

Seismic Behavior of High-rise Building having Symmetric and Asymmetric Setback with Steel Bracing

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DECLARATION

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in any other University and that all sources of materials used for the thesis have been duly acknowledged.

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TABLE OF CONTENTS

| | |
|---|------|
| ACKNOWLEDGMENT | iv |
| TABLE OF CONTENTS | v |
| LIST OF FIGURES | vii |
| LIST OF TABLES | viii |
| LIST OF NOTATIONS..... | ix |
| Symbols in Abbreviations | x |
| ABSTRACT | xi |
| 1. INTRODUCTION | 1 |
| 1.1. Background | 1 |
| 1.2. STATEMENT OF THE PROBLEM | 1 |
| 1.3. Objectives | 1 |
| 1.4. Scope of the Study | 2 |
| 1.5. Methodology | 3 |
| 1.6. Thesis Organization | 3 |
| 2. LITERATURE REVIEW | 4 |
| 2.1 . Seismic Behaviour of Setback Reinforced Concrete Building | 4 |
| 2.1. Criteria for Setback in Buildings with Code Perspective | 7 |
| 2.2. Structural Systems | 9 |
| 2.2.1. Loading-oriented classification | 10 |
| 2.2.2. Material-Oriented Classification | 11 |
| 2.2.3. Framing-Oriented Classification | 12 |
| 2.3. Lateral Load Resisting Systems..... | 12 |
| 2.3.1. Moment resisting -Rigid frame structures | 13 |
| 2.3.2. Braced frame system | 13 |
| 2.4. Steel Bracing Systems in RC structure | 14 |

| | | |
|--------|--|----|
| 2.4.1. | External Bracing System | 15 |
| 2.4.2. | Internal Bracing System | 16 |
| 2.4.3. | Eccentric and Concentric Bracing Systems..... | 16 |
| 2.5. | Brace Layout Effect and brace-frame connection | 19 |
| 2.6. | Discussions on Previous Research..... | 21 |
| 3. | MODELING OF STRUCTURAL SYSTEMS | 22 |
| 3.1. | Introduction..... | 22 |
| 3.2. | Computer Modeling..... | 22 |
| 3.3. | Description of the Building Structure | 22 |
| 3.4. | Materials used for the modeling of Structural System | 27 |
| 3.4.1. | Earthquake analysis | 28 |
| 3.4.2. | Structural Regularity | 30 |
| 4. | ANALYSIS OF RESULTS AND DISCUSSION..... | 34 |
| 4.1. | Results..... | 34 |
| 4.1.1. | Lateral displacements in selected column | 34 |
| 4.1.2. | Inter-story drift ratio in selected column | 37 |
| 4.1.3. | Shear force in selected column..... | 39 |
| 4.1.4. | Bending moment in selected column..... | 40 |
| 4.2. | Discussions | 41 |
| 4.2.1. | Discussion on lateral displacement | 41 |
| 4.2.2. | Discussion on story drift..... | 41 |
| 4.2.3. | Discussion on column shear force and bending moment | 42 |
| 5. | CONCLUSIONS AND RECOMMENDATIONS..... | 45 |
| 5.1. | CONCLUSIONS | 45 |
| 5.2. | RECOMMENDATIONS FOR FUTURE STUDY | 46 |
| | REFERENCES | 47 |

LIST OF FIGURES

| | |
|--|----|
| Figure 2.1 Overview of building TO-9: | 6 |
| Figure 2.2 Partial collapse of o’Higgins office tower in Chile [2] | 7 |
| Figure 2.3 Criteria for regularity of buildings with setbacks | 9 |
| Figure 2.4 Interior structures[7]..... | 11 |
| Figure 2.5 Exterior structures[7] | 11 |
| Figure 2.6 Comparisons of structural system in concrete[8]..... | 12 |
| Figure 2.7 Schematic of the model bracing scheme[14] | 15 |
| Figure 2.8 Connection detail of; (a) the steel brace to concrete frame, (b) the steel cross braces to each other.[3]..... | 16 |
| Figure 2.9 Various types of eccentrically steel bracing frames. (a) V-bracing, (b) K-bracing, (c) X-bracing, (d) Y-bracing[17] | 17 |
| Figure 2.10 Eccentric braced frame (EBF) and behaviour of EBF. [20]..... | 18 |
| Figure 2.11 Different types of concentrically braced frames | 19 |
| Figure 2.12 detail of some practical brace-frame connections:..... | 21 |
| Figure 3.1 Floor plan with position of bracing and highlighted column (HC) of the RC building..... | 24 |
| Figure 3.2 RC (regular chevron) bracing figure 3.3 AV (asymmetric V- bracing)..... | 26 |
| Figure 3.4 SX (symmetric setback with X-bracing)..... | 27 |
| Figure 4.1 lateral displacement values of each bracing types for regular and symmetric setback story Building | 36 |
| Figure 4.2 lateral displacement values of each bracing types for regular and asymmetric setback story Building | 36 |
| Figure 4.3 Inter story drift ratio of each bracing types for regular and symmetric setback story Building | 38 |
| Figure 4.4 Inter story drift ratio of each bracing types for regular and asymmetric setback story Building | 38 |

LIST OF TABLES

| | |
|---|----|
| Table 3-1 Assumed Loading consideration and data in ETABS software for this study | 27 |
| Table 3-2 Basic value of the behavior factor, q_0 , for systems regular in elevation..... | 29 |
| Table 3-3 General Parameters considered during Analysis..... | 30 |
| Table 3-4 Consequences of structural regularity on seismic analysis and design..... | 31 |
| Table 4-1 Maximum lateral displacement in (mm) for the highlighted column in X direction..... | 34 |
| Table 4-2. inter-story drift ratio (%) for the highlighted column in X direction..... | 37 |
| Table 4-3. Maximum shear forces in column in kN for the highlighted column..... | 39 |
| Table 4-4. Maximum bending moment in column in kNm for the highlighted column..... | 40 |
| Table 4-5 Comparison of percentage reduction of maximum displacements in X direction (mm) | 41 |
| Table 4-6 Comparison of percentage reduction of maximum inter-story drift ratio in X direction (mm)..... | 42 |
| Table 4-7 Comparison of percentage reduction of sudden increase shear force in X direction for symmetric setback at 2nd story..... | 43 |
| Table 4-8 Comparison of percentage reduction of sudden increase shear force in X direction for Asymmetric setback at 5TH story | 43 |
| Table 4-9 Comparison of percentage reduction of sudden increase bending moment in Z direction for symmetric setback at 2nd story..... | 44 |
| Table 4.10 Comparison of percentage reduction of sudden increase bending moment in Z direction for Asymmetric setback at 5th story..... | 44 |

LIST OF NOTATIONS

- d_i = the lateral drift in story i
- d_r = design inter-story drift, evaluated difference of the average lateral displacements at the top and bottom of the storey under consideration
- g = acceleration of gravity
- h_i = height of i^{th} story
- EBCS = Ethiopian building code of standards
- EN = European standard
- F_y = Nominal yield strength
- F_u = Ultimate tensile strength
- q = Structural behaviour factor
- H = Height of the building from basement
- L = horizontal dimension of the lateral force-resisting system
- W = horizontal dimension of setback
- E = Young's modulus of Concrete
- M_s = surface-wave magnitude
- Q_0 = Basic value of the behavior factor
- k_w = prevailing failure mode
- $R_{j,d}$ = is the design resistance of the connection;
- $R_{pl,Rd}$ = is the plastic resistance of the connected dissipative member based on the design yield stress of the material
- $R_{U,Rd}$ = is the upper bound of the plastic resistance of the connected dissipative member;
- Y_{0V} = is the over strength factor

SYMBOLS IN ABBREVIATIONS

| | |
|-----------|---|
| ETABS | = Extended Three-Dimensional Analysis of Building Systems |
| CBFs | = concentrically braced frames |
| EBFs | = eccentric braced frames |
| X-bracing | = X type bracing system |
| V-bracing | = V type bracing system |
| MRSF | =moment-resisting space frames |
| RC | =reinforced concrete |
| CQC | =Complete Quadratic Combination |
| DCM | =medium ductility class |
| DCH | = high ductility class |
| B.M | =Bending Moment |
| S.F | =Shear Force |

ABSTRACT

Construction of vertical geometric irregular buildings is very common due to space, architectural and functional constraints. This paper is concerned with the behaviour of various vertical geometrical irregularities of symmetric and asymmetric setback by different types of bracing. For this study twenty five story buildings 12 modeling have been analyzed considering different types of vertical geometric irregularities and different steel bracings using response spectrum analysis with the help of ETABS 2015 software. The response of the these setback structures are observed with lateral displacement, story drift, shear force and bending moment.

From addition of X type brace, V type brace and Inverted V type brace shows that use of X-type of bracing is found more efficient and significantly contributes to the structural stiffness and reduces the maximum interstorey drift and lateral displacement of the frames.

This study may help the practicing engineers to improve and understanding about seismic susceptibility of setback buildings, and using steel bracing is one of the advantageous concepts which can be used to strengthen or retrofit the existing structures..

Keywords: symmetric and asymmetric setback, Steel Bracing, RC building, Response Spectrum Analysis.

1. INTRODUCTION

1.1. Background

The presence of set-backs at specific levels of the elevation is a very common kind of vertical geometrical irregularity in building structures which needed for aesthetic architecture requirements and brings sufficient daylight and ventilation for the lower storey in an urban locality with closely spaced high rise buildings. But, damage is generally happens at location of this structural setback present in the building systems. Therefore these Structural systems with geometrical irregularity need resistance mechanism especially in areas of high seismic regions to sustain its stability without sudden collapse. By the addition of bracing systems, load will be transferred out through the frame and passes on to the braces. The potential advantages of using concentric steel bracing are their high strength, stiffness, economical, occupies less space and adds much less weight to the existing structure. For this study X bracing, V bracing and Inverted V bracing are used and find out which bracing is more effective in resisting lateral deformation by considering an 12 storied irregular and regular RC building.

1.2. STATEMENT OF THE PROBLEM

In the past and present time, most of the reinforced concrete structures designed with vertical geometric irregularity for many purposes. But they were not considering the effect of setback for lateral forces. Therefore, Structures which have such kinds of geometric irregularity should be study the behaviour and response by seismic load with different bracing types. So, Seismic Behavior of High-rise Building having Symmetric and Asymmetric Setback with Steel bracing has become an important topic to answer these problems.

1.3. Objectives

Design codes have not given particular attention to the setback building form. The main objective of this thesis is to compare and evaluate the effectiveness of different types of bracing systems in reinforced concrete (RC) multi-storeyed building with different setback along the elevation of high rise buildings under earthquake loads. The goal of this research is to study the seismic behaviour of RC building with vertical geometric irregularities with different types of bracing.

The salient objectives of the present study have been identified as follows:

1. To perform a comparative study on reinforced concrete moment resisting frames (MRF) of 25 stories with bracing and to identify the most efficient and suitable lateral loads resistant steel bracing, with different configuration of setback.
2. Comparison between regular and vertical irregular building on the basis of shear force, bending moment, storey drift, and node displacement with and without different bracing systems.
3. To investigate the most efficient types of bracing for seismic responses of RC framed regular and vertical geometric irregular structures.

1.4. Scope of the Study

The present study is limited to RC multi-storeyed building frames with only vertical geometric irregularity was studied. Setbacks building with 25 stores with different degrees of irregularity are considered. The buildings Column was modelled as fixed to the base. The contribution of infill wall to the stiffness was not considered however, Loading due to infill wall was taken into account. The analysis was done using Response Spectrum Method corresponding to Zone IV in Adama city. The plan asymmetry arising because of the vertical geometric irregularity strictly calls for three-dimensional analysis to account properly for torsion effects. This is not considered in the present study. The study considers on concentrically types of bracing systems having a structural resistance capacity for lateral loads. The axes of the members are made to align concentrically at the joints. And also comparison between un-braced and braced is made. The study doesn't consider any aesthetical effects of the bracing for provision of doors and windows. Soil structure interaction effects are not considered.

1.5. Methodology

The steps undertaken in the present study to accomplish the above-mentioned objectives are as follows:

1. Carry out extensive literature review, to establish the objectives of the research work.
2. Select an exhaustive set of regular and model setback building 3D models with different heights (1 to 25 storeys), for G+25 story with a symmetrical plan configuration of square shape provided with 8 x 8 bays assuming bay width of 5 and 3 m in both horizontal direction and different irregularities (limit to 12 setback 3D models with brace and without three types of bracing).
3. Analyse each of the 12 building models, using all the major dynamic analysis of response spectrum analysis.
4. Comparison the result of seismic analysis at different location of setback with inverted V-bracing, V-bracing and X-bracing.
5. Presentation of all the results prepared in the form of graphs and tables.

1.6. Thesis Organization

This thesis is divided into five chapters:

Chapter 1: Gives a general introduction with theoretical background, methodology, objective and scope of the study and organization of the thesis.

Chapter 2: briefly reviews on behaviour of setback reinforced setback building, criteria for setback buildings, classifications of structural system, lateral load resisting system and steel bracing systems in RC structure are considered.

Chapter 3: discusses about the modelling type, modelling software and loading consideration in the modelled buildings.

Chapter 4: discusses about the analysis result of modelling with bracing and without bracing and give discussion for shear force, bending moment, joint displacement and inter-story drift ratio values for the highlighted column.

Chapter 5: The main conclusion and recommendations that can be drawn from the current Studies are summarized, and also suggestions for future studies are outlined.

2. LITERATURE REVIEW

2.1. Seismic Behaviour of Setback Reinforced Concrete Building

Reinforced concrete is an adaptable construction material widely used in the construction of high rise structures in the recent time. The number of 100 tallest building constructed using steel has reduced by at least 15% each decade since 1970. By the end of 2010, only 22% of the tallest building was steel. Of these approximately 50% are constructed with concrete and most of tall building were built for office purpose. [1]

The behaviour of a multi-storey RC framed building during strong earthquake motions depends on the allocation of mass, stiffness, and strength in both the horizontal and vertical planes of a building. The occurrence of a setback in the building results in sudden reductions of the floor area, which in turn results in change of mass and stiffness along the building height. In multi-storeyed RC framed buildings, damage from earthquake ground motion generally initiates at locations of structural weaknesses present in the lateral load resisting frames. There are many examples of failure of buildings in past earthquakes due to such vertical discontinuities in the world.

Many investigations have been performed to understand the behaviour of irregular structures as well as setback structures and to find out method of improving their performance. Buildings with irregular structural configurations are subjected to severe damage than simple regular buildings during earthquakes in high seismic zones. Particularly buildings over 18 stories having a setback are more affected by lateral load. [2]

There are four aspects of reinforced concrete buildings that architects and design engineers work with to create the earthquake-resistant design of a building, namely seismic structural configuration, lateral stiffness, lateral strength and ductility, in addition to other aspects like form, aesthetics, functionality and comfort of building. Lateral stiffness, lateral strength and ductility of buildings can be ensured by strictly following most seismic design codes.

Buildings with rectangular plans and straight elevation stand the best chance of doing well during an earthquake, because inertia forces are transferred without having to bend due to the geometry of the building. But, buildings with setbacks and central openings offer geometric constraint to the flow of inertia forces; these inertia force paths have to bend before reaching the ground. Even though, reinforced concrete buildings are more rigid

buildings, when vertical geometric irregularity occurs it becomes flexible than regular one. And also they display more lateral displacement and story drift than regular buildings. But it can be controlled by providing lateral support mechanism like bracing structures.

Joining steel bracing directly to concrete frame is easy to construct and incurs little cost. However, the connection should be strong enough to satisfy transfer the load between the brace and frame. Based on the test result indicated a considerable increase in the in-plane strength of the concrete frame due to steel bracing. As an overall conclusion it is noted that, with proper connection between the brace and frame, the steel brace could be a feasible alternative or supplement to shear wall in concrete framed building in seismic area. [3]

a) Failures occurred during the past earthquakes

A building structure may collapse or suffer severe damage under the action of seismic forces due to sudden change in mass, stiffness and strength along vertical. The presence of structural irregularities triggers the structural collapse. A typical example of the detrimental effects that these discontinuities can induce is in the case of building with a setback. Inspection of earthquake damage of actual building has shown that the structure system with setbacks is one of the serious problems during severe earthquake ground shaking. The next subsections give examples of building failures that have occurred during the past earthquakes due to presence of setbacks.

b) Failure of setback structures

The setback structures are quite common in modern buildings as evident from existing realistic buildings. The failure of structures during previous earthquakes has been reported by researchers [4] as shown from Figures 2.1. This section describes the particular behaviour of TO 9 G+23 building during Chile earthquake 2010.

Also and figure 2.2 it is shown another good example on how setback structure is susceptible for collapse.

Detail over view of figure 2.1 is (a) West side view, (b) East side view, (c) South side view and close-up of deformed axis, (d) Plan view, (e) Details of the main collapse at story 12, (f) Damage in short columns in axis 1A, (g) Overall condition of the 21st storey.



Figure 2.1 Overview of building TO-9:



Figure 2.2 Partial collapse of o'Higgins office tower in Chile [2]

Assessment of the performance of building structures during past earthquakes suggests that vertical geometric irregularities are one of the important causes of damage during occurrence of an earthquake. Setback structure may occur due to irregular distribution of mass, stiffness and strength along the height of the building.

2.1. Criteria for Setback in Buildings with Code Perspective

Setback buildings are characterised by staggered abrupt reductions in floor area along the height of the building, with resulting drops in mass, strength and stiffness. This setback affects the mass, strength, stiffness, centre of mass and centre of stiffness of setback building. Dynamic characteristics of such buildings differ from the regular building due to changes in geometrical and structural property. Because of these behaviour all design codes defines plan irregularity and vertical irregularity as two major types of irregularity. Vertical geometric irregularity or Setback building is one among the vertical irregularity defined in two codes as follow:

I. EURO CODE- 8 AND EBCS EN-8 [5&6]

Euro code 8 (EC 2004) and Ethiopian Building Code Standard 8(EBCS EN 2013) design guidelines contain criteria for classification of vertically regular and irregular structures, where a structure is defined as being “irregular” when the ratio of one of the quantities (such as masses or strength) between adjacent stories exceeds a minimum prescribed value. For a building to be categorised as being regular in elevation, it shall satisfy the following:

When setbacks are present, the following additional conditions apply:

- a) For gradual setbacks preserving axial symmetry, the setback at any floor shall be not greater than 20 % of the previous plan dimension in the direction of the setback as shown in Figures 2.3 (a) and (b).
- b) For a single setback within the lower 15 % of the total height of the main structural system, the setback shall be not greater than 50 % of the previous plan dimension as illustrated in figure 2.3 (c). In this case the structure of the base zone within the vertically projected perimeter of the upper stories should be designed to resist at least 75% of the horizontal shear forces that would develop in that zone in a similar building without the base enlargement.
- c) if the setbacks do not preserve symmetry, in each face the sum of the setbacks at all stories shall be not greater than 30 % of the plan dimension at the ground floor above the foundation or above the top of a rigid basement, and the individual setbacks shall be not greater than 10 % of the previous plan dimension as illustrated in figure 2.3 (d).

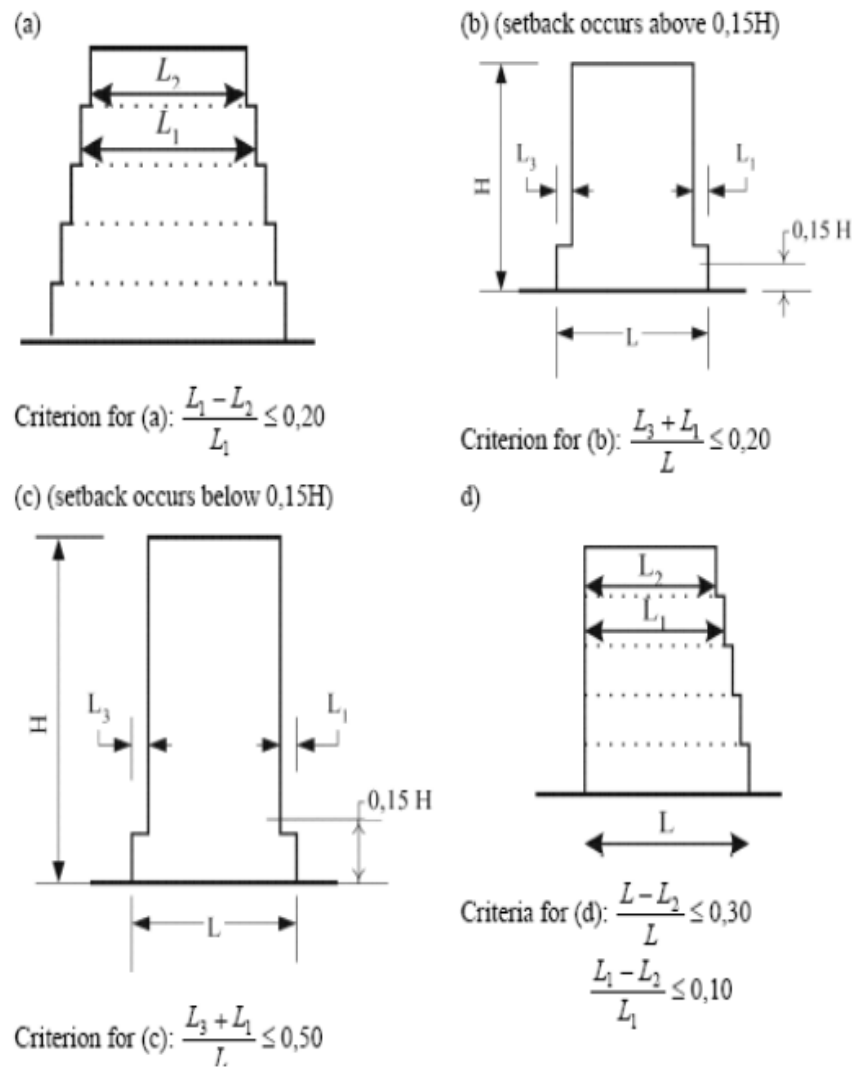


Figure 2.3 Criteria for regularity of buildings with setbacks

2.2. Structural Systems

There are different types of tall building structural systems, and the various ways of classifying them. The structural system on a building must resist both gravity and lateral loads (i.e. wind, earthquake). As the height of the building increases, the lateral loads begin to dominate the structural concepts. Most structural systems have been shown to have optimum building heights, or rather, optimum height-to-width ratios. Figure 2.6 schematically compares some frequently used concrete systems on the basis of structural efficiency (as measured by weight per square foot of the system versus height of the building). It is extremely difficult to create a classification system that succeeds in isolating consistent criteria for tall building structural systems. This is due to the large number of possible variables connected with high-rise structures, such as the number of stories,

building material, framing system, load resistance properties, etc. Tall buildings themselves are diverse in nature of usage, location, geometric shape and architectural design. This indicates some in the difficulties in arriving at an accurate method for classifying high-rise structures. After consideration of the various structural classification schemes developed and available in literature, three general approaches can be identified: these are:-

- a) Loading-oriented classification (a listing of tall building structural members and subsystems by the load they resist, i.e., lateral and vertical).
- b) material-oriented classification (a listing of tall building structural systems by their main structural material), and
- c) Framing-oriented classification (listing tall building structural systems by their framing method).

2.2.1. Loading-oriented classification

This classification was developed by [1]. It groups "building blocks" based on a listing of vertical load resisting members, horizontal load resisting subsystems, and combination systems. The items grouped together to form the vertical resisting members include columns, bearing walls, hangers, and transfer girders. The items grouped together to form the lateral load resisting members include moment resisting frame, braced frame, shear walls, and combination systems. Items grouped under combination systems are tubes and core interactive structures, and are called "combination" because they usually are required to resist both lateral and vertical loads.

On the other means structural systems classify as internal structure and external structure based on the distribution of the components of the primary lateral load-resisting system over the building as shown in figure 2.4 and figure 2.5 [7]. A system is categorized as an interior structure when the major part of the lateral load resisting system is located within the interior of the building. Likewise, if the major part of the lateral load-resisting system is located at the building perimeter, a system is categorized as an exterior structure. It should be noted, however, that any interior structure is likely to have some minor components of the lateral load-resisting system at the building perimeter, and any exterior structure may have some minor components within the interior of the building. This classification of structural systems is presented more as a guideline and should be treated as such. It is imperative that each system has a wide range of height applications depending

upon other design and service criteria related to building shape, aspect ratio, architectural functions, load conditions, building stability and site constraints. [7]

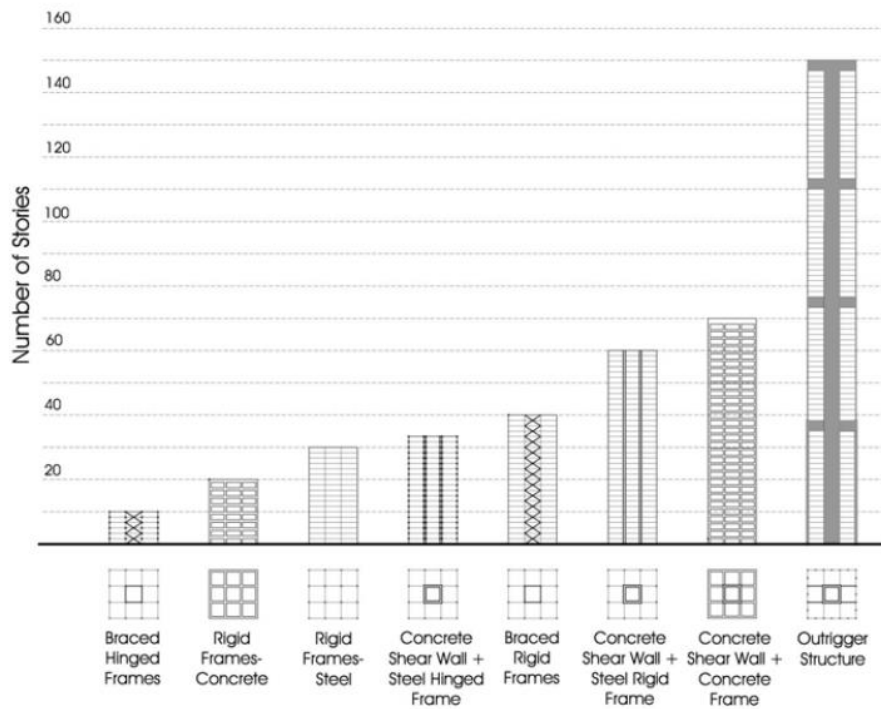


Figure 2.4 Interior structures[7]

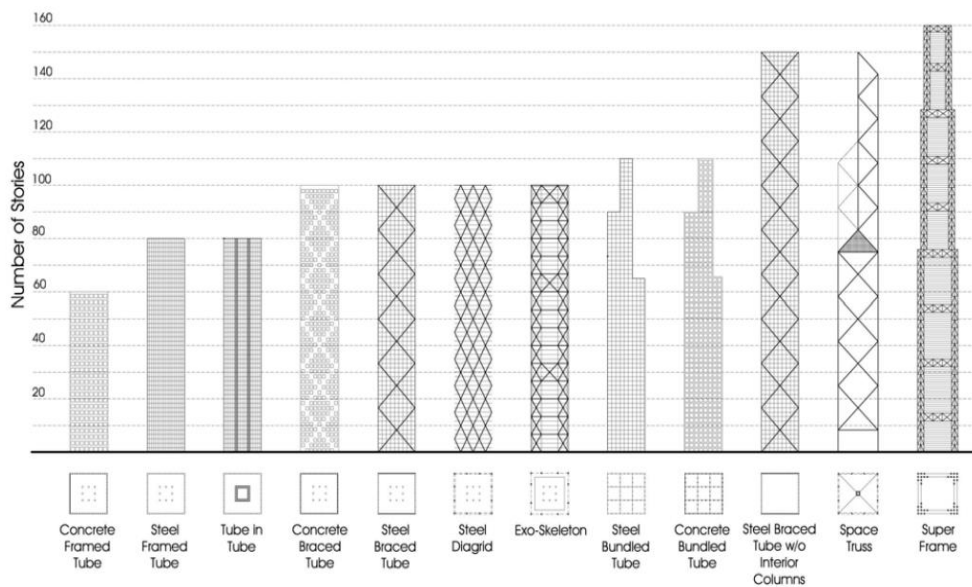


Figure 2.5 Exterior structures[7]

2.2.2. Material-Oriented Classification

Material-oriented classification uses by [8] to discuss the different responses of various steel, concrete and mixed structural systems to lateral loads.

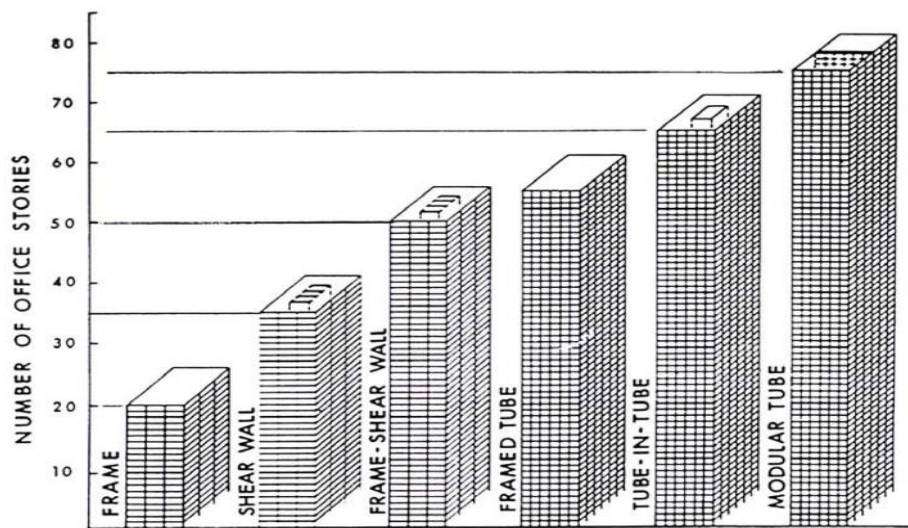


Figure 2.6 Comparisons of structural system in concrete[8]

2.2.3. Framing-Oriented Classification

This approach attempts to classify tall building structural systems by a description of the structural framing system. This framing-oriented classification scheme is one that separates the structure into three categories: the structural framing system, the bracing system, and the floor framing system [9].

2.3. Lateral Load Resisting Systems

Lateral load resisting systems are structural elements which resist seismic, wind and eccentric gravity loads. They are structural elements that provide its basic lateral strength and stiffness, and without which the structure would be laterally unstable. A number of structural systems provide the varying architectural needs are available in concrete as well as steel. The confrontation of high rise buildings to earthquake is the main determinant in the formulation of new structural systems that develop by the continuous efforts of structural engineers to increase building height while keeping the deflection within acceptable limits and minimizing the amount of materials.

Loading-oriented classification scheme organizes the structural components with the lateral load resisting members include moment resisting frame, braced frame, shear walls, and combination systems. The following sections present an overview of the behaviour of various lateral load resisting members based on these structural classification schemes [1].

2.3.1. Moment resisting -Rigid frame structures

Moment resisting frame, also called moment frame or rigid frame, is a structure that utilizes moment resisting connections between columns and girders throughout its perimeter to resist the lateral loads applied

In buildings up to 20 stories in RC and up to 30 stories in steel, frame action usually takes care of lateral resistance except for very slender buildings. For buildings with over 20 stories in reinforced concrete frame and over 30 stories in steel, the rigidity of the frame system remains mostly insufficient for lateral sway resulting from wind and earthquake actions and it needs huge dimensions of frame beams and complex connections are required that the usage of a moment resisting frame gets uneconomical. [8-12].

So according to these literature reviews it is better to use steel brace with RC building over 20 stories.

2.3.2. Braced frame system

The braced frame is a common system employed to resist the significant lateral loads that exceptionally tall structures are subjected to.

The advantages of braced frames from a structural engineering standpoint are vast. Braced frames carry the lateral forces in an axial manner (through the diagonal elements) rather than through the bending of elements which is highly inefficient.

The largest drawback for braced frames is that the scheme is obstructive and significantly reduces openings within bays. The large bracing covers a significant part of the bay windows.

Rigid frame systems are not efficient for buildings taller than 20 stories reinforced concrete frame and over 30 stories in steel, because lateral deflection due to the bending of columns causes the drift to be too large.[10].

In itself the braced frame is not economical if the buildings size is above 20 to 30 floors but combined with another system, such as the moment frame, it can become more effective. If the braced frame, or shear walls, and a rigid frame are combined, it produces a greater amount of lateral stiffness. This is because of the way the two systems react to the horizontal loads. With the moment frames shear deformation and the bracing's bending

deformation the combined deformation is more efficient. A braced rigid frame structural in Tube Mega Frame Concept system is most efficient when between 40-60 stories. [12]

On the other ways according to [9], four over-all groupings of structural systems have been identified. These are the bearing wall system, the core system, the frame system, and the tube system. Each system has inherently different lateral load resistant properties and thus tends to be "efficient" over different height regions are observe below:-

The bearing wall system due to the self-weight of the structural components (solid concrete or masonry), usually becomes inefficient (cost of the structural system versus its height) above the 15-30 story range of height.

The tube system can be thought of as a spatial frame with all the vertical elements positioned at the exterior. The range of height efficiency is influenced by the type and amount of bracing employed in the tube, but in general, a tube structure is considered the most efficient for the tallest buildings (60 stories and greater).

The efficiency of the frame system depends upon the rigidity of the connections and the amount and position of bracing. Stiffening can be achieved through a solid core, shear walls or diagonal bracing. As more bracing is incorporated into the spatial frame, the range of efficient height is increased. The upper limit is in the range of 60 stories.

Based on [9] framing system classification, Bracing Subsystems are five categories that bracing is efficient. The first categories (numbers storeys 11-20) are Frame Bracing One Plane, (numbers storeys 21-30) are Frame Bracing Two Planes, (numbers storeys 31-40) are Core Braced (Two Directions), (numbers storeys 41-50) are Core With Hat/Belt Truss and (numbers storeys 51-60) are Core Braced and Hat/Belt Truss.

2.4. Steel Bracing Systems in RC structure

One of the most suitable choices in design and improvement of reinforced concrete frames is using steel bracings. The bracing systems can be grouped according to their location in the reinforced concrete frames as internal or external and according to their connection style as eccentric or concentric bracing system. [13].

Based on [3] investigation carried through a series of tests conducted on number of steel braced model. The test result indicates a considerable increase in the in-plane strength of the frame due to steel bracing. As an overall conclusion it is noted that, with proper

connection between the brace and the frame, the steel bracing could be a viable alternative or supplement to shear wall in concrete framed buildings in seismic area. [3]

2.4.1. External Bracing System

In external bracing system, the steel trusses are introduced to the exterior frames of the building.

The model bracing scheme consists of X-braces that were continuous across two stories. The braced model is shown schematically in figure 2.7. [14]

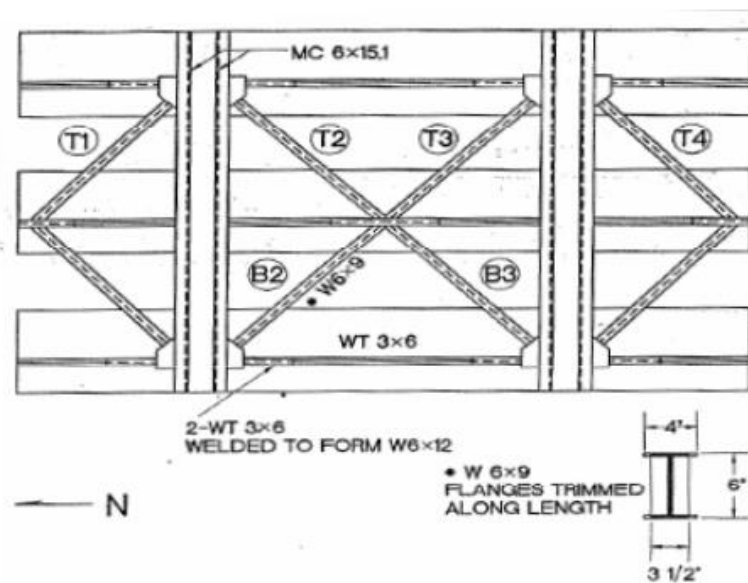


Figure 2.7 Schematic of the model bracing scheme [14]

Bracing system elements attached to the side faces of the concrete columns also increased column shear capacities significantly. The lateral capacity of the strengthened frame was governed by brace buckling and eventual connection failures and column shear failures.

This study recommends that the designer must consider the failure mechanism of the original frame under lateral deformations. The bracing system can improve the frame strength and stiffness, but cannot change the frame mode of failure. The weak column – strong beam frame leads to an unwanted mode of failure so this type frame should be transferred into a strong column – weak beam frame. This can be achieved by strengthening the columns or by weakening the beams. The first option is feasible, but costly. However weakening the beam is attractive because of its simplicity. The aim of the weakening is to decrease the beam flexural capacity enough to guarantee that under lateral

loading hinges will develop in the beams before the failure of the column. This can be succeeded by coring or cutting beams. Because of the ductility of the flexural hinges, lateral strength was improved or increased slightly. Inelastic behaviour was transferred from the columns to the beams, thus preventing column damage and increasing the energy dissipation capacity of the frame.

2.4.2. Internal Bracing System

In internal bracing system, steel trusses or bracing members are introduced to the empty space enclosed by columns and beams of reinforced concrete frames. The effectiveness of using internal steel trusses to retrofit existing reinforced concrete frames was investigated by a number of researchers. They state that such a method allows upgrading the seismic capacity of existing structures. [3] and [16]

The testing program was determined the effectiveness of different diagonal bracing arrangements to increase the lateral load capacity of the existing concrete frames and observe the relative behaviour of tension and compression braces. In order to reduce the buckling tendency of the compression brace in the X-brace system, the two diagonal braces were also connected to each other at their cross-point by a steel plate. The connection to the frame is done by welding the braces to the sides of a steel plate which is welded to an equal angle positioned and pre-cast at the corners of the frame. The connection details are shown in Figure 2.8.

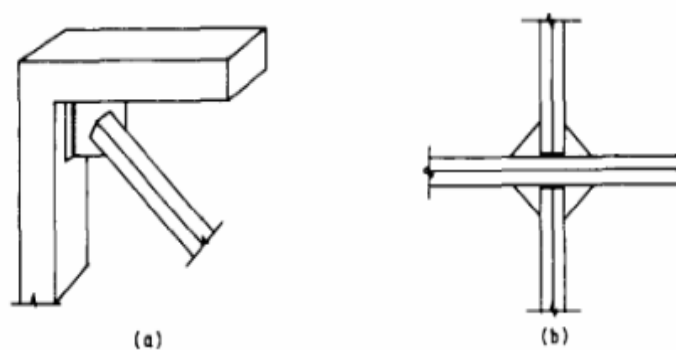


Figure 2.8 Connection detail of; (a) the steel brace to concrete frame, (b) the steel cross braces to each other.[3]

2.4.3. Eccentric and Concentric Bracing Systems

As it is mentioned the bracing system can also be classified as eccentric and concentric bracing systems. Each of these systems has some advantages as well as disadvantages.

Eccentric Bracings reduce the lateral stiffness of the system and improve the energy dissipation capacity. Due to eccentric connection of the braces to beams, the lateral stiffness of the system depends upon the flexural stiffness of the beams and columns, thus reducing the lateral stiffness of the frame. The actions are transferred to the braces by bending and shear in an active link. This link prevents buckling of the braces. The active link is one of the most important members of this bracing system, and this member has to be designed to remain elastic at low load levels, and to deform in elastically during overloading of the structure. So, the system dissipates large amounts of energy. Different researchers proposed comparisons of the efficiencies of different forms of eccentric bracings. [17] and [20]

By using eccentric bracing, the forces are transferred to the brace members through bending and shear forces developed in the ductile steel link. Different brace patterns were used. These patterns can be V-bracing (a), K-bracing (b), X-bracing (c), and Y-bracing (d), as shown in figure 2.9.

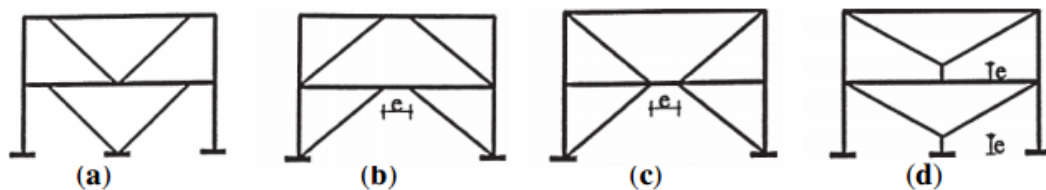


Figure 2.9 Various types of eccentrically steel bracing frames. (a) V-bracing, (b) K-bracing, (c) X-bracing, (d) Y-bracing[17]

In this study, the most important points were that steel brace members should be designed to behave elastically when subjected to an earthquake loading and the connection between the vertical shear link and the reinforced concrete frame should have sufficient capacity to transmit forces when subjected to seismic loads.

The seismic performance of non-ductile RC buildings with eccentric steel bracing of inverted Y type is investigated. 10, 15 and 20 storey buildings are analysed by using pushover analysis. In RC frames, the concrete beams are incapable of performing as a ductile link for the steel bracing system that is inserted in the frame bays. A vertical steel shear link may be introduced by the inverted Y bracing pattern. [20]

In his investigation inverted Y type of bracing with shear link is used on RC frame. The link assumed to acts as cantilever. Connection between link and beam is considered as

fixed and the connection between brace members and link is treated as pinned one. The deformation of the steel bracing system in eccentric bracing frame results mainly from the link yielding while the deformation of the RC frame is developed mainly by the formation of the plastic hinges in the frame members. The inelastic hinging system shown in figure 2.10 represents one possible failure mechanism.

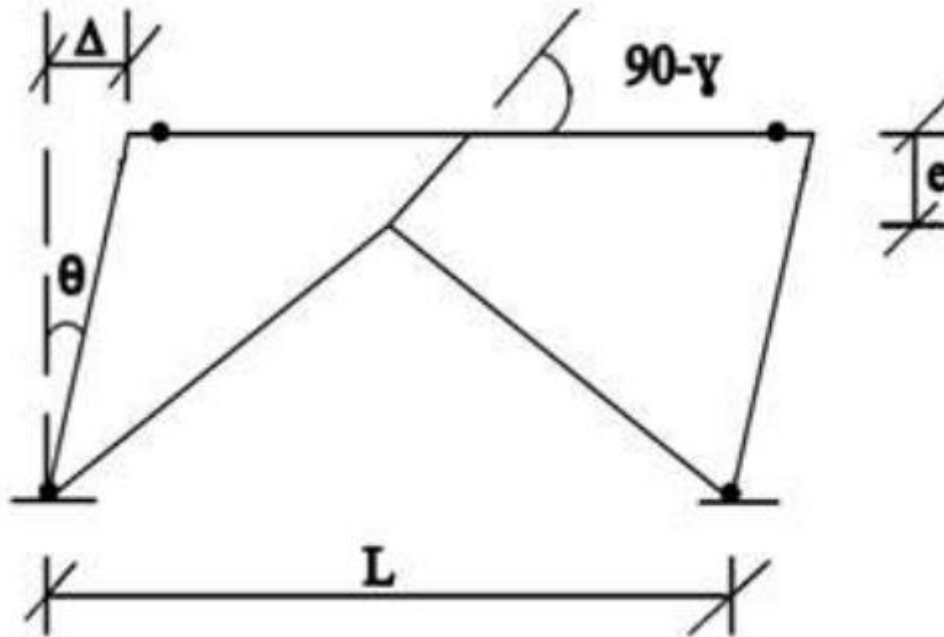


Figure 2.10 Eccentric braced frame (EBF) and behaviour of EBF. [20]

Finally he proposed that EBF reduces all the seismic hazards efficiently hence EBFs are well suitable for seismic regions till 15 storeys and Increased area of bracing makes building stiffer and reduces ductility and energy absorption capacity of building and increased link length is vice-versa.[20]

Concentric braces also improve strength and stiffness, but the energy dissipation capacity and inelastic behaviour remain poor due to the buckling of the diagonal brace. Concentrically braced frames have suitable lateral stiffness to prevent relative drift due to lateral load impacts resulting from earthquake. Such braces are part of relatively stiff systems and compatible with common needs of architecture with varied forms as shown Figure 2.11. Concentrically braced frames are used in different forms such as cross, diametric V-shape, Chevron (inverted-v), K shape, etc. Those types of braces have not any link length between the connection points of bracing and beams that differs from

eccentrically bracing type. The concentric bracings increase the lateral stiffness of the frame, thus increasing the natural frequency and also usually decreasing the lateral drift.

Generally, the use of steel concentrically bracing systems instead of Shear walls provides lower stiffness and resistance for a structure but it should not be forgotten that such a system has lower weight and more useful for architectural purposes.

Different researchers proposed comparisons of the efficiencies and compatible with common needs of architecture of different forms of concentric bracings. [18-19]

For this research paper emphasis is given for concentrically types. These are X-bracing, inverted V-bracing and K-bracing with vertical geometrical irregularity building arrangements with similar cross section for comparison purpose.

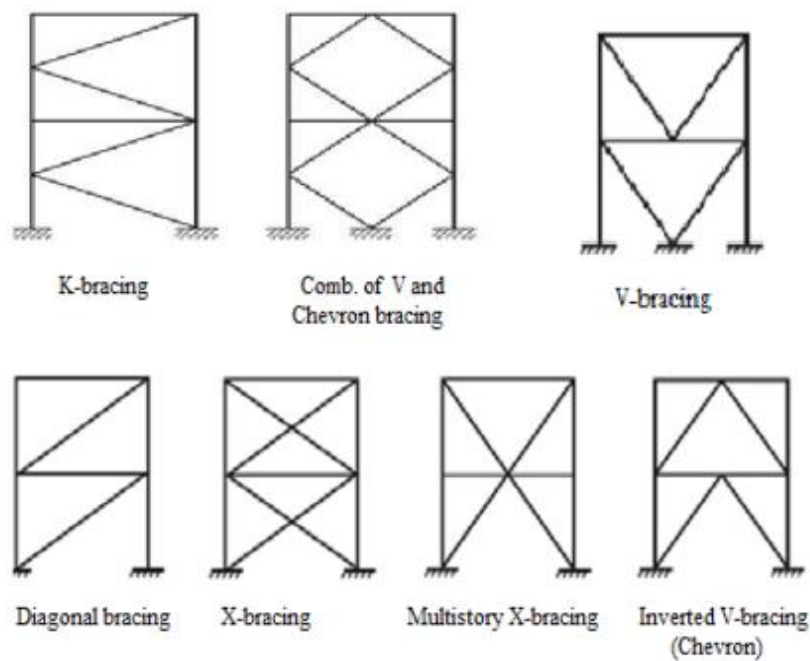


Figure 2.11 Different types of concentrically braced frames

2.5. Brace Layout Effect and brace-frame connection

Laying out the bracings has an important effect on the lateral load resistance of reinforced concrete frames. Creation of some undesirable weak links must be avoided in the process. From structural point of view, it may be desirable to brace as many bays of the frame as

possible, so that increases in strength and the stiffness are distributed uniformly. However, cost and functional considerations may limit the number of the braced bays. An exterior bracing system is also advantages because of the torsional behaviour of the structure under earthquake effects. Increasing the exterior bracing maximize the structural symmetry and the torsional resistance. However, if only the exterior frames are strengthened, the slabs have to be strong enough to carry the additional seismic shear to exterior frames.

The effect of the distribution of the steel bracings over the story height on the rehabilitation of the reinforced concrete frame building was investigated by different researchers.

From all arrangements, bracing in middle of frame of building have the lowest time period, minimum story displacement and Minimum drift compared to other cases. And also Bracings at corners have higher time period and maximum story drift when it compare to the middle bracing arrangement. [21-22]

Brace–frame connection also has an important effect on the lateral load resistance of reinforced concrete frames. Creation of some undesirable weak links between frames must be avoided in the process. The advantage of joining steel bracing directly to the concrete frame is that the connection is easy to construct and incur little cost. However, the connection should be strong enough to safely transfer the load between the brace and the frame. This should be true for both connections, set-up during the construction of concrete frame and connections constructed after the construction of the frame. A number of connection arrangements of both types are shown in the Figure 2.12 is a) And (b) connection arrangement for frame under construction; (c) and (d) connection arrangement for existing frames. The connection appeared to be capable of carrying large loads. [3]

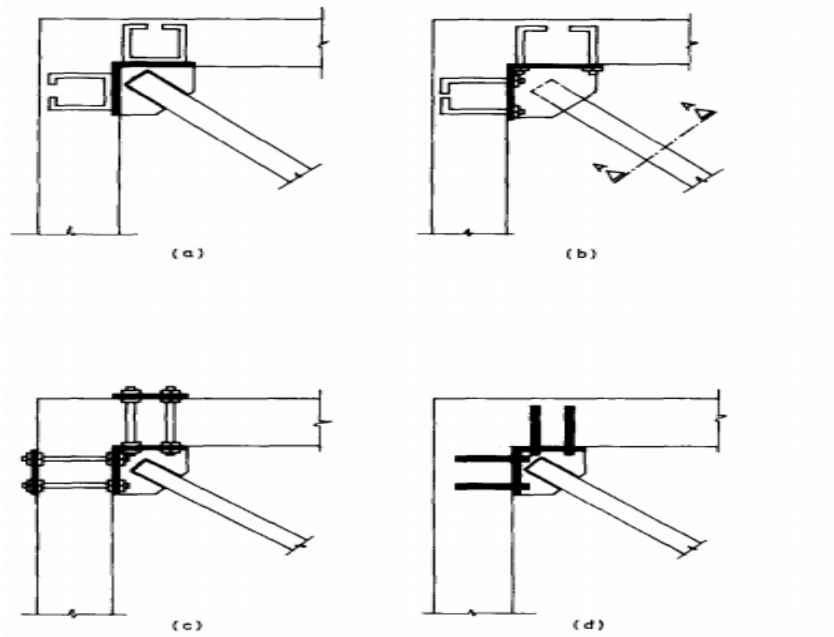


Figure 2.12 detail of some practical brace-frame connections:

2.6. Discussions on Previous Research

The presence of structural irregularity changes the seismic response and the change in the seismic response depends upon type of structural irregularities. Structural irregularities seen in above literatures are on regular and vertical geometric irregularities of building. On comparing research works regarding regular and vertical geometric irregularity brace structure, it was found that large numbers of research works were conducted on regular building but, no one investigators did on the behaviour of vertical geometric irregularities with different bracing types.

3. MODELING OF STRUCTURAL SYSTEMS

3.1. Introduction

The study in this thesis is based on basically on linear dynamic analysis of symmetric and asymmetric setback reinforced concrete buildings with three types of concentric bracing models using response spectrum method based on EuroCode-8, 2004. Equivalent lateral force procedures may be used to determine the distribution of design forces in regular buildings, while linear dynamic analysis is required for setback structures. By requiring different levels of analysis for regular and setback structures, the building codes imply that the nature of the dynamic response is different for the two types of buildings. The first part of this chapter presents a summary of various parameters defining the computational models, the basic assumptions and the building geometries considered for this study.

3.2. Computer Modeling

For the analysis work, minimum of twelve models with two types of setback irregularity and one regular high rise reinforced concrete frame building (G+25) floors are made to know the most efficient bracing type and the realistic behavior of these building during earthquake. These buildings were modeled using ETABS 2015 Integrated Software for Structural Analysis and Design [24]. ETABS is a powerful program that can greatly enhance an engineer's analysis and design capabilities for structures. There are two main groups model of structural components. These are the reinforced concrete building and three types of steel bracing system in bay of reinforced concrete frame which is attached to joints of the frame. A linear response spectrum analysis was conducted using Euro code 8-2004 and EBCS EN -8 versions of 2013.

3.3. Description of the Building Structure

In this study, one office buildings with twenty five stories is selected. Starting from first floor up to twenty floors of building, geometric irregularity in elevation exists with a variety of heights. The structural system used for these buildings is taken as concrete moment-resisting space frames (MRSF) and inverted V-bracing, V-bracing and X-bracing system, and the soil type is considered as class B. The ductility class of the building is taken as “medium”, (DM). Furthermore, the design acceleration has been taken as 0.15g which corresponds to that used for very high seismic zone (Zone 4) in EBCS EN-8, 2013.

For higher story building above sixteen stores 8 bay configurations should be preferred because they have generally lesser values of critical seismic parameters. [2] Thus In this study, A G+25 story reinforced concrete building of 8X8 bays have been considered for investigating the effectiveness of these three types bracing in regular and setback irregularity models. The length and width of the building is 36m regular in plane. Height of all story is 3.2m and width of bays are 3m and 5m habitually use in Ethiopia. Preliminary sizes of structural components are assumed by experience. The assumed size of columns in this building is 600 x 600 mm and the size of beams is 300 x 500 mm. For consideration of diaphragm action Diaphragm is assigned at each floor. The floor diaphragms are assumed to be semi-rigid. The building models are studied in seismic zone IV of Adama city Ethiopia. Later on different types of steel bracings are provided on the outer periphery of the models on all the four sides and analyzed. The non-structural element and components that do not significantly influence the building behavior were not modeled. The main beams rest centrally on columns to avoid local eccentricity. The effect of soil structure interaction is ignored in analysis. The columns are assumed to be fixed at the ground level. The height to width ratio of the buildings is taken to be one for equal treatments of lateral load in all setback arrangement and bracing.

Two types of structural configuration are studied.

1. Reinforced concrete multi-story building regular and different setback irregularities without bracing system.
2. Reinforced concrete multi-story building regular and two types of setback irregularity with X-bracing, V-bracing and inverted V-bracing systems.

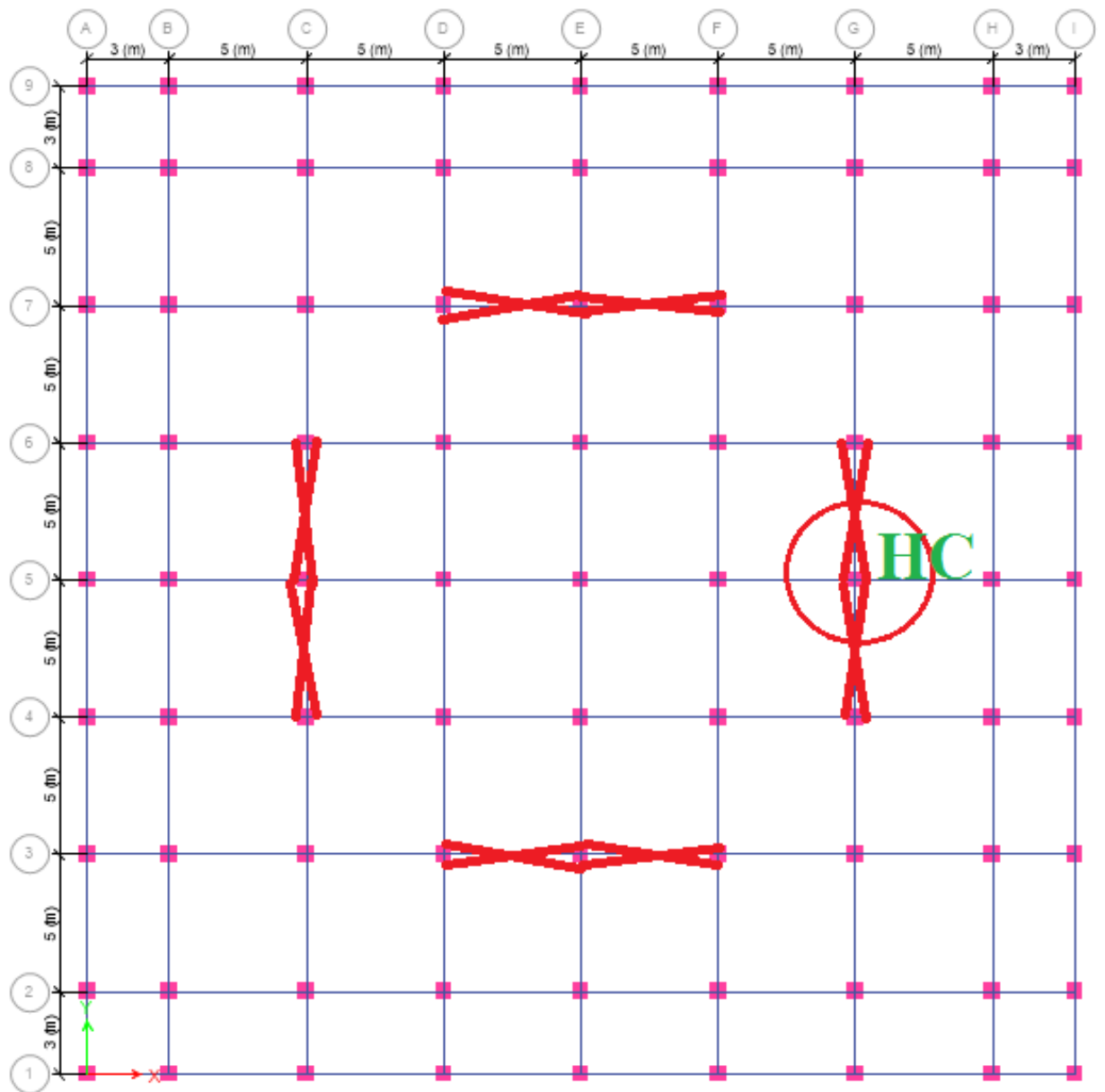


Figure 3.1 Floor plan with position of bracing and highlighted column (HC) of the RC building.

Location of different steel bracings are shown in figure 3.1 sited in the same location for all story building types in order to differentiate the behaviour of setback building with different types of bracings in high rise structures.

Three different concentric types of braces have been implemented in twelve frames with 25-storey at the same location. These three types of bracing V-bracing, inverted V-bracing, and X-bracing are provided within the frame two bays.

The information of setback frames geometry for the twelve models including regular building are shown with different percentage of setbacks. For this study one symmetric

setback equal to 50 % of the previous plan dimension sited at first floor to the lower 15 % of the total height of the main structural system and setback equals 30% of the previous plan dimension sited at fourth floor above 15 % of the total height of the main structural system.

Notations of these 12 models are:

R = regular building model without bracing

RV=regular building model with V-bracing

RC= regular building model with chevron bracing

RX= regular building model with X-bracing

S= symmetric setback building model with setback ratio equal to 50% without bracing

SV= symmetric setback building model with V-bracing

SC= symmetric setback building model with chevron bracing

SX= symmetric setback building model with –bracing

A=asymmetric setback building model with setback ratio equal to 30% without bracing

AV= asymmetric setback building model with V-bracing

AC= asymmetric setback building model with chevron bracing

AX= asymmetric setback building model with X-bracing

HC=highlighted column that taken to compare lateral displacement and inter story drift ratio values with different bracings.

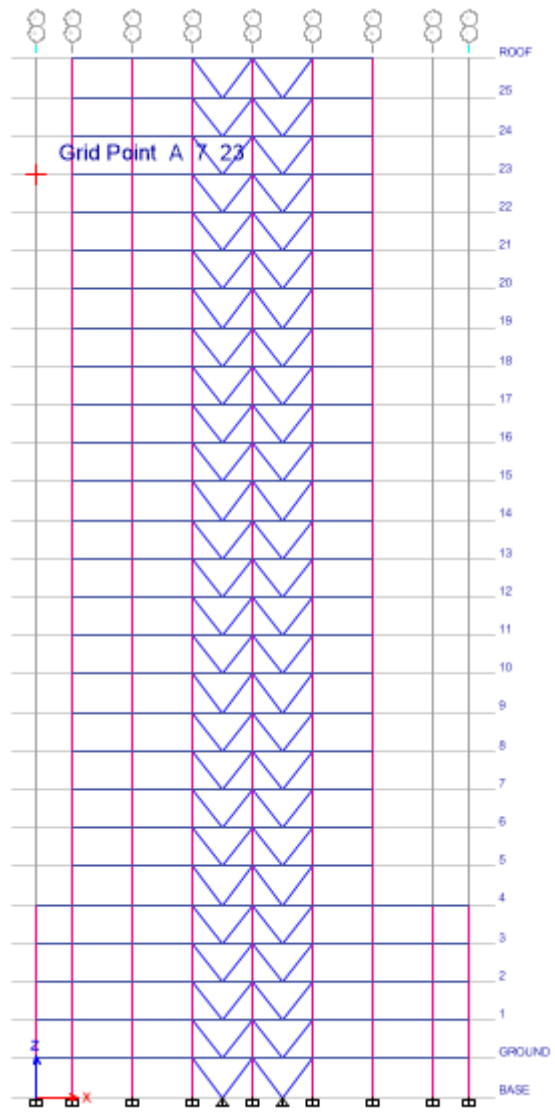
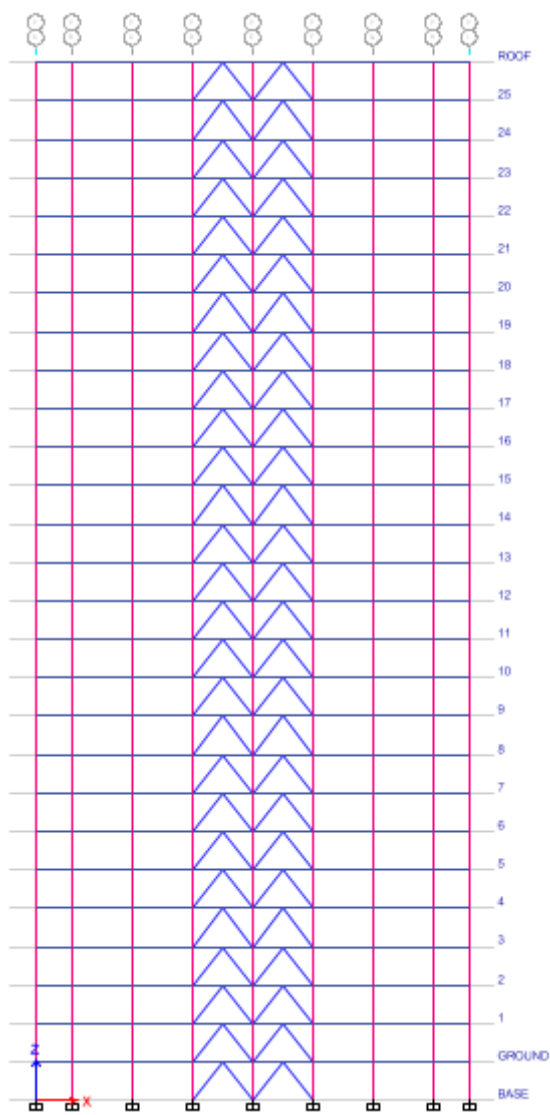


Figure 3.2 RC (regular chevron) bracing figure 3.3 AV (asymmetric V- bracing)

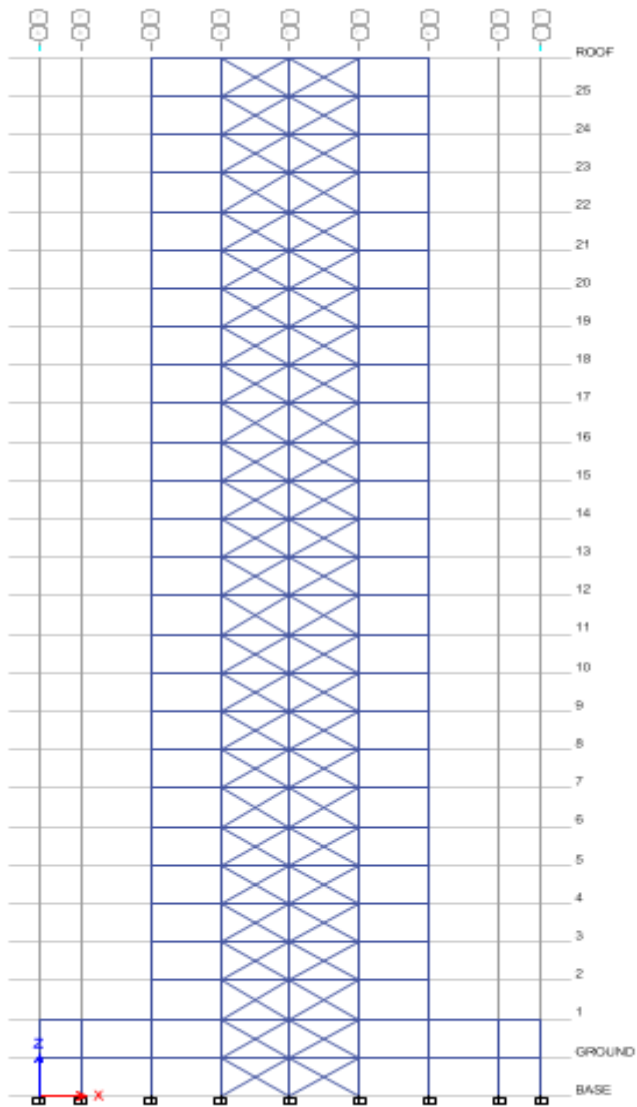


Figure 3.4 SX (symmetric setback with X-bracing)

3.4. Materials used for the modeling of Structural System

Table 3-1 Assumed Loading consideration and data in ETABS software for this study

| SI No. | Contents | Description |
|--------|--------------------------------|--------------------------|
| 1 | Grade of Concrete | C-30 |
| 2 | Young's modulus of Concrete, E | 29000MPa |
| 3 | Density of Concrete | 25 kN/m ³ |
| 4 | Poisson's ratio of Concrete | 0.2 |
| 5 | Grade of Steel | S-400 |
| 6 | Young's modulus of Steel | 200000 N/mm ² |

| | | |
|----|--------------------------|---------------------------|
| 7 | Density of Steel | 78.5 kN/m ³ |
| 8 | Poisson's ratio of Steel | 0.3 |
| 9 | Slab thickness | 0.15m |
| 10 | Bracing section | 150x150x15mm |
| 11 | Floor finish | 2 kN/m ² |
| 12 | Live load on Roof | 2 kN/m ² |
| 13 | Live load on Floor | 3 kN/m ² |
| 14 | Wall load | 12.5 kN/m ² |
| 15 | Earthquake load | As per the code provision |

For analysis of these RC building different loading is considered. These are self-weight of the structure, external wall load, live load, and earthquake loads are considered. The slab load in this study is loaded on beam by transferring live load and dead load separately.

These loads and dimensions of the frame are taken by assuming the building is to produce similar service at each level of the floors systems and in order to select the most effective types of bracing in the modeled vertical geometric irregularity. Because the main target of the study is to evaluate and identify the effectiveness of bracing in vertical geometric irregularity buildings and the behavior of geometric irregularity with seismic load.

3.4.1. Earthquake analysis

The lateral load analysis of this study is based on Euro code 8 design manuals on ETABS concrete design preferences. This is due to the new EBCS EN version of 2013 is not having national annex on ETABS. But all the inputs data's are based on EBCS EN 2013.

Response spectrum method is used for analysis of these models and minimum required modes considered. Modal combination implemented using CQC method. The response spectrum is simply a plot of the peak or steady-state response (displacement, velocity or acceleration) of a series of oscillators of varying natural frequency, which are forced into motion by the same base vibration or shock. The resulting plot can then be used to pick off the response of any linear system, given its natural frequency of oscillation. One such use is in assessing the peak response of buildings to earthquakes. Response spectra can also be used in assessing the response of linear systems with multiple modes of oscillation (multi-degree of freedom systems), although they are only accurate for low levels of damping. Model analysis is performed to identify the modes, and the response in that mode can be

picked from the response spectrum. This peak response is then combined to estimate a total response. The earthquake spectrum, on the other hand, is an average of a number of earthquake records modified for site specific conditions and then smoothed out for design purposes which are specified by the appropriate building code.

EBCS EN 2013 suggests two different design spectrums. If deep geology is not accounted, the recommended choice is the use of two types of spectra: Type 1 and Type 2. If the earthquakes that contribute most to the seismic hazard defined for the site for the purpose of probabilistic hazard assessment have a surface-wave magnitude, M_s , not greater than 5.5, it is recommended that the Type 2 spectrum is adopted. And for the more seismically active regions Type 1 spectrum is adopted. In this study, Type 1 design spectrum is selected in order to notice the effect of earthquake on vertical geometric irregular building and bracing systems which may give maximum lateral displacement. In addition, there are also different parameters that are considered as an input for analysis. From which behaviour factor (q) is one factor that affect the analysis result. According to EBCS EN 2013 for regular structural systems, the behaviour factor q should be taken with upper limits to the reference values which are given in Table 3.2. But if the building is non-regular in elevation the upper limit values of q listed in Table 3.2 should be reduced by 20%.

The upper limit value of the behaviour factor q , to account for energy dissipation capacity, shall be derived for each design direction as follows:

$$q = q_o Kw \geq 1.5 \text{-----} (3.1)$$

Table 3-2 Basic value of the behavior factor, q_o , for systems regular in elevation

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

When the multiplication factor α_u/α_1 has not been evaluated through an explicit calculation, for buildings which are regular in plan and Multi-story, multi-bay frames or frame-equivalent dual structures in this study use: $\alpha_u/\alpha_1=1.3$.

The factor k_w reflecting the prevailing failure mode in structural systems with walls shall be taken as: 1.00, for frame and frame-equivalent dual systems.

For this study the following parameters are considered for earthquake analysis as per Euro code 8-design of structures for earthquake resistance using ETABS version 2015.

Table 3-3 General Parameters considered during Analysis

| S.No | Parameters | Values |
|-------------|----------------------------------|---|
| 1 | Design Ground Acceleration, ag/g | 0.15g |
| 2 | Design spectrum type | 1 |
| 3 | Ground type | B |
| 4 | Behaviour factor | 3.9 for regular MRF |
| | | 3.12 for irregular MRF |
| | | 6 for regular MRF with concentric bracing |
| | | 4.8 for irregular MRF with concentric bracing |
| 5 | Accidental eccentricity | 0.05 |

3.4.2. Structural Regularity

For the purpose of seismic design, building structures are categorized into being regular or non-regular. The distinction as regular or non-regular in plan or in elevation or in both has implications on the Structural modeling, method of analysis and values of behaviour factor being as:-

- The structural model, which can be either a simplified planar model or a spatial model;

- The method of analysis, which can be either a simplified response spectrum analysis (lateral force procedure) or a modal one;
- The value of the behaviour factor q , which shall be decreased for buildings non-regular in elevation see table 3.4.

With regard to the implications of structural regularity on analysis and design, separate consideration is given to the regularity characteristics of the building in plan and in elevation Table 3.4.

Table 3-4 Consequences of structural regularity on seismic analysis and design

| Regularity | | Allowed Simplification | | Behaviour factor |
|------------|-----------|------------------------|-------------------------|-----------------------|
| plan | Elevation | Model | Linear-elastic Analysis | (for linear analysis) |
| yes | yes | Planar | Lateral force | Reference value |
| yes | no | planar | Modal | Decrease value |
| no | yes | spatial | Lateral force | Reference value |
| no | no | spatial | Modal | Decrease value |

It is very important to know the regularity of structure before analysis is started. In this study the building is regular in plan that satisfies the following criteria of EBCS EN 2013 provisions:-

- With respect to the lateral stiffness and mass distribution, the building structure shall be approximately symmetrical in plan with respect to two orthogonal axes.
- The slenderness $\lambda = L_{\max}/L_{\min}$ of the building in plan shall be not higher than 4, where L_{\max} and L_{\min} are respectively the larger and smaller in plan dimension of the building, measured in orthogonal directions.

But, it is not regular in elevation in order to study the behaviour of vertically geometric irregularity with lateral seismic load by taking first setback dimension according to criteria of Euro code 8 or EBCS EN 2013 below:-

- When gradual setbacks preserving axial symmetry, the setback at any floor equal to 20 % of the previous plan dimension in the direction of the setback.

- For a single setback within the lower 15 % of the total height of the main structural system, the setback equal to 50 % of the previous plan dimension.
- if the setbacks do not preserve symmetry, or when the setback preserve asymmetric setback in each face the sum of the setbacks at all stores equal to 30 % of the plan dimension at the ground floor above the foundation or above the top of a rigid basement, or when the individual setbacks equal to 10 % of the previous plan dimension.

3.5. Design Method for Bracing Systems

Concentric braced frames shall be designed so that yielding of the diagonals in tension will take place before failure of the connections and before yielding or buckling of the beams or columns.

Braced-frame members are designed to resist the forces specified by the building code based on the type of structural system selected and the location of the building site relative to various faults and seismic source zones, as determined from seismic risk or zonation maps.

All bracing connections are required to be capable of resisting the maximum expected force that could be delivered to them by the bracing configuration. The design intent is that the strength of the brace frame components (beams, columns, connections) be larger than the expected maximum capacity of the brace member. By ensuring this, the failure of a braced-frame system is intended to be controlled by yielding and buckling of the braces only, not the other elements of the frame.

According to euro codes in structures of more than two stories the non-dimensional slenderness of diagonal members should be:

$$1.3 < \lambda < 2 \text{-----} (3.2)$$

in frames with X bracings.[25] For the section to be safe, the yield resistance $N_{pl,Rd}$ of the bracing diagonals should be greater than the axial tension force N_{Ed} computed under the seismic action effect: $N_{pl,Rd} > N_{Ed}$. [25]

In order to satisfy a homogeneous dissipative behaviour of the diagonals, it should be checked that the maximum value (Ω_{max}) does not differ from the minimum value (Ω_{min}) by more than 25%.

The over strength factor to apply the capacity design criteria is calculate by:

$$\Omega_i = \frac{N_{pl,Rd,i}}{N_{Ed,i}} \text{-----} (3.3)$$

Columns with axial forces should meet the following minimum resistance requirement:

$$\frac{N_{Ed}}{N_{pl,Rd}} * M_{ED} \leq 1 \text{-----} (3.4)$$

Where

$$N_{Ed} = N_{Ed,G} + 1.1 * N_{Ed,E} * \gamma_{ov} * \Omega_0 \text{-----} (3.5)$$

And $N_{pl,Rd}$ is the design buckling resistance of the beam or the column in accordance with EN 1993, taking into account the interaction of the buckling resistance with the bending moment defined as its design value in the seismic design situation:

$$M_{Ed} = M_{Ed,G} + 1.1 * \gamma_{ov} * M_{Ed,E} * \Omega_0 \text{-----} (3.6)$$

The connections of diagonal members to the structure have to provide adequate over strength to permit the development of the expected dissipative mechanism.

For fillet weld or bolted non dissipative connections, the following expression should be satisfied:

$$R_{i,d} \geq \gamma_{ov} * 1.1 * R_{pl,Rd} = R_{U,R} \text{-----} (3.7)$$

As Per UBC manual width-thickness ratios of brace must fulfill with requirements for compact members as defined by: [26]

$$\frac{b}{t} \leq \frac{65}{\sqrt{f_y}} \text{-----} (3.8)$$

4. ANALYSIS OF RESULTS AND DISCUSSION

All the 12 building models with different setback irregularities are analyzed for linear dynamic behavior using commercial software ETABS 2015. This chapter presents the analysis results and relevant discussions. According to the objectives of the present study, the results presented here are focused nodal displacements, shear force, bending moment and drifts of the highlighted column (HC) that are determined and observed for a comparison of different bracing results. The lateral displacements, inter-story drifts ratio and action force of RC regular frame and setback irregularity with and without bracing have been analyzed in X direction is presented in the next section. The results of braced RC buildings are compared each other with various types of steel bracings and compared with un-brace one and bare frame.

4.1. Results

4.1.1. Lateral displacements in selected column

The lateral displacements of regular building, symmetric setback building equal to 50% of the previous plan dimension sited at first floor to the lower 15 % of the total height of the main structural system and asymmetric setback equals 30% of the previous plan dimension sited at fourth floor above 15 % of the total height of the main structural system by taking the highlighted column are presented in Table 4.1 and figure 4.1 and figure 4.2.

The results are compared with that of buildings with various types of bracings. It can be observed that the maximum lateral displacements are reduced due to the presence of bracings

Table 4-1 Maximum lateral displacement in (mm) for the highlighted column in X direction

| story | R | RC | RV | RX | S | SC | SV | SX | A | AC | AV | AX |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 26 | 533 | 324 | 337 | 318 | 591 | 216 | 231 | 214 | 511 | 233 | 246 | 231 |
| 25 | 528 | 318 | 331 | 311 | 586 | 210 | 224 | 207 | 507 | 229 | 242 | 226 |
| 24 | 522 | 311 | 324 | 304 | 579 | 203 | 217 | 200 | 501 | 224 | 236 | 221 |
| 23 | 515 | 304 | 316 | 296 | 571 | 196 | 209 | 192 | 493 | 217 | 229 | 213 |
| 22 | 506 | 295 | 308 | 288 | 560 | 188 | 201 | 184 | 484 | 209 | 221 | 206 |
| 21 | 495 | 286 | 299 | 278 | 548 | 180 | 193 | 176 | 472 | 201 | 213 | 197 |

| | | | | | | | | | | | | |
|------|------|------|------|-----|------|-----|-----|------|------|-----|------|------|
| 20 | 483 | 277 | 289 | 269 | 534 | 172 | 184 | 168 | 459 | 193 | 204 | 189 |
| 19 | 469 | 266 | 278 | 258 | 517 | 164 | 175 | 159 | 444 | 184 | 195 | 180 |
| 18 | 454 | 255 | 266 | 247 | 500 | 155 | 166 | 151 | 427 | 175 | 185 | 170 |
| 17 | 438 | 243 | 254 | 235 | 480 | 146 | 156 | 142 | 409 | 165 | 175 | 161 |
| 16 | 420 | 231 | 242 | 223 | 459 | 136 | 147 | 132 | 388 | 155 | 165 | 151 |
| 15 | 401 | 218 | 228 | 210 | 436 | 127 | 137 | 123 | 367 | 145 | 154 | 141 |
| 14 | 380 | 204 | 214 | 196 | 411 | 117 | 127 | 113 | 344 | 134 | 143 | 130 |
| 13 | 359 | 190 | 200 | 182 | 386 | 108 | 116 | 104 | 319 | 124 | 132 | 120 |
| 12 | 336 | 176 | 185 | 168 | 358 | 98 | 106 | 94.2 | 293 | 113 | 120 | 109 |
| 11 | 312 | 161 | 170 | 154 | 330 | 88 | 96 | 84.6 | 266 | 102 | 109 | 98.1 |
| 10 | 287 | 146 | 154 | 139 | 300 | 78 | 86 | 75.2 | 238 | 91 | 97.3 | 87.4 |
| 9 | 262 | 130 | 139 | 124 | 269 | 69 | 75 | 65.8 | 209 | 80 | 85.8 | 76.8 |
| 8 | 235 | 115 | 123 | 109 | 237 | 59 | 65 | 56.7 | 179 | 69 | 74.4 | 66.3 |
| 7 | 208 | 100 | 107 | 94 | 205 | 50 | 56 | 47.9 | 149 | 58 | 63.1 | 56 |
| 6 | 181 | 85 | 91.2 | 80 | 171 | 41 | 46 | 39.4 | 119 | 48 | 52 | 46 |
| 5 | 153 | 70.2 | 75.8 | 66 | 137 | 33 | 37 | 31.3 | 89.4 | 38 | 41.1 | 36.2 |
| 4 | 124 | 55.9 | 60.7 | 52 | 103 | 25 | 28 | 23.8 | 64.6 | 28 | 31.2 | 27.3 |
| 3 | 95.4 | 42.2 | 46.1 | 39 | 69.1 | 18 | 20 | 16.9 | 48.3 | 22 | 23.9 | 20.9 |
| 2 | 66.7 | 29.2 | 32.1 | 27 | 37.2 | 11 | 13 | 10.6 | 33.2 | 15 | 16.7 | 14.5 |
| 1 | 38.7 | 17.2 | 19 | 16 | 13.2 | 5.4 | 6.4 | 5.36 | 19.2 | 8.8 | 9.73 | 8.44 |
| 0 | 13.7 | 6.46 | 7.16 | 6 | 4.58 | 2.1 | 2.4 | 2.06 | 6.81 | 3.1 | 3.47 | 3.01 |
| base | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

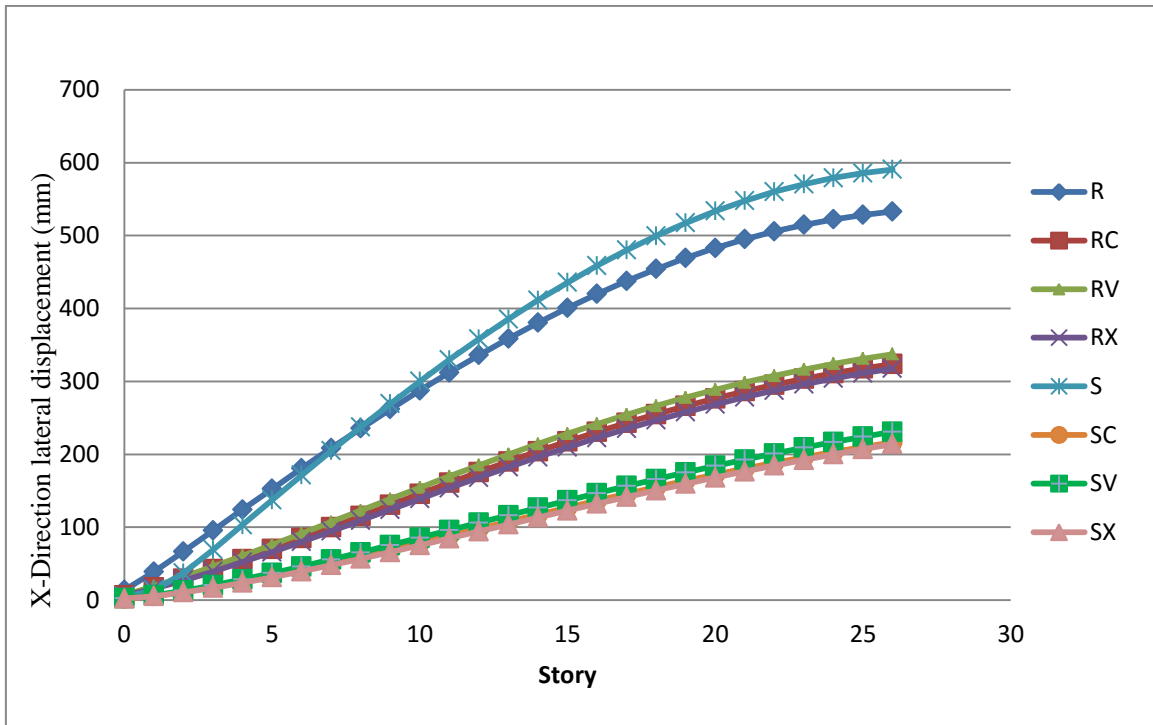


Figure 4.1 lateral displacement values of each bracing types for regular and symmetric setback story Building

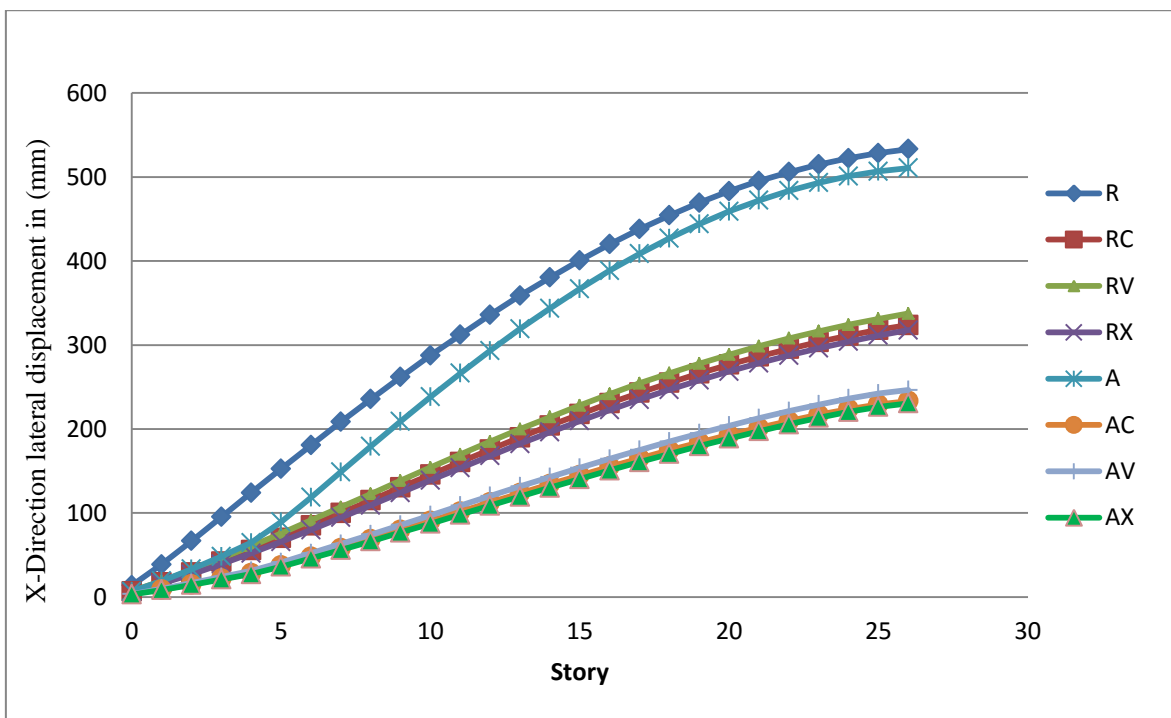


Figure 4.2 lateral displacement values of each bracing types for regular and asymmetric setback story Building

4.1.2. Inter-story drift ratio in selected column

Table 4-2. inter-story drift ratio (%) for the highlighted column in X direction

| Story | R | RC | RV | RX | S | SC | SV | SX | A | AC | AV | AX |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|
| 26 | 0.15 | 0.19 | 0.19 | 0.2 | 0.17 | 0.2 | 0.22 | 0.22 | 0.16 | 0.41 | 0.24 | 0.24 |
| 25 | 0.2 | 0.22 | 0.22 | 0.23 | 0.23 | 0.22 | 0.23 | 0.23 | 0.21 | 0.39 | 0.25 | 0.25 |
| 24 | 0.25 | 0.24 | 0.25 | 0.25 | 0.29 | 0.23 | 0.25 | 0.24 | 0.28 | 0.36 | 0.28 | 0.28 |
| 23 | 0.3 | 0.26 | 0.27 | 0.27 | 0.35 | 0.24 | 0.26 | 0.25 | 0.35 | 0.35 | 0.3 | 0.3 |
| 22 | 0.34 | 0.29 | 0.3 | 0.29 | 0.41 | 0.25 | 0.27 | 0.26 | 0.41 | 0.33 | 0.32 | 0.32 |
| 21 | 0.39 | 0.31 | 0.32 | 0.31 | 0.47 | 0.26 | 0.28 | 0.27 | 0.46 | 0.33 | 0.34 | 0.34 |
| 20 | 0.44 | 0.33 | 0.34 | 0.33 | 0.53 | 0.27 | 0.29 | 0.28 | 0.52 | 0.35 | 0.36 | 0.35 |
| 19 | 0.48 | 0.36 | 0.36 | 0.35 | 0.58 | 0.28 | 0.3 | 0.28 | 0.57 | 0.36 | 0.38 | 0.36 |
| 18 | 0.53 | 0.38 | 0.38 | 0.37 | 0.63 | 0.29 | 0.3 | 0.29 | 0.62 | 0.38 | 0.39 | 0.38 |
| 17 | 0.57 | 0.4 | 0.4 | 0.39 | 0.68 | 0.3 | 0.31 | 0.29 | 0.67 | 0.39 | 0.41 | 0.39 |
| 16 | 0.61 | 0.41 | 0.42 | 0.41 | 0.73 | 0.3 | 0.32 | 0.3 | 0.72 | 0.41 | 0.42 | 0.4 |
| 15 | 0.65 | 0.43 | 0.44 | 0.42 | 0.78 | 0.31 | 0.32 | 0.3 | 0.77 | 0.42 | 0.43 | 0.41 |
| 14 | 0.68 | 0.44 | 0.45 | 0.44 | 0.82 | 0.31 | 0.32 | 0.3 | 0.81 | 0.43 | 0.44 | 0.42 |
| 13 | 0.72 | 0.46 | 0.47 | 0.45 | 0.86 | 0.31 | 0.33 | 0.3 | 0.85 | 0.43 | 0.45 | 0.42 |
| 12 | 0.75 | 0.47 | 0.48 | 0.46 | 0.9 | 0.31 | 0.33 | 0.3 | 0.89 | 0.44 | 0.45 | 0.42 |
| 11 | 0.78 | 0.47 | 0.49 | 0.46 | 0.94 | 0.31 | 0.32 | 0.3 | 0.92 | 0.44 | 0.45 | 0.42 |
| 10 | 0.81 | 0.48 | 0.49 | 0.47 | 0.97 | 0.3 | 0.32 | 0.3 | 0.96 | 0.44 | 0.45 | 0.42 |
| 9 | 0.83 | 0.48 | 0.5 | 0.47 | 1 | 0.3 | 0.32 | 0.29 | 0.98 | 0.43 | 0.45 | 0.42 |
| 8 | 0.85 | 0.48 | 0.5 | 0.46 | 1.03 | 0.29 | 0.31 | 0.28 | 1.01 | 0.43 | 0.45 | 0.41 |
| 7 | 0.87 | 0.47 | 0.49 | 0.46 | 1.05 | 0.28 | 0.3 | 0.27 | 1.02 | 0.43 | 0.45 | 0.41 |
| 6 | 0.88 | 0.46 | 0.49 | 0.44 | 1.07 | 0.27 | 0.29 | 0.25 | 1.02 | 0.44 | 0.46 | 0.42 |
| 5 | 0.89 | 0.45 | 0.47 | 0.43 | 1.08 | 0.25 | 0.27 | 0.24 | 0.89 | 0.4 | 0.43 | 0.38 |
| 4 | 0.9 | 0.43 | 0.46 | 0.41 | 1.07 | 0.23 | 0.25 | 0.22 | 0.56 | 0.28 | 0.3 | 0.27 |
| 3 | 0.9 | 0.41 | 0.44 | 0.38 | 1 | 0.21 | 0.24 | 0.2 | 0.49 | 0.25 | 0.27 | 0.24 |
| 2 | 0.88 | 0.38 | 0.41 | 0.35 | 0.76 | 0.18 | 0.2 | 0.17 | 0.47 | 0.24 | 0.26 | 0.23 |
| 1 | 0.78 | 0.33 | 0.37 | 0.31 | 0.27 | 0.11 | 0.12 | 0.1 | 0.43 | 0.22 | 0.24 | 0.21 |
| 0 | 0.43 | 0.2 | 0.22 | 0.19 | 0.14 | 0.06 | 0.08 | 0.06 | 0.24 | 0.13 | 0.15 | 0.13 |

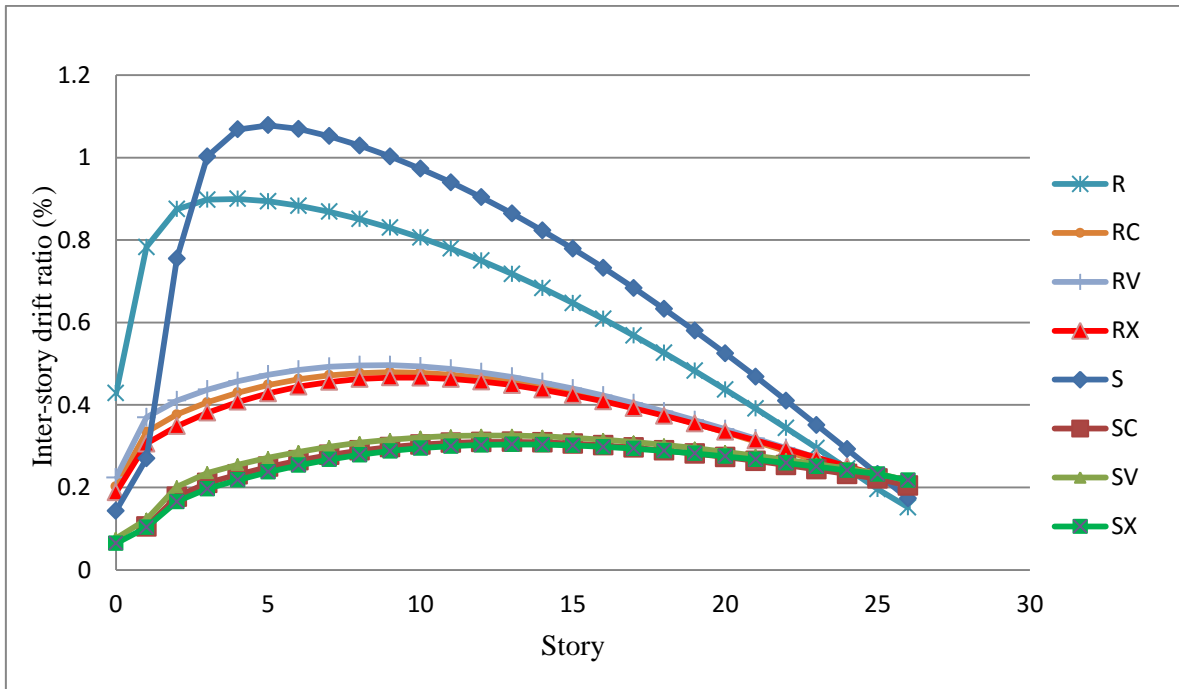


Figure 4.3 Inter story drift ratio of each bracing types for regular and symmetric setback story Building

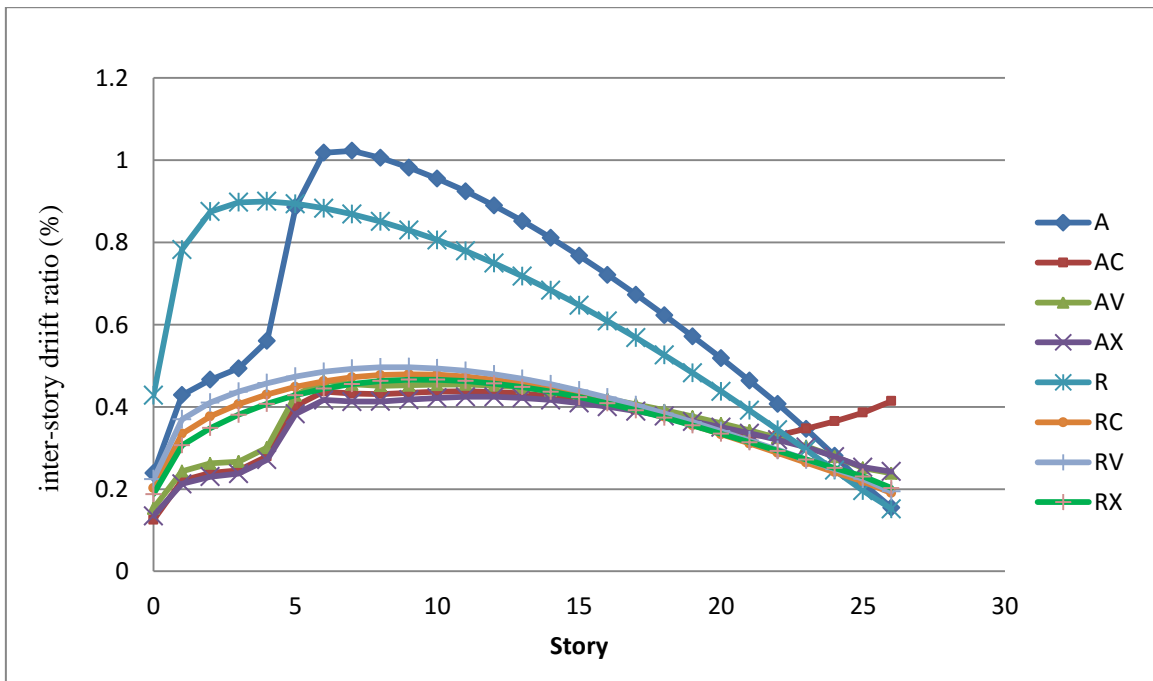


Figure 4.4 Inter story drift ratio of each bracing types for regular and asymmetric setback story Building

4.1.3. Shear force in selected column

Table 4-3. Maximum shear forces in column in kN for the highlighted column

| story | R | RC | RV | RX | S | SC | SV | SX | A | AC | AV | AX |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|
| 26 | 75.2 | 94.4 | 97.9 | 101 | 70.5 | 75.8 | 75.3 | 78.9 | 65.9 | 68.8 | 66.7 | 68 |
| 25 | 67.3 | 76.7 | 79.3 | 80.7 | 55.5 | 58.7 | 59.1 | 59.9 | 55.6 | 57.1 | 57.2 | 58.4 |
| 24 | 86.2 | 87 | 89.5 | 90.1 | 63.5 | 62.8 | 63 | 64.1 | 64 | 61.6 | 61.8 | 62.8 |
| 23 | 99.1 | 92.6 | 95 | 95 | 69.5 | 63.9 | 64.3 | 65 | 72.3 | 64.5 | 64.8 | 65.4 |
| 22 | 113 | 99.1 | 102 | 101 | 77.4 | 65.4 | 65.8 | 66.2 | 79.2 | 66.3 | 66.6 | 66.9 |
| 21 | 126 | 105 | 108 | 106 | 85.4 | 66.7 | 67.2 | 67.3 | 85.7 | 67.8 | 68.2 | 68.2 |
| 20 | 138 | 111 | 114 | 112 | 93 | 67.9 | 68.4 | 68.3 | 92.4 | 69.3 | 69.8 | 69.4 |
| 19 | 151 | 117 | 120 | 117 | 100 | 68.9 | 69.6 | 69.2 | 99.2 | 70.7 | 71.3 | 70.6 |
| 18 | 163 | 123 | 125 | 122 | 108 | 69.8 | 70.6 | 69.9 | 106 | 72.1 | 72.8 | 71.8 |
| 17 | 174 | 128 | 130 | 127 | 115 | 70.6 | 71.5 | 70.5 | 113 | 73.4 | 74.2 | 72.9 |
| 16 | 185 | 132 | 135 | 131 | 122 | 71.2 | 72.2 | 70.9 | 120 | 74.5 | 75.4 | 73.8 |
| 15 | 196 | 136 | 139 | 135 | 128 | 71.6 | 72.8 | 71.2 | 126 | 75.4 | 76.5 | 74.6 |
| 14 | 205 | 140 | 143 | 138 | 135 | 71.8 | 73.1 | 71.3 | 132 | 76.1 | 77.3 | 75.1 |
| 13 | 215 | 143 | 146 | 140 | 141 | 71.7 | 73.2 | 71.1 | 138 | 76.5 | 77.9 | 75.3 |
| 12 | 223 | 145 | 148 | 142 | 147 | 71.4 | 73.1 | 70.6 | 143 | 76.6 | 78.2 | 75.3 |
| 11 | 230 | 146 | 150 | 143 | 152 | 70.8 | 72.6 | 69.9 | 148 | 76.4 | 78.1 | 75 |
| 10 | 237 | 146 | 151 | 143 | 157 | 69.9 | 71.9 | 68.9 | 152 | 75.8 | 77.8 | 74.2 |
| 9 | 243 | 146 | 151 | 142 | 162 | 68.7 | 70.9 | 67.5 | 157 | 75 | 77.1 | 73.2 |
| 8 | 248 | 144 | 150 | 140 | 166 | 67.1 | 69.6 | 65.9 | 161 | 73.8 | 76.2 | 71.9 |
| 7 | 252 | 142 | 147 | 137 | 170 | 65.2 | 67.9 | 63.8 | 165 | 73.4 | 76.2 | 71.3 |
| 6 | 255 | 138 | 144 | 133 | 173 | 62.9 | 65.9 | 61.4 | 155 | 67.7 | 70.8 | 65.6 |
| 5 | 256 | 133 | 140 | 127 | 177 | 60.1 | 63.4 | 58.6 | 221 | 103 | 108 | 101 |
| 4 | 257 | 126 | 134 | 120 | 181 | 57.2 | 60.9 | 55.5 | 121 | 69.9 | 73.6 | 68.5 |
| 3 | 256 | 118 | 127 | 111 | 184 | 52.4 | 56.1 | 50.3 | 165 | 87.1 | 92.7 | 85 |
| 2 | 254 | 109 | 118 | 101 | 227 | 64.4 | 71.1 | 60.2 | 139 | 72.2 | 78.1 | 70.2 |
| 1 | 251 | 101 | 113 | 90.7 | 45 | 28.2 | 31.5 | 29.4 | 132 | 65.5 | 71.9 | 63.5 |
| 0 | 247 | 128 | 142 | 121 | 108 | 49.1 | 57.1 | 2.06 | 127 | 3.13 | 66.7 | 58.4 |

4.1.4. Bending moment in selected column

Table 4-4. Maximum bending moment in column in kNm for the highlighted column

| story | R | RC | RV | RX | S | SC | SV | SX | A | AC | AV | AX |
|-------|------|-----|-----|-----|------|------|------|------|------|------|------|------|
| 26 | 89.3 | 119 | 123 | 129 | 95.6 | 102 | 99 | 102 | 90.5 | 89.4 | 87 | 88.5 |
| 25 | 91.3 | 116 | 120 | 123 | 86.3 | 90.5 | 91.2 | 94.1 | 83.3 | 86.2 | 84.1 | 85.4 |
| 24 | 117 | 129 | 133 | 135 | 96.1 | 95 | 95.5 | 98 | 88.1 | 85.1 | 85.2 | 87.2 |
| 23 | 139 | 139 | 143 | 143 | 99.5 | 97.6 | 98.2 | 100 | 99.7 | 94.2 | 94.6 | 96.3 |
| 22 | 161 | 149 | 153 | 153 | 106 | 100 | 101 | 102 | 112 | 99.8 | 100 | 102 |
| 21 | 182 | 159 | 163 | 162 | 117 | 103 | 103 | 104 | 122 | 104 | 104 | 105 |
| 20 | 203 | 169 | 173 | 171 | 129 | 105 | 106 | 106 | 131 | 106 | 107 | 107 |
| 19 | 224 | 179 | 183 | 179 | 141 | 107 | 108 | 108 | 141 | 109 | 110 | 109 |
| 18 | 243 | 188 | 192 | 188 | 153 | 109 | 110 | 109 | 152 | 111 | 112 | 111 |
| 17 | 262 | 196 | 201 | 196 | 165 | 110 | 112 | 111 | 162 | 114 | 115 | 113 |
| 16 | 280 | 204 | 209 | 203 | 176 | 112 | 113 | 112 | 174 | 116 | 117 | 115 |
| 15 | 298 | 212 | 216 | 210 | 188 | 113 | 115 | 113 | 185 | 118 | 120 | 117 |
| 14 | 314 | 218 | 223 | 216 | 199 | 114 | 116 | 114 | 195 | 120 | 122 | 119 |
| 13 | 330 | 223 | 229 | 220 | 210 | 115 | 117 | 114 | 206 | 121 | 123 | 120 |
| 12 | 344 | 228 | 233 | 224 | 220 | 115 | 117 | 114 | 215 | 122 | 125 | 121 |
| 11 | 357 | 231 | 237 | 227 | 230 | 115 | 117 | 114 | 225 | 123 | 125 | 121 |
| 10 | 369 | 233 | 239 | 228 | 239 | 114 | 117 | 113 | 233 | 123 | 126 | 121 |
| 9 | 380 | 233 | 240 | 228 | 248 | 113 | 116 | 112 | 243 | 122 | 125 | 120 |
| 8 | 389 | 232 | 240 | 226 | 257 | 112 | 115 | 110 | 254 | 121 | 124 | 118 |
| 7 | 396 | 229 | 238 | 223 | 265 | 110 | 114 | 108 | 275 | 122 | 126 | 119 |
| 6 | 402 | 225 | 234 | 218 | 273 | 107 | 111 | 105 | 270 | 110 | 114 | 106 |
| 5 | 406 | 219 | 229 | 210 | 283 | 104 | 109 | 102 | 503 | 214 | 224 | 208 |
| 4 | 409 | 210 | 221 | 201 | 306 | 101 | 106 | 98.1 | 256 | 128 | 134 | 125 |
| 3 | 413 | 200 | 212 | 190 | 347 | 92.7 | 97.9 | 89.4 | 268 | 137 | 145 | 133 |
| 2 | 424 | 188 | 201 | 176 | 578 | 134 | 148 | 124 | 238 | 120 | 130 | 117 |
| 1 | 472 | 185 | 205 | 166 | 104 | 61.4 | 69 | 61.5 | 245 | 118 | 130 | 115 |
| 0 | 669 | 328 | 363 | 307 | 250 | 113 | 133 | 112 | 337 | 157 | 174 | 151 |

4.2. Discussions

4.2.1. Discussion on lateral displacement

Comparing the results obtained for top lateral displacement in X direction for G+25 regular, symmetric and asymmetric setback storied buildings, it can be found that the X and inverted V type bracing system reduce the lateral displacement significantly. The variation of displacements and the percentage reduction in displacement for the braced frame in comparison to that of un-braced frame is presented. From the table below shows that the addition of X type bracing will reduce maximum lateral displacement in the symmetric setback models. Maximum displacement is seen in this S-model. The reduction varies from 40.4% to 63.7% by the use of X type bracing, 39.3% to 63.4% by using chevron type bracing and 36.7% to 60.9% by the use of V type bracing for both regular and irregular modeling. We can see there is a reduction of 63.7% in the Model-S by using X type steel bracing.

Table 4-5 Comparison of percentage reduction of maximum displacements in X direction (mm)

| Un-brace model | Chevron brace | % reduced compared to un-brace | V-brace | % reduced compared to un-brace | X-brace | % reduced compared to un-brace |
|----------------|---------------|--------------------------------|----------|--------------------------------|----------|--------------------------------|
| R | RC | $\frac{R * RC}{R} * 100$ | RV | $\frac{R * RV}{R} * 100$ | RX | $\frac{R * RX}{R} * 100$ |
| 533.0412 | 323.808 | 39.25 | 337.3982 | 36.70 | 317.6971 | 40.39 |
| S | SC | $\frac{S * SC}{S} * 100$ | SV | $\frac{S * SV}{S} * 100$ | SX | $\frac{S * SX}{S} * 100$ |
| 590.7192 | 216.4705 | 63.35 | 230.9448 | 60.90 | 214.0262 | 63.76 |
| A | AC | $\frac{A * AC}{A} * 100$ | AV | $\frac{A * AV}{A} * 100$ | AX | $\frac{A * AX}{A} * 100$ |
| 510.5718 | 233.219 | 54.32 | 246.3822 | 51.74 | 230.6364 | 54.82 |

4.2.2. Discussion on story drift

Story drift of the models are also reduced by the addition of steel bracings as shown in the table2 and figure 4.3 and figure 4.4 above. For comparison purpose in this study maximum inter story drift ratio is considered. From the table4.6 below shows that the addition of X type bracing reduced maximum inter-story drift ratio in the symmetric setback models (S).

Maximum inter story drift ratio is seen in model-S. The reduction for setback irregular models and regular models varies from 52.08% to 77.97% by the use of X type bracing, 49.82% to 76.84% by the use of chevron bracing and 47.03% to 74.78% by using V type bracing. We can see there is a reduction of 77.97% in the model-S (symmetric setback model) by using X type steel bracing. Maximum inter story drift ratio for setback irregular model (without bracing) is above setback area after two and three story for symmetric setback and asymmetric setback respectively. And for regular models it is between 2nd floor and 4th floor. This shows the frame structure deflects when there is sudden increase of bending.

Table 4-6 Comparison of percentage reduction of maximum inter-story drift ratio in X direction (mm)

| Un-brace model | Chevron brace | % reduced compared to un-brace | V-brace | % reduced compared to un-brace | X-brace | % reduced compared to un-brace |
|----------------|---------------|--------------------------------|---------|--------------------------------|---------|--------------------------------|
| R | RC | $\frac{R * RC}{R} * 100$ | RV | $\frac{R * RV}{R} * 100$ | RX | $\frac{R * RX}{R} * 100$ |
| 0.8939 | 0.4486 | 49.82 | 0.4735 | 47.03 | 0.4283 | 52.08 |
| S | SC | $\frac{S * SC}{S} * 100$ | SV | $\frac{S * SV}{S} * 100$ | SX | $\frac{S * SX}{S} * 100$ |
| 1.0785 | 0.2498 | 76.84 | 0.272 | 74.78 | 0.2375 | 77.97 |
| A | AC | $\frac{A * AC}{A} * 100$ | AV | $\frac{A * AV}{A} * 100$ | AX | $\frac{A * AX}{A} * 100$ |
| 1.0181 | 0.4373 | 57.05 | 0.4634 | 54.48 | 0.4169 | 59.05 |

4.2.3. Discussion on column shear force and bending moment

For comparison purpose in this study column shear force and bending moment near the irregularity (at 2nd story for model S and at 5th story for model A) are considered for the selected column and presented in Table 4.7 to Table 4.10. The reduction of shear force and bending moment are compared with that of selected column near setbacks with various types of bracings. It can be seen that the bracings decrease the bending moments and shear forces in columns and it increase the axial compression in the columns to which it connected. Since reinforced concrete columns are strong in compression, it may not pose a problem to retrofit in reinforced concrete frame using concentric steel bracings. It seen that the bending moment and shear force values are smaller for the regular and setback

irregular buildings with X types of bracing systems. We can see there is a reduction of shear force and bending moment by 73.44% and 78.57% respectively in the model-S (symmetric setback model) by using X type steel bracing.

Table 4-7 Comparison of percentage reduction of sudden increase shear force in X direction for symmetric setback at 2nd story

| Un-brace model | Chevron brace | % reduced compared to un-brace | V-brace | % reduced compared to un-brace | X-brace | % reduced compared to un-brace |
|----------------|---------------|--------------------------------|---------|--------------------------------|---------|--------------------------------|
| R | RC | $\frac{R * RC}{R} * 100$ | RV | $\frac{R * RV}{R} * 100$ | RX | $\frac{R * RX}{R} * 100$ |
| 253.98 | 108.962 | 57.10 | 118.25 | 53.44 | 100.91 | 60.27 |
| S | SC | $\frac{S * SC}{S} * 100$ | SV | $\frac{S * SV}{S} * 100$ | SX | $\frac{S * SX}{S} * 100$ |
| 226.67 | 64.36 | 71.61 | 71.12 | 68.62 | 60.2 | 73.44 |

Table 4-8 Comparison of percentage reduction of sudden increase shear force in X direction for Asymmetric setback at 5TH story

| Un-brace model | Chevron brace | % reduced compared to un-brace | V-brace | % reduced compared to un-brace | X-brace | % reduced compared to un-brace |
|----------------|---------------|--------------------------------|---------|--------------------------------|---------|--------------------------------|
| R | RC | $\frac{R * RC}{R} * 100$ | RV | $\frac{R * RV}{R} * 100$ | RX | $\frac{R * RX}{R} * 100$ |
| 256.24 | 132.7 | 48.21 | 139.6 | 45.52 | 127.1 | 50.40 |
| A | AC | $\frac{A * AC}{A} * 100$ | AV | $\frac{A * AV}{A} * 100$ | AX | $\frac{A * AX}{A} * 100$ |
| 221.2 | 103.15 | 53.37 | 108.22 | 51.10 | 100.7 | 54.50 |

Table 4-9 Comparison of percentage reduction of sudden increase bending moment in Z direction for symmetric setback at 2nd story

| Un-brace model | Chevron brace | % reduced compared to un-brace | V-brace | % reduced compared to un-brace | X-brace | % reduced compared to un-brace |
|----------------|---------------|--------------------------------|---------|--------------------------------|---------|--------------------------------|
| R | RC | $\frac{R * RC}{R} * 100$ | RV | $\frac{R * RV}{R} * 100$ | RX | $\frac{R * RX}{R} * 100$ |
| 424.24 | 187.59 | 55.78 | 201.14 | 52.58 | 175.68 | 58.58 |
| S | SC | $\frac{S * SC}{S} * 100$ | SV | $\frac{S * SV}{S} * 100$ | SX | $\frac{S * SX}{S} * 100$ |
| 578.48 | 134.35 | 76.77 | 147.92 | 74.42 | 123.97 | 78.56 |

Table 4.10 Comparison of percentage reduction of sudden increase bending moment in Z direction for Asymmetric setback at 5th story

| Un-brace model | Chevron brace | % reduced compared to un-brace | V-brace | % reduced compared to un-brace | X-brace | % reduced compared to un-brace |
|----------------|---------------|--------------------------------|---------|--------------------------------|---------|--------------------------------|
| R | RC | $\frac{R * RC}{R} * 100$ | RV | $\frac{R * RV}{R} * 100$ | RX | $\frac{R * RX}{R} * 100$ |
| 406.27 | 218.57 | 46.20 | 228.66 | 43.71 | 210.5 | 48.18 |
| A | AC | $\frac{A * AC}{A} * 100$ | AV | $\frac{A * AV}{A} * 100$ | AX | $\frac{A * AX}{A} * 100$ |
| 502.54 | 213.9 | 57.43 | 224.23 | 55.38 | 208.13 | 58.58 |

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

High rise buildings with vertical setback irregularity have not given attention in previous researches. In the present study, a detailed analytical study of setback building with different bracing types has been carried out to decrease these shortcomings. In the present study, an attempt is also made to find which type of bracing is effective to resist lateral deformation in a regular multistoried RC framed building and vertical geometric irregular building.

Following conclusion can be representing from the obtaining results:

- When preserving symmetric vertical configuration with setback equal to 50 % of the previous plan dimension at first floor at center of building of model-S, it seen sudden increase of shear force and bending moment of the column. And by using X-bracing it can be reduced the sudden increase action forces above 73.44% compared to un-braced models.
- Lateral displacement and inter story drift ratio increases as vertical geometric irregularity present in the building. As a result sited of such irregularities affects the performance of the building.
- The maximum reduction in the lateral displacement and inter story drift ratio occurs after the application of X-bracing system for all regular and irregular models.
- The building frames with X- bracing and chevron bracing system have almost equal values of minimum possible bending moments and shear force in comparison to V type of bracing systems.
- As it is seen from graphs and tables, the behavior of each bracing doesn't change as the regular building changes to different vertical geometric irregularity i.e. for the three types of building models, X-bracing performs better. The next favorite is chevron bracing. V-bracing has lesser efficiency it compares from two types of bracing to resist lateral displacement and inter story drift ratio
- From the above conclusions it is clear that the use of vertical geometric irregular configuration will cause greater damage to the structure during earthquakes. Hence addition of steel bracings is most efficient and improves its lateral load carrying capacity.

5.2. RECOMMENDATIONS FOR FUTURE STUDY

- In this present study analysis is based on the linear static response spectrum analysis. This is not sufficient to study the nonlinear behaviour of the structure. To know the complete behaviour of the structure with irregularity from linear stage to the collapse stage, nonlinear dynamic analysis study is required. Hence there is scope for future work to study the behaviour irregular shapes both plan and vertical, by performing nonlinear dynamic analysis by considering torsion effect.
- In this study only considered that the seismic behaviour of vertical geometric irregular structure with bracing. It can be study the seismic behaviour for vertical geometric irregular structures together stiffness irregularity and mass irregularity with geometric irregularity with bracing for future study.
- The present study is limited to seismic behaviour reinforced concrete (RC) multi-storied building with different setbacks. There is a future scope of study on seismic behaviour of steel structure having vertical irregularity.

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