"EFFECT OF STIFFNESS IN THE BEHAVIOUR OF FRAMED BUILDINGS IN EARTHQUAKES"

A Dissertation submitted in partial fulfillment of the requirement for the Award of degree of

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

By

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CERTIFICATE

This is to certify that the dissertation entitled **“Effect of Stiffness in the Behaviour of Framed Buildings in Earthquakes”** being submitted by me, to the **Delhi Technological University, New Delhi,** for the award of degree of Master of Technology in **Structural Engineering** is a bonafide work carried out by me. The research reports and the results presented in this thesis have not been submitted in parts or in full to any other University or Institute for the award of any degree.

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This is to certify that the above statement made by the candidate is true to the best of my knowledge and belief.

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I specially thank all the people who are active in this field. Reference material (pictures, tables and forms) from various national and international reports and journals, are included in this report as per the requirements and all these are quoted under the reference section at the last of this project report.

Mamta Tewari

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Structural Engineering

ABSTRACT

The purpose of this project work is to study the effect of stiffness in the behaviour of framed buildings in earthquakes. The lateral stiffness of a framed structure does play a significant role in defining its response to the seismic forces. As per the studies sufficient lateral stiffness is a requisite for all the structures so that they function well under minor earthquake forces and give full resistance to such forces without any structural failure.

Main objective of this research work is to study the effect of the lateral stiffness on the response of a G+4 storey building [3-D frame], subjected to seismic forces. The building frame model has been analyzed by Response Spectrum method, with the help of STAAD Pro software as per IS 1893:2002.

Changes in various parameters have been considered to bring a change in the stiffness of the building model and conclusions have been drawn.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF EARTHQUAKES

The tectonic activities within the interior of the earth, lead to many physical features on the surface of the earth, one of which is **earthquake**. An earthquake can be defined as the abrupt movement of the rocks in the earth's crust, which is a consequence of relative motion, between the tectonic plates in the earth's interior surface.

Due to the movement of plate tectonics in the earth, there is the deformation in rocks, which in turn leads to the storage of elastic strain energy in these rocks. When, rocks along a weak region in the Earth's crust reach their strength, a sudden movement takes place there; opposite sides of the crack, suddenly slip and a huge amount of stored elastic energy is erupted in the interface [1].

The point where an earthquake originates is referred to as the focus. An epicenter lies on the earth's surface, directly above the focus of the earthquake. If an earthquake has focal depth of around 70 km, then it is classified as a shallow-focus earthquake, while those in between 70-100 km are referred to as the intermediate focus earthquakes. Those, with more than 300 km focus, are deep focus earthquakes.

Elastic strain energy released during a seismic condition is in the form of seismic waves. These waves thus produced, are capable of devastating a building, causing severe damages to the roads, induce slope instability, landslides etc.

The extent of damage caused by a seismic force during an earthquake depends on the focal depth, the size, and the topography. The size of an earthquake is defined by the amount of energy released during an earthquake or by the degree of devastation caused, i.e. the intensity.The regions in which the seismicity is confined, is referred to as the seismic zones.

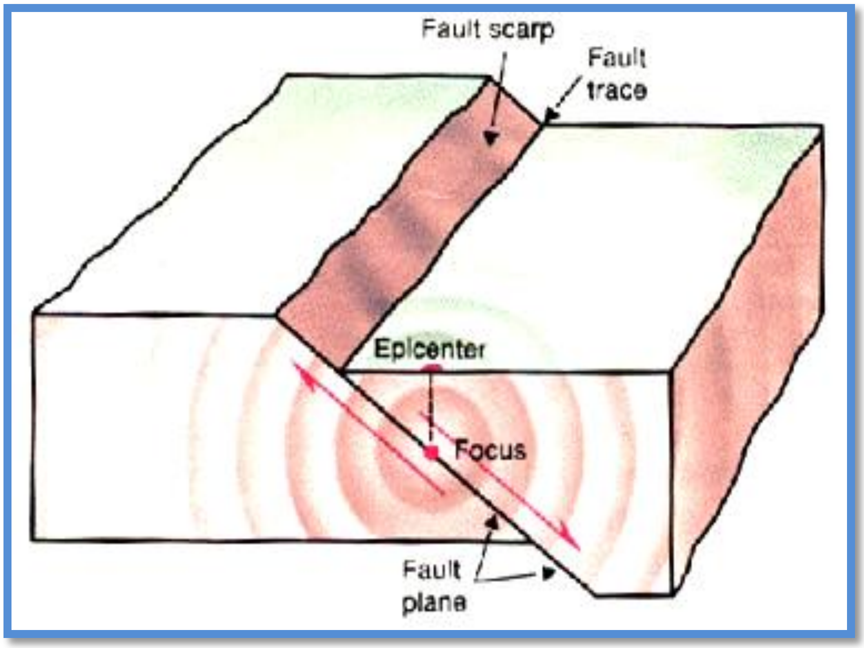


Figure*1[1]: Diagrammatic view of a fault plane.

1.2 SEISMIC WAVES

The strain energy that erupts during an earthquake traverses in all directions through the interior surface of the earth. The waves are classified as – surface waves and body waves. Further, surface waves consist of- Love waves, and Rayleigh waves. On the other hand, body waves comprise of- Primary waves (P-waves) and Secondary waves (S-waves).

The particles under P-waves move in the direction of the wave and go through longitudinal strains. While, in case of S-waves they vibrate perpendicular to the direction of seismic waves. Love waves cause the movement of the surface, in the same way as that caused by the S-waves, the only difference that lies is, they do not have any vertical component. In case of Rayleigh waves, the particles vibrate elliptically.

P-waves have the maximum velocity relative to Love and Rayleigh waves. It is observed that, the maximum damage to the structures, on the earth's surface is caused by the combined effect of S-waves and the Love waves.

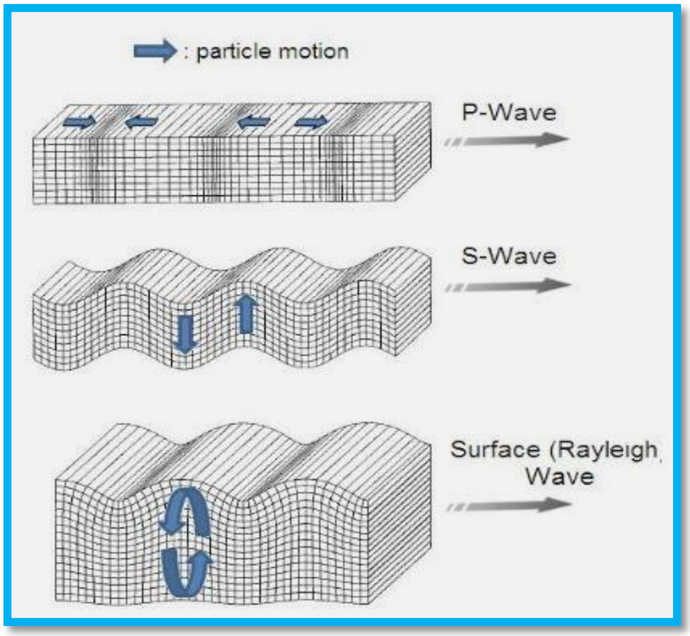


Figure 2*[1]: Types of seismic waves.

1.3 PAST EARTHQUAKES IN INDIA

In the past hundred years, many dominant earthquakes have emerged in India. There were certain earthquakes, in the past that caused devastating effects. In between 1897 to 1950, four earthquakes of M>8 have emerged. The Bhuj earthquake of 2001 was of magnitude 7.7. In Assam, an earthquake of great intensity occurred, which caused damage up to 500 km. The phenomenon of liquefaction was observed in Bihar-Nepal earthquake in 1934. The Chamoli earthquake, in the year 1991, was disastrous in its effect.

A seismic zone is the one which is prone to earthquake. The varying topography in different parts of the country leads to different impact of earthquakes, at these locations. A seismic zone map is thus used to recognize, these areas.

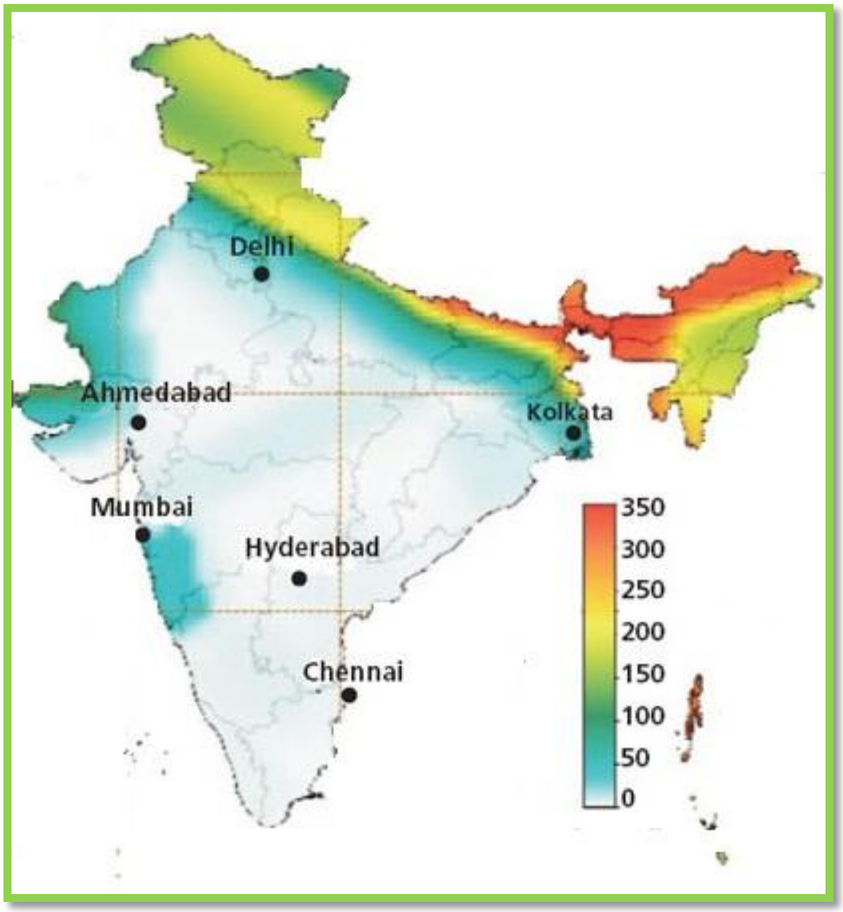


Figure 3*[1]: Peak ground acceleration showing severity of tremor in different parts of India.

The Seismic zones, in India have been divided into four categories- II, III, IV, and V.As per the seismic zone map, revised in 2002.

1.4 SEISMIC EFFECTS ON THE STRUCTURES

The severity of damage to a structure does not only depend on the size of the earthquake but also upon the construction practice adopted for these structures, in a particular region. Today in India, buildings are constructed giving due considerations to the seismic forces, but in the past there was no consideration given to the seismic forces, this can lead to severe damages in such structures, due to lack of design requirements for earthquakes. The lateral forces developed because of earthquake are transferred by the floor slab to the walls or columns and then to the substructure. So, it is important that each of components of the structure and the joints between them shall be designed such that, there is safe transfer of the inertial forces.

The older construction practice comprises of masonry wall construction. In such structures the walls are comparatively thin, and cannot take much seismic force in the direction of their thickness. The collapse of many masonry structures, in 1991 Uttarkashi earthquake is an example of such a kind.However, collapse of many framed buildings in 2002, Bhuj earthquake was a result of poor design and detailing of columns.

It is observed that, tall buildings have more severe impact of earthquake on them,than the others. Also the building structures, which have large plan area, suffer damage of the same kind. It is seen that the buildings with simple geometry show better resistance to the earthquake forces, while those having V, H, U and + shaped plans suffer noticeable damage.

Figure * 4[2]: Collapse of a framed building due to failure of ground floor columns in Bhuj,2001

The irregular buildings have an uneven distribution of mass and stiffness, which leads to additional torsional forces, during an earthquake. The stiffness of a building plays a major role in its vulnerability. Thus, the further study of this project work will be based on the effect of the stiffness on the response of framed buildings during earthquakes.

CHAPTER 2

LITERATURE REVIEW

2.1 DEFINITION OF FRAMED STRUCTURES

A Framed building comprises of the assembly of beams and columns. The most significant feature of a frame, is its strength.Moreover, framed structuresare the structures formed by the framed elements usually in the form of columns and beams, and could be strengthened more by the inclusion of rigid floor membranes and walls. RCC and steel are the most common materials used in construction of framed structures.The building frames used in construction are of various types, following are some which have been discussed and also their response to lateral forces has been discussed in brief.

2.1.1 Steel Moment Frames

Framework comprises of assembly of steel beams and columns. Roof and Floor frames comprise of cast – insitu concrete slabs or with concrete fill held up by steel beams, or steel trusses etc. In steel frames, the lateral forces are resisted by stiffness which is a result of beam-column connections. When all joints act as a moment resisting, then the entire frame behaves this way, and resist the lateral forces. However, if selected joints behave to be moment resisting then resistance is by distinct frame lines.

2.1.2 Steel Braced Frames

Buildings with framework of column, beams and diagonal braces. Such Frames resist forces by the bracing action of their diagonal members.

2.1.3 Steel Frames with Concrete Shear Walls

Framework comprises of assembly of steel beams and columns. Roof and Floor frames comprise of cast – in situ concrete slabs or with concrete fill held up by steel beams, or steel trusses etc. The concrete shear walls resist lateral forces in this case.

2.1.4 Concrete Moment Frames

These buildings consist of a frame assembly of cast-in-place concrete beams and columns. Floor and roof framing consists of cast-in-place concrete slabs, concrete beams, one-way joists, two-way waffle joists, or flat slabs. Lateral forces are resisted by concrete moment frames that develop their stiffness through monolithic beam-column connections.

2.1.5 Concrete Shear Wall Buildings

In such buildings, floors are held up by concrete columns or the bearing walls. Shear walls act as the lateral force resisting elements. Shear walls are provided with heavy reinforcement such that these walls behave relatively stiffer to other walls. In more recent construction, shear walls occur in isolated locations and are more heavily reinforced with concrete slabs and are stiff relative to the walls.

2.1.6 Concrete Frame with Infill Masonry Shear Walls

This type of construction is an older type. It consists of assembly of beams and columns. Wall comprises of infill panels which are composed of concrete or solid clay brick etc. The seismic behavior of a building depends upon interaction between infill and frames.

In this chapter, we will go through the previous work which has been done in the past and form necessary basis for the work which is to be done in this project. Literature review helps us in providing, the background which is required to serve the purpose of the present work. This topic will focus on wide range of journals that depict the role of stiffness in the behavior of seismic framed buildings.

2.2 DEFINITION OF STIFFNESS

The displacement of a framed building under an earthquake force is measured by a characteristic of the building, which is referred to as the stiffness. Stiffness can be defined as the property of a structure by which it shows resistance to the external deflection. It is the force required to cause a unit displacement in the structure. The stiffness of the structure is required to resist lateral forces is the lateral stiffness. If a building has more stiffness then it will deflect less. Figure indicates the drift for a certain stiffness of the framed building.

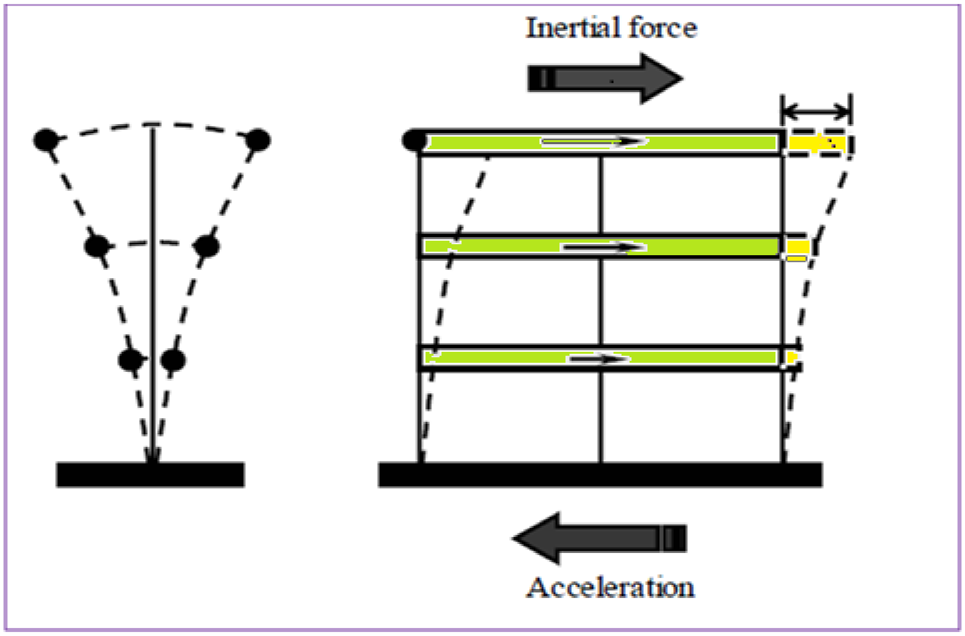


Figure 5*[3]: Seismic forces generated by vibrating the masses.

A building shall have an elastic behavior when, earthquakes of low magnitude , occur because such earthquakes would certainly occur during the life of the building. However, it would not be economical,to design an ordinary building such that it behaves elastically, during earthquake forces of high magnitude as these seismic forces are likely to occur rare in the lifetime of the building.The design standards permit certain degree of risk of damage during severe earthquakes. Such flexibilty is due to lack of resources.Thus the only thing we shall ensure in such conditions is that the buildings shall not collapse so that there is no loss to the lives[3].

2.3 PRINCIPLE FOR DESIGN OF STIFF STRUCTURES

(a) The regularity in the force path makes a structure stiff. In other words direct path of internal force makes the structure stiffer.

(b) Uniformity in internal forces, enhance the stiffness of the structure.

(c) If the number of internal forces is less, then, the structure stiffens more.

In order to ensure adequacy of stiffness the path of internal forces should not be indirect. Simplicity of plan and elevation is must to have sufficient stiffness. The walls and columns should be continuous, so that the forces are transmitted to the base through the shortest path. If any such discontinuity lies in the path of forces, then it may subsequently damage the building. Hence, soft stories and hanging columns should be avoided in a structure.

2.4 FACTORS GOVERNING STIFFNESS OF A FRAMED BUILDING

1) Degree to which the ends of the members are fixed.

2) Modulus of elasticity of the material used, “E”.

3) The moment of inertia , “I” also called as the sectional stiffness.

4) Length of the structural component under consideration.

5) Soil conditions.

2.4.1 Boundary conditions

The stiffness of the structure is also influenced by the joint conditions. Fixed joints constraints the displacement of the structural component in all directions and thus this joint is regarded as the best one to impart more stiffness to the structural component.The rotation of columns at the base is determined by the two conditions.

The first is that the detailing of the structure and its design creates rotational displacement at the joints. The other condition is that, the soil underneath the footings of the columns creates rotational flexibility. If the base of the column is completely fixed then the lateral displacement at the first storey is restricted, that causes flexural behavior near the base of the column.If the rotational motion occurs at the base due to partial fixity at the base, then it increases the lateral displacement in lower stories than the above stories. This type of behavior is termed as shear type behavior, Figure 6. The full rotational constraint results in flexural type of behavior as shown in Figure 7.

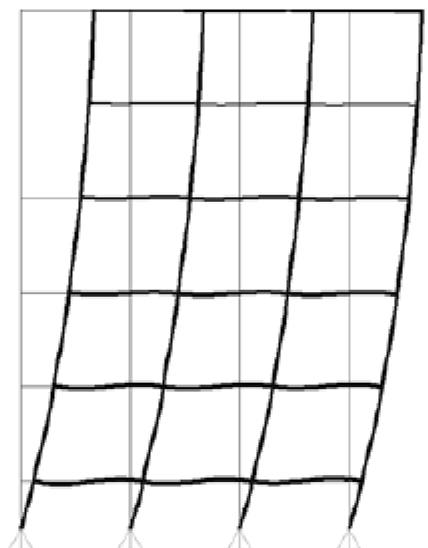


Figure 6*[3]: Shear type behavior

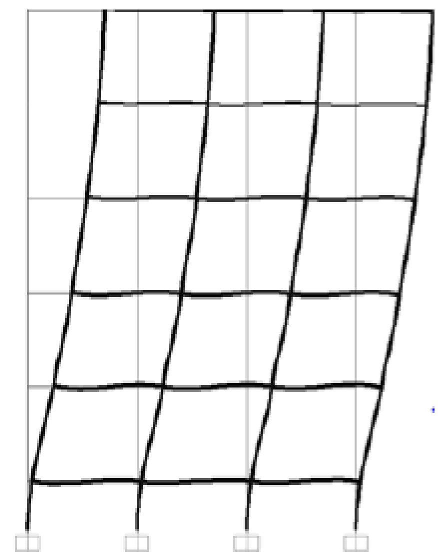


Figure 7*[3]: Flexure type behavior

2.4.2 Modulus of Elasticity

Stiffness depends on the material, shape and boundary conditions. Thus,elastic modulus of material of any structure is an intensive property and defines its stiffness.The more elastic, the material of structural type is, it will impart more stiffness to the framed building.

2.4.3 Sectional Stiffness

The area moment of inertia of the column's cross-section certainly governs the property of stiffness. Sectional stiffness deals with the distribution of material close to or away from the centre of gravity of column. If thes ectional stiffness increases , it results in increment of bending stiffness.

2.4.4 Length of the Structural Component

In the past, it has been seen, in cases of RCC framed buildings, which have varied length of columns within a particular storey, faced a significant damage in the columns of shorter length than the taller ones,during earthquakes. More damage to the shorter column is because it attracts more lateral forces than the tall column. If there is an increase in the column size, then both the stiffness and mass of the building increases. However, if this increase is relatively more than % increase in mass, then the natural period reduces and the frequency of cycles increases.

2.4.5 Soil Conditions

The stiffness of soil also influences the response of building in seismic conditions. Type of soil also contributes in the response of the building. For understanding effect of soil flexibility on earthquake behavior of buildings, the following are considered:
(a) Three types of soil (flexible, medium and stiff): Soil is considered to behave elastically, and its flexibility is incorporated through the Modulus of Sub-Grade Reaction.
(b) Three types of foundations (isolated footings pile and raft): Soil is modeled as elastic springs along the length of the pile and below the raft and footings.

The parameters like **stiffness, mass, type of soil and foundation** do regulate the response of a framed building in earthquakes. In other words they are significant properties that control the response of any building during seismicity. Thus, the dynamic behavior of a framed building could be assessed better by two fundamental parameters namely mass and the stiffness. It is seen that the structures with high stiffness ratio attract more lateral forces and are more unstable. Moreover, a symmetrical building behaves well in seismic conditions due to equal distribution of storey stiffness and the mass distribution at the floor level. Bhuj earthquake in 2001, led to the failure of many multistoried framed buildings due to irregularity in mass and stiffness distribution at different floor levels.

As reported by Bhattacharya et al., there is change in the distribution of the shear force at different storey levels due to change in stiffness of the building when subjected to seismic forces. According to Bureau of Indian Standards, a multi storey framed building which is regular and symmetric in nature is taken as to be simplified lumped mass model in order to analyze it for varying parameters namely mass and stiffness. The conclusion drawn out of studies was that, stiffness and mass are the fundamental parameters to evaluate the base shear and nodal force of the framed building. Irregular distribution of these both leads to a significant adverse effect, during seismic condition.Any sudden change in mass and stiffness can lead to an increase in the base shear of the building. The work suggested that in areas which lie in the seismic zones, there it is always safe having high rise framed buildings of equal storey stiffness and floor mass in order to have stable buildings with optimum magnitude of seismic forces[4].

For a framed building to behave as a seismic resistant building it must have a symmetric and regular shape plan. This is a basic principle involved in the design of earthquake resistant structures. Unsymmetrical frames are usually prone to torsional effects i.e. such structures are also subjected to twisting moments during an earthquake. If the centre of mass and centre of stiffness of a building do not coincide then torsional effects are seen. During earthquake, building is prone to lateral and torsional motion. Stiffness contributes in defining the behavior of a framed building. At the stage of conceptual design, stiffness of the structure plays a significant role. To study the effect of stiffness in dynamic analysis of a building, we evaluate natural frequency by changing stiffness and thus estimate the base shear for different cases[5].

Effect of infill stiffness on the seismic performance of multi storey RC framed buildings

It is a known that masonry infill walls which are not reinforced do not resist “gravity loading” but such panels do have share in supplying more stiffness to the structure when subjected to forces which are an outcome of earthquake. Thus it can be said, that if we do not take into account the stiffness due to infills, then we would surely not make a correct estimation of the true lateral stiffness and natural frequency of the building. It was observed that if infill stiffness is considered for a soft storey, then the base shear and lateral displacement at that level are of high magnitude. The base shear capacity of the structure increases by 69% on taking into account the contribution of infill stiffness as well. The total storey shear force increases considerably as the stiffness of the building increases[6].

Behavior of a short column in earthquake

In the past, it has been seen in cases of RCC framed buildings which have varied length of columns within a particular storey faced significant damage in the columns of shorter length than the taller ones,during earthquakes. The reason for short columns not behaving well during an earthquake is that both short and tall columns deflect horizontally by the same magnitude and since the short column is stiffer than the taller one so it takes large seismic forces (Figure 8).

High stiffness corresponds to high magnitude of forces required to deflect it. If not designed for relatively higher magnitude of forces, then the short columns may face serious effects during earthquakes. The response of such a kind is referred to as the Short Column Effect[7].

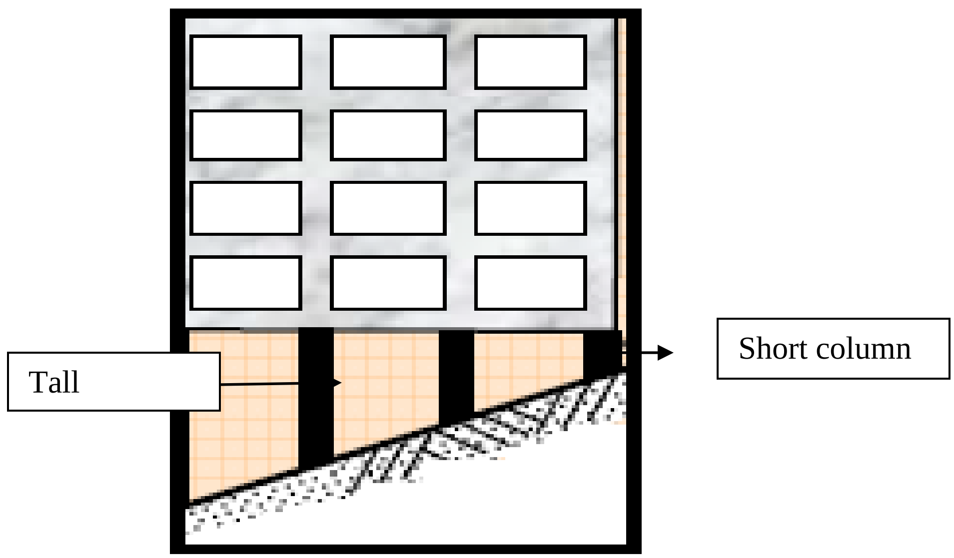


Figure 8*[7]: Building with short columns

Dynamic Behavior of RC Frame Building with Soft Storey

It is a general construction practice in case of multi storey framed buildings, to provide an open space at the first storey level for parking lots. Usually, such practice is considered to be dangerous for the buildings constructed in earthquake prone areas. The provision of soft storey leads to increment in displacement and ductility requirements of the structure. Thus, ignorance of this could cause disastrous consequences.

This paper by N.Arlekar et al. states that there should be steps taken as early as possible for balancing the lateral stiffness of the soft storey and the stiffness of the stories above it ,in order to avoid adverse effects caused due to irregular distribution of stiffness.

During seismicity, a structure is subjected to lateral forces, inducing, total base shear which primarily depends on the natural frequency of the structure. On the other hand, the distribution of seismic force at different storey height of a building, primarily, depends on the mass and stiffness characteristics at that level. In case of multi storey framed buildings which have upper stories comparatively stiffer than the lowermost storey ,have large inter storey drift in the storey with relatively less stiffness, whereas the inter storey drift in the other ones is small. Storey shear in this case is, maximum at first storey level. Therefore, the columns at this level, necessitate the need for much better strength requirements. The columns in other stories have unequal share of lateral force, due to sudden changes in the stiffness characteristics, this causes the local stress concentration. Framed buildings with soft stories do face significant damage during earthquakes. It is very important that buildings of such a kind shall be analyzed carefully and designed with utmost care. Figure shows the damage that is caused in the column of soft storey due to irregularity in the stiffness of the structure [8].

Figure 9*[1]: Damage to columns in the soft storey of a framed building during earthquake

CHAPTER 3

AIMS AND OBJECTIVES

3.1 INTRODUCTION

Earthquakes are catastrophic and occur at intervals, regular in nature in various parts of India. It is reported that about 60% country's area is under the threat of severe earthquakes. Today framed buildings of RCC are a general construction practice in India. Thick Masonry wall construction is not suitable as it reduces the carpet area of the room, moreover the overall mass of the structure also increases, and hence it attracts more lateral forces. Lateral forces i.e. wind and earthquakes forces become more prominent with increase in height of any structure. Thus as a structural system, frames are better than load bearing walls, under such conditions

In recent earthquakes that occurred in different parts of the country some disastrous consequences were faced due to the negligence of earthquake forces in design and detailing of the structural system. This has lead to awareness in regard to the design of structures for seismic forces. In India we follow IS 1893:2002 and IS 13920 for the analysis and ductile detailing of framed buildings.

There are various parameters on which the response of a building depends during seismicity. These are soil conditions, mass distribution at different floor levels of a building, strength and lateral stiffness of a building.Stiffness can be defined as the property of a structure by virtue of which, it can resist excessive deformation during earthquake. Stiffness plays an important role in influencing the dynamic behavior of any structure.
The stiffness of various framed structures like RCC frames, wooden frames, steel frames, and frames with infills is different and hence these frames behave differently under same seismic condition. Drift of a frame under earthquake forces is actually a measure of its stiffness, which is defined as the force causing unit deflection. It is seen that stiffer a building is, the less it will deflect and vice –versa.In order to avoid torsional effects, there should be

symmetry and regularity in mass distribution, stiffness and strength, in other words the center of mass and center of rigidity of the structural system should always coincide.

It is important while designing a framed building for a low magnitude earthquake, that it should respond elastically, as, such earthquakes are likely to occur during its lifetime. On the other hand, if we design such buildings for high magnitude earthquakes then there could be a bit of flexibility in regard to risk of damage to the structural components. A building must possess an adequate stiffness which can be attained by more lateral load resisting components like frames, braces, and shear walls in tall buildings etc. so that there may not be damage to the structure during low intensity earthquakes.

As there are many framed buildings in India which were constructed without any adoption of seismic design code thus many of them may not possess sufficient stiffness to overcome the effect of even low level earthquake forces.The present work is an analytical study based on the effect of stiffness on the response of framed building during a seismic action.

3.2 STATEMENT OF THE PROBLEM

“Negligence of requisite stiffness leads to damage in structures, even under low level earthquakes; over stiff structures attract more lateral forces”.

It is important to have requisite stiffness in an RCC framed building. This characteristic of stiffness shall be given due consideration while analyzing and designing a framed building for earthquake forces. Lateral stiffness of a structure can be enhanced by equipping it with load resisting elements in lateral direction (shear walls, braces, masonry walls in small RC framed buildings).

If a structure lacks the adequate stiffness, then it is likely to undergo intense damage, under the impact of low magnitude earthquakes as well. It is important to mention that the buildings which hold substantial significance like hospitals, commercial buildings, institutions etc. shall have adequacy in stiffness such that they behave elastically well, when subjected to earthquakes, which are rare of a kind.

Many times we underestimate the contribution of certain elements to the stiffness of the whole structure, but they can contribute significantly in resisting lateral forces, during a seismic condition. The Soft storeys clearly depict the case of irregularity in stiffness and hence, the effect of stiffness on the first storey is seen through the profile of lateral displacement of a building, further the shear force and bending moment in the columns at the first storey level could be studied.

The research problem covers a wide area .This project work aims at studying the variation of base shear, storey shear , natural frequency and time period etc. with the change in stiffness of the building model.

3.3 SCOPE AND CONNOTATION OF RESEARCH

The mass and stiffness distribution are two basic parameters to evaluate the dynamic response of a building. A building structure with high stiffness ratio, is subjected to instability and attracts huge storey shear. A building symmetry is achieved with the even distribution of floor masses and storey stiff nesses.

If any change in the stiffness of the building frame occurs, then the lateral force or the base shear is also affected. Irregular distribution of structural stiffness plays a vital role in seismic condition. Unreinforced masonry infill wall panels may not contribute towards resisting gravity loads, but contribute significantly in terms of enhanced stiffness under earthquake induced forces. Ignoring infill stiffness may result in underestimation of stiffness and natural frequency.

Today multi storey RCC framed building construction, is common throughout India. In metropolitan cities like Delhi, Mumbai etc. such framed buildings demand for open space at the first storey in order to provide for parking facilities to the vehicles, they can also serve the purpose for public gatherings, or provide enough space for retail shops etc. This can help save the expenses incurred on, an extra horizontal space. An open space at the 1st storey leads to decrement in the stiffness of that storey when compared to the upper stories. As a result, the open storey behaves supple compared to the other stories. This causes local stress concentration at the connections in second storey which is followed by excessive deformations, which are permanent in nature. Moreover, there is formation of plastic hinges at the extremes of the column in first storey, as major part of energy developed during a seismic action, is released by these columns, turning the storey into a mechanism.

A better understanding of the effect of stiffness is helpful, in estimating the behavior of framed buildings and can lead to construction of much safer buildings. So, the significance of the research is that optimum stiffness required for the building could be assessed which leads to an economical and safe design.

3.4 AIMS AND OBJECTIVES

The objective of this project work is to study the effect of stiffness on the behavior of framed buildings in earthquakes. Thus, by subjecting a framed building to different stiffness conditions, its response to the earthquake forces is studied**.** The project work comprises of two parts. The first experimental part has the following objectives-

- To study the general behavior of two different single storey frames of same mass but different stiffness characteristics, using horizontal shake table test.
- To have comparative study of the variation in natural frequency and time period in the two different cases.

The second part is the analytical study using the software, which has following objectives-

- To model and analyze a G+4 framed storey building, by considering different cases of stiffness of the framed building, using STAAD Pro.
- To observe, the response of the framed building for different cases of change in the stiffness of the test building.
- To compute storey displacement, natural frequency, time period, mass participation, peak storey shear and base shears for different cases.
- To graphically represent the results thus obtained, for different cases.
- Comparison of the results and to draw conclusions.

3.5 RESEARCH METHODOLOGY

The Approach of linear analysis is viable to those structures, which have regular geometry and are restricted to a certain height. Another name for this analysis is Equivalent Static Analysis Method. The Linear Dynamic Method is used in Time History Method and Response Spectrum Method or Modal Superposition Method.

Dynamic method is advancement in static method. It considers much higher modes of vibration, which can give a better understanding of actual distribution of lateral forces, within elasticity, in a building frame. This project work uses STAAD Pro. for the analysis of the building. The method used in STAAD for analysis is the Response Spectrum Method.

3.6 OUTLINE OF THE THESIS

Chapter 1: Introduction: this chapter defines the objective of the study, background, significance of the thesis work.

Chapter 2: Literature Review: this chapter presents the previous work done in the related field and forms the basis for the research work.

Chapter 3: Methodology: this chapter presents the description of the method of analyses which has been followed for the analysis of the test model.

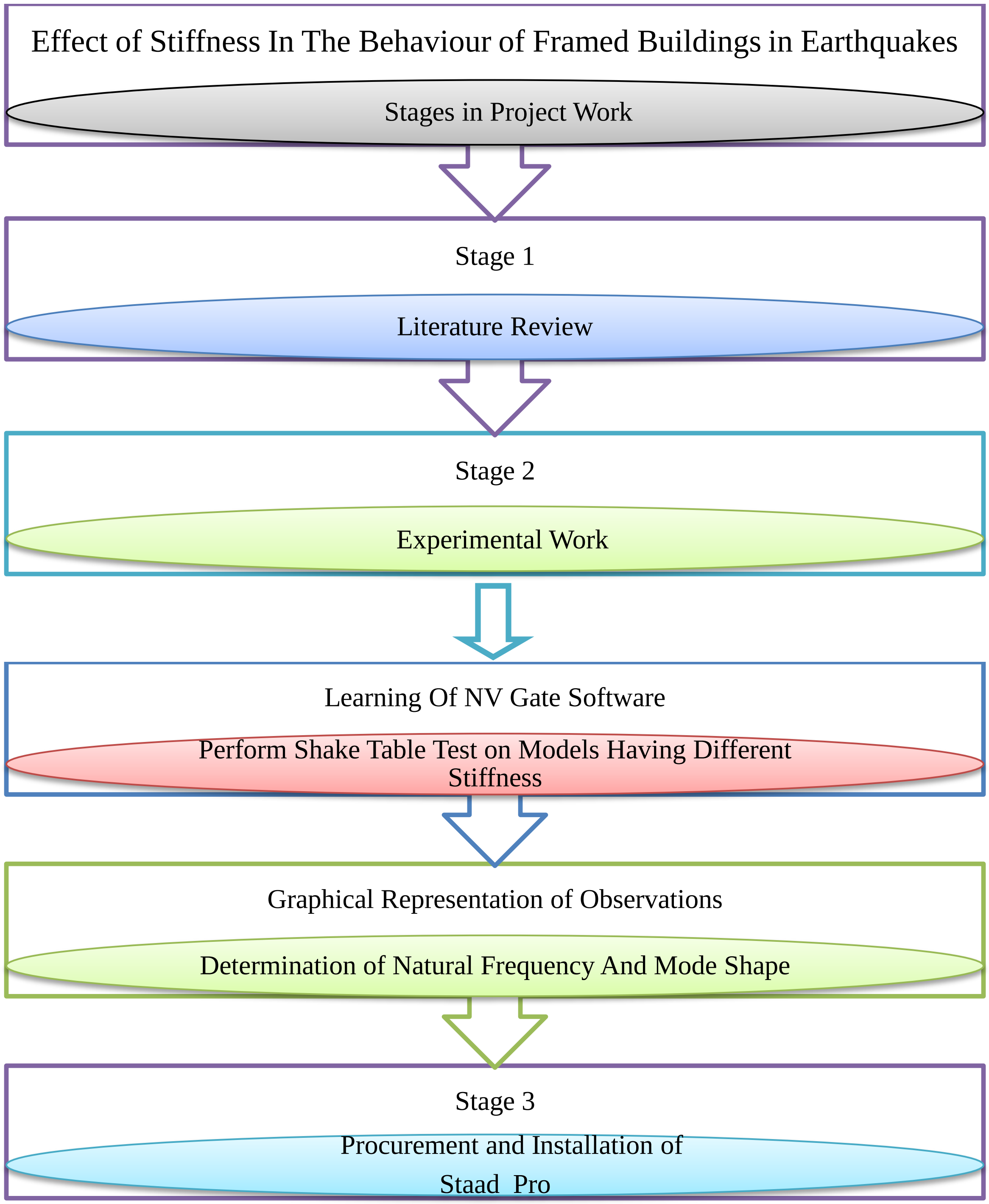
Chapter 4: Study to Assess General Behavior of Frames: this chapter presents the results of the experimental work done in the analysis of two simple frames each with different stiffness.

Chapter 5: Model Development: this chapter presents the model development of a G+4 Storey RCC framed building, by using STAAD PRO.

Chapter 6: Analysis and Results: The test building model is analyzed for cases of different stiffness. Various results are obtained and are plotted graphically.

Chapter 7: Comparison and conclusion: Comparative study of the results, obtained for different cases. Recommendation for future work is also presented.

WORKFLOW


Effect of Stiffness In The Behaviour of Framed Buildings in Earthquakes
Stages in Project Work
Stage 1
Literature Review
Stage 2
Experimental Work
Learning Of NV Gate Software
Perform Shake Table Test on Models Having Different Stiffness
Graphical Representation of Observations
Determination of Natural Frequency And Mode Shape
Stage 3
Procurement and Installation of
Staad Pro

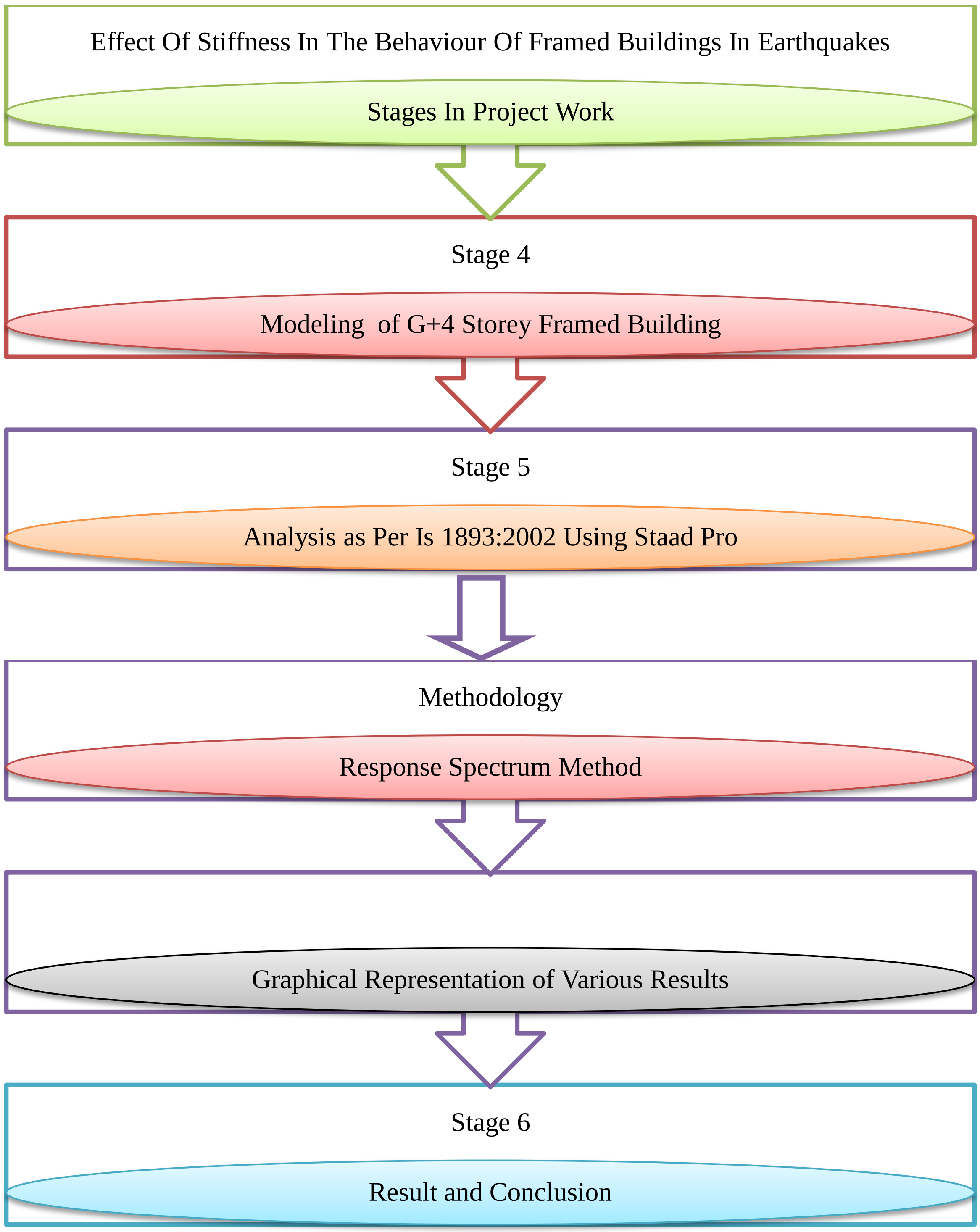


Figure 10: Flow chart depicting the workflow.

CHAPTER 4

METHODOLOGY

4.1 PRINCIPLE FOR ANALYSIS OF FRAMED BUILDINGS

1. In the seismic analysis of a framed building, only the horizontal component of seismic force is taken into account. Vertical component of it is usually ignored. It is assumed that the earthquake forces act in the longitudinal and transverse directions.
2. A seismic force is assumed to act at the floor slab level. Also if the distribution of mass and type of framing is in a manner that the force acts at the mid storey height, in that case, local stress is taken into account.
3. Rigid diaphragm action is assumed in the floor slab, in the horizontal direction. Thus, it is assumed that all the structural elements in the frame in a particular storey have the same relative displacement.
4. If irregular stiffness leads to eccentricity between the centre of stiffness and centre of gravity, then the twisting moment shall be taken into consideration.
5. The stress analysis of a framing element is done complyingwith the elastic theory.
6. Condition of the foundation should be taken into consideration.

4.2 STATIC AND DYNAMIC ANALYSIS

The Approach of linear analysis is viable to those structures, which have regular geometry and are restricted to a certain height. Another name for this analysis is Equivalent Static Analysis Method. The Linear Dynamic Method is used in Time History Method and Response Spectrum Method or Modal Superposition Method. Dynamic method is advancement in static method. It considers much higher modes of vibration, which can give a better understanding of actual distribution of lateral forces, within elasticity in a building frame.

A noteworthy difference between linear dynamic and static analysis is the magnitude of forces and their distribution along the height of the framed building or a structure. When the inelastic response of the structure is taken into consideration then this approach is referred toas the Non-linear static analysis, which is a refinement in linear analysis method. It is comparatively a simple method to be implemented for the analytical studies.

In non-linear static analysis we assume, a number of static incremental horizontal loads along the height of the structure. This method informs in a better way regarding the strength, ductility requirements and the deformation of the structure. This allows us to recognize those members which may behave critically during seismic conditions and may reach their limit states, thus this helps us in designing and detailing of these members. Such members are therefore taken special care of in terms of strength and stability. Non-linear static analysis has many drawbacks associated with it, like it does not consider the effect of higher modes of vibrations, change in the loading patterns and consequences of resonance. Push- over analysis which is based on non-linear static analysis has gained a lot of popularity despite of various shortcomings.

The actual behavior of the structure under earthquake could be assessed more precisely by the Non-linear dynamic method or the time history method. In this method we consider the elasto-plastic nature of the structural member and the differential equations of motion are directly integrated to get the desired response of the structure.

4.3 ASSUMPTIONS IN SEISMIC RESISTANT DESIGN OF STRUCTURES

The following assumptions are made in IS-1893 (2002) for seismic (1) resistant design of structures (Clause: 6.2, IS 1893-2002):

1. Seismic forces cause ground motions which are impulsive in nature. These motions are uneven and quite complicated in their action. The time period and the amplitude of these forces vary continuously with time. Thus, at steady state harmonic excitations, the type of resonance obtained may not build up amplitudes of such magnitude.

2. Earthquake is not expected to occur at the same time as wind, or maximum flood conditions or maximum sea waves.

3. Elastic modulus of materials has value same as that for static analysis if an exact value is not available for use in the seismic condition.

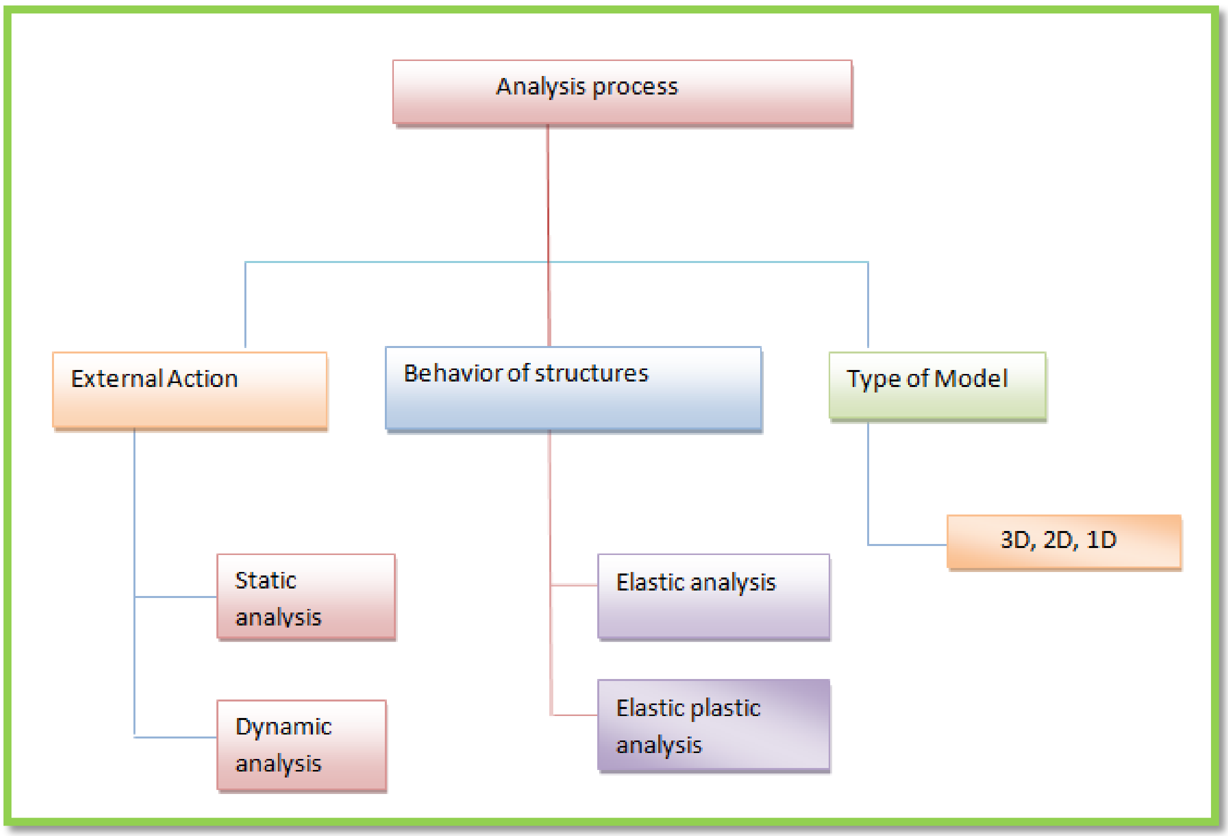


Figure 11: Method of analysis

Once the structural model has been selected, it is possible to perform analysis to determine the seismically induced forces in the structures. The procedure of analysis depends on three factors:

(1) Applied loads.

(2) The behavior of structure or structural materials.

(3) Type of structural model selected

Code based procedure for seismic analysis-

Dominant characteristics of method of analysis of earthquake resistant buildings as mentioned in Indian Standard, 1893 (part I): 2002 are discussed below.

4.4 RESPONSE SPECTRUM METHOD

If the modes other than the fundamental ones have dominant effect on the behavior of a structure there the Response Spectrum Method is used. Modal response is determined for single degree of freedom system using specified design spectrum. Thus, for a multiple degree of freedom system the various modal responses obtained from SDOF are superimposed to get the resultant response.

In this method, there are many modes of vibration of the framed building which are taken into account and the behavior of the building is judged by the combination of these modes. Design spectrum, which is a result of modal mass and the modal frequency, is useful for obtaining a response due to a certain mode. The number of modes thus obtained is combined, to get the total response of the building. The combination methods used are-

1. Square Root of the Sum of Squares (SRSS).
2. Addition of Absolute Peak Values.
3. Complete Quadratic Combination- used for closely spaced modes.

In the Response Spectrum Analysis, the following procedure is adopted-

1. The design spectrum is chosen.
2. Inclusion of modes of vibration, which are to be used in the seismic analysis.
3. For the respective mode, the response of the spectrum is observed.
4. Calculation of modal participation factor with respect to SDOF read from the curve.
5. The total response is obtained by the combination of all the modes.
6. Highest obtained response is converted into moments and shear forces. The peak storey shear acting in mode k, with storey height (i), is given on the next page.

$$Q_i = A_k \theta_{ik} P_k W_i$$

Where,

A_k = Design horizontal spectrum value.

Θ_{ik}= Mode shape coefficient.

P_k = Modal participation factor.

W_i= Seismic weight at the ithstorey.

$$P_k = \frac{\sum_{i=1}^{n} W_i \theta_{ik}}{\sum_{i=1}^{n} Wi\theta_{ik}^2}$$

The SRSS combination is used to obtain the peak storey shear in i^{th}storey .The consideration of all modes for lateral forces at each storey is given by the following equation-

$F_{roof}=V_{roof}$

$F_i = V_i – V_{i+1}$

The peak response of the structure is calculated CQC is as following-

Complete Quadratic Combination (CQC) method-

$$\lambda = \sqrt{(\sum\sum \lambda_i \ \ P_i \lambda_j)}$$

Where,

λ_i= response quantity in mode j,

P_i = cross modal coefficient,

λ_i= response quantity in mode j.

CHAPTER 5

EXPERIMENTAL STUDY TO ASSESS SEISMIC BEHAVIOUR OF FRAMES

5.1 MODEL DESCRIPTION

Shake Table Shake table is used as an experimental technique to record the behavior of a framed building in order to validate its dynamic behavior during seismicity. This device is used to produce vibrations in the structural components or the building models with simulating ground motion of different frequencies. Recorded earthquakes and time histories could be regenerated by this device.

A shake table that functions only in one direction i.e. the horizontal direction is referred to as the horizontal shake table. This device has simple harmonic motion. The principle that works behind its mechanism is the one that goes on well with the “crank mechanism”. The mechanism is simple, as just the rotational motion of motor is converted into the linear motion of the shake table. The shake table includes the following components as its integral part:

- Sliding Table.
- Forcing mechanism.
- Control system

The structure to be tested can be fitted on these shake tables at any desired inclination with respect to the direction of the motion, applied at the base.At the top of the table there is a circular plate that acts as a base for the structural models and it consists of array of circular perforations. This plate is of stainless steel.There are steel guides fitted on top of bearings. The circular plate moves linearly on these guides. The table bottom is of steel frame and bearings are connected to it. The lowermost plate is attached to the foundation plate by means of bolts.

Forcing Mechanism

It includes rod, crank, accelerating medium like gears,coupling and electric motor.The rod attached to the crank passes the rotational motion to the crank by means of gears and electric coupling. Due to some sort of arrangements of screws in crank mechanism, we can even fix the amplitude of the motion as per the required need .The drive mechanism for the shake table has been shown in Figure 12.

Control System

- The frequency of the ground motion simulated in the shake table could be changed by changing the speed of the electric motor.
- Single storey frame: two frames each having a slab resting on four aluminum rods. The two frames have different stiffness property due to different length of the column. The mass parameter remaining the same.

Figure 12: Horizontal shake table

- Transducer in this experiment will measure the movement in x- direction. Since the motion is being given in the horizontal direction and we are taking a single storey.

frame for analysis thus only one transducer is required. This way the measurement of the displacement could be carried out for the experiment. Sensitivity of the transducer for the present experiment is 96.98 mV/g .

- Analyzer: the signals thus produced could be displayed into a meaningful language by means of analyzer. Here, in this experiment the transducers are connected to the OROS Ethernet (Figure 13) and we can analyze the signals on our computer system by suitable connections and use of software namely OROS NV gate.

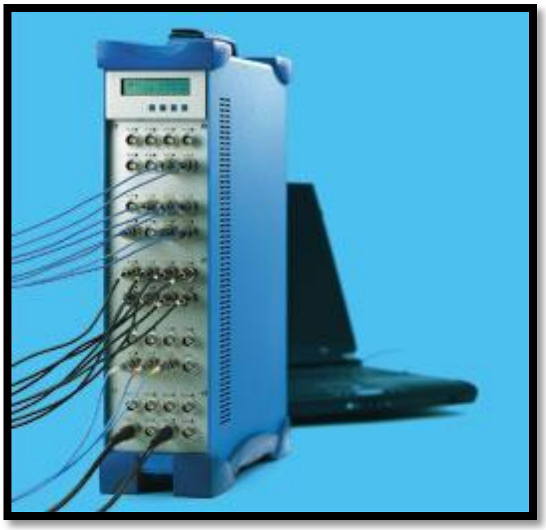


Figure 13*[2]: OROS analyzer

Thus, these are the experimental set ups required to perform the analysis of a single storey frame under seismic excitations.

5.2EXPERIMENTAL PROCEDURE

Objective: to find out the natural frequencies of two single storied frames with different stiffness and thus to study the effect of stiffness in the behavior of the two frames.

Model 1(Stiff Frame)

Frame 1 comprises of a slab which is supported by four aluminum columns. The dimensions and masses of slab and column are as following:

1. Mass of slab , M_s= 595.6 g
2. Mass of column , M_c = 63 g
3. Mass of screws used for slab-column connection ,M_i = 43 g
4. Total mass , M = 764.6 g

The dimensions of slab for Frame 1 are as following:

1. Length of the slab , l_s = 30.5 cm
2. Width of the slab , b_s= 10 cm
3. Thickness of the slab, d_s = 1.4 cm

The dimensions of column for Frame 1 are as following:

1. Length of the column , l= 32 cm
2. Width of the column , b = 2.5 cm
3. Thickness of the column , d =0.292 cm

Experimental results are as following –

Table 1: Displacement corresponding to applied frequency.

Frequency(Hz)	Top floor F1 (10^{-3}mm)
1.1	672
1.2	679
1.3	688
1.4	689
1.5	766
2.0	775
3.0	848
4.0	942
5.0	1009

6.0	1042
6.5	1202
7.0	1368
7.5	2044
8.0	2544
8.4	2023
8.8	2876
9.0	3543
9.4	1368
9.6	1624
10.0	1108
10.2	789
10.4	710
10.8	673
11.0	776
11.2	824
11.4	1009
11.6	1042
11.8	1145
12.0	1202
12.2	1248
12.4	1363
12.6	1453
12.8	2436
13.0	4319
13.2	7031
13.4	7849
13.6	6981
13.8	3212
14.0	2139
14.2	1146
14.4	1114
14.6	1105
14.8	984
15.0	976
15.2	844
15.3	766
15.5	676
15.7	668
15.9	660
16.0	1452
16.2	1323
16.4	3543

16.6	1224
16.8	1202
16.9	1109
17.0	1098
17.2	1084
17.4	1065
17.6	1045
17.8	978
18.0	842
18.2	785
18.4	766
18.6	734
18.8	733
19.0	712

Graph plotted for the above root mean square values of displacement is as following-

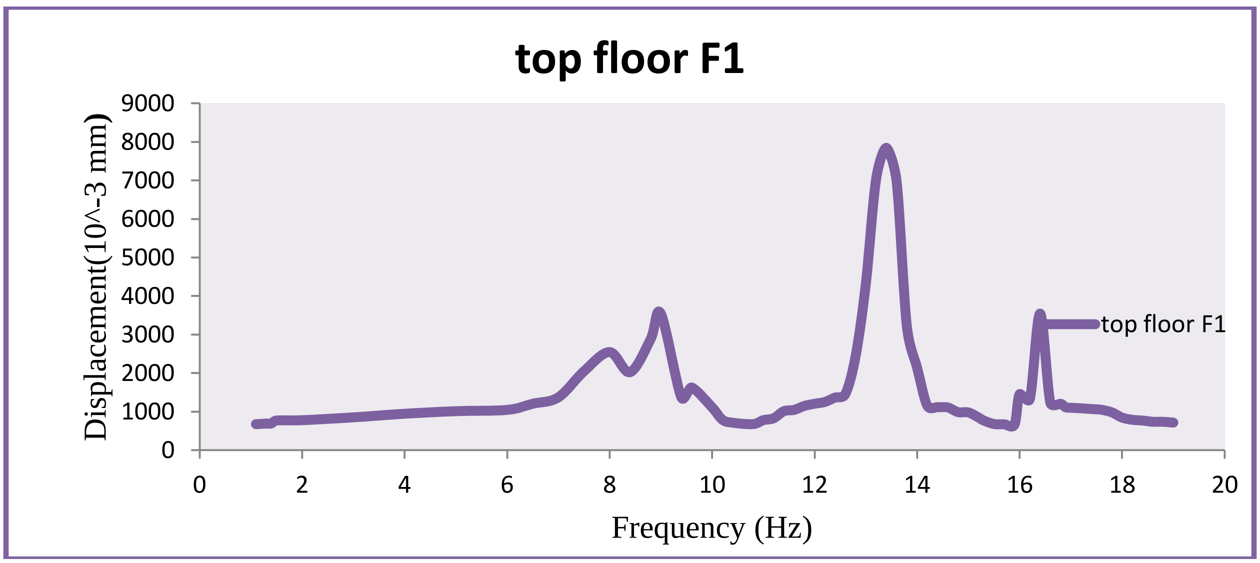


Figure 14: Displacement v/s frequency graph.

Model 2 (Less Stiff Frame)

Frame 2 comprises of a slab which is supported by four aluminum columns. The dimensions and masses of slab and column are as following:

1. Mass of slab , M_s= 595.6 g
2. Mass of column , M_c = 63 g
3. Mass of screws used for slab-column connection , M_i = 43 g

4. Total mass , M = 764.6 g

The dimensions of slab for Frame 2 are as following:

1. Length of the slab , l_s = 30.5 cm
2. Width of the slab , b_s= 10 cm
3. Thickness of the slab, d_s = 1.4 cm

The dimensions of column for Frame 2 are as following:

1. Length of the column , l= 44.4 cm
2. Width of the column , b = 2.5 cm
3. Thickness of the column , d =0.292 cm

Experimental results are as following-

Table 2: Displacement corresponding to applied frequency

Frequency(Hz)	Top floor F1(10^{-3}mm)
1.1	973
1.2	987
1.3	1236
1.4	1356
1.5	1467
1.7	1344
2.0	1487
2.2	1670
2.4	1722
2.6	1654
2.8	1633
3.0	4578
3.2	7823
3.5	5894
3.8	2758
4.0	1679
4.2	3876
4.4	1743
4.6	965
4.8	1478
5.0	1895
5.2	2456
5.4	1456
5.6	1498
5.8	1500

6.0	2985
6.2	3813
6.4	5788
6.6	8457
6.8	11052
7.0	17112
7.2	21439
7.4	16875
7.6	5087
7.8	4327
8.0	3262
8.2	1345
8.4	1254
8.6	1188
8.8	1054
9.0	1036
9.2	986
9.4	954
9.6	934
9.8	955
10.0	1453
10.2	2098
10.4	2547
10.6	1289
10.8	1452
11.0	1323
11.2	1098
11.4	987
11.6	923
11.8	957
12.0	1098
12.2	1084
12.4	1065
12.6	1045
12.8	978
13.0	933
13.2	1035
13.4	974
13.6	965
13.8	1022
14.0	1094

From the obtained root mean square values of displacement, we can plot the graph , which is as following:

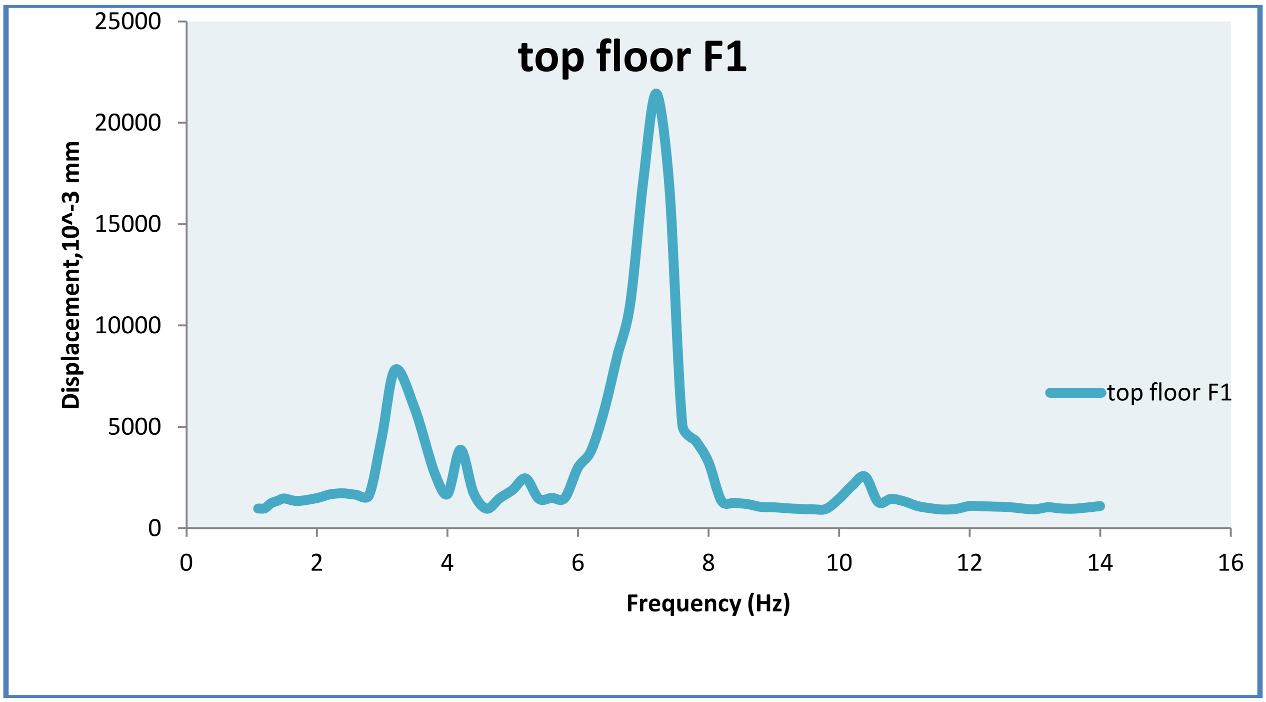


Figure 15: Displacement v/s frequency graph

Conclusion

The maximum displacement for the relatively flexible frame, which is model no. 2 is far more than the maximum displacement for the stiffer one i.e model no. 1. Also the natural frequency of the flexible frame is lower than the stiffer one.

5.3 THEORETICAL ANALYSIS

Objective: the objective of the theoretical analysis of single storey framed building in earthquakes is to find out that how the stiffness of a building effects its natural frequency and hence its response to earthquakes. The motive here will be to analyze two framed models of different stiffness and hence, theoretically, find out their behaviour.

Single Degree of Freedom System-

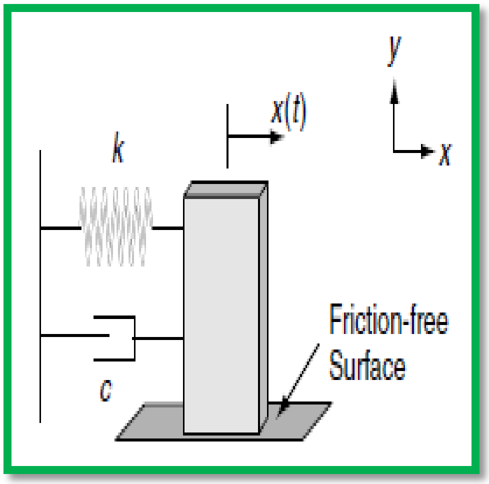
At a time, the minimum no. of independent coordinates that define the position of all components of a system is described as the single degree of freedom system. SDOF requires a single coordinate to define its position at a certain instant of time.

While theoretically analyzing a single storey framed building we assume the practical structures as a system comprising of finite lumped masses, springs and dampers i.e the shear beam model. In which we consider the flexural rigidity of the beam and the slab to be infinite such that the frame does not undergo any rotation, thus we idealize a framed building to behave as a spring as with lumped mass.

To simplify the analysis we consider two assumptions:

1. Mass of the columns is neglected.
2. No rotations at the top of columns due to infinite rigidity of the horizontal members like beams.

Thus under these conditions a single storey frame may be modeled by spring mass system. As shown in the Figure 16.A simple system under vibrations can be best represented by a mass system having connection to a spring and a damper. The simplest vibratory system can be described by a single mass connected to a spring and a damper. As the system represents single degree of freedom system, the mass moves in the same direction where the spring elongates.



Spring mass system

Figure 16: Spring mass model for a single storey framed building.

The structures capable of developing elastic restoring forces are said to exhibit the oscillations corresponding to simple harmonic motions. Such structural systems could be modeled as a spring mass model. Many of the structural systems can be modeled in this form as it is the most basic model of vibration of any system.

Mathematical model:

Applying D'Alemberts principle for SDOF system to obtain the basic mathematical expression for a single storey framed building which has been modeled as a lumped mass model.

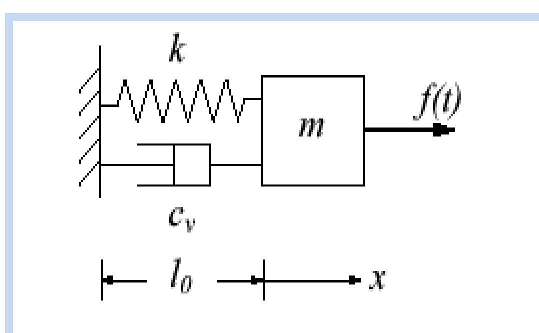


Figure 17: Spring mass model for SDOF

A simple system under vibrations can be best represented by a mass system having connection to a spring and a damper. The simplest vibratory system can be described by a single mass connected to a spring and a damper. As the system represents single degree of freedom system, the mass moves in the same direction where the spring elongates. The mathematical equation for such model is as following-

$$m\ddot{x} + c_v(\dot{x}) + k(x) = F(t)\sin\omega t$$

Now, we consider a system with free vibration. In this system we give an initial displacement to the model and then release the force, also we are not taking damping into consideration for the analysis of our model, thus we get the equation form as:

$$m\ddot{x} + k(x) = 0$$

Now, solution to this differential equation of motion is same as that of second order linear differential equations. Stiffness, k and mass, m are constants, and also the right hand side of the equation is equal to zero ,therefore it further transforms the equation into a homogeneous equation having coefficients as constants. We assume a trial solution to the obtained differential equation, which is as follows:

$x = A\cos\omega t$……… (a)

Or

$x = B\sin\omega t$ ……… (b)

Where A,B are constants,

ω is denotes physical characteristic of the system . On substituting the value of x from either (a)

or (b) ,we get equation as :

$$(-m\omega^2 + k)\,A\cos\omega t = 0$$

$(-m\omega^2 + k) = 0$,in order to satisfy the above equation at any instant.

Thus, $\omega = \sqrt{k/m}$

Where, ω is the natural frequency of the system.

$x = x_0\cos\omega t + (v_0/\omega)\sin\omega t$, we obtain this equation after solving for constants A,B.

This is the expression for the displacement x which is a function of time,t for a simple oscillator. This is the equation for single degree of freedom system which is required for our model. We would proceed further with the model taken in actual practice and thus calculatethe natural frequencies of the models. The displacement corresponding to the natural frequency would be the maximum in theoretical as well as experimental analysis.

The displacement for single degree of freedom which is un damped and subjected to external harmonic excitation is as following-

$$\boldsymbol{x(t) = \frac{F_0}{(1-r^2)k}(sin\overline{\omega}t - rsin\omega t)} \qquad \text{……..(c)}$$

The above equation (c) is the response and is obtained by combining the harmonic terms of different frequencies. It is observed that the resultant motion is non harmonic but in actual practice, damping forces will always be in the system even if small thus the natural frequency term in the above expression vanishes. Thus this term is gives the transient response of the system. The term for forcing frequency is as following:

$$\boldsymbol{x(t) = \frac{F_0/k}{(1-r^2)} sin\overline{\omega}}\mathrm{t} \qquad \text{……….(d)}$$

The equation (d) is referred to as the steady – state response. It is clear from equation (c) that in case of no damping in the system, the transient will not vanish and the response is given by equation (c), it can also be seen from equation (c) and (d) that when the forcing frequency is equal to the natural frequency , the amplitude of the motion increases up to infinity.

A system is said to be in resonance when the external applied frequency matches up with the natural frequency of the system. Under such condition, the amplitude of the oscillation will increase gradually to infinity which may lead to the structure failure due to the inadequacy in the strength of materials.

Model under study: to study the effect of stiffness in the framed building we are taking into consideration two single storied framed building models. The dimensions and other properties related to the models are given on the next page.

Model 1

Frame 1 comprises of a slab which is supported by four aluminum columns. The dimensions and masses of slab and column are as following:

1. Mass of slab , M_s= 595.6 g
2. Mass of column , M_c = 63 g
3. Mass of screws used for slab-column connection , M_i = 43 g
4. Total mass , M = 764.6 g

The dimensions of slab for, Frame 1 are as following:

1. Length of the slab , l_s = 30.5 cm
2. Width of the slab , b_s= 10 cm
3. Thickness of the slab, d_s = 1.4 cm

The dimensions of column for, Frame 1 are as following:

1. Length of the column , l= 32 cm
2. Width of the column , b = 2.5 cm
3. Thickness of the column ,d = 0.292 cm

Figure 18: The actual frame under consideration

This frame has been modeled as a spring-mass model with single degreeof freedom as shown in Figure 17.Damping is not considered while analyzing this model , hence we proceed further with an un-damped single degree of freedom system.

The calculations are:

Equation of motion is $m\ddot{x} + c_v(\dot{x}) + k(x) = F(t)\sin\omega t$

$C_v = 0$ also to find out ω we equate F(t)sinωt =0, thus the equation reduces to:

$m\ddot{x} + k(x) = 0$.

Thus, $= \sqrt{k/m}$,where , ω is termed as the natural frequency of the system.

Now, k = stiffness of the spring = 4 k_c

where, k_c = stiffness of column(since all the columns have same material and geometric properties therefore each have the stiffness k_c).

$$= \frac{12\,EI}{L^3}$$

E = modulus of elasticity of aluminum = 0.7×10^{11} N/mm^2

L = length of column = 0.32 cm

I = moment of inertia of column = 5.18×10^{-11}mm^4

$$K = \frac{48EI}{L^3} = 5312 \text{ N/m}$$

$$\text{Thus,} \quad \omega = \sqrt{\frac{5312}{764\times10^{-3}}} = 83.4 \text{ rad/s}$$

Natural frequency in hertz is given as **f = 13.27 Hz.**

Model 2

Frame 2 comprises of a slab which is supported by four aluminum columns. The dimensions and masses of slab and column are as following:

1. Mass of slab , M_s= 595.6 g
2. Mass of column , M_c = 63 g
3. Mass of screws used for slab-column connection , M_i = 43 g
4. Total mass , M = 764.6 g

The dimensions of slab for Frame 2 are as following:

1. Length of the slab , l_s = 30.5 cm
2. Width of the slab , b_s= 10 cm
3. Thickness of the slab, d_s = 1.4 cm
4. The dimensions of column for Frame 2 are as following:
1. Length of the column , l= 44.4 cm
2. Width of the column , b = 2.5 cm
3. Thickness of the column , d =0.292 cm

Figure 19: The actual frame under consideration

This frame has been modeled as a spring-mass model with single degree of freedom. Damping is not considered while analyzing this model.

Further, for un-damped single degree of freedom system the calculations are as following – Refer to fig (15):

Equation of motion is $m\ddot{x} + c_v(\dot{x}) + k(x) = F(t)\sin\omega t$

C_v= 0 also to find out ω we equate F(t)sinωt =0, thus the equation reduces to:

$m\ddot{x} + k(x) = 0$.

Thus, $= \sqrt{k/m}$, where , ω is termed as the natural frequency of the system.

Now, k = stiffness of the spring = 4 k_c

Where, k_c = stiffness of column(since all the columns have same material and geometric properties therefore each have the stiffness k_c).

$$= \frac{12\,EI}{L^3}$$

E = modulus of elasticity of aluminum = 0.7×10^{11} N/mm^2

L = length of column = 0.32 cm

I = moment of inertia of column = 5.18×10^{-11}mm^4

$$k = \frac{48EI}{L^3} = 2043 \text{ N/m}$$

Thus, $\omega = \sqrt{\frac{2043}{764 \times 10^{-3}}}$ = 51.7 rad/s

Natural frequency in hertz is given as **f = 8.2 Hz**

5.4 RESULT AND CONCLUSION

1. In the analysis of the two frames with different stiffness, it was observed that the natural frequency of flexible frame (frame 2) is less than that of the stiff frame (frame 1).Thus resonance will occur at much lower frequency in case of less stiff frame than a stiffer frame.
2. In the experimental analysis it was seen that the two frames behave differently if they have same mass but different stiffness properties.
3. Frame which was more flexible or rather less stiff than the other had lower natural frequency and relatively much higher magnitude of displacement on the top floor.
4. Theoretical analysis gave approximately the same values of natural frequencies of the two frames, as obtained in case of experimental analysis.
5. The natural period of vibration is less in case of stiff frame than the flexible one.
6. A framed building shall be flexible, to resist damage at high magnitude of earthquake force but it is also desired that it shall have sufficient stiffness to avoid damage at low level earthquakes.

CHAPTER 6

MODELLING WITH STAAD

6.1 INTRODUCTION

This work presents the analysis of a framed building (G+4) for varying cases of lateral stiffness, using STAAD Pro. This research work is an approach, to study the effect of this lateral stiffness on the response of a 3-D frame, when it is subjected to seismic forces. The analysis method used in STAAD Pro, is the Response Spectrum Method conforming to IS 1893:2002. STAAD PRO is equipped with advanced finite element method and dynamic analysis capabilities. It features rapid analysis, and visualization tools.

A G+4 storey building $[3\ DFrame]$ was analyzed for all possible load combinations (i.e live load, dead load, earthquakes loads). STAAD Pro is user friendly and allows us to easily draw a frame, assign dimensions and thus input geometrical properties of all components along with definition of loads. Then as per the assigned specifications, we analyze the RCC frames.

The model of framed building, consists of length along x-axis is15.65 m, dimension along z-axis is 33 m.The y- axis comprises of G+4 stories. The height of ground floor is 2.25 m and that of the rest of the floors is 3.3 m. The loads to which the structure was subjected were, Dead load, Live load and Seismic loads, which had their calculation basis same as mentioned in IS 875 (Part 1): 1987 and IS1893 (Part 1):2002. The dimensions were assigned to the columns and the beams along with the material specification. The supports at the base of the building are fixed and the code of practice, for the analysis in STAAD Pro.is defined.

Thereafter, the program is run for analysis. It is the post processing mode by which, the deflection of the members is studied, taking into account a suitable load combination. The value of generated internal forces along with the BMDs and SFDs could also be analyzed.

6.2 LOAD TYPE

6.2.1 Dead Load

The dead load comprises of weight due to all structural components of a structure in other words these are the permanent parts of the construction work or rather remain always with the structure. The dead consists of self weight of all structural components like floor, walls, beams, columns, roof etc. also floor finishes, false ceilings, false doors and other permanent constructions in the structure. The unit weight of RCC and Plain concrete made with sand and gravel or crushed natural aggregate are 25 KN/mm^2 and 24 KN/mm^2 respectively as per IS 875. If dimensions of the members are known then we can easily calculate self weights of all members[10]

6.2.2 Imposed Load

Imposed loads are the movable loads or the live loads within a building. They are not permanent construction of a structure. It includes weight of furniture, mobile partitions, vibratory effects, impact loads, point loads and uniform loads.

6.2.3 Earthquake Load

- Design Lateral Force: The lateral seismic force is evaluated for the building as a whole. This force shall then be used for the design of the entire structure. The floor diaphragm action further decides its distribution to horizontal load resisting components.
- Design Seismic Base Shear: The summation of all design lateral seismic forces at the base of the building is referred to as the Design Seismic Base Shear (V_B). The expression for this force as given in IS 1893(Part 1) : 2002, clause no. 7.5.3 is :

$$V_B = A_h W$$

Where,

A_h = Design horizontal acceleration spectrum, using the fundamental natural period T_a , in the direction under consideration.

W = Seismic Weight of the Building.

6.2.4 Fundamental Natural Period

It is the time period with long modal vibration period. The fundamental natural period of vibration (T_a), in seconds of a moment resisting frame building without brick infill is given as:

$T_a = 0.075\ h^{0.75}$ for RCC frame building

$= 0.085\ h^{0.75}$ for steel frame building

Where,

h = height of the building which does not include the basement walls connected to columns of the building or to the ground floor deck. The inclusion of the basement storeys is when they are not connected this way.

In case of moment resisting frame with brick infills , the evaluation of the fundamental period is done by the following empirical formula given in the IS code:

$$T_a = 0.09\frac{h}{\sqrt{d}}$$

Where,

h = height of the building in mm

d = base dimension of the building at the plinth level , in the direction of considered horizontal seismic force.

6.2.5 Distribution of Design Force

The distribution of base shear at different heights of the building is given by the following expression, as per IS 1893:2002.

$$Q_i = V_B \frac{W_i h_i^2}{\sum W_{j} H_j^2}$$

Where,

Q_i = Design lateral force at i^{th}floor,

W_i = Seismic weight of i^{th} floor,

h_i = i^{th} floor height from the base,and

n = no. of storeys in the building, where the weights are positioned.

6.2.6 Dynamic Analysis

Dynamic Analysis is carried out to evaluate the seismic force which is to be used for design and is to be distributed at different floors of the building and also to the other components that resist the horizontal force. The buildings for dynamic analysis are:

a) Regular Buildings: Frame buildings exceeding the height of 40 m in seismic Zones IV and V and the ones in Zones II and III with height greater than 90 m.

b) Irregular Buildings: Frame building in Zones IV and V with height greater than 12 m and with height more than 40 m Zones II and III.

If there lies irregularities in the design of a building then the analytical model thus framed for the prototype shall represent it accurately. Buildings that are not regular in plan cannot be modeled for dynamic analysis. Dynamic method for frame buildings can be carried out by Response Spectrum Method or Time History Method.

If the modes other than the fundamental ones have dominant effect on the behavior of a structure there the Response Spectrum Method is used. Modal response is determined for single degree of freedom system using specified design spectrum. Thus, for a multiple degree of freedom system the various modal responses obtained from SDOF are superimposed to get the resultant response.

6.3 ANALYTICAL STUDY OF G+4 FRAMED BUILDING

In the present study a G+4 Storey framed building has been modeled and eight different cases of the building are prepared, each case with different stiffness. Thus, the effect of stiffness on the dynamic response of the framed building is studied, to draw a suitable conclusion. Figure shows the plan of the building under study. The following screen shots have been taken from STAAD Pro.

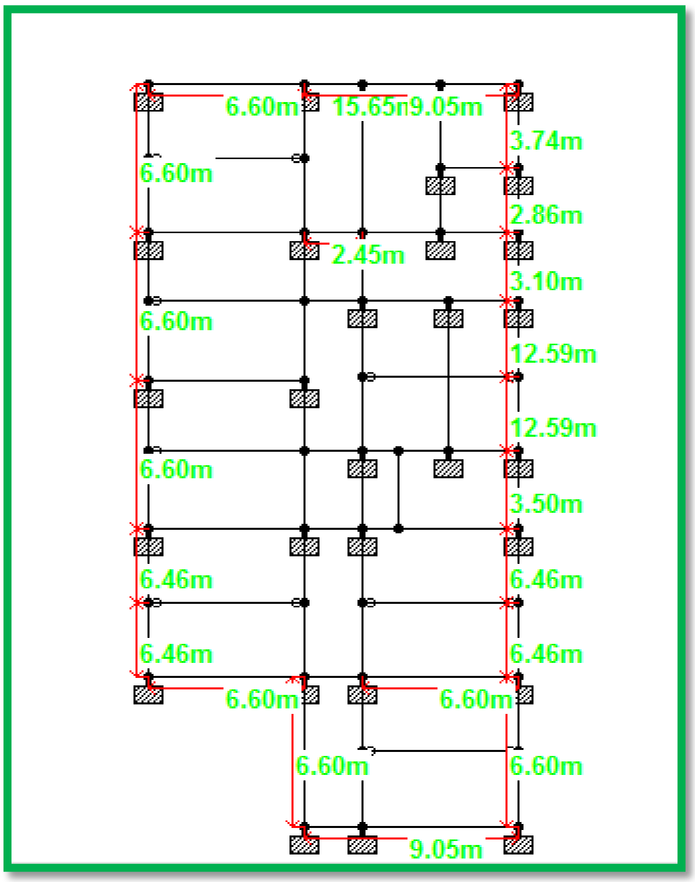


Figure 20: Plan of a G+4 storey framed building.

BEAMS

- Plinth beams: 0.45 m× 0.50 m (prismatic)

0.6 m× 0.30 m (prismatic)

- Type I Beams: 0.6 m × 0.3 m (prismatic)
- Type II Beams: 0.45 m × 0.3 m (prismatic)

COLUMNS

Columns are rectangular in section with dimensions as described below-

- Type A Columns: 0.45 m × 0.6 m
- Type B Columns: 0.6 m × 0.45 m

6.3.1 Characteristics of the Framed Building

Length= 15.65 m along x-axix

Width =   33.0 m along z-axis

Height =15.45 m (height of the ground storey is 2.25 m and that of the other stories is 3.3 m).

Wall load

- Wall load acting as the member load = -14.3 kN/m.
- Wall load as the member load = -8.1 kN/m.
- Wall load acting on the member number "27" = -9.8 kN/m.
- Load acting on roof due to parapet wall = -5.8 kN/m.

Dead Load on the building-

a) Intensity of the floor load acting on the structure is as following-

- Floor load of Type 1 = -4.75 kN/m^2
- Floor load of Type 2 = -14.75 kN/m^2
- Floor load of Type 3 = -8 kN/m^2

b) Dead load acting as the member load-

- Member load 1 = -18.6 kN/m.
- Member load 2 = -24.0 kN/m.

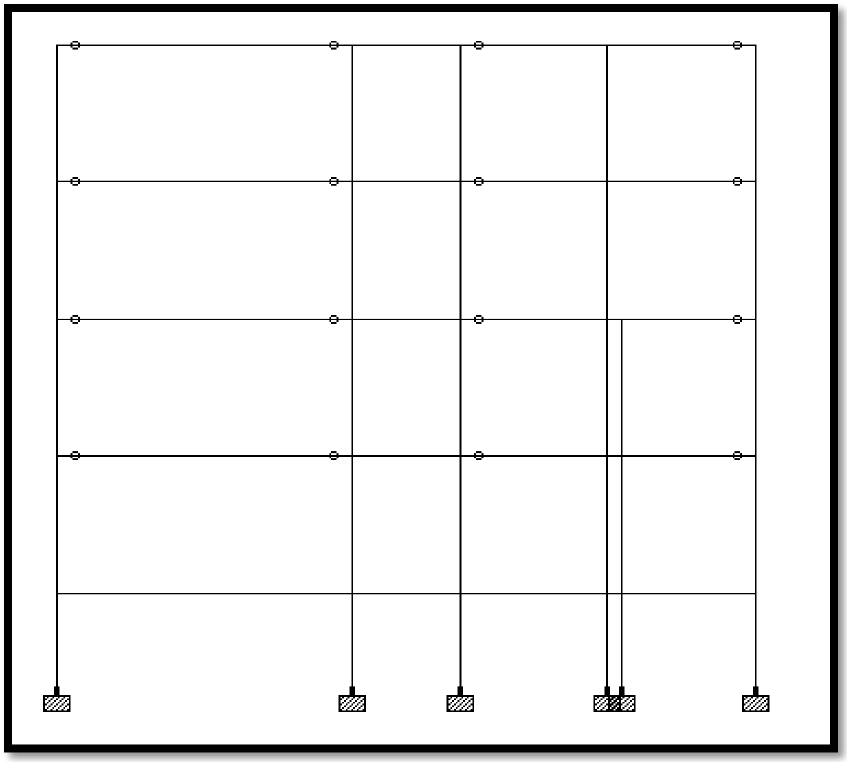


Figure 21: Elevation of a G+4 storey framed building.

Live load on the building-

a) Intensity of the floor load on the building is following-

- Floor load of Type A = - 3 kN/m^2.
- Floor load of Type B = - 1 kN/m^2.
- Floor load of Type C = - 2 kN/m^2.
- Live load on the roof = - 1.5 kN/m^2.

b) Live load as a member load, on the building is as following-

- Member load of Type I = -10 kN/m.
- Member load of Type II = -13.2 kN/m.

6.3.2 Defining Sectional Properties

Member property is allocated in order to define the type of section of the members of the building and also the material type which is to be assigned to the member. Member property could be generated in STAAD Pro. by using the sub tab "property" in the window of the program. The section of beams and columns has already been discussed in previous section.Prismatic beams and columns have been used.

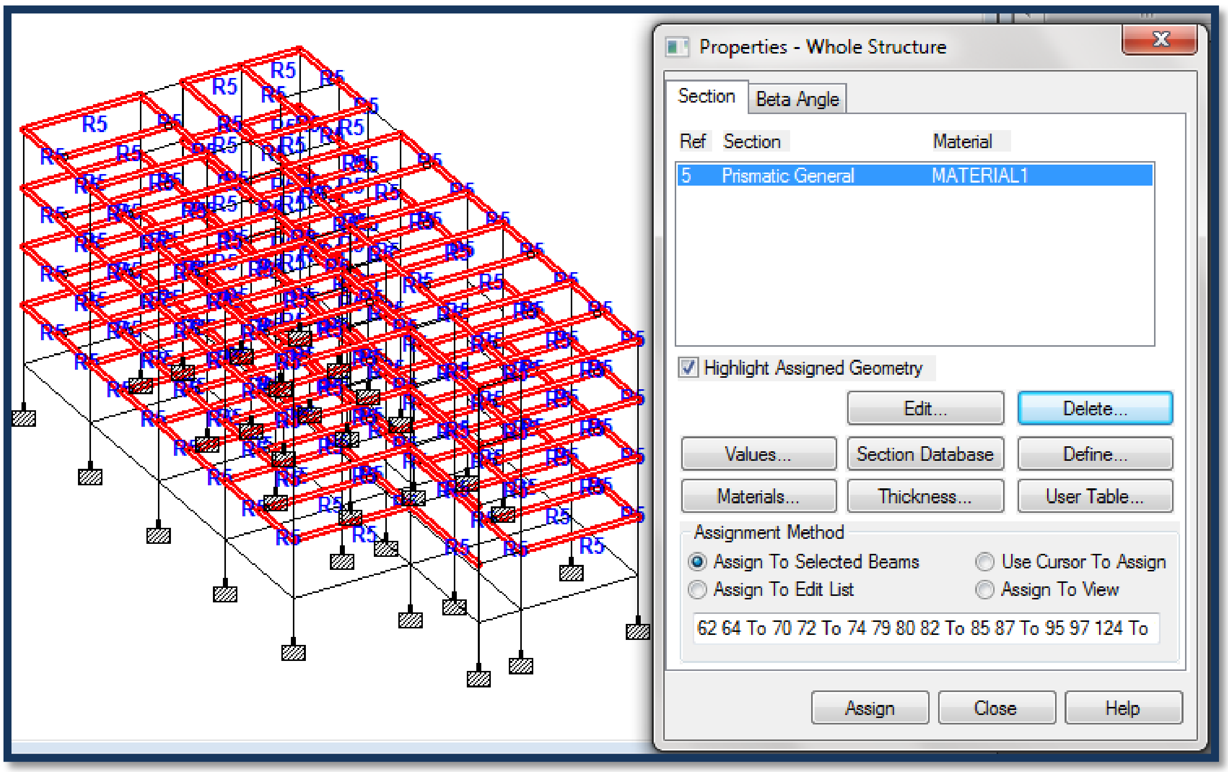


Figure 22: Assign sectional properties to the members

6.3.3 Assigning Supports

The base of the building is provided with a fixed support. This fixed support is assigned to the building. The supports are generated and allocated to the base of the building using the tab "General" and then the sub tab "Support".

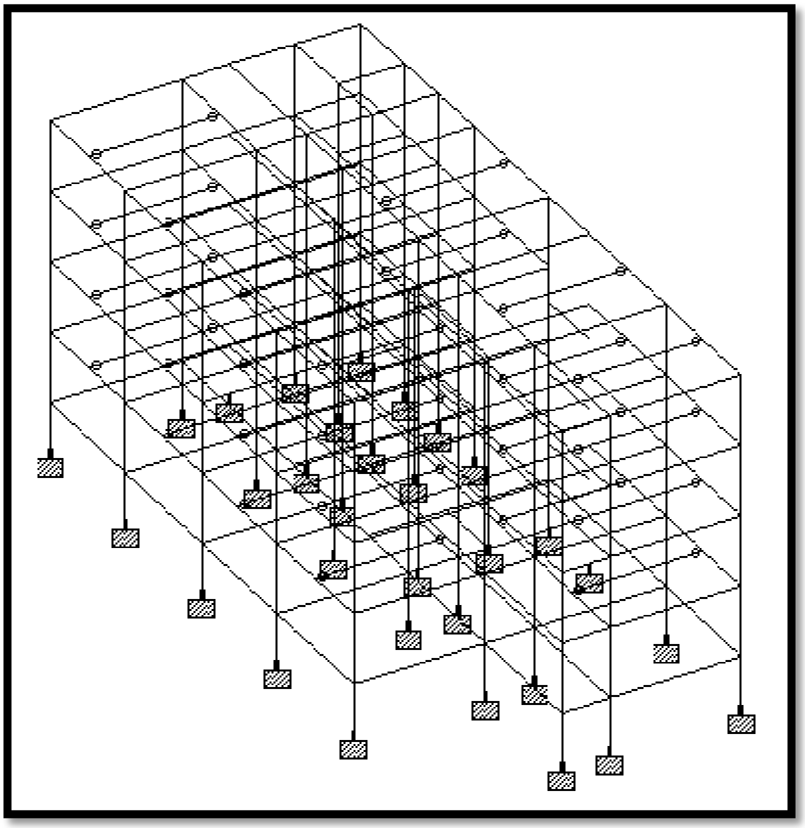


Figure 23: Fixed supports at the base.

6.3.4 Specification of the Type of Material

The types of material used for the structure or the structural components are specified, along with the values of constants as per the Indian Standard Code.

6.3.5 Generation of Loads

Loads are assigned to the structure and its members by using the load generator in STAAD Pro. In STAAD the categories of load are defined. The types of loads which has been used in analysis are as following-

a. Dead load.
b. Live load.

c. Self weight.

d. Wall load

e. Load combinations.

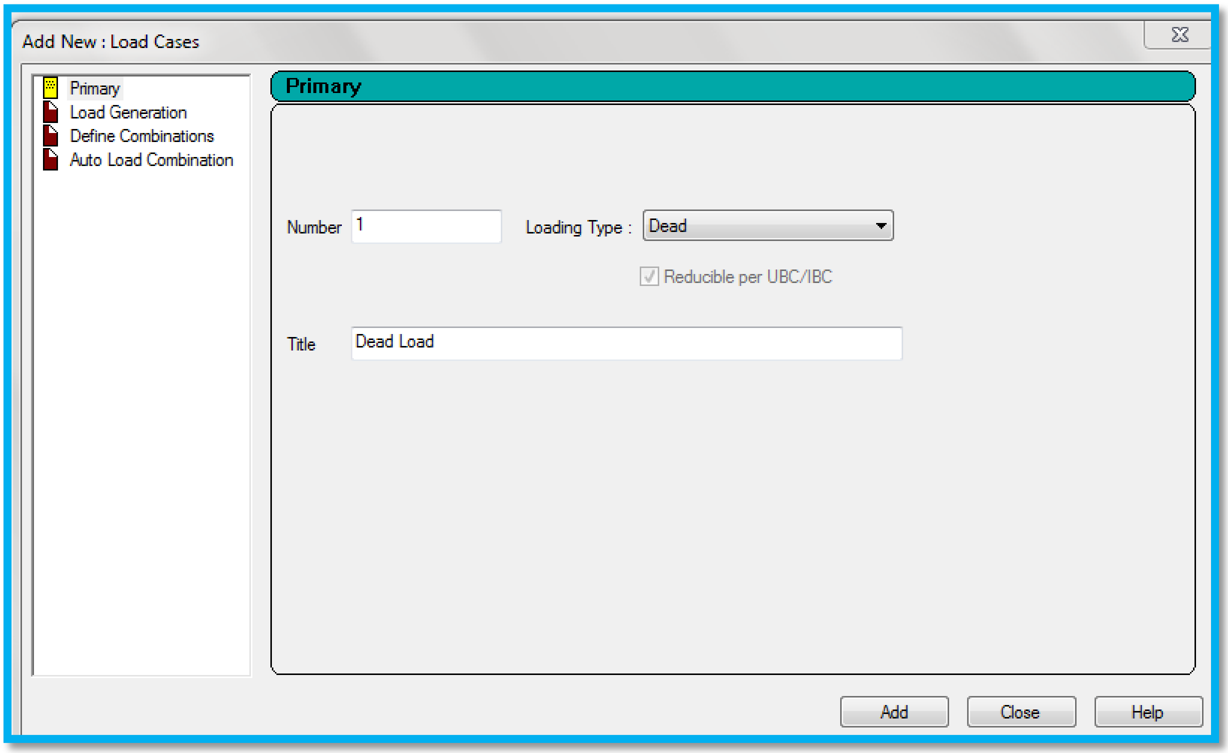


Figure24: Primary load cases

6.3.6 Dead load

It may include the floor load or member load. The dead load comprises of weight due to all structural components of a structure. The building has been subjected to various intensities of floor loads, which have different range of actions. Floor loads are -14.75 kN/m^2, -8 kN/m^2, and -4.75 kN/m^2. Dead loads acting as member loads are of magnitude, -24 kN/m and -18.6 kN/m. Figure shows the dead load acting on the framed building.

6.3.7Live Load

The live load applied on the framed building is of different intensities. Live load on roof is -1.5 kN/m^2. Live load as a floor load is of intensities -1 kN/m^2, -2 kN/m^2,and -3 kN/m^2. Live load as a member load is of magnitude -10 kN/m , -13.2 kN/m.

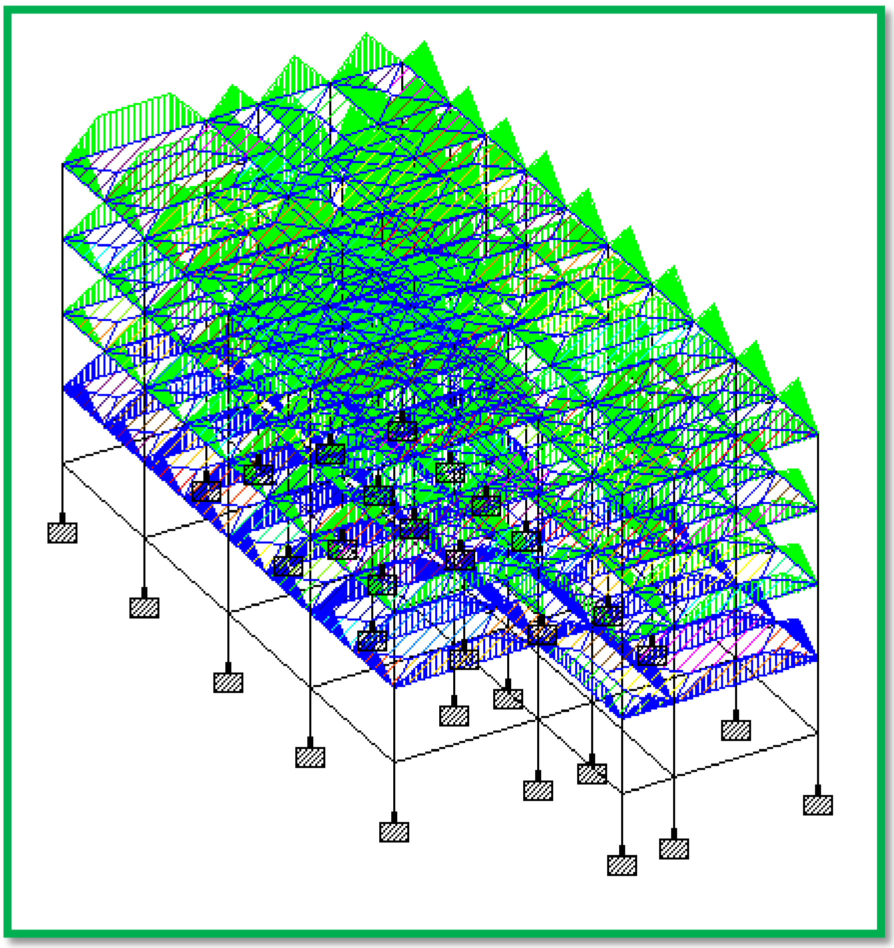


Figure 25: Dead load as floor load and member load on the structure.

6.3.8 Selfweight

Self weight is generated by the software itself by defining the primary load case, as the self weight in the "load & definition" tab.Self weight is the loading due to all structural components of the framed building.

6.3.9 Wall Load

Loading due to wall is distributed to the members .The wall load which has been considered is shown in figure (26).Wall load acting as the member load is of magnitude, -8.1 kN/m and -14.3 kN/m. parapet wall load is considered as -5.8 kN/m

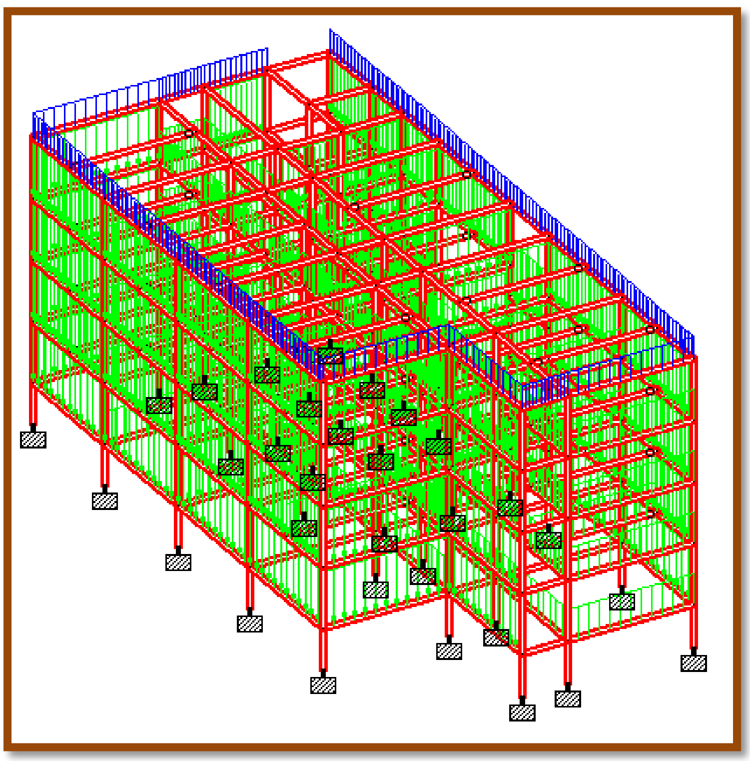


Figure 26: Wall load acting as the member load on the building.

6.3.10 Seismic Load

The earthquake forces are calculated following the guidelines, mentioned in IS 1893(Part I):2002. The software can generate seismic force provided that, the code which is to be followed, is defined. The lateral seismic forces are generated in the two horizontal directions i.e. X and Z directions.

$$V_B = A_h W$$

Where,

A_h = Design horizontal acceleration spectrum, using the fundamental natural period T_a, in the direction under consideration.

W = Seismic Weight of the Building.

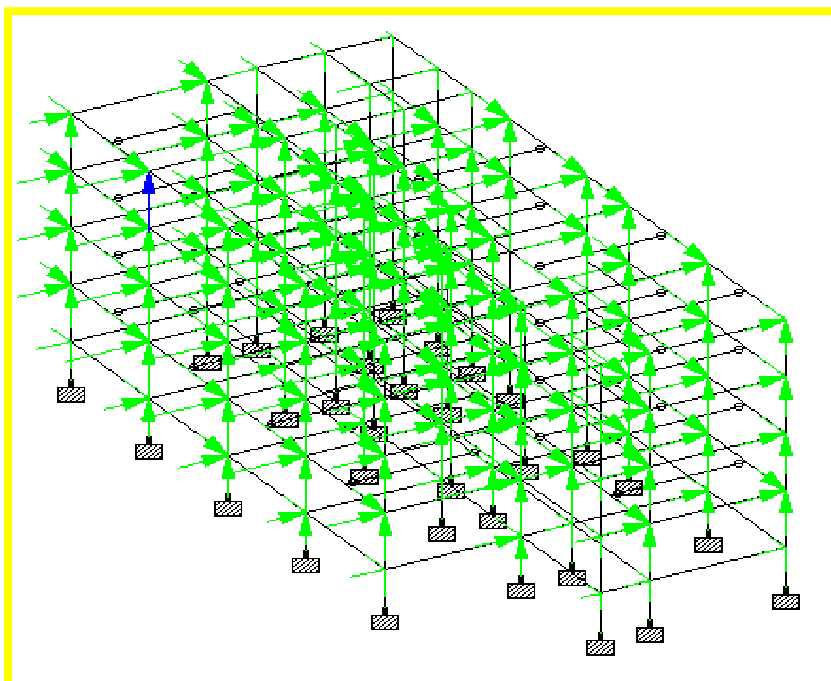


Figure 27: Seismic forces as generated by STAAD Pro.

6.3.11 Load Combination

The analysis of the structure proceeds with the consideration of the load combinations. The various loads like the dead load, live load, wall loads, seismic loads etc. are considered in a proper proportion and thus the structure is analyzed using the load cases which are the combinations of these.

CHAPTER 7

RESULTS AND CONCLUSION

In this project work, a G+4 storey framed building has been analyzed. There are eight different cases of the same building such that each case represents the percentage increase in the stiffness of all its columns by 5%. Thus, with the change in stiffness parameter, the variation in the building model for base shear, peak storey shear, storey displacement, mass participation factor, natural frequency and time period is studied.

The results obtained for different cases of the building model have been shown graphically. Stiffness has been increased by increasing the moment of inertia about X-axis, such that the areas of cross-section of the columns remain the same. This leads to an increase in the stiffness of the framed building, but more or less the mass of the framed building remains the same.

7.1BRIEF OF BUILDING CASES

The building cases are obtained by changing the moment of inertia of the building model. The different cases of the building model have been discussed below, along with the requisite output parameters which are required to make a comparative study between different cases of the model. The original building has two type of geometry assigned to all the columns of the framed building. The following table shows the different cases which are to be analyzed. The original building model has, all the columns of two cross sections, i.e. 0.45 m × 0.60 m and 0.60 m× 0.45 m. Table no. shows the different cases of the building model which are obtained by an increment in stiffness of all the columns by 5%. The sectional properties of columns in the considered cases of the building model have been shown in tabular form in the next page.

7.2 STOREY DISPLACEMENT

Storey displacement of a building corresponds to the lateral displacement of a particular storey when subjected to seismic forces. In STAAD Pro. each storey is divided into a number of nodes, such that each node displaces when subjected to the seismic force. To study the whole storey displacement, a master node is selected in a manner such that, itis close to the centre of mass and to a close extent represents the behavior of the storey as a whole. The rest of the nodes are selected as the slave nodes, which means that they will show a displacement same as that of the master node. The graphical results obtained for different stories while taking into consideration the different cases of the building model, have been discussed as following.

Table 3: Different cases of the building model

CASE No.	Column (Type 1)	Column (Type 2)	% Increase in Stiffness
I	0.47 m × 0.57 m	0.63 m × 0.43 m	5
II	0.49 m × 0.54 m	0.66 m × 0.40 m	10
III	0.52 m × 0.51 m	0.69 m × 0.38 m	15
IV	0.54 m × 0.48 m	0.72 m × 0.36 m	20
V	0.56 m × 0.45 m	0.75 m × 0.33 m	25
VI	0.58 m × 0.42 m	0.78 m × 0.31 m	30
VII	0.60 m × 0.40 m	0.81 m × 0.29 m	35
VIII	0.63 m × 0.36 m	0.84 m × 0.27 m	40

7.2.1 Results for Ground Storey

The results are obtained for displacement of the storey in x and z axes. These results are for load case 1(EQX).Figure 28 and Figure 29 , shows the graphical representation of displacement in x and z axes respectively. It is general trend that, if the stiffness increases along a certain direction then the displacement along that direction decreases.

Table 4: Displacement in x direction (mm)

First storey displacement		
S.No.	Increase in stiffness (%)	Displacement in x direction(mm)
1	5	1.59
2	10	0.75
3	15	0.69
4	20	0.65
5	25	0.63
6	30	0.62
7	35	0.59
8	40	0.58

As the stiffness increases about x-axis it is seen that the lateral displacement shows a decreasing trend. The graphical representation of the data in table 4 has been plotted on the next page.

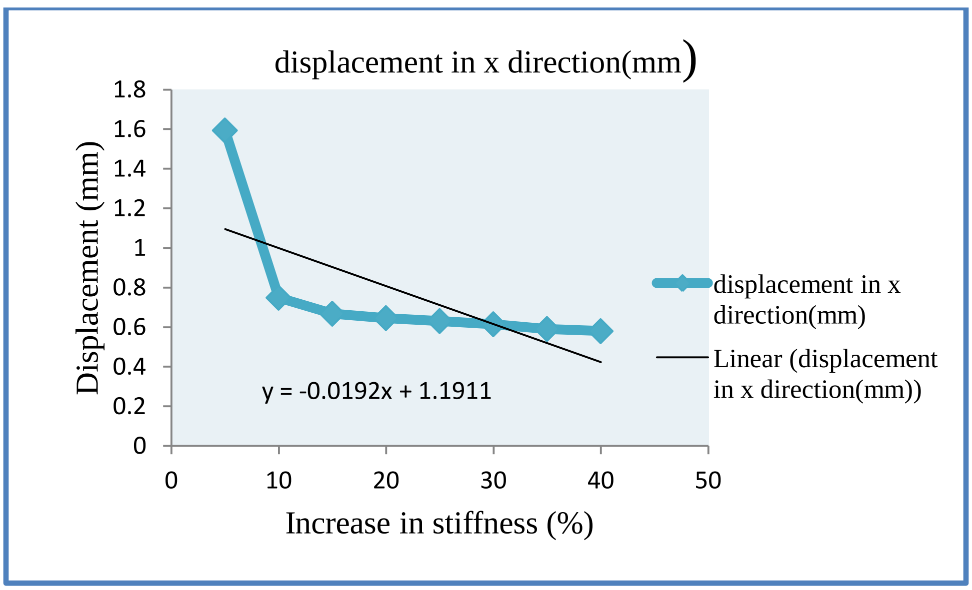


Figure 28:Displacement in x direction (mm)

The equation for trend line obtained, is shown in the graph itself, it clearly depicts that as the stiffness increases about x axis the displacement in x direction decreases.

As the stiffness increases about x-axis it is seen that the lateral displacement shows an increasing trend in the z direction.

Table 5:Displacement in z direction (mm)

First storey displacement		
S.No.	Increase in stiffness (%)	Displacement in z direction(mm)
1	5	1.52
2	10	0.74
3	15	0.84
4	20	1.01
5	25	1.23
6	30	1.43
7	35	1.52
8	40	1.74

In first three cases the displacement along z direction decreases but thereafter an increment in storey displacement along z –axis is observed.

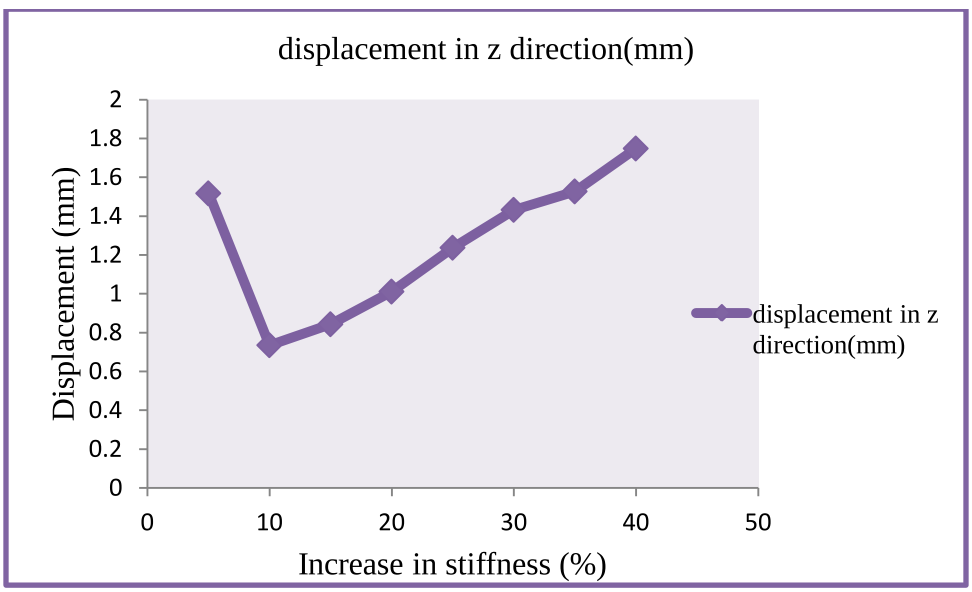


Figure 29:Displacement in z direction (mm)

7.2.2 Results for Second Storey

The results are obtained for displacement of the storey in x and z axes. These results are for load case 1(EQX).Figure 30 and Figure 31 , shows the graphical representation of displacement in x and z axes respectively.

Table 6:Displacement in x direction (mm)

Second storey displacement		
S.No.	increase in stiffness %	Displacement in x direction(mm)
1	5	6.72
2	10	3.13
3	15	2.74
4	20	2.62
5	25	2.55
6	30	2.46
7	35	2.34
8	40	2.25

The graph plotted for the second storey displacement, shows that along x-direction displacement is decreasing.

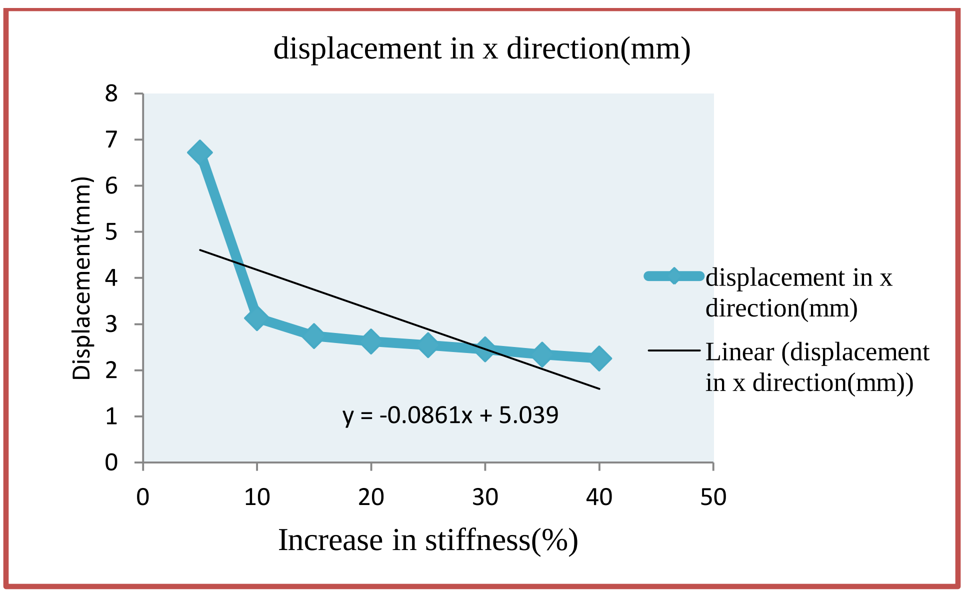


Figure 30: Displacement in x direction(mm)

As the stiffness increases about x-axis it is seen that the lateral displacement shows initially decreasing,then an increasing trend in the z direction.

Table 7:Displacement in z direction (mm)

Second storey displacement		
S.No.	Increase in stiffness (%)	Displacement in z direction(mm)
1	5	6.24
2	10	2.87
3	15	3.07
4	20	3.51
5	25	4.31
6	30	5.12
7	35	5.56
8	40	6.48

In first two cases the displacement along z direction decreases, but thereafter an increment in storey displacement along z –axis is observed.

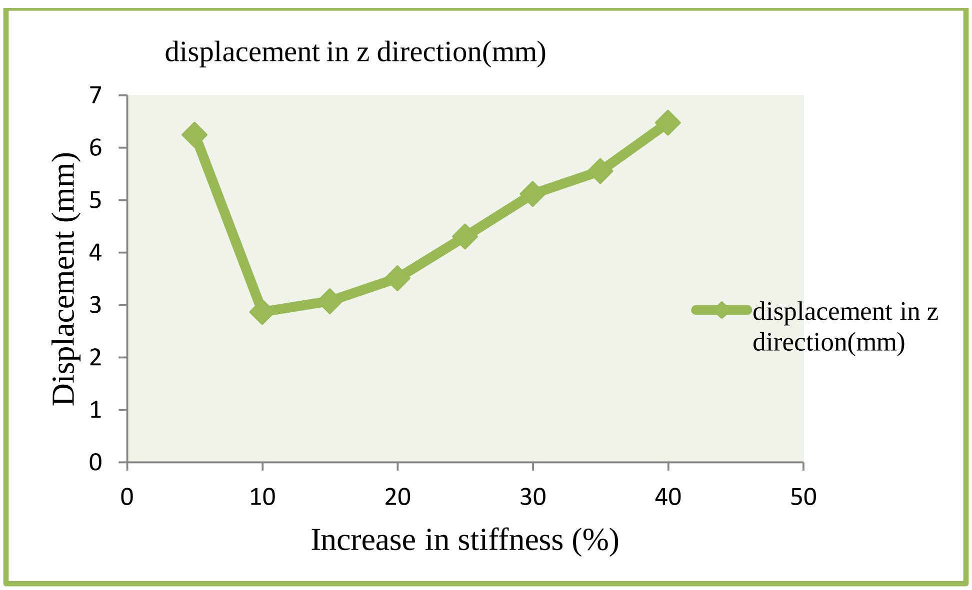


Figure 31: Displacement in z direction (mm)

7.2.3 Results for Third Storey

The results are obtained for displacement of the storey in x and z axes. These results are for load case 1(EQX).Figure 32 and Figure 33, shows the graphical representation of displacement in x and z axes respectively.

Table 8: Displacement in x direction (mm)

Third storey displacement		
S.No.	Increase in stiffness (%)	Displacement in x direction(mm)
1	5	10.05
2	10	4.47
3	15	4.21
4	20	4.05
5	25	3.94
6	30	3.82
7	35	3.62
8	40	3.57

Displacement changes suddenly in the first two cases and thereafter the change is not that abrupt.

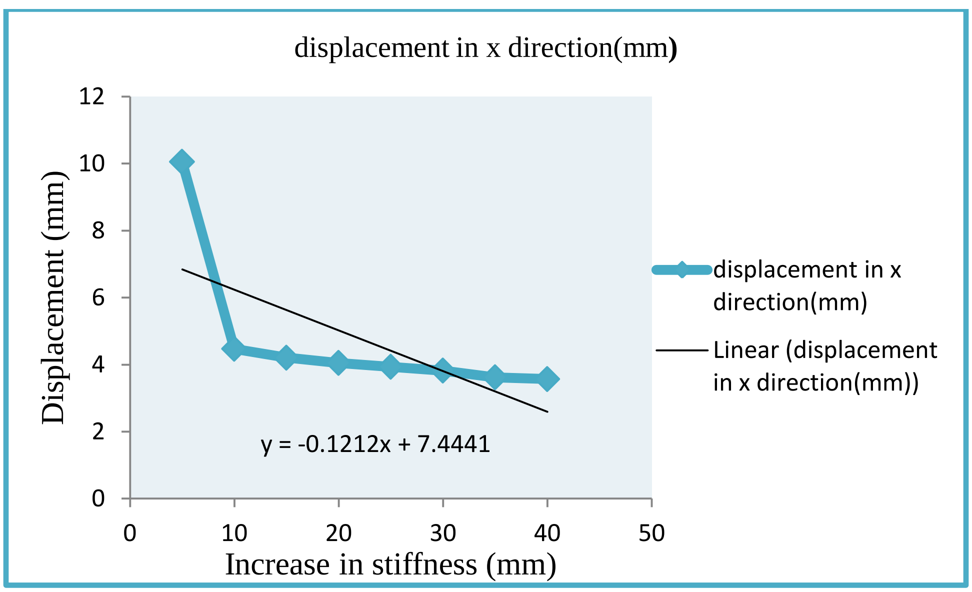


Figure 32: Displacement in x direction (mm)

As the stiffness increases about x-axis it is seen that the lateral displacement shows an increasing trend in the z direction.

Table 9: Displacement in z direction (mm)

Third storey displacement		
S.No.	Increase in stiffness (%)	Displacement in z direction(mm)
1	5	11.53
2	10	5.87
3	15	5.97
4	20	6.80
5	25	8.60
6	30	9.27
7	35	9.81
8	40	11.13

In first two cases the displacement along z direction decreases, but thereafter an increment in storey displacement along z –axis is observed.

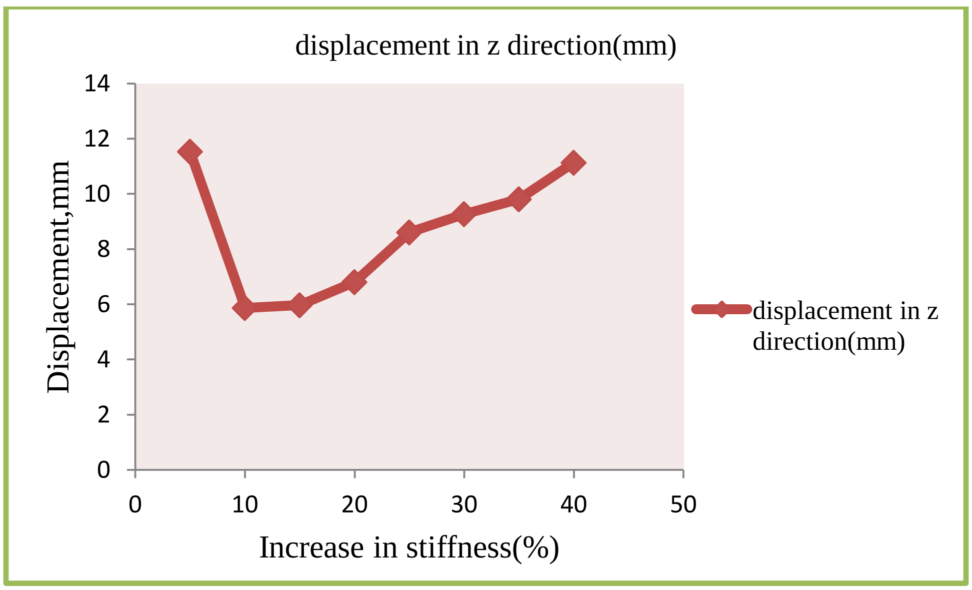


Figure 33: Displacement in z direction (mm)

7.2.4 Results for Fourth Storey

The results are obtained for displacement of the storey in x and z axes. These results are for load case 1(EQX).Figure 34 and Figure 35 , shows the graphical representation of displacement in x and z axes respectively.

Table 10: Displacement in x direction (mm)

Fourth storey displacement		
S.No.	Increase in stiffness (%)	Displacement in x direction(mm)
1	5	10.46
2	10	6.60
3	15	5.85
4	20	5.60
5	25	5.43
6	30	5.24
7	35	4.99
8	40	4.81

As the stiffness increases about x-axis it is seen that the lateral displacement shows a decreasing trend. The graphical representation of the data in Table 10 has been plotted on the next page.

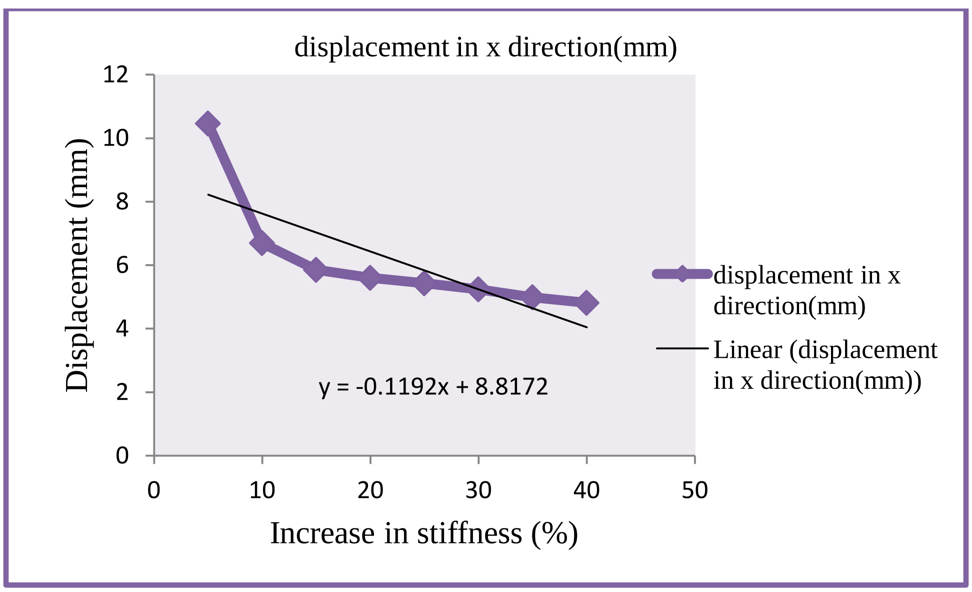


Figure 34: Displacement in x direction (mm)

As the stiffness increases about x-axis it is seen that the lateral displacement shows an increasing trend in the z direction.

Table 11: Displacement in z direction (mm)

Fourth storey displacement		
S.No.	Increase in stiffness (%)	displacement in z direction(mm)
1	5	11.85
2	10	5.94
3	15	6.84
4	20	8.23
5	25	10.07
6	30	11.63
7	35	12.36
8	40	14.06

In first two cases the displacement along z direction decreases, but thereafter an increment in storey displacement along z –axis is observed.

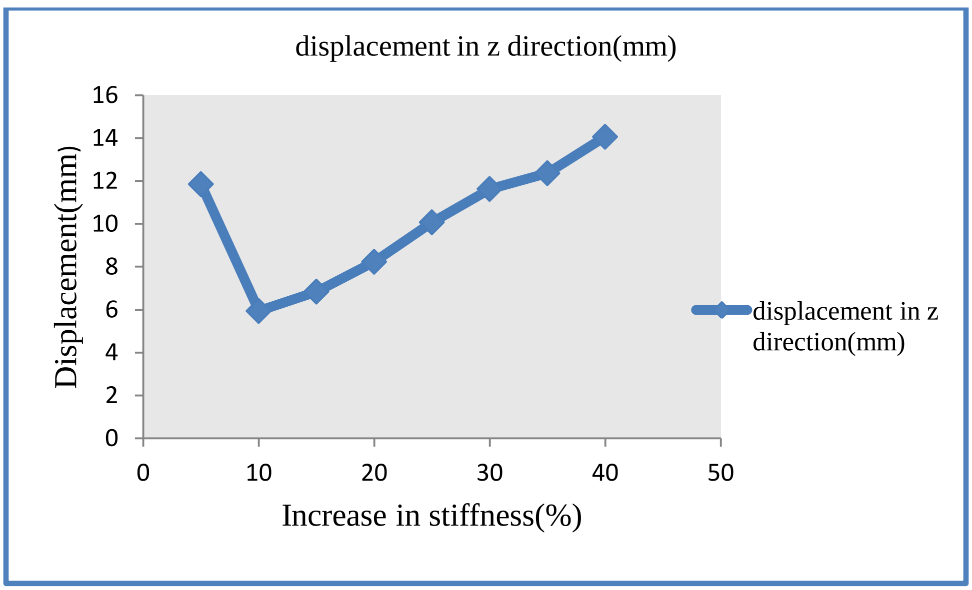


Figure 35: Displacement in z direction (mm)

7.2.5 Results for Fifth Storey

The results are obtained for displacement of the storey in x and z axes. These results are for load case 1(EQX).Figure 36and Figure no 37, shows the graphical representation of displacement in x and z axes respectively.

Table 12: Displacement in x direction (mm)

Fifth storey displacement		
S.No.	Increase in stiffness (%)	Displacement in x direction(mm)
1	5	10.907
2	10	7.469
3	15	6.526
4	20	6.247
5	25	6.057
6	30	5.846
7	35	5.568
8	40	5.371

The equation for trend line obtained is shown in the graph itself. It clearly depicts that as the stiffness increases, about x axis, the displacement in x direction increases.

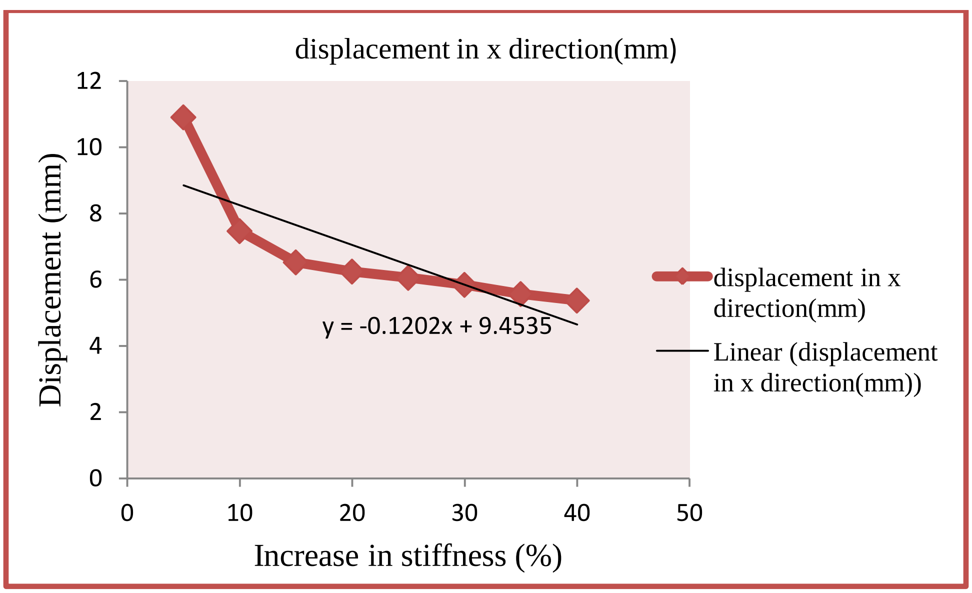


Figure 36: Displacement in x direction (mm)

As the stiffness increases about x-axis it is seen that the lateral displacement shows an increasing trend in the z direction.

Table 13: Displacement in z direction (mm)

Fifth storey displacement		
S.No.	Increase in stiffness (%)	Displacement in z direction(mm)
1	5	12.28
2	10	6.56
3	15	7.37
4	20	8.71
5	25	10.69
6	30	12.48
7	35	13.37
8	40	15.36

In first two cases the displacement along z direction decreases, but thereafter an increment in storey displacement along z –axis is observed.

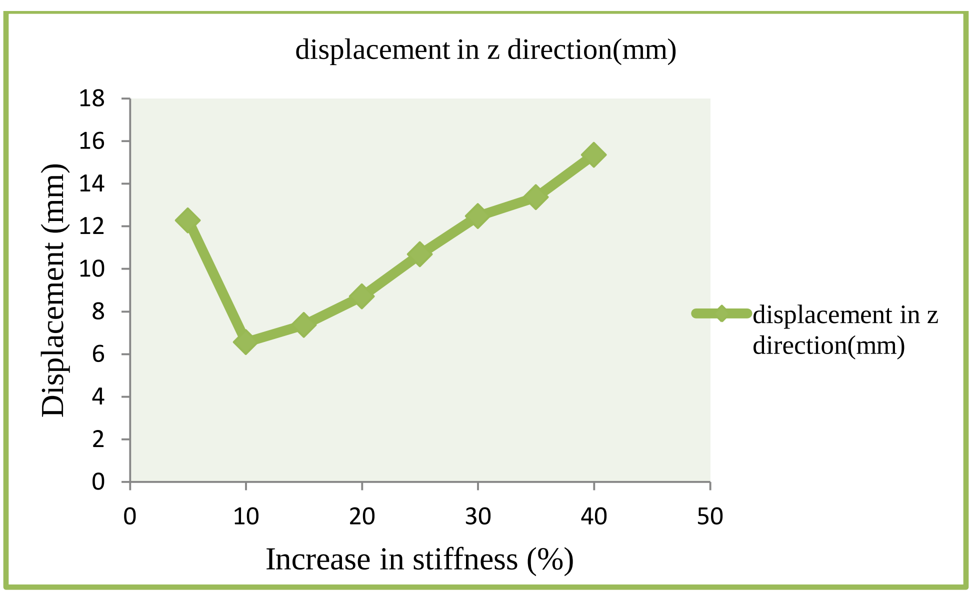


Figure 37: Displacement in z direction (mm)

7.3 FREQUENCY

The frequency of a structure is expressed in cycles/second. It is the number of vibrations per second by a structure when subjected to a seismic force. As, the structure grows more stiff its frequency increases. For the different cases of the building model, the graph for natural frequency has been plotted.The graph has been plotted for the load case I (EQX), and mode1

Table 14:Variation in the frequency of the building model with % increase in stiffness.

Mode 1		
For load case 1(EQX)		
S.No.	% Increase in stiffness	Natural frequency (cycles/second)
1	5	1.9
2	10	2.0
3	15	2.1
4	20	2.2
5	25	1.9
6	30	1.7
7	35	1.6
8	40	1.4

In mode 1, the natural frequency of the test model increases in first four cases. Thereafter, a decrement in its value is recorded for further cases.

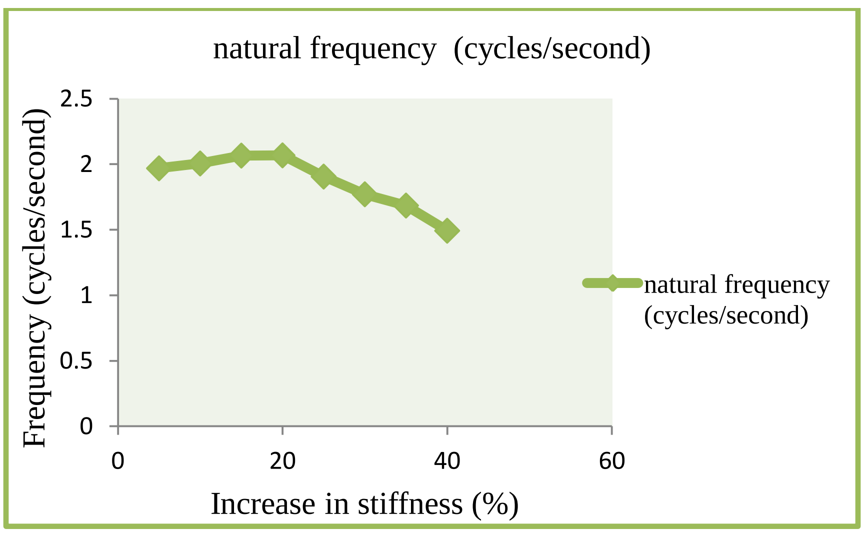


Figure 38: Variation of natural frequency with %increase in stiffness.

7.4 TIME PERIOD

The time period of any structure is the time taken by a structure to complete one cycle of vibration when subjected to a seismic force. As the stiffness increases, it is observed that the time period decreases. For the building model ,which is a G+4 storey framed building, with varied cases,it is observed that in the first four cases the time period decreases with percentage increase in stiffness, while in other cases the trend is increasing upwards.

Table 15:Variation of time period with % increase in stiffness

Mode 1		
For load case 1(EQX)		
S.No.	% Increase in stiffness	Time period (seconds)
1	5	0.51
2	10	0.50
3	15	0.40
4	20	0.48
5	25	0.52
6	30	0.56
7	35	0.59
8	40	0.67

Graphical representation of time period in Figure 39. The mode of vibration that has been taken consideration is mode 1 and load case is 1 (EQX).

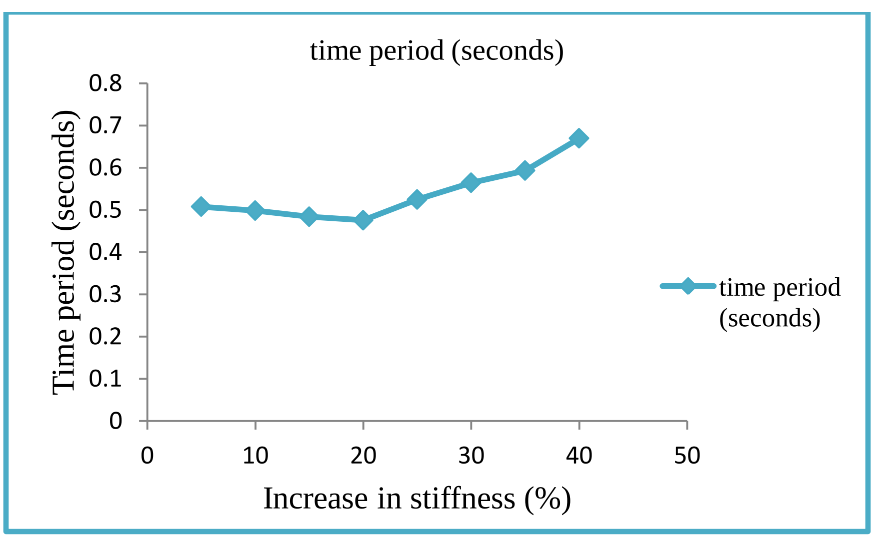


Figure 39: Variation of time period with % increase in stiffness.

7.5 MASS PARTICIPATION FACTOR

The contribution of a certain mode of vibration in the dynamic analysis of a framed building is decided by the effective modal mass corresponding to that mode. From the studies, it is observed, that as the stiffness increases there is an increase in mass participation factor. In this project work i.e. the dynamic analysis of G+4 storey, it is observed that as the stiffness of the model increases there is increase in mass participation factor

Table 16: % variation in the mass participation factor (in x-direction)

Mass participation factor		
Mode 1		
S.No.	Increase in stiffness%	Cumulative mass participation in x (%)
1	5	63.31
2	10	65.78
3	15	68.78
4	20	71.00
5	25	73.12
6	30	75.05
7	35	77.45
8	40	78.99

As, the stiffness of the building model increases there is increase in mass participation factor (in X- direction).

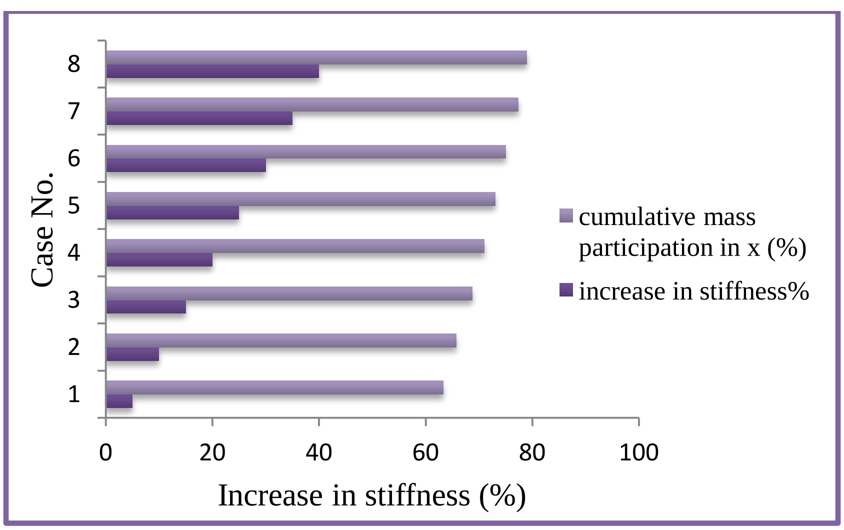


Figure 40: Bar chart depicting the % variation in mass participation factor in x-direction.

It is observed that there is a decrease in the percentage variation in mass participation factor. As, the stiffness increases about x-axis therefore, this variation in z-direction is expected. The result obtained for cumulative mass participation factor (%) in z-direction is represented in tabular form in table number 17.

Table 17: % variation in the mass participation factor (in x-direction).

Mass participation factor		
Mode 1		
S.No.	Increase in stiffness(%)	Cumulative mass participation in z (%)
1	5	1.13
2	10	0.78
3	15	0.49
4	20	0.34
5	25	0.24
6	30	0.16
7	35	0.09
8	40	0.05

It is seen that the effective modal mass in z- direction, which contributes in dynamic analysis, is very less and as the stiffness increases, about x-axis, the contribution of modal mass goes on decreasing. Figure 41, depicts the percentage variation in mass participation with the percentage increase in stiffness.

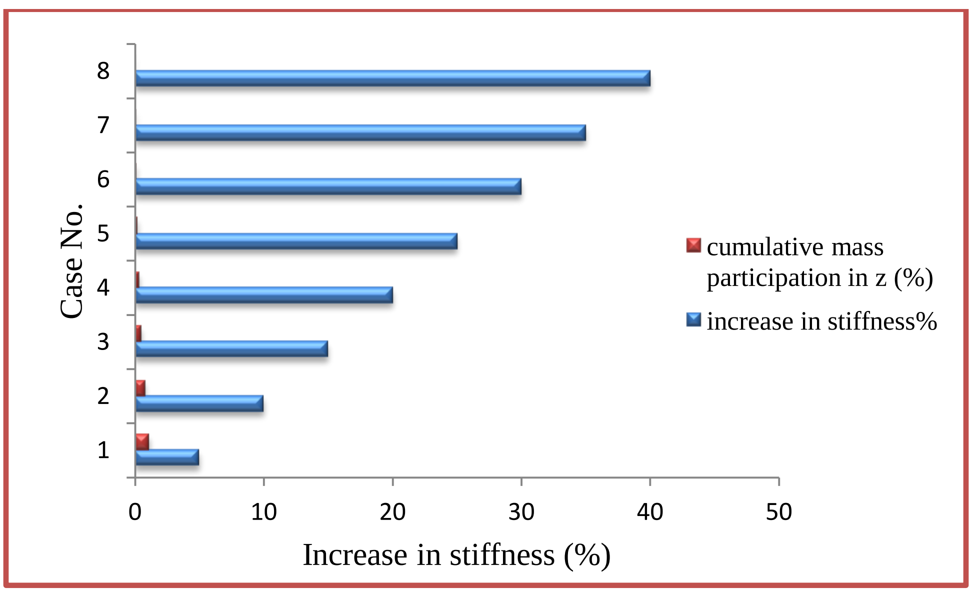


Figure 41: Bar chart depicting the % variation in mass participation factor in z-direction.

7.6 BASE SHEAR

Total horizontal force at the base of the building is referred to as the base shear. It is expressed in kN. For the present case, a G+4 storey building is analyzed, to study the variation in base shear in both x and z direction with percentage increase in stiffness. The base shear is observed once in x-direction by considering load case1 (EQX) and then in z-direction for load case 2 (EQZ).

7.6.1 Base Shear in X-Direction

As there is percentage increase in the stiffness of the building, it is expected that the base shear shall increase but since the mass of the building is more or less the same, therefore the base shear in the building shall not show a considerable variation. In the present work analysis of the structure is done for the load case1 (EQX), thus base shear is observed in x-direction. The base shear is observed for the vibrational mode 1. Table 18 shows the variation of base shear with the percentage increase in stiffness in x-direction.

Table 18: Variation in the base shear with percentage increase in stiffness (in x-direction).

Base shear		
Response load case 1(EQX)		
Mode 1		
S.No.	Increase in stiffness (%)	Base shear in x (kN)
1	5	1169.72
2	10	1194.87
3	15	1205.08
4	20	1212.93
5	25	1213.76
6	30	1203.19
7	35	1201.93
8	40	1197.03

The analytical study shows that the base shear in the building model increases for the first five cases but for the rest of the three cases, a decrement in the value of the base shear in x-direction is observed. However this kind of behavior is unknown.

The graphical representation of the base shear in x-direction with respect to increase in stiffness has been shown in figure. For the first five cases the slope of the graph increases, thereafter it goes down. It is also seen that, there not a considerable change in the base shear, as, the cases considered for the test model have almost the same cross sectional area of the columns, the only difference lies in the moment of inertia of the columns about a particular axis.

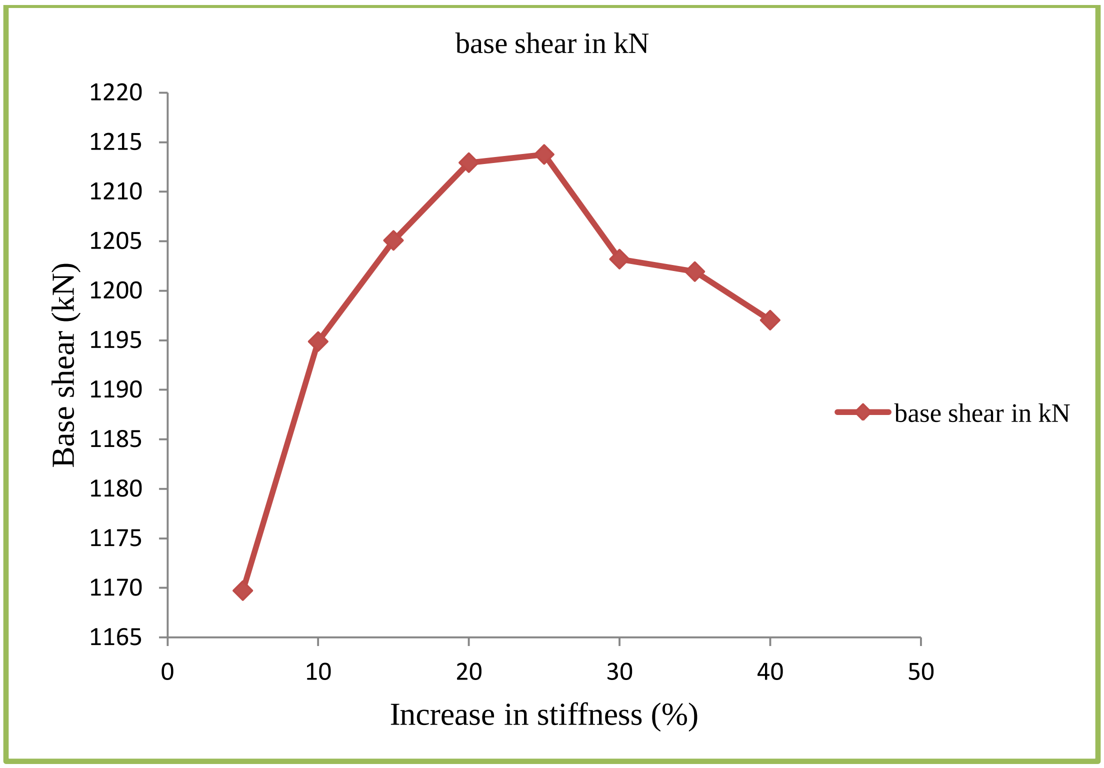


Figure 42: Variation in base shear in x-direction, with % increase in stiffness.

7.6.2 Base Shear in Z-Direction

To observe the variation in base shear in z-direction, load case 2 (EQZ) is considered. As, the stiffness increases in the x-direction, therefore base shear is observed to be decreasing as the percentage variation in the stiffness of the model increases. The result is presented in the tabular form in Table 19. The base shear has been studied for the vibration mode 1.

Table 19:Variation in the base shear with percentage increase in stiffness (in z-direction).

Base shear		
Response load case 2 (EQZ)		
Mode 1		
S.No.	Increase in stiffness (%)	Base shear in kN
1	5	20.84
2	10	14.16
3	15	8.61
4	20	5.86
5	25	5.45
6	30	3.97
7	35	2.6
8	40	1.37

Figure shows the graphical representation of the variation of base shear in z direction with percentage increase in the stiffness of G+4 storey building.

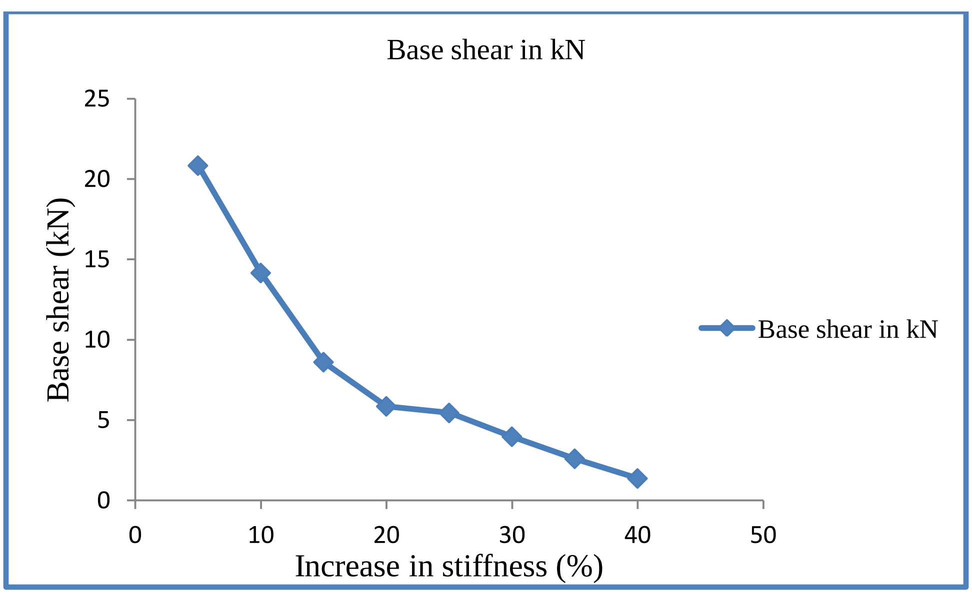


Figure 43: Variation in base shear in z-direction, with % increase in stiffness.

7.7 Peak Storey Shear

The peak storey shear force (V_i) in storey i due to all modes considered is obtained by combining those due to each mode as per SRSS. If the building does not have closely spaced modes, than the peak response quantity due to all modes considered shall be obtained as per Square Root of Sum of Square method.

Table 20 :Peak storey shear in x-direction (kN)

Peak storey shear in x-direction (kN)					
Load case 1 (EQX)					
Case	1st storey shear (kN)	2nd storey shear (kN)	3 rdstorey shear (kN)	4th storey shear (kN)	5th storey shear (kN)
I	1383.38	1353.27	1158.24	868.22	460.00
II	1997.52	1956.44	1660.85	1221.35	596.87
III	1968.38	1927.38	1637.2	1198.88	586.34
IV	1984.6	1943.1	1651.38	1206.71	590.34
V	1996.86	1954.92	1662.07	1212.99	593.71
VI	1996.67	1954.55	1662.81	1210.98	593.46
VII	1997.33	1954.73	1663.66	1209.67	593.35
VIII	1999.88	1956.98	1667.01	1208.67	593.34

Peak Storey Shear is maximum at the first storey and decreases with increase in the storey height. As the stiffness is increased, a net increase in peak storey shear is observed in a particular storey for different cases.

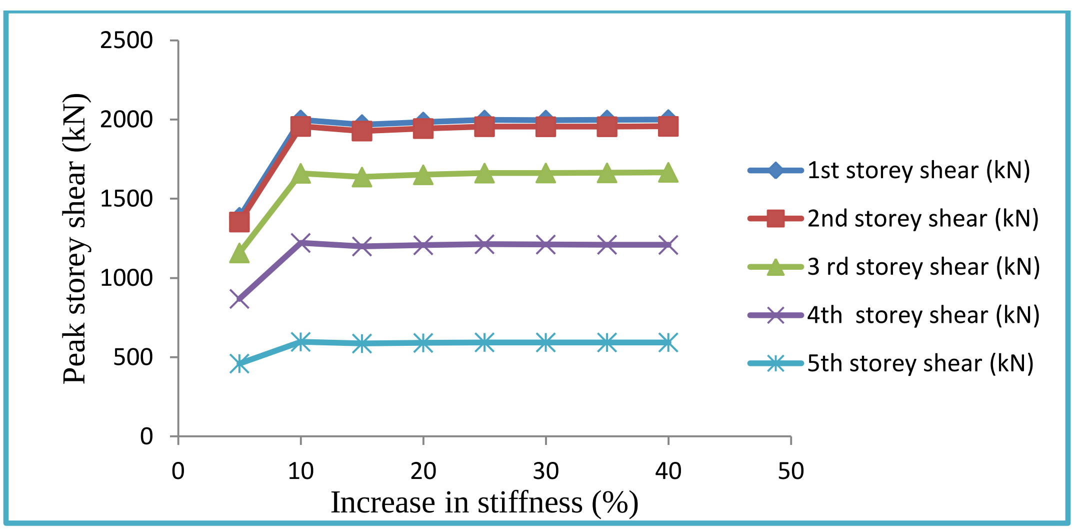


Figure 44: Variation in peak storey shear, in different stories, with % increase in stiffness.

7.8 CONCLUSION

In the present work a G+4 storey building was analyzed for seismic force. The different cases of the framed building were taken into consideration. Various cases of the building model have an increasing order of stiffness. Following conclusion may be drawn after the analysis-

1. When the stiffness of the building is increased along x-axis, it is observed that the storey displacement in the respective direction decreases.
2. The storey displacement in z-direction is observed to be increasing. The cause behind such behavior could be the decrease in the stiffness of the building in the z-direction due to the condition of keeping the same cross sectional area of columns.
3. The frequency of a structure increases, as it grows stiffer. In the present building model, with increasing cases of stiffness, it was observed that natural frequency increases initially for certain cases, and then the rate of increase changes.
4. The time period for the framed building is also appropriately affected due to the changes in the stiffness.
5. The base shear of the building goes on increasing as the stiffness of the framed building increases. For later cases of increase in stiffness, a minor decrement in value of base shear is also observed. However, this change in the value of base shear is not significant. Since, the mass of the building remains almost unchanged, thus a considerable change in the base shear of the building is not realized. The results of decreasing base shear, for increment lateral stiffness could be because of irregular geometry of the framed building.
6. The mass participation of the building is also affected. It increases in the x-direction, as the lateral stiffness for various cases of the building model goes on increasing in the x-direction.
7. The peak storey shear is maximum at the first storey level, and it decreases with the storey number. It is observed that, as the stiffness of the building model increases, it attracts more seismic forces, hence the storey shear in a particular storey shows an increasing trend.

7.9 SCOPE OF FUTURE WORK

Following may be the scope of future work-

1. The analysis of a regular structure could also be done and comparison could be done in regard to the change in response of the framed building with respect to change in stiffness.
2. Estimating an optimum stiffness in a structure, so that most economic design of the framed building could be done from the earthquake point of view.
3. Contribution of infill stiffness to the framed structure in the seismic condition could be another field of research.
4. The future work in this research work includes the analysis of irregular structures with a much refined analytical technique namely non-linear dynamic analysis or the time history method, in which the elasto- plastic behavior of the structural elements is taken into consideration.

APPENDIX- A

STAAD SPACE

START JOB INFORMATION

ENGINEER DATE 21-JAN-14

END JOB INFORMATION

INPUT WIDTH 79

UNIT METER KN

JOINT COORDINATES

1 0 0 0; 2 6.6 0 0; 3 9.05 0 0; 4 15.65 0 0; 5 0 0 6.6; 6 6.6 0 6.6;

7 9.05 0 6.6; 8 15.65 0 6.6; 9 9.05 0 9.7; 10 15.65 0 9.7; 11 0 0 13.2;

12 6.6 0 13.2; 13 9.05 0 16.3; 14 15.65 0 16.3; 15 9.05 0 19.8;

16 15.65 0 19.8; 17 0 0 19.8; 18 6.6 0 19.8; 19 9.05 0 26.4; 20 15.65 0 26.4;

21 0 0 26.4; 22 6.6 0 26.4; 23 9.05 0 33; 24 15.65 0 33; 25 6.6 0 33;

26 0 2.25 0; 27 6.6 2.25 0; 28 9.05 2.25 0; 29 15.65 2.25 0; 30 0 2.25 6.6;

31 6.6 2.25 6.6; 32 9.05 2.25 6.6; 33 15.65 2.25 6.6; 34 9.05 2.25 9.7;

35 12.65 2.25 9.7; 36 0 2.25 13.2; 37 6.6 2.25 13.2; 38 15.65 2.25 9.7;

39 9.05 2.25 16.3; 40 12.65 2.25 16.3; 41 15.65 2.25 16.3; 42 9.05 2.25 19.8;

43 15.65 2.25 19.8; 44 0 2.25 19.8; 45 6.6 2.25 19.8; 46 0 2.25 26.4;

47 6.6 2.25 26.4; 48 9.05 2.25 26.4; 49 15.65 2.25 26.4; 50 6.6 2.25 33;

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UNIT MMS NEWTON

DEFINE MATERIAL START

ISOTROPIC MATERIAL1

E 25000

POISSON 0.17

DENSITY 2.4e-005

DAMP 7.90066e+033

END DEFINE MATERIAL

UNIT METER KN

CONSTANTS

MATERIAL MATERIAL1 MEMB 1 TO 85 87 TO 142 144 147 149 TO 172 174 TO 228 230 -

233 235 TO 243 245 TO 249 252 255 TO 258 260 TO 314 316 319 321 TO 370 372 -

373 TO 374 376 TO 401 403 406 408 TO 455 458 TO 504

MEMBER PROPERTY INDIAN

*COLUMN

37 TO 61 98 TO 122 185 TO 209 271 TO 295 358 TO 370 372 TO 374 376 TO 382 -

450 TO 455 461 462 485 TO 504 PRIS YD 0.45 ZD 0.6

414 TO 419 PRIS YD 0.6 ZD 0.45

*PLINTH BEAM

1 3 TO 13 16 TO 23 26 TO 34 36 123 423 424 427 428 463 TO 466 -

468 PRIS YD 0.6 ZD 0.3

2 14 15 24 25 35 420 TO 422 425 426 429 467 PRIS YD 0.45 ZD 0.3

*BEAMS

62 64 TO 70 72 TO 74 79 80 82 TO 85 87 TO 95 97 124 TO 142 144 147 149 151 -

152 TO 157 159 TO 161 166 167 169 TO 172 174 TO 182 184 210 TO 228 230 233 -

235 237 TO 243 245 TO 247 252 255 TO 258 260 TO 268 270 296 TO 314 316 319 -

321 TO 327 329 TO 338 341 TO 355 357 383 TO 401 403 406 408 TO 413 469 470 -

472 TO 474 476 TO 478 480 TO 482 484 PRIS IY 100 YD 0.6 ZD 0.3

63 71 75 TO 78 81 96 150 158 162 TO 165 168 183 236 248 249 269 328 339 340 -

356 430 TO 449 458 TO 460 471 475 479 483 PRIS IY 100 YD 0.45 ZD 0.3

SUPPORTS

1 TO 79 96 TO 102 108 TO 111 114 TO 120 123 TO 128 133 136 137 139 TO 145 -

151 153 154 157 TO 159 161 TO 163 166 TO 171 176 179 180 184 TO 190 196 197 -

200 TO 202 204 205 208 TO 215 220 223 224 227 228 239 TO 262 PINNED

MEMBER RELEASE

127 138 TO 142 213 224 TO 228 299 310 TO 314 326 386 397 TO 401 -

413 START FX FZ MX MY MZ

127 140 TO 142 213 226 TO 228 299 312 TO 314 326 386 399 TO 401 -

413 END FX FZ MX MY MZ

LOAD 3 WALL

SELFWEIGHT Y -1

MEMBER LOAD

1 3 5 6 9 TO 12 15 TO 17 20 22 26 28 31 32 34 62 64 66 67 70 TO 73 76 TO 78 -

81 83 87 89 92 93 95 123 TO 125 128 130 132 135 137 144 147 149 151 153 154 -

157 158 160 163 TO 165 168 170 174 176 179 180 182 210 211 214 216 218 221 -

223 230 233 235 237 239 240 243 246 249 256 260 262 265 266 268 296 297 300 -

302 304 307 309 316 319 321 TO 323 325 427 428 458 TO 460 UNI GY -14.3

2 4 7 8 13 14 19 23 24 29 30 33 36 63 65 68 69 74 75 80 84 85 90 91 94 97 -

126 129 131 133 134 136 140 142 150 152 155 156 159 161 162 167 169 171 172 -

175 177 178 181 184 212 215 217 219 220 222 236 238 241 242 245 247 248 252 -

255 257 258 261 263 264 267 270 298 301 303 305 306 308 324 423 -

424 UNI GY -8.1

25 UNI GY -9.8

327 TO 329 332 335 337 340 343 346 347 349 352 353 355 TO 357 384 387 389 -

391 394 396 403 410 412 UNI GY -5.8

LOAD 4 DL

FLOOR LOAD

****

*   FIRST FLOOR LVL

****

YRANGE 5.55 5.55 FLOAD -4.75 XRANGE 0 15.7 ZRANGE 0 33.1

*ADD TOILET

YRANGE 5.55 5.55 FLOAD -14.75 XRANGE 9 15.7 ZRANGE 0 6.7

****

* SECOND FLOOR LVL

****

YRANGE 8.85 8.85 FLOAD -4.75 XRANGE 0 15.7 ZRANGE 0 33.1

*ADD TOILET

YRANGE 8.85 8.85 FLOAD -14.75 XRANGE 9 15.7 ZRANGE 0 6.7

****

* THIRD FLOOR LVL

****

YRANGE 12.15 12.15 FLOAD -4.75 XRANGE 0 15.7 ZRANGE 0 33.1

*ADD TOILET

YRANGE 12.15 12.15 FLOAD -14.75 XRANGE 9 15.7 ZRANGE 0 6.7

****

* TERRACE LVL

****

YRANGE 15.45 15.45 FLOAD -8 XRANGE 0 15.7 ZRANGE 0 33.1

MEMBER LOAD

*STAIR

429 UNI GY -18.6

85 172 258 458 TO 460 UNI GY -24

LOAD 5 LL

FLOOR LOAD

****

*   FIRST FLOOR LVL

****

YRANGE 5.55 5.55 FLOAD -3 XRANGE 0 15.7 ZRANGE 0 33.1

*ADD CORRIDOR

YRANGE 5.55 5.55 FLOAD -1 XRANGE 6.5 9.1 ZRANGE 0 33.1

YRANGE 5.55 5.55 FLOAD -1 XRANGE 9 12.7 ZRANGE 9.6 16.4

*ADD STORE

YRANGE 5.55 5.55 FLOAD -2 XRANGE 9 15.7 ZRANGE 6.5 9.75

YRANGE 5.55 5.55 FLOAD -2 XRANGE 0 6.7 ZRANGE 23 26.5

YRANGE 5.55 5.55 FLOAD -2 XRANGE 9 15.7 ZRANGE 29.6 33.1

*DEDUCT TOILET

YRANGE 5.55 5.55 FLOAD 1 XRANGE 9 15.7 ZRANGE 0 6.7

****

*   SECOND FLOOR LVL

****

YRANGE 8.85 8.85 FLOAD -3 XRANGE 0 15.7 ZRANGE 0 33.1

*ADD CORRIDOR

YRANGE 8.85 8.85 FLOAD -1 XRANGE 6.5 9.1 ZRANGE 0 33.1

YRANGE 8.85 8.85 FLOAD -1 XRANGE 9 12.7 ZRANGE 9.6 16.4

*ADD STORE

YRANGE 8.85 8.85 FLOAD -2 XRANGE 9 15.7 ZRANGE 6.5 9.75

*DEDUCT TOILET

YRANGE 8.85 8.85 FLOAD 1 XRANGE 9 15.7 ZRANGE 0 6.7

****

*   THIRD FLOOR LVL

****

YRANGE 12.15 12.15 FLOAD -3 XRANGE 0 15.7 ZRANGE 0 33.1

*ADD CORRIDOR

YRANGE 12.15 12.15 FLOAD -1 XRANGE 6.5 9.1 ZRANGE 0 33.1

*ADD STORE

YRANGE 12.15 12.15 FLOAD -2 XRANGE 9 15.7 ZRANGE 6.5 9.75

*DEDUCT TOILET

YRANGE 12.15 12.15 FLOAD 1 XRANGE 9 15.7 ZRANGE 0 6.7

****

*   TERRACE LVL

****

YRANGE 15.45 15.45 FLOAD -1.5 XRANGE 0 15.7 ZRANGE 0 33.1

MEMBER LOAD

*STAIR

429 UNI GY -10

85 172 258 458 TO 460 UNI GY -13.2

LOAD COMB 6 (DL +EQ.LL)

3 1.0 4 1.0 5 0.5

PERFORM ANALYSIS

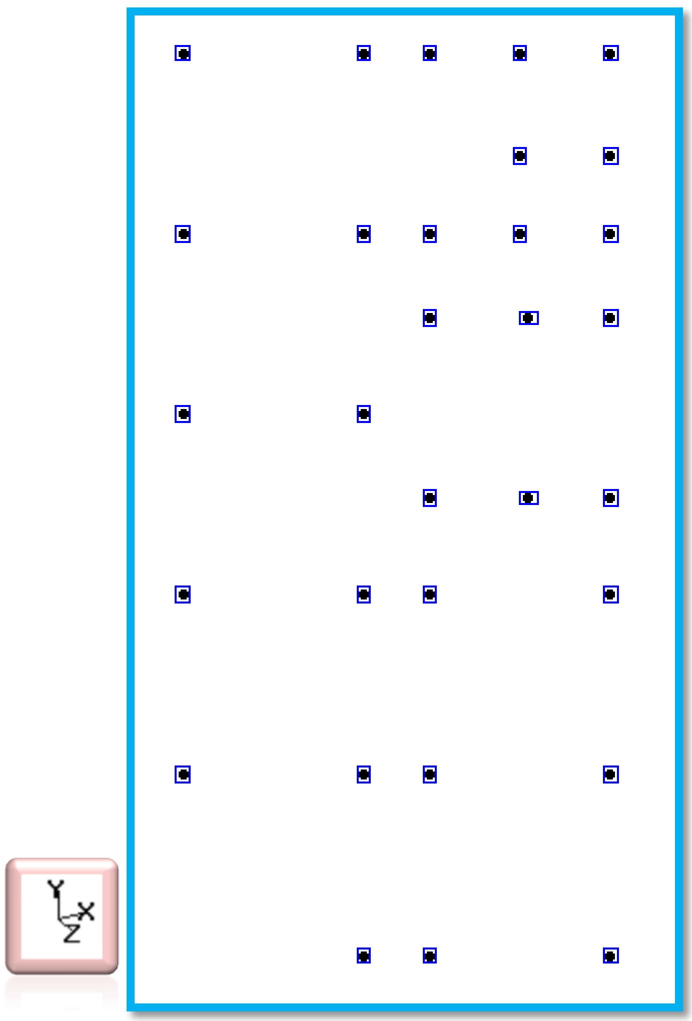
LOAD LIST 6

PRINT SUPPORT REACTION ALL

FINISH

APPENDIX-B

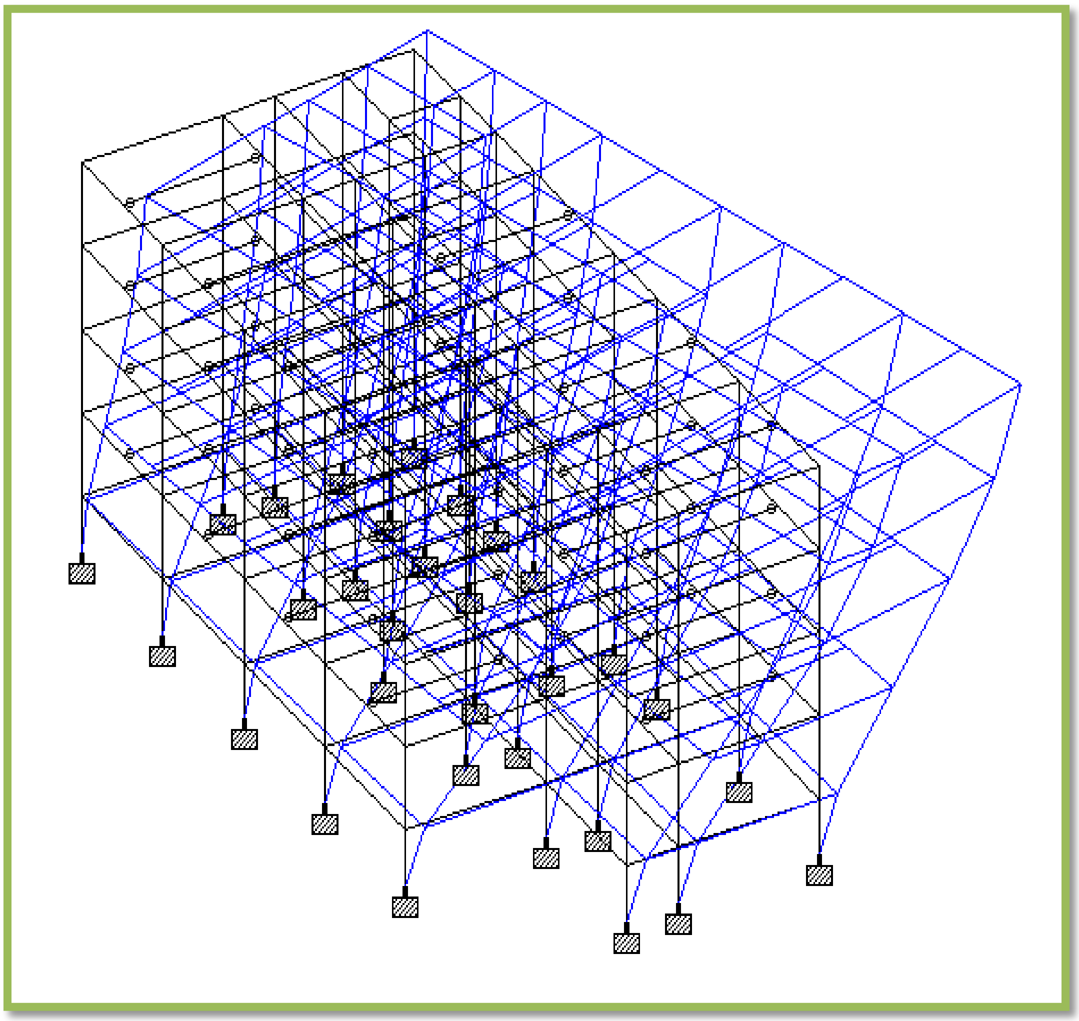
1. PLAN OF ORIENTATION OF COLUMNS IN THE G+4 STOREY FRAMED BUILDING.



Screen shots taken from STAAD Pro.

APPENDIX –B

2. MODE SHAPE 1 FOR G+4 STOREY FRAMED BUILDING



Screen shots from STAAD Pro.-Deflected shape of the building with respect to mode 1.

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