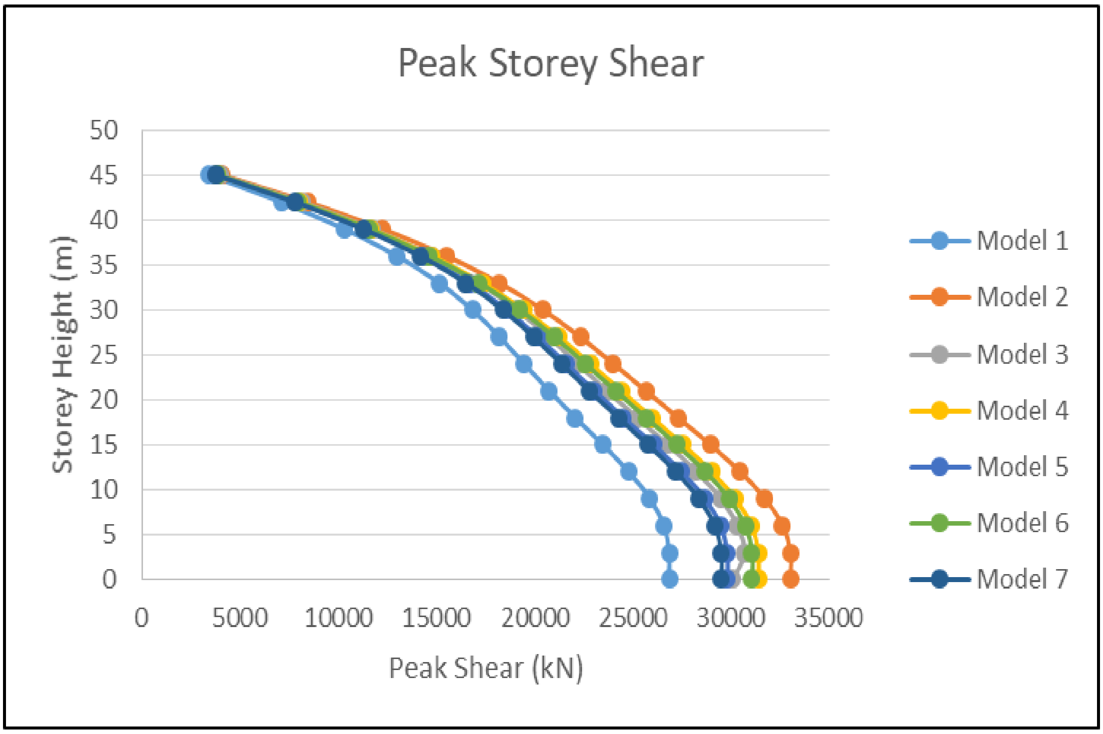


Fig. 5.12 Peak storey shear for Different models

The graph has been shown to display the comparable trend for the decrease in storey shear value per storey from the bottom to the top of the building. In general, it has been observed that the storey shear values at the base was maximum and the decreased as we moved up to the next storey level. Storey shear is minimum at the top most floor. The comparison of the values shows the structure which can bear the maximum storey shear is most feasible and effective.

In the case of Model-2, relative to other braced and unbraced systems, it can withstand with high shear values at different storey level so it the most case suitable case braced frame and is seen in the graph Fig.4.12.

4.9 Validation of Thesis Work

On comparison with the previous study conducted by Aniket Katte, D.B. Kulkarni and P.P. Kumar Reddy, P. Ravi Kumar it was concluded that the X-type bracing is the most efficient one and the locations for the bracing at the mid bays is most feasible. The reduction in the displacements were almost similar. The data, analysis and results are compared in the table 4.10.

Table 4.10 Validation of the study conducted

Model Description	**Thesis Work**	**Aniket Katte, D.B. Kulkarni**	**P.P. Kumar Reddy, P. Ravi Kumar**
Analysis	Dynamic	Dynamic	Dynamic
Software used	STAAD.Pro V8i	E Tabs	E Tabs
Model Storey	G+14	G+15	G+9
Plan Dimension	12 x 12 m	16 x 16 m	25 x 20 m
Different bracings used	X-type, Inverted-V type and V-type	X bracing	X, diagonal, chevron and V bracings
Location of the bracing	Mid-bays and corner bays	Mid-bays, corner and core bays	Mid-bays
Beam	Concrete (450 x 450 mm)	Steel (ISWB 300 and ISLB 150)	Concrete (300 x 450 mm)
Column	Concrete (600 x 600 mm)	Steel (ISHB 200-250/16 & ISHB 300-400/16)	Concrete (380 x 600 mm)
Steel Bracing	ISMB 200	ISA 110 x 110 x 10	ISMB 300
Seismic Zone	IV	IV	II, III, IV and V
Soil Type	Medium	Medium	Medium
Parameters studied	Time period, storey drift, displacement, bending moment, base shear and peak storey shear	Displacement and storey drift	Displacement, storey drift and storey shear
Results	The displacement and drift of the structure was reduced by 32.29% and 20 % approx. with the use of X-bracing at the mid bays of the structure.	The displacement and drift of the structure was reduced by 34.45% and 38.05% with the use of X-bracing.	In Zone IV, maximum storey displacement of a building is reduced by 36.94% and The story shear of a braced building was very high when compared to unbraced building.
Conclusion	X-bracing provided at the mid-bays of the structure is the most efficient	X-bracing provided at the core and mid-bays of the structure is the most efficient	The X-type of bracing shows the best performance.

4.10 Performance Based Ranking

After the analysis and results the different models with and without bracings is compared. The bare frame (model-1) is the source taken to compare the different models with different bracings systems provided at two different locations in the building. The parametric study shows the performance of different models in the seismic zone IV. Based on the performance of the models considered for the analysis, these are ranked from 1 to 6 shown in the table 4.11.

Table 4.11 Performance based ranking of the braced models

	Performance based ranking of the structural configurations investigated					
Model	Model-2	Model-4	Model-6	Model-3	Model-5	Model-7
Ranking	1	2	3	4	5	6

Thus the model-2 i.e. the RC framed structure with X Bracing in the mid 2-bays is ranked-1 based on its overall performance and the least ranked model is model-7 i.e. the RC framed structure with V-Bracing on the side bays.

4.11 Summary

This chapter comprises the results which includes tables and graphs for the different models taken for the analysis. The tables includes the data for the different parameters and also the reduction in the parameters on the braced frames. Validation of the work is also mentioned in this chapter.

Summary and Conclusions

Chapter 5 SUMMARY AND CONCLUSIONS

5.1 General

The present work specifically focuses on the study of the seismic response of G+14 storey building. The key aim of the study is to compare the effect of braced frames over unbraced frame in a structure in the seismic zone IV. The different parameters namely time period, storey displacement, storey drift, base shear, peak storey shear and maximum bending moment have been considered to achieve the objective and have been defined in Chapter 3. Using STAAD.Pro V8i software, three major types of bracing, namely X-bracing, Inverted V-bracing and V-bracing, were analyzed for seismic load by response spectrum analysis at two separate positions on the outside of the structure. The results generated from the analysis for the six different parameters such as the time period, the storey displacement of the building, storey drift, base shear, maximum bending moment for the column and peak storey shear were compared to the unbraced frame model and discussed in Chapter 4. In the following part, the conclusions of the study work are concluded.

5.2 Conclusions

For all the selected parameters namely, storey displacement, storey drift, base shear, maximum bending moment and peak storey shear, all braced frame models were analyzed by response spectrum analysis using STAAD.Pro V8i software. From the study of braced models, it was found that in the respective seismic zone considered i.e., zone IV, the braced structure displayed greater seismic resistance than an unbraced structure. In order to achieve improved results, a better spot for providing the different bracing was also observed. In comparison, it was found that model-2, i.e. the model with X-Bracing provided on the outside of the structure and on the mid bays, is a comparatively best choice from the structural point of view among all models considered. Therefore, the following conclusions display only the values of model-2.

1. Building’s response during earthquake is known as time period, which means greater the time period greater is the response and lesser the time period, less is the response. As the time period of model-2 is less it means it is stiffer or it has more

stiffness. Time period for the unbraced structure is 1.393 seconds which when compared with braced structure is more. In braced buildings, model-2 shows the lowest time period which is 1.125 thus it is the most effective compared to others. By comparing model-2 with the bare frame (model-1), time period is reduced by 19.24%.

2. As compared to the bare frame, the lateral displacement of the bracing system decreases with an increase in the building height. Compared to the other structural models of other bracing (inverted-V bracing and V-bracing) and unbraced structures in zone IV, the structural model-2 displays less lateral displacement. The reduction in lateral displacement values for model-2 in zone IV at a storey height of 24 m and 45 m is 35.98% and 32.29% respectively.
3. The overall base shear correlation reveals that in the case of model-2 and model-3, the base shear value is high relative to other models. As compared to the un-braced RC frame model, the base shear of the braced models increases.
4. By using various forms of bracing in the model, the storey drift is minimized. Compared to the braced and unbraced structures, a structural model with X-bracing provided on the exterior of the structure and on the middle bays (model-2) shows less floor drift. The reduction in storey drift values for the model-2, compared with bare frame at storey height of 24 m and 45 m is 42.41% and 13.17% respectively.
5. Compared to the unbraced frame, bending moment values for the column provided at the center are lower in the braced frame. In contrast to the other models, the braced model with the X-bracing provided in the mid bays has the least possible bending moment. Therefore, the X-bracing provided in the middle two bays of the structure is more efficient.
6. Peak storey shear values at different levels of the building in the braced frame model increased when compared to unbraced frame model. The frame model-2 gave the better results as it could take more shear than the other models. It changes from minimum at the top to maximum at the bottom of the building. Thus, model-2 is more advantageous than other models.

5.3 Future Scope

There is a vast research study in this research field for future study. For additional analysis, the following possibilities can be used in research work:

1. In a further study, we can consider irregularity in the building.
2. Instead of steel bracing, the performance of a building can also be studied by using concrete bracing.
3. Eccentrically braced frame (EBF's) can also be used in the future study.
4. We can use the time history method for analysis in further studies.
5. Different soil conditions can be considered for the further research work.
6. Different zones can be considered and which bracing system will be more advantageous can be evaluated in the further studies.
7. These CBF's and EBF's can also be taken as retrofitting techniques for further studies.

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ABSTRACT

Name : Deepak Chauhan
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Buildings are physical structures which provide shelter and safety for people. People prefer to live in their own individual spaces, so there is a requirement for many tall buildings to be constructed. Tall buildings have their own drawbacks such as lower resistance to wind and earthquake. Thus these buildings, if constructed in high seismic areas, may be susceptible to the severe damage which further leads to loss of life. Along with gravity load, structure has to withstand the lateral loads subjected to the building due to earthquake thus different lateral load resisting techniques are used now-a-days to make a tall structure stiff and stable. The present study focuses on the study of RC framed structure provided with three different type of bracing systems. For this study, a G+14 storied RC frame structure has been considered and the structural behavior has been studied for the seismic zones IV. The RC framed models are analyzed by Response spectrum Method using a computer aided software i.e., STAAD.Pro V8i. The structural behavior has been studied by using different types of bracing system such as X-bracing, Inverted-V bracing and V-bracing provided on the exterior faces of the buildings and at different locations on all the four sides. Comparative study of the braced and unbraced models is conducted for the parameters i.e. time period, base shear, storey drift, storey displacement, bending moment and peak storey shear. It has been observed that the storey displacement, storey drift, bending moment and time period of the braced frame decrease when compared to the un-braced frame and the base shear value of the braced models increases. Peak storey shear values are more for the braced frames. It is concluded that the model with the X-bracing provided at the mid-bays on the exterior faces of the buildings significantly contribute to structure stiffness as compared to the other bracing system.

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नाम	:	दीपक चौहान	परिचायक	:	५४०४५
सेमेस्टर, प्रवेश वर्ष	:	प्रथम, २०१८-१९	डिग्री	:	प्रौद्योगिकी निष्णात
प्रमुख	:	संरचनात्मक अभियांत्रिकी	विभाग	:	जनपद अभियांत्रिकी
शोध का शीर्षक	:	स्टील ब्रेसिंग युक्त आरसी मल्टीस्टोरी बिल्डिंग का विश्लेषण			
सलाहकार	:	श्री सुनील कुमार			

इमारतें भौतिक संरचनाएं हैं जो लोगों को आश्रय और सुरक्षा प्रदान करती हैं। लोग अपने स्वयं के व्यक्तिगत स्थानों में रहना पसंद करते हैं, इसलिए कई ऊंची इमारतों के निर्माण की आवश्यकता होती है। लंबी इमारतों की अपनी कमियां हैं जैसे हवा और भूकंप के लिए कम प्रतिरोध। इस कारण, उच्च भूकंपीय क्षेत्रों में निर्मित ये इमारतें गंभीर क्षति के लिए अतिसंवेदनशील हो सकती हैं जो आगे चलकर जीवन की क्षति का कारण बन सकती हैं। गुरुत्वाकर्षण भार के साथ, संरचना को भूकंप के कारण इमारत के अधीन पार्श्व भार का सामना करना पड़ता है। इस प्रकार एक अलग संरचना को कठोर और स्थिर बनाने के लिए विभिन्न पार्श्व भार प्रतिरोध तकनीकों का उपयोग आजकल किया जाता है। वर्तमान अध्ययन तीन अलग-अलग प्रकार के ब्रेसिंग प्रणाली के साथ प्रदान की गई आरसी फ्रेमयुक्त संरचना के अध्ययन पर केंद्रित है। इस अध्ययन के लिए, G+14 मंजिला आरसी फ्रेम संरचना पर विचार किया गया है और भूकंपीय क्षेत्र IV के लिए संरचनात्मक व्यवहार का अध्ययन किया गया है। आरसी फ्रेम वाले मॉडल का विश्लेषण एक कंप्यूटर एडेड सॉफ्टवेयर यानी STAAD.Pro V8i का उपयोग करके रिस्पॉन्स स्पेक्ट्रम मेथड द्वारा किया गया है। संरचनात्मक व्यवहार का अध्ययन संरचना के विभिन्न प्रकारों का उपयोग करके किया गया है जैसे कि एक्स-ब्रेसिंग, इनवर्टेड-वी ब्रेसिंग और वी-ब्रेसिंग इमारतों के बाहरी चेहरों पर और विभिन्न स्थानों पर प्रदान किया गया है। ब्रेस्ड और अनब्रेस्ड मॉडल का तुलनात्मक अध्ययन विभिन्न मापदंडों अर्थात् समय अवधि, आधार कतरनी, मंजिला बहाव, मंजिला विस्थापन, झुकने क्षण और शिखर मंजिला कतरनी के लिए आयोजित किया गया है । यह देखा गया है कि अन-ब्रेस्ड फ्रेम की तुलना में ब्रेस्ड फ्रेम का स्टोरेज विस्थापन, मंजिला बहाव, झुकने का क्षण और समय कम हो जाता है और ब्रेस्ड मॉडल का बेस शियर मूल्य बढ़ जाता है। शिखर मंजिला कतरनी मान ब्रेस्ड फ्रेम के लिए अधिक हैं। यह निष्कर्ष निकाला गया है कि इमारतों के बाहरी चेहरों पर मिड-बे पर प्रदान किए गए एक्स-ब्रेसिंग के साथ मॉडल अन्य ब्रेसिंग प्रणाली की तुलना में संरचना की कठोरता में महत्वपूर्ण योगदान देता है।

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