EFFECT OF MASS IRREGULARITIES ON THE RESPONSE OF BUILDING UNDER SEISMIC EFFECT

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Submitted by

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CERTIFICATE

Certified that the thesis entitled “The Effect of Mass Irregularities on the Response of Building under the Seismic Effect” submitted by SAURABH GEHLOD in fulfilment of the requirements for the award of the degree of Master of Technology in Structural Engineering, is the candidate’s own work carried out by him under my supervision and guidance. The work presented in the thesis has not been submitted for the award of any other degree of this or any other University/Institute.

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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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SAURABH GEHLOD

ABSTRACT

If a building has irregular distribution in mass, strength and stiffness or any combination of these then the building may be called as an irregular building. The irregularity limits are found to be different in different codes. Many times irregularity in building may be intentionally provided due to functional and aesthetic considerations. However past earthquake records indicate that these building have not performed well in seismic excitation condition.

Research works undertaken in the past indicate that location of an irregularity in a structure is an important parameter. In the present study mass irregularity in an aluminium frame is considered. The mass irregularity is created by applying additional mass at different floor level. The eigenvalue analysis is calculated of the framed model. The calculated eigenvalue is compared with those from commercial Etabs software.

In the present study it shows that the variation of mass along the height of the building affects the floor displacement of the building. The dynamic characteristics of the buildings are affected by the location of mass irregularities. Experimental results are validated by those obtained from the consideration of mathematical models of Etabs.

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CHAPTER 1

INTRODUCTION

During an earthquake the building may suffer damages at the point of weakness. The points of weakness are termed as the irregularity in the structure. The irregularity in the structure is due to mass variation, strength variation, and stiffness variation. The irregularity in mass, stiffness, and strength may be in plan or in elevation. To give better performance in an earthquake, the building should satisfy four main parameters that are simple and regular shape configuration and adequate lateral strength, stiffness and ductility. The structures with regular and simple configuration may undergo considerably much less damages during seismic excitation than the irregular structures. The irregular building does not perform well during an earthquake. Still, the irregular buildings are designed. This is because of their functional use and architectural appearances.

The building is classified as irregular due many reasons, like mass irregularity, stiffness irregularity and strength irregularity. As per is IS-1893 (Part 1):2002, the building is considered as irregular due to following type of irregularity:

1.1 Horizontal irregularity or plan irregularity

(1) Torsion irregularity: A structure is considered torsion irregular when floor diaphragms are rigid in their own plan in with respect to the vertical structural elements that resist the lateral forces. When the maximum story drift calculated with the eccentricity at one end of the building transverse to and axis is more than 1.2 times the average of the story drift calculated at the two ends of the buildings.

(2) Re-entrant corners: When the projections of the building beyond the re-entrant corner are greater than 15% of its plan dimension in the given dimensions, the buildings are considered as irregular of re-entrant corners.

(3) Diaphragm Discontinuity: The building is considered as diaphragm irregular when the cut out or openings in the diaphragm is greater than 50% of the gross enclosed diaphragm area or changes in the diaphragm stiffness is more than 50% from one story to the next story.

(4) Out of plane offsets: When the lateral resisting element is out of plane of vertical elements, the building is considered as out of plane offsets. V. Non parallel systems. The building comes under this category of irregularity when the vertical members resisting the lateral force are not parallel to or symmetric about the major orthogonal axes or the lateral resisting members.

1.2 Vertical irregular buildings

(1) Stiffness irregularity

a) Soft story: A soft story is considered when the lateral strength of the story under consideration is less than 70% of that in the story above the considered story or less than 80% of the average lateral stiffness of the three storys above the considered story**.**

b) Extreme soft story: A story is considered as extreme soft story when the lateral stiffness is less than 60% of the average stiffness of the three storys above the considered story.

(2) Mass irregularity: Mass irregularity is considered if any story in the building having seismic weight more than 200% of the adjacent story. In case of roofs, irregularity is not considered.

(3) Vertical geometric irregularity: Vertical geometrical irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any story is more than 150% of that in its adjacent story.

(4) In plane discontinuity: in vertical elements resisting lateral force. An in plane offset of the lateral force resisting elements greater than the length of those elements.

(5) Discontinuity in capacity: weak story A weak story is one in which the story lateral strength is less than 80% of that in the story above. The story lateral strength is the total strength of all seismic force resisting elements sharing the story shear in the considered direction.

1.3 Dynamic characteristics of the buildings

The building vibrates during an earthquake excitation. The vibrations cause inertia force in the building. The inertia force developed is depends on the intensity and duration of oscillation. These characteristics are called dynamic characteristics of the buildings. The main parameters of the buildings are modes of vibration and damping. A mode of vibration of a building is defined by Deformed Shape and Natural Time Period in which building vibrates.

1.3.1 Natural Time Period

The time taken by the building to complete one cycle of oscillation is called natural time period. It is an important property of a building controlled by mass m and stiffness k. the natural time period is related by

$$\mathbf{T_n = 2\pi(m/k)^{(1/2)}}$$

The building with larger mass and flexible has larger natural time period than the light and stiff building. When building vibrates, there is a deformed shape of oscillation.

The reciprocal of natural time period (T_n) of a building is known as natural frequency (f_n).The building offers least resistance when it vibrate at its natural time period (or natural frequency). It undergoes large displacement when vibrate at its natural frequency than other frequencies. Generally, natural time periods of 1 to 20 the buildings are in the range of 0.05-2 sec. most of the engineers considered natural time period and not natural frequency. When the frequency of oscillation of the ground is at or near any of the natural frequency of the building, resonance occurs. There is no surety that the natural frequency of the vibrating building is same as the shaking of the ground for sustained duration. Usually the response of the building increased when the ground shaking have frequencies near to natural frequency of the building. It is noticed during the 1985 Mexico City earthquake, where the buildings having small natural time period collapsed. While those have natural time periods outside the range performed normally. This happens almost for uniform soil strata.

1.3.2 Fundamental natural time period of the buildings

Building has many frequencies, at which it vibrates and offers least resistant to ground shaking induced during an earthquake or wind and other internal elements like vibrating machines fixed on it. The mode of oscillation with largest time period (least natural frequency) is called fundamental mode of oscillation. And the corresponding natural time period is called fundamental time period and the corresponding natural frequency is called fundamental natural frequency. The natural modes of a building are infinitely large in number. But for designing the building the numbers of modes of oscillation are finite.

Usually, the natural time period of the buildings depends on the mass and stiffness of the buildings. Following are the parameters which affect the building's natural time period:

1. The natural time periods of the structure decreases with increase in stiffness.

2. The natural time period of the structure reduces with decrease in mass.

3. The height of the buildings also affect the time periods. Taller building have larger natural time period than the smaller one.

4. Flexible buildings have larger natural time period as compared to stiff buildings.

5. The in filled wall also affect natural time period of the buildings.

1.3.3 Mode shape

Mode shape of vibration is depends on the natural time period of the buildings. The deformed shape of the building, when it vibrates at or near the natural time period is known as the mode shape. For every building there are number of mode shapes associated with natural time periods of the buildings. Corresponding to fundamental time period, the mode shape is called as fundamental mode shape. It can be first, second and third depending upon the natural time period of different modes.

Factors affecting mode shapes

1. It depends on the stiffness of the buildings.

2. It depends on mass distribution of buildings.

3. Support conditions of the buildings.

4. Height of the buildings.

5. Infill walls.

1.3.4 Damping

When the building vibrates by ground shaking due to seismic excitation comes back to rest after some time. This phenomenon occurs due to dissipation of energy into other forms (in the form of heat and sound). This conversion of earthquake energy in to some other form is called as damping.

CHAPTER 2

OBJECTIVE, SCOPE AND METHODLOGY OF THE STUDY

2.1 Objective of the study

The objective of this study is to understanding the behaviour of the building under structural irregularity. The structural irregularities are mass irregularity, stiffness irregularity plan irregularity and other type of irregularities. Here vertical mass irregularity is considered.

As per IS 1893:2002 (Part 1) the expression given to calculate the fundamental time period is a function of height of the building and plan dimension of the building. But in actual the fundamental time period also affected due to change in irregularity and change in mass variation at different floor level.

In this project work the objective is to show that the natural time period is also a function of change in mass at different floor level and distribution of mass.

Following are the objectives of this study:

1. To study the mass irregularities of the building.

2. To find out the dynamics characteristics of the frame with or without mass variation.

The dynamic characteristics are: time period, frequencies and mode shapes.

2.2 Scope of the study

The scope of this work is limited to find out the change in natural frequencies, time period and mode shapes of the building frame model with or without mass variation at different floor level under varying cases of floor stiffness. The location of mass to which level is best suited is studied.

2.3 Steps of the study

Following are the steps utilized in this project work:

1) Literature review

Literature survey was carried out to understand the irregularity type of the structure. The response of the structure during earthquake is studied. The change in the fundamental time period of the building due to irregularity of the building is studied. The failure of the irregular building due to past earthquake was studied.

2) Mathematical formulation

Mathematical formulation is carried out to find the natural frequency of the Aluminium frame modal. The change in the natural frequency of the frame modal is calculated due to change in the mass at different floor level under varying cases of floor stiffness. The details about the addition of mass are presented in analytical calculation. Following cases are considered

Case 1: bare frame with no walls

Case 2: frame with all story closed by walls

Case 3: frame with 1st story as soft story

Case 4: frame with 2nd story as soft story

Case 5: frame with 3rd story as soft story

Case 6: frame with 4thstory as soft story

All the above cases are further divided into four sub cases as follow:

a) Without mass variation.

b) With additional mass on 1st floor.

c) With additional mass on 2nd floor.

d) With additional mass on 3rd floor.

3) Data collection

The data collection was mainly based on the tests conducted on the prepared model. The data collected was frequency of the signals, dimensions of the frame modal, and other relevant information related to the experimental arrangements.

4) Experimental arrangements and model testing

All the equipment required during the course of study was arranged. Test was conducted on the Aluminium frame modal to find out the floor displacement and corresponding natural frequency. The model is arranged and fitted to the shake table to perform the testing procedure. The frame modal is available in the Delhi Technological University, Civil Engineering Department, and Earthquake Engineering Laboratory. Testing on frame modal is carried out to study the pattern of floor displacement at guiding frequency and the fundamental frequency was found out at resonant.

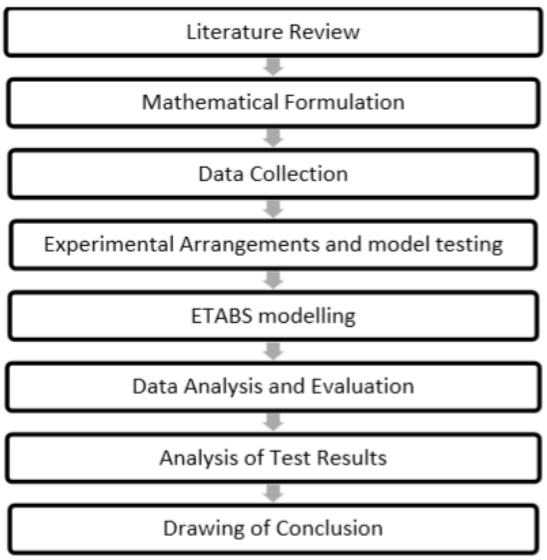
5) ETABS modelling

Frame is modelled in the commercial ETABS software to validate the result that is obtained from analytical and experimental procedure.

6) Data analysis and evaluation

The test results of the frame modal were compared with respect to calculate by the eigenvector analysis and the results were presented using table, pictures, and graphs.

2.4 Work flow chart



CHAPTER 3

LITERATURE REVIEW

The performance of the building structures during past year earthquakes give the idea that the plan irregularities are one of the most sever cause of damage during the seismic excitation. The plan irregularity can be due to irregular distribution of mass along the horizontal and vertical direction, stiffness in horizontal or vertical direction, and strength along the plan. Number of research was carried out in past years to understand the behaviour of the irregular structure during past earthquake.

Sarkar et al. (2010) [1] gave a new method of quantifying irregularity in vertical irregular structure frames, accounting for the dynamic characteristics (mass and stiffness). The following are the results are obtained:

a) Calculation of vertical mass irregularity suitable for stepped building, known as irregular index is proposed, accounting for the variation in mass and stiffness in the direction of the height of the structure.

b) An empirical formula was given to calculate the fundamental time period of the stepped building as a function of irregularity index.

Karavasilis et al. (2008) [2] has studied the inelastic seismic response of steel frame with mass irregularity at different floor level. The analysis of the test showed that the strength of beam column, the number of storey in the building and the location of the heavier mass influence the inelastic deformation demands, while the response does not much vary with the mass ratio.

Devesh et al. (2006) [3] studied on the increase in the drift demand in the building portion of setback structure and on the increase in the seismic demand for buildings with irregular distribution in mass, strength and the stiffness. The results showed that the more seismic demand was obtained for the combined stiffness and strength irregularity. It was obtained the behaviour of the building is influenced by the type of the frame model.

Poonam et al. (2012) [4] studied the vertical irregular buildings behaves different one than the regular buildings. The study showed that any storey, either first or any other storey, should not be weak or soft storey than the storey above or below. It was obtained that the irregular distribution in mass also adds to the increased response of the buildings. The irregularity in mass is to be provided at appropriate floor and at appropriate location so that the response of the structure does not affect so much.

Fernandez (1983) [5] calculated the elastic and inelastic seismic response of frames. He is considered multi-storey building frame. Study is carried out on frame with irregular distribution of stiffness and mass. He concluded that there was increases in storey drift due to decrease in stiffness. The structures perform well under seismic excitation due to regular variation in mass and stiffness. The better the regularity, the better will be performance of the buildings. The uneven or abrupt variation in mass affect the building time period and storey drift.

Moelhe (1984) [6] studied the seismic response of reinforced concrete structures with or without irregularities. For the study he has considered a nine storey building frames. The structure consists of wall. The irregularity is due to discontinuous of structural walls at different level of the storey. He has found out that the response of the reinforced building does not only depend on the irregularity but also on the distribution of irregularity along the height.

Moehle and Alarcon (1986) [7] performed the experimental analysis to validate the analytical results. He considered a small prototype reinforced concrete building frame given a ground motion. The testing is done with help of shake table. The irregularity is created in the mode frame by discontinuous shear wall at the first floor level. They noted down the displacement of the top floor. He concluded that the ductility demand increases drastically due to abruptly change in irregularity in the building.

Barialoa and Brokken (1991) [8] found out the effect of stiffness and strength irregularity on seismic response of multi-storey structure frames. He has considered 8 storey building frame for analytical study. Three different time periods are considered for the analysis as low medium and high. They have considered weak and strong type of buildings. The base shear was 15 percent in weak storey of the total seismic weight of the building. The base shear for strong storey was 30 percent of total seismic weight of the building. The results was concluded. They have found that the natural time period of the building increases during the ground shaking and this was more predominant in case of weaker structures.

Ruiz and Diederich (1989) [9] determined analytical modelling on 5 and 12 storey building frame models with or without strength irregularities. The irregularity was introduced with or without infill walls. First of all they have considered first storey as weak storey. And then the infill walls are provided at the top of the model. In the third situation they have modelled infill walls ductile. They have found out that the performance of the building affected by time period of seismic excitation with infill walls.

Nassar and Krawinkler (1991) [10] determined the dynamical characteristics of multi-storey buildings. They have considered 5, 10, 20, 30, 40 storey building. The buildings were single degree of freedom system and multi degree freedom system. They have taken different natural time periods of the seismic excitation ranging from 0.217-2.051. They concluded that presence of weak storey will produced ductility and more overturning moment

Esteva (1992) [11] determined the seismic response of the structure frames with strength irregularity. He performed non-linear analysis. The strength irregularity is created with first storey as weak storey. The study deals with the bilinear behaviour of the building. He does not take into account the p-delta effect. He concluded that the dynamical characteristic of the building did not affected by the setback irregularity.

Wong and Tso (1994) [12] taken elastic response spectrum analysis to find out dynamic characteristics of the building. They have considered setback irregularity and it was observed that the structure with this irregularity had larger modal mass abruptly distribution of seismic load as compared to static codel procedure.

Al-Ali and Krawinkler (1998) [13] determined the irregularity of mass, strength and stiffness. They considered individual irregularity. In first case they have considered the mass irregularity. In second case they have considered the stiffness irregularity. In third case they have considered the strength irregularity. They have taken a 10 story building model to study the behaviour of building. They obtained that when irregularity is considered as separately, the effect of strength irregularity is more compared to other two irregularities. The displacement of the top floor was maximum due to strength irregularity. The effect of mass irregularity on the floor displacement is much less than other irregularity. They have combined the two irregularities and the results shows that the impact of strength and stiffness on roof displacement was more severe to that of other irregularity combinations.

Manfliulo et al. (2002) [14] determined the dynamic characteristics of the multi-story buildings. He has considered 5 and 9 storey building model. He has considered the mass irregularity, strength irregularity and stiffness irregularity. By the analytical study he has found that the variation in mass does not affect the plastic demands. The irregularity due to strength enhanced the seismic demand of the building. However the seismic demand not affected by irregular strength in columns. Finally he made conclusion that the parameter of storey strength given in EC8 and IBC codes was inadequate to predict strength irregularity due to strength variation.

Das and Nau (2003) [15] determined the impact of mass, stiffness and strength on inelastic seismic response of taller building with having large number of storeys. For analytical sturdy they have considered different storeys with number of storeys ranging from 5-20 were modelled as shown in figure 3.1. The structural irregularity in these model was considered. The irregularities were mass irregularity, stiffness irregularity, strength irregularity and masonry infill's. The modelling was done as per ACI 1999 and UBC 97. The mode shape and fundamental time period was calculated. The result of regular and irregular building was compared. The code gives the increase in storey drift of 2 percent. But the result was just abruptly showing the increase in story drift. The storey drift changes unevenly due the combination of irregularity. They have concluded that mass irregularity affect less damage of the building than the other irregularities

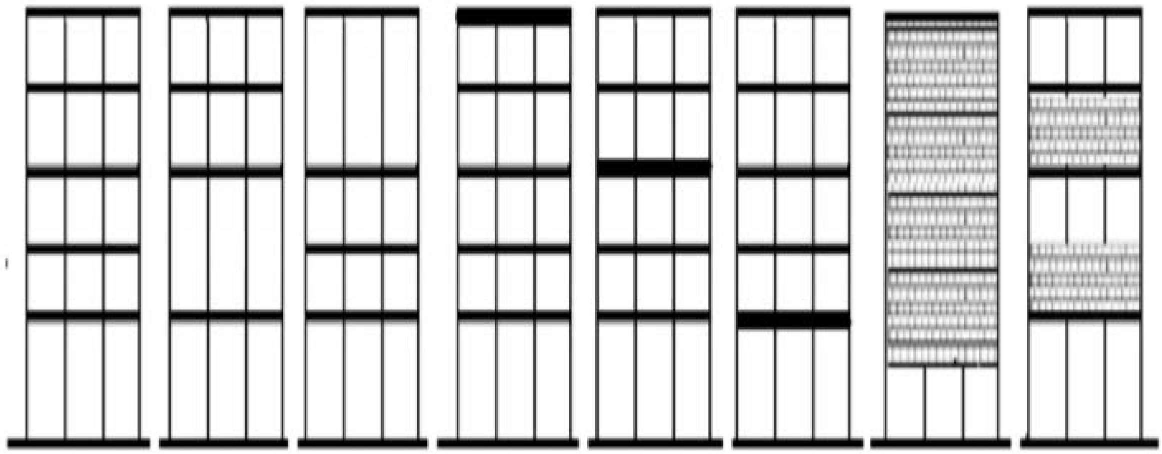


Fig. 3.1 different type of vertically irregular building models as per Das and Nau (2003)

Chintanpakde and Chopra (2004) [16] determined the effects of combination of stiffness and strength irregularities. They had considered 12 storey frame model. The theory of strong column and weak beam theory were applied. The irregularity was created at different level of floor. Time history analysis was carried out. It was obtained that when the stiffness and strength irregularity apply in combination, the effect on response of the building was more severe. For deformation, the irregularity must be present at lower level of storey.

Tremblay and Poncet (2005) [17] determined the dynamic characteristic of the building frames with vertical mass irregularity. The analysis was done as per NBCC guidelines. The static and dynamic analysis were carried out it was observed that the codes provision were ineffective in mass irregularity of buildings.

Ayidin (2007) [18] determined the seismic response of building with mass variation. He was considering the ELF procedure to analyse the frame. The buildings were modelled as 5 to 20 storey buildings. The mass irregularity was introduced by variation in mass of one storey by keeping the mass of other storey constant. The result was obtained and concluded. It was found that the code processors ineffective in calculating the seismic response. The result from the code was over estimated.

Vipul H. Vyas and C. S. Sanghvi [19] Structural control is basically the modification of the properties of a structure, the modification of the structures properties include changes in the damping and stiffness of the structures Study of dynamic response of building is carried out on three storied soft storey building model & three stories soft storey building model with seismic damper. The experimental set ups which would enable the study of basic issues related to acceleration, velocity, displacement, damping, natural frequency, mode shape, natural period, etc. Model made up with steel bars and plate. Upon completion of the model, static stiffness tests and free vibration tests are perform to determine the actual properties of the model such as stiffness, damping ratio, and natural frequencies of vibration. Comparison of the system properties identified experimentally with those predicted by the theory or simulated numerically.

Mrs. Rekha B., Mr. Supreeth [20] Experimental studies were carried out on a three storied building frame model consisting of columns and slabs. The base of the building frame was subjected to harmonic motion using horizontal shake table. The natural frequencies and mode shapes were obtained. The natural frequencies and mode shapes were also computed from eigenvalue analysis by modelling the building frame as a 3 degree of freedom undamped lumped mass system. The analytical values of natural frequencies are observed to be lower when compared to the experimental values.

Robin Davisi, Praseetha Krishnan [21] Two typical existing buildings located in moderate seismic zones of India (as per IS: 1893-2002[1]) are identified. Features like plan irregularity and vertical irregularity (soft storey) are found in one of the buildings, while the other is fairly symmetric. Infill’s were modelled using the equivalent strut approach. Static analysis (for gravity and lateral loads), response spectrum analysis and non-linear pushover analysis (assigning the hinge properties to beams and column sections) were performed. It is observed that the seismic demand at the soft storey level is significantly large when infill stiffness is considered, with larger base shear and larger displacements. This effect, however, is not found to be significant in the symmetric building (without soft storey).

CHAPTER 4

MATHEMATICAL FORMULATION AND ANALYSIS

4.1 Introduction

Modal analysis is the study of the dynamic properties of structures under vibration excitation in structural engineering, modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate. A normal mode of an oscillating system is pattern of motion in which all parts of the system move sinusoidally with the same frequency and with a fixed phase relation. Eigenvector analysis determines the undamped free vibration mode shapes and frequencies of the system. These natural modes provide an excellent insight into the behaviour of the structure. Ritz vector analysis seeks to find modes that are excited by a particular loading. Ritz vectors can provide a better basis than do eigenvectors when used for response- spectrum or time- history analyses that are based on modal superposition. Thus, modal analysis is done by following methods,

1. Eigenvector analysis.

2. Ritz vector analysis

4.2 Eigen value analysis

The aim of this eigenvector analysis is to find out the natural frequency of the Aluminium frame model. The frames shown in figure 4.1 are approximated by a four-dof shear beam models as shown in figure 4.2. It may be noted that the all type of frames can be modelled mathematically by using similar models. The parameters m, k and c however, would be different for different models.

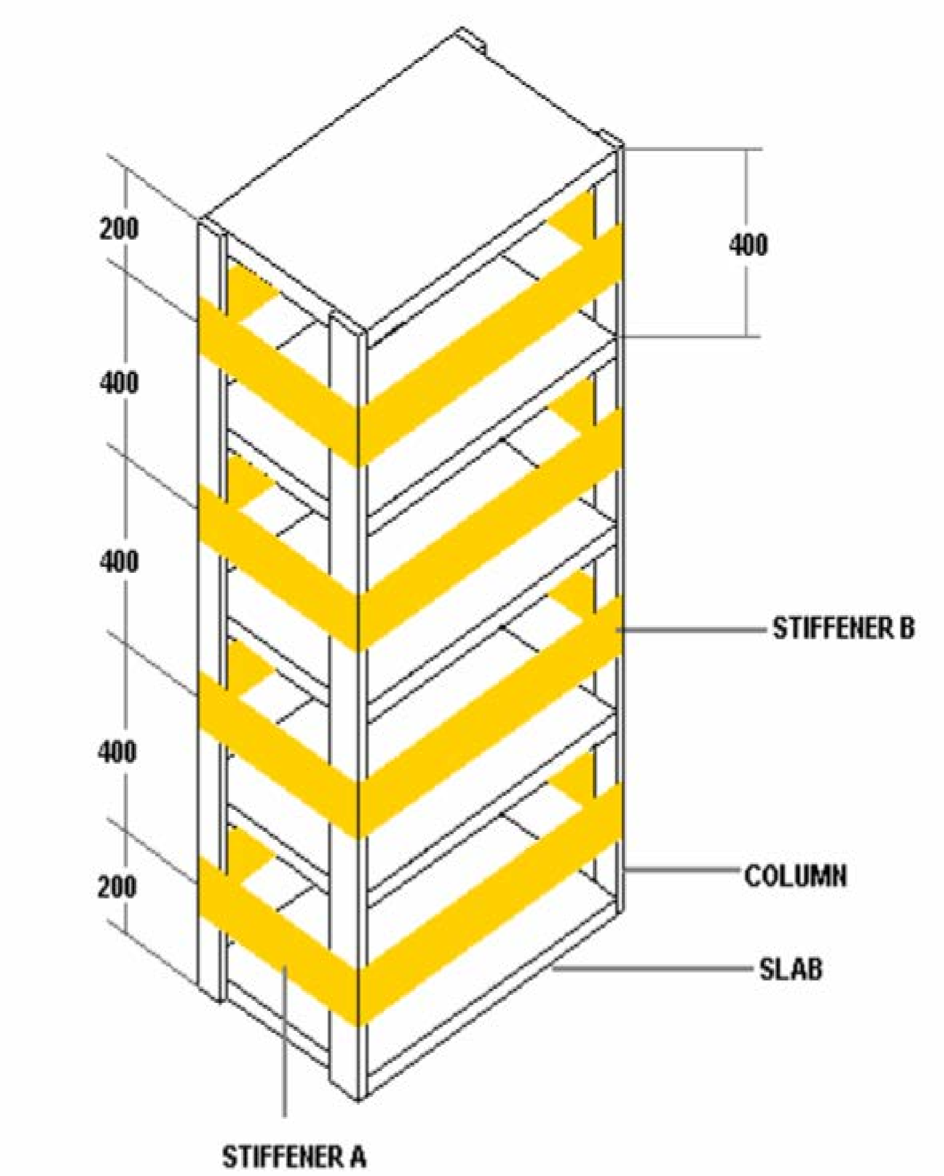


Fig 4.1 Experimental model (NPEEE)

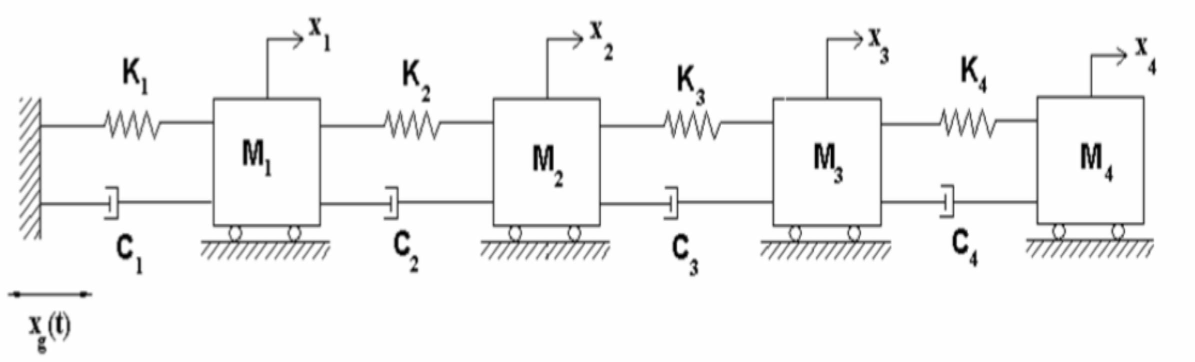


Fig 4.2 Four degree of freedom beam model of frame

Free body diagrame of frame model shown in Fig 4.2 is as shown in Fig 4.3

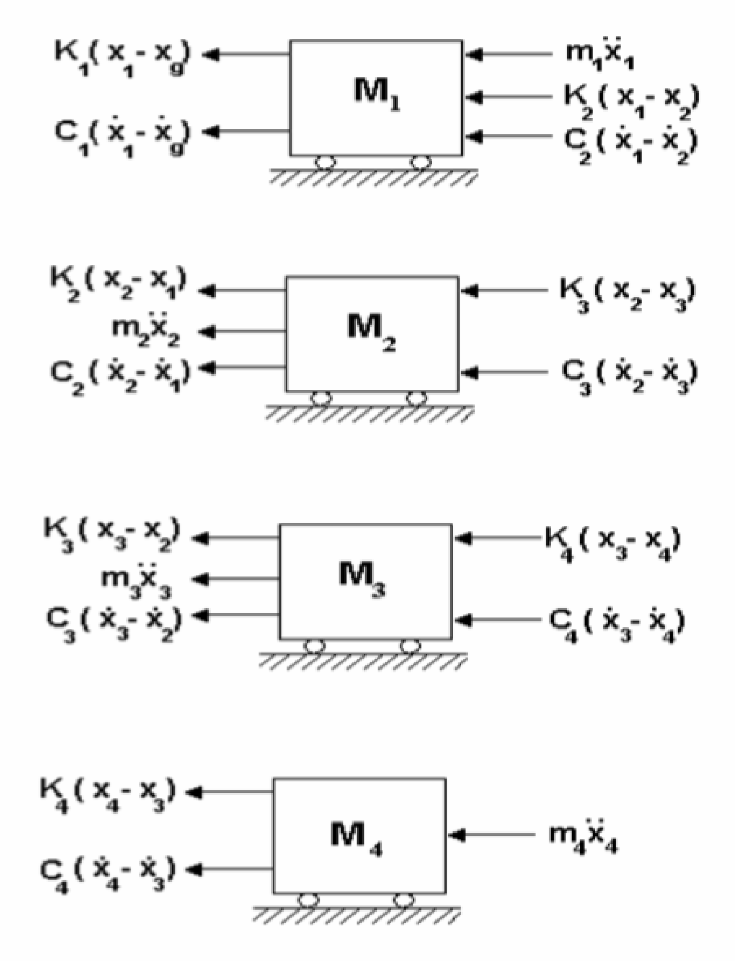


Fig 4.3 Free body diagram of beam model of frame

Based on the free body diagrams shown in figure 4.3 the following equations of motion can be setup for the system in figure 4.2:

$$
\begin{aligned}
&m_1\ddot{x}_1 + c_1(\dot{x}_1 - \dot{x}_g) + c_2(\dot{x}_1 - \dot{x}_2) + k_1(x_1 - x_g) + k_2(x_1 - x_2) = 0 \\
&m_2\ddot{x}_2 + c_2(\dot{x}_2 - \dot{x}_1) + c_3(\dot{x}_2 - \dot{x}_3) + k_2(x_2 - x_1) + k_3(x_2 - x_3) = 0 \\
&m_3\ddot{x}_3 + c_3(\dot{x}_3 - \dot{x}_2) + c_4(\dot{x}_3 - \dot{x}_4) + k_3(x_3 - x_2) + k_4(x_3 - x_4) = 0 \\
&m_4\ddot{x}_4 + c_4(\dot{x}_4 - \dot{x}_3) + k_4(x_4 - x_3) = 0
\end{aligned}
$$

________(1)

The above equation can be written in matrix form as below [22]

$$\begin{bmatrix} m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \\ 0 & 0 & m_3 & 0 \\ 0 & 0 & 0 & m_4 \end{bmatrix} \begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{x}_4 \end{Bmatrix} + \begin{bmatrix} c_1+c_2 & -c_2 & 0 & 0 \\ -c_2 & c_2+c_3 & -c_3 & 0 \\ 0 & -c_3 & c_3+c_4 & -c_4 \\ 0 & 0 & -c_4 & c_4 \end{bmatrix} \begin{Bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{Bmatrix} + \begin{bmatrix} k_1+k_2 & -k_2 & 0 & 0 \\ -k_2 & k_2+k_3 & -k_3 & 0 \\ 0 & -k_3 & k_3+k_4 & -k_4 \\ 0 & 0 & -k_4 & k_4 \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{Bmatrix} =$$

$$\begin{bmatrix} c_1+c_2 & -c_2 & 0 & 0 \\ -c_2 & c_2+c_3 & -c_3 & 0 \\ 0 & -c_3 & c_3+c_4 & -c_4 \\ 0 & 0 & -c_4 & c_4 \end{bmatrix} \begin{Bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{Bmatrix} \dot{x}_g + \begin{bmatrix} k_1+k_2 & -k_2 & 0 & 0 \\ -k_2 & k_2+k_3 & -k_3 & 0 \\ 0 & -k_3 & k_3+k_4 & -k_4 \\ 0 & 0 & -k_4 & k_4 \end{bmatrix} \begin{Bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{Bmatrix} x_g$$

_______(2)

In a more compact form, the equation reads

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = [C]\{\Gamma\}\dot{x}_g + [K]\{\Gamma\}x_g$$

_______ (3)

Here, $\{\Gamma\}$ is 4×1 vector of ones.

Eigenvector analysis

Eigenvector analysis determines the undamped free-vibration mode shapes and frequencies of the system. These natural modes provide an excellent insight into the behaviour of the structure.

$$[m]\{\ddot{x}_r\} + [k]\{x_r\} = 0$$

_____(4)

When floors of a frame reach there extreme displacement at the same time and pass through the equilibrium position at the same time, then each characteristic defected shape is called as natural mode of vibration of an MDF system.

During the natural mode of vibration of an MDF system there is a point of zero displacement that does not move at all. The point of zero displacement is called as node. As the number of mode increases, number of node increases accordingly.

In free vibration, the system will oscillate in a steady-state harmonic fashion-

$$x = (a \sin wt + b \cos wt)$$

Where a and b are constants.

Thus,

$$\ddot{x} = -w^2 (a \sin wt + b \cos wt)$$

Such that,

$$\ddot{x} = -w^2 x \qquad \text{\_\_\_\_\_ (5)}$$

Substituting equation (5) in equation (4), we will get,

$$(-mw^2 + k)x = 0$$

This equation is called as matrix eigenvalue problem.

Trivial solution of above equation is x=0, means the system is at rest.

For non- trivial solution,

$$|-mw^2 + k| = 0 \qquad \text{\_\_\_\_\_\_(6)}$$

Where, m and k have their usual meaning, i.e., mass matrix and stiffness matrix respectively. Rewriting in that form:

$$\begin{bmatrix} m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \\ 0 & 0 & m_3 & 0 \\ 0 & 0 & 0 & m_4 \end{bmatrix} -w^2 + \begin{bmatrix} k_1 + k_2 & -k_2 & 0 & 0 \\ -k_2 & k_2 + k_3 & -k_3 & 0 \\ 0 & -k_3 & k_3 + k_4 & -k_4 \\ 0 & 0 & -k_4 & k_4 \end{bmatrix} = 0 \qquad \text{\_\_\_\_\_\_(7)}$$

4.3 Dimension Parameters:

Plate length (x-direction) = 300 mm

Plate width (y-direction) = 150 mm

Plate thickness (z-direction) = 12.7 mm

Column thickness (x-direction) = 6 mm

Column width (y-direction) = 25.1 mm

Column height of each storey (z-direction) = 400 mm

Moment of inertia of column area about y-axis,

$$I_{yy} = \frac{bd^3}{12}$$

(Here, b = 25.1 mm and d = 6 mm)

$$I_{yy} = 451.8\ mm^4$$

Stiffness of each column,

$$k_c = \frac{12EI}{l^3}$$

(Here, l = 400 mm)

Modulus of Elasticity of aluminium, E = 0.69 × 105 N/mm^2

$$k_c = 5845.25\ N/m$$

Thus, stiffness of each storey,

$$k_{open} = 4k_c = 23381\ N/m$$

and

Stiffness of closed story k_{closed} = 415455 N/m

4.4 Weight Parameters:

Mass of each slab = 1.54 kg

Mass of column of single storey = 0.651 kg

Mass of stiffener A of single story= 0.54 kg

Mass of stiffener B of single story= 0.26 kg

4.5 Calculation natural frequency

4.5.1 Case-1: bare frame with no walls

Case-1 (a): without mass variation on floor levels.

M_1 = 1.54 + .65 = 2.19 kg

M_2 = 1.54 + .65 = 2.19 kg

M_3 = 1.54 + .65 = 2.19 kg

$M_4 = 1.54 + \frac{.65}{2} = 1.865$ kg

And

K_{open} = 23381 N/m

K_{closed} = 415455 N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 1375.72\ (rad/s)^2$

$W_2^2 = 11264.61\ (rad/s)^2$

$W_3^2 = 25955.56\ (rad/s)^2$

$W_4^2 = 38313.30\ (rad/s)^2$

As,

$f = \frac{w}{2\pi}$

Hence,

$$f_1 = 5.90\ Hz$$

$$f_2 = 16.88\ Hz$$

$$f_3 = 25.64\ Hz$$

$$f_4 = 31.15\ Hz$$

Case-1 (b): Additional mass on slab of 1st floor = 3.0 kg

$M_1 = 1.54 + .65 + \mathbf{3} = 5.19$ kg

$M_2 = 1.54 + .65 = 2.19$ kg

$M_3 = 1.54 + .65 = 2.19$ kg

$M_4 = 1.54 + \frac{.65}{2} = 1.865$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 1265\ (rad/s)^2$

$W_2^2 = 7103\ (rad/s)^2$

$W_3^2 = 19926\ (rad/s)^2$

$W_4^2 = 35958\ (rad/s)^2$

As,

$f = \frac{w}{2\pi}$

Hence,

$$f_1 = 5.66\ Hz$$

$$f_2 = 13.41\ Hz$$

$$f_3 = 22.46\ Hz$$

$$f_4 = 30.17\ Hz$$

Case-1 (c): Additional mass on slab of 2nd floor = 3.0 kg

M_1 = 1.54 + .65 = 2.19 kg

M_2 = 1.54 + .65 + **3** = 5.19 kg

M_3 = 1.54 + .65 = 2.19 kg

$M_4 = 1.54 + \frac{.65}{2} = 1.865$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 1063\ (rad/s)^2$

$W_2^2 = 8148\ (rad/s)^2$

$W_3^2 = 23777\ (rad/s)^2$

$W_4^2 = 31264\ (rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 5.18\ Hz$$

$$f_2 = 14.36\ Hz$$

$$f_3 = 25.54\ Hz$$

$$f_4 = 28.14\ Hz$$

Case-1 (d): Additional mass on slab of 3rd floor = 3.0 kg

M_1 = 1.54 + .65 = 2.19 kg

M_2 = 1.54 + .65 = 2.19 kg

M_3 = 1.54 + .65 + **3** = 5.19 kg

$M_4 = 1.54 + \frac{.65}{2} = 1.865$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 914 $(rad/s)^2$

W_2^2 = 11203 $(rad/s)^2$

W_3^2 = 18927 $(rad/s)^2$

W_4^2 = 33208 $(rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 4.81\ Hz$$

$$f_2 = 16.82\ Hz$$

$$f_3 = 21.89\ Hz$$

$$f_4 = 29.00\ Hz$$

4.5.2 Case-2: frame with all story closed by walls

Case-2 (a): without mass variation on floor levels.

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 18700\ (rad/s)^2$

$W_2^2 = 152320\ (rad/s)^2$

$W_3^2 = 345940\ (rad/s)^2$

$W_4^2 = 500560\ (rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 21.76\ Hz$$

$$f_2 = 62.11\ Hz$$

$$f_3 = 93.60\ Hz$$

$$f_4 = 112.60\ Hz$$

Case-2 (b): Additional mass on slab of 1st floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 17530\ (rad/s)^2$

$W_2^2 = 106060\ (rad/s)^2$

$W_3^2 = 277160\ (rad/s)^2$

$W_4^2 = 477590\ (rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 21.07\ Hz$$

$$f_2 = 51.83\ Hz$$

$$f_3 = 83.78\ Hz$$

$$f_4 = 109.98\ Hz$$

Case-2 (c): Additional mass on slab of 2nd floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 15270\ (rad/s)^2$

$W_2^2 = 119020\ (rad/s)^2$

$W_3^2 = 317620\ (rad/s)^2$

$W_4^2 = 426430\ (rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 19.66\ Hz$$

$$f_2 = 54.90\ Hz$$

$$f_3 = 89.69\ Hz$$

$$f_4 = 103.93\ Hz$$

Case- 2 (d): Additional mass on slab of 3rd floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_3 =1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 13500 (rad/s) ^{2}

W_2^2 = 150600 (rad/s) ^{2}

W_3^2 = 276670 (rad/s) ^{2}

W_4^2 = 437570 (rad/s) ^{2}

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 18.49\ Hz$$

$$f_2 = 61.76\ Hz$$

$$f_3 = 83.71\ Hz$$

$$f_4 = 105.2\ Hz$$

4.5.3 Case-3: frame with 1st story as soft story

Case-3 (a): without mass variation on floor levels.

$M_1 = 1.54 + .65 + \frac{(.54+.26)}{2} = 2.59$ kg

$M_2 = 1.54 + .65 + (.54 + .26) = 2.99$ kg

$M_3 = 1.54 + .65 + (.54 + .26) = 2.99$ kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 2060$ (rad/s)^2

$W_2^2 = 100820$ (rad/s)^2

$W_3^2 = 313370$ (rad/s)^2

$W_4^2 = 492810$ (rad/s)^2

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 7.22\ Hz$$

$$f_2 = 50.53\ Hz$$

$$f_3 = 89.09\ Hz$$

$$f_4 = 111.72\ Hz$$

Case-3 (b): Additional mass on slab of 1st floor = 3.0 kg

$M_1 = 1.54 + .65 + \frac{(.54+.26)}{2} + \mathbf{3} = 5.59$ kg

$M_2 = 1.54 + .65 + (.54 + .26) = 2.99$ kg

$M_3 = 1.54 + .65 + (.54 + .26) = 2.99$ kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

$K_{open} = 23381$ N/m

$K_{closed} = 415455$ N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 1640$ (rad/s)^2

$W_2^2 = 70470$ (rad/s)^2

$W_3^2 = 269270$ (rad/s)^2

$W_4^2 = 476750$ (rad/s)^2

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 6.44\ Hz$$

$$f_2 = 42.24\ Hz$$

$$f_3 = 82.58\ Hz$$

$$f_4 = 109.89\ Hz$$

Case-3 (c): Additional mass on slab of 2nd floor = 3.0 kg

$M_1 = 1.54 + .65 + \frac{(.54+.26)}{2} = 2.59$ kg

$M_2 = 1.54 + .65 + (.54 + .26) + \mathbf{3} = 5.99$ kg

$M_3 = 1.54 + .65 + (.54 + .26) = 2.99$ kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

$K_{open} = 23381$ N/m

$K_{closed} = 415455$ N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 1610\ (rad/s)^2$

$W_2^2 = 93030\ (rad/s)^2$

$W_3^2 = 251150\ (rad/s)^2$

$W_4^2 = 424090\ (rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 6.38\ Hz$$

$$f_2 = 48.54\ Hz$$

$$f_3 = 79.76\ Hz$$

$$f_4 = 103.64\ Hz$$

Case-3 (d): Additional mass on slab of 3rd floor = 3.0 kg

$M_1 = 1.54 + .65 + \frac{(.54+.26)}{2} = 2.59$ kg

$M_2 = 1.54 + .65 + (.54 + .26) = 2.99$ kg

$M_3 = 1.54 + .65 + (.54 + .26) + \mathbf{3} = 5.99$ kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

$K_{open} = 23381$ N/m

$K_{closed} = 415455$ N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 1600 \text{ (rad/s)}^2$

$W_2^2 = 41330 \text{ (rad/s)}^2$

$W_3^2 = 92350 \text{ (rad/s)}^2$

$W_4^2 = 262630 \text{ (rad/s)}^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 6.36\ Hz$$

$$f_2 = 32.35\ Hz$$

$$f_3 = 48.365\ Hz$$

$$f_4 = 81.56\ Hz$$

4.5.4 Case-4: frame with 2nd story as soft story

Case-4 (a): without mass variation on floor levels.

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

$M_2 = 1.54 + .65 + \frac{(.54+.26)}{2} = 2.59$ kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 2740 (rad/s) ^{2}

W_2^2 = 145690 (rad/s) ^{2}

W_3^2 = 177450 (rad/s) ^{2}

W_4^2 = 452050 (rad/s) ^{2}

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 8.33\ Hz$$

$$f_2 = 60.74\ Hz$$

$$f_3 = 67.04\ Hz$$

$$f_4 = 107.06\ Hz$$

Case-4 (b): Additional mass on slab of 1st floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

M_2 = 1.54 + .65 + $\frac{(.54+.26)}{2}$ = 2.59 kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

M_4 = 1.54 + $\frac{.65}{2}$ + $\frac{(.54+.26)}{2}$ = 2.26 kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 2740 (rad/s) ^{2}

W_2^2 = 73220 (rad/s) ^{2}

W_3^2 = 176430 (rad/s) ^{2}

W_4^2 = 452030 (rad/s) ^{2}

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 8.33\ Hz$$

$$f_2 = 43.06\ Hz$$

$$f_3 = 66.85\ Hz$$

$$f_4 = 107.00\ Hz$$

Case-4 (c): Additional mass on slab of 2nd floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

$M_2 = 1.54 + .65 + \frac{(.54+.26)}{2} + \mathbf{3} = 5.59$ kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 2010 $(rad/s)^2$

W_2^2 = 41762 $(rad/s)^2$

W_3^2 = 147410 $(rad/s)^2$

W_4^2 = 119960 $(rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 7.135\ Hz$$

$$f_2 = 32.52\ Hz$$

$$f_3 = 55.12\ Hz$$

$$f_4 = 61.10\ Hz$$

Case-4 (d): Additional mass on slab of 3rd floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

$M_2 = 1.54 + .65 + \frac{(.54+.26)}{2} = 2.59$ kg

M_3 =1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 1970 (rad/s)^2

W_2^2 = 145520 (rad/s)^2

W_3^2 = 177320 (rad/s)^2

W_4^2 = 313930 (rad/s)^2

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 7.06\ Hz$$

$$f_2 = 60.71\ Hz$$

$$f_3 = 67.01\ Hz$$

$$f_4 = 89.17\ Hz$$

4.5.5 Case-5: frame with 3rd story as soft story

Case-5 (a): without mass variation on floor levels.

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_3 =1.54 + .65 + $\frac{(.54+.26)}{2}$ = 2.59 kg

M_4 = 1.54 + $\frac{.65}{2}$ + $\frac{(.54+.26)}{2}$ = 2.26 kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 4250 (rad/s)^2

W_2^2 = 59090 (rad/s)^2

W_3^2 = 348050 (rad/s)^2

W_4^2 = 366540 (rad/s)^2

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 10.37\ Hz$$

$$f_2 = 38.68\ Hz$$

$$f_3 = 93.89\ Hz$$

$$f_4 = 96.35\ Hz$$

Case-5 (b): Additional mass on slab of 1st floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

$M_3 = 1.54 + .65 + \frac{(.54+.26)}{2} = 2.59$ kg

$M_4 = 1.54 + \frac{.65}{2} + \frac{(.54+.26)}{2} = 2.26$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

$W_1^2 = 4240\ (rad/s)^2$

$W_2^2 = 44880\ (rad/s)^2$

$W_3^2 = 240910\ (rad/s)^2$

$W_4^2 = 348720\ (rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 10.36\ Hz$$

$$f_2 = 33.71\ Hz$$

$$f_3 = 78.11\ Hz$$

$$f_4 = 93.98\ Hz$$

Case-5 (c): Additional mass on slab of 2nd floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

M_3 =1.54 + .65 + $\frac{(.54+.26)}{2}$ = 2.59 kg

M_4 = 1.54 + $\frac{.65}{2}$ + $\frac{(.54+.26)}{2}$ = 2.26 kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (9), we will get,

W_1^2 = 4220 $(rad/s)^2$

W_2^2 = 34270 $(rad/s)^2$

W_3^2 = 317310 $(rad/s)^2$

W_4^2 = 348620 $(rad/s)^2$

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 10.33\ Hz$$

$$f_2 = 29.46\ Hz$$

$$f_3 = 89.65\ Hz$$

$$f_4 = 96.97\ Hz$$

Case-5 (d): Additional mass on slab of 3rd floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_3 =1.54 + .65 + $\frac{(.54+.26)}{2}$ + **3** = 5.59 kg

M_4 = 1.54 + $\frac{.65}{2}$ + $\frac{(.54+.26)}{2}$ = 2.26 kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 2650 (rad/s)^2

W_2^2 = 58950 (rad/s)^2

W_3^2 = 259380 (rad/s)^2

W_4^2 = 366020 (rad/s)^2

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 8.19\ Hz$$

$$f_2 = 38.64\ Hz$$

$$f_3 = 81.05\ Hz$$

$$f_4 = 96.28\ Hz$$

4.5.6 Case-6: frame with 4th story as soft story

Case-6 (a): without mass variation on floor levels.

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2} = 1.865$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 9970 (rad/s)^2

W_2^2 = 34060 (rad/s)^2

W_3^2 = 219010 (rad/s)^2

W_4^2 = 452050 (rad/s)^2

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 15.89\ Hz$$

$$f_2 = 29.41\ Hz$$

$$f_3 = 74.62\ Hz$$

$$f_4 = 107.00\ Hz$$

Case-6 (b): Additional mass on slab of 1st floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2}$ = 1.865 kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 9880 (rad/s) ^{2}

W_2^2 = 30420 (rad/s) ^{2}

W_3^2 = 141730 (rad/s) ^{2}

W_4^2 = 393880 (rad/s) ^{2}

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 15.81\ Hz$$

$$f_2 = 27.75\ Hz$$

$$f_3 = 59.91\ Hz$$

$$f_4 = 99.88\ Hz$$

Case-6 (c): Additional mass on slab of 2nd floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) + **3** = 5.99 kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2} = 1.865$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 9630 (rad/s)^2

W_2^2 = 25610 (rad/s)^2

W_3^2 = 199640 (rad/s)^2

W_4^2 = 341040 (rad/s)^2

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 15.61\ Hz$$

$$f_2 = 25.45\ Hz$$

$$f_3 = 71.11\ Hz$$

$$f_4 = 92.94\ Hz$$

Case-6 (d): Additional mass on slab of 3rd floor = 3.0 kg

M_1 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_2 = 1.54 + .65 + (.54 + .26) = 2.99 kg

M_3 =1.54 + .65 + (.54 + .26) = 2.99 kg

$M_4 = 1.54 + \frac{.65}{2} = 1.865$ kg

And

K_{open}=23381 N/m

K_{closed}=415455 N/m

On substituting these values in equation (7), we will get,

W_1^2 = 9280 (rad/s)^2

W_2^2 = 23630 (rad/s)^2

W_3^2 = 177710 (rad/s)^2

W_4^2 = 430970 (rad/s)^2

As,

$$f = \frac{w}{2\pi}$$

Hence,

$$f_1 = 15.33\ Hz$$

$$f_2 = 24.46\ Hz$$

$$f_3 = 67.09\ Hz$$

$$f_4 = 104.48\ Hz$$

CHAPTER 5

EXPERIMENTAL PROGRAM

5.1 Introduction

Aluminium frame model is used for the experimental analysis. The frame is considered four story shear building model. Model available in Delhi Technological University, Earthquake Laboratory is used. The test is conducted to find out the mode shape and frequencies of the model. Testing was done with symmetric frame and asymmetric frames. Then apply additional mass at different floor level to see the behaviour of the building model due to this mass irregularity. The variation in mass at different floor level is done as described in analytical procedure. The dimension parameter is same as described in analytical procedure. Figure 5.1 and 5.2 show the details of the frame model.

Following cases are adopted while carrying out the experimental analysis:

Case 1: bare frame with no walls

Case 2: frame with all story closed by walls

Case 3: frame with 1st story as soft story

Case 4: frame with 2nd story as soft story

Case 5: frame with 3rd story as soft story

Case 6: frame with 4thstory as soft story

All the above cases are further divided into four sub cases as follow:

a) Without mass variation on floor level

b) With additional mass on 1st floor =3 kg

c) With additional mass on 2nd floor = 3 kg

d) With additional mass on 3rd floor = 3 kg

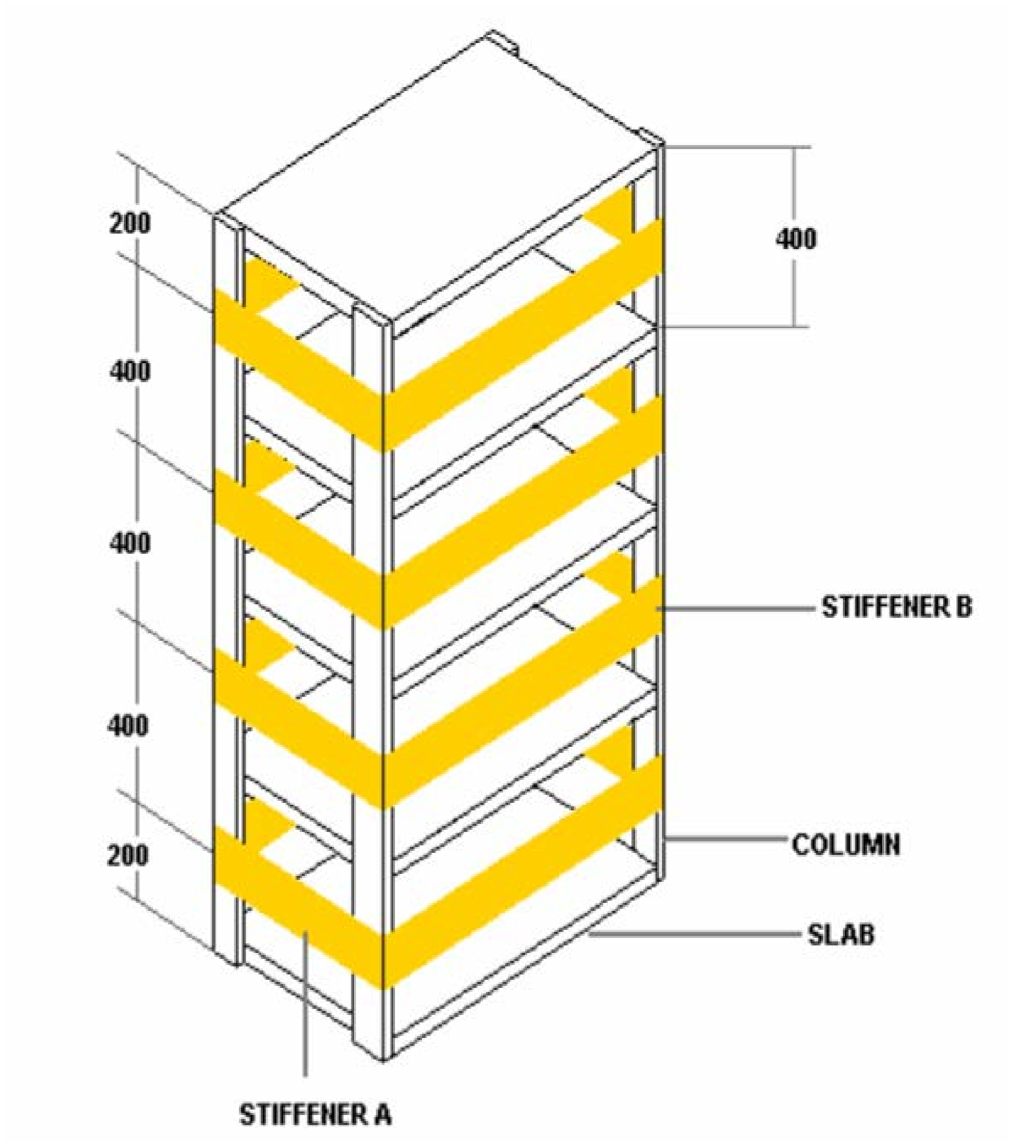


Fig. 5.1 experimental model (NPEEE)

Fig. 5.2 experimental model

5.2 Equipment used in the experimental analysis

The equipment used in the experimental analysis are given in the table 5.1

Table 5.1 provides the details of instruments to be used in the experimental study.

No.	Equipment	Quantity
1	Oscilloscope	1
2	Accelerometers	4
3	Display unit	1
4	Transducers conditioning amplifiers	1
5	Shake table	1

1) Oscilloscope

OROS 3-Series/NV Gate analyser system type OR36 software analysis was used to measure the free vibration for the modal. It can be used for both free vibration as well as forced vibration study. This has the channels to connect the cables for analysing both input and output signals. The FFT analyser is shown in Figure 5.3.

Fig. 5.3 oscilloscope

2) Accelerometer

Accelerometer combines high sensitivity, low and small physical dimensions making them ideally suited for modal analysis. It can be easily fitted to different test objects using section mounting clips. The accelerometer which is used in the present experimental analysis of free vibration test is presented in figure 5.4.

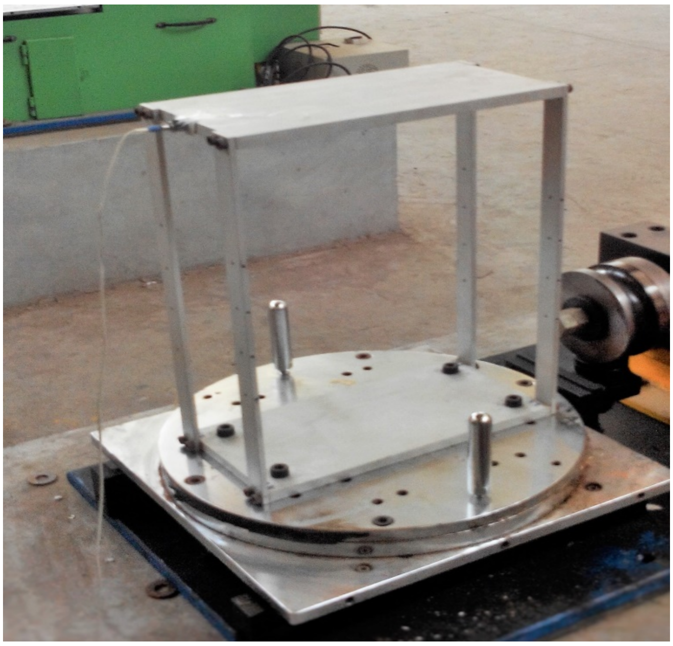


Fig. 5.4

3) Display unit

This is mainly in the form of PC. When the excitation occurs to the structure, the signals transfer to the portable PUSLE and after conversion this comes in graphical form through the software and display on the screen of PC. Mainly the data includes graphs of force vs. time, frequency vs. time, frequency vs. displacement, frequency vs. acceleration etc. The display unit is show below in Figure 5.5.

Fig. 5.5 display unit

4) Details of the sensors used

No.	Sensor	Sensitivity m(V)/g
1	1	96.98
2	2	91.72
3	3	92.72
4	4	96.02

5.3 Preliminary measurements

a) The geometric and material properties of the testing system are collected. The particular related to the experiment is given in table

b) Taking the mass and stiffness properties of the model, eigen value analysis is carried out to calculate the natural frequencies.

c) The data related to the sensors. The sensitivities of sensors are noted down.

d) The initial displacement of the base motion is noted down by running the electric motor a particular frequency.

e) This base motion displacement should be kept constant.

f) The experimental setup is so arranged so that the displacement in the x direction is obtained. The experimental setup is shown in figure

g) Now the frame is set to run and the frequency of the motor changed. By gradually increasing the frequency of the motor, floor displacement is recorded. When the resonance occurs the floor displacement is drastically changes. At the resonant condition the floor displacement is very high. Note that the resonance frequency should not be missed.

5.4 Determination of natural frequencies of frame

5.4.1 Case-1: bare frame with no walls

In this case a four storied bare frame model with no walls is used to study effect of mass irregularity. Here cases with no mass variation and then with variation of mass at different floor level is studied and corresponding natural frequency is found in laboratory.

As the model have higher mode at higher frequencies as calculated analytically, hence it is not possible to produce such higher frequencies in laboratory due to limitation of set up hence only 1st mode at lower frequencies are studied.

Case-1 (a): without mass variation on floor levels.

Four storied bare frame with no walls model is as shown in figure below:

Figure 5.6 bare frame model without mass variation on floor

The record of frequency vs. floor displacement is presented in table 5.2 and the frequency vs. floor displacement graph is plotted in figure 5.7

Table 5.2 Floor displacement corresponding to guiding frequency without mass variation

Frequency (Hz)	Floor Displacement (μm)			
	F1	F2	F3	F4
1.4	372	458	559	592
1.8	520	586	655	740
2.4	712	705	783	805
2.8	740	790	805	855
3.2	905	1203	1330	1420
3.6	1065	1407	1431	1548
4.0	1206	1383	1775	2453
4.4	1350	1456	1656	3965
4.8	1442	1763	1448	3365
5.2	1106	2056	2120	2963
5.6	895	4456	2322	4456
5.8	2630	7890	8654	8692
6.0	5398	10115	13534	15208
6.2	2296	6520	9663	9865
6.4	1656	3656	6756	6652
6.8	1230	2427	4452	4856
7.2	890	1263	2365	3303

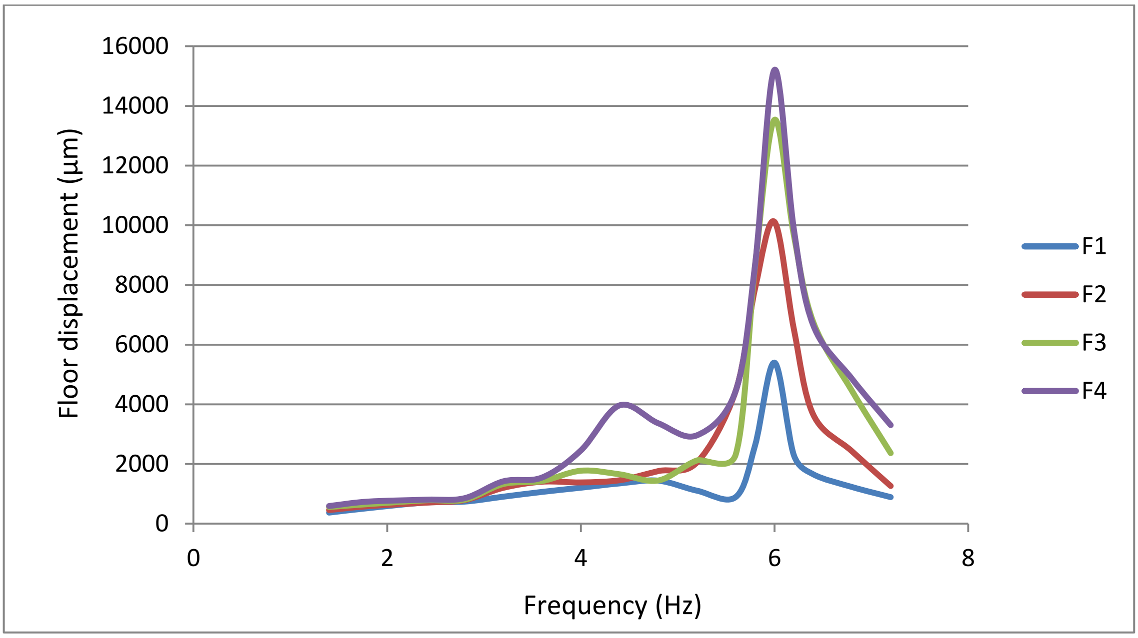


Fig. 5.7 floor displacement corresponding to guiding frequency without mass variation

The graph shows above in figure 5.7 gives the details of displacement of floor with increase in the frequency. The floor displacement is maximum for the top floor in fundamental mdof vibration.

Resonance is achieved at frequency of 6.0 Hz.

Case-1 (b): Additional mass on slab of 1st floor = 3.0 kg

In this case additional load of 3 kg is applied on 1st floor of frame as shown in the figure;

Figure 5.8 bare frame model with mass variation on 1st floor

The record of frequency vs. floor displacement is presented in table 5.3 and the frequency vs. floor displacement graph is plotted in figure 5.9.

Table 5.3 floor displacement corresponding to guiding frequency (additional mass on 1st floor)

Frequency (Hz)	Floor Displacement (µm)			
	F1	F2	F3	F4
1.8	408	482	571	604
2.4	516	596	622	757
2.8	716	729	802	781
3.2	735	867	969	991
3.6	866	1254	1234	1151
4.0	769	985	1658	1365
4.4	653	1362	2230	2064
4.8	1021	1565	2859	2123
5.2	1104	864	3105	4250
5.6	2456	3652	6620	8890
5.8	5704	9860	12847	14303
6.0	2165	7826	5512	8620
6.2	1653	4830	5512	6523
6.4	1405	3320	2356	3025
6.8	1526	2369	2685	3214

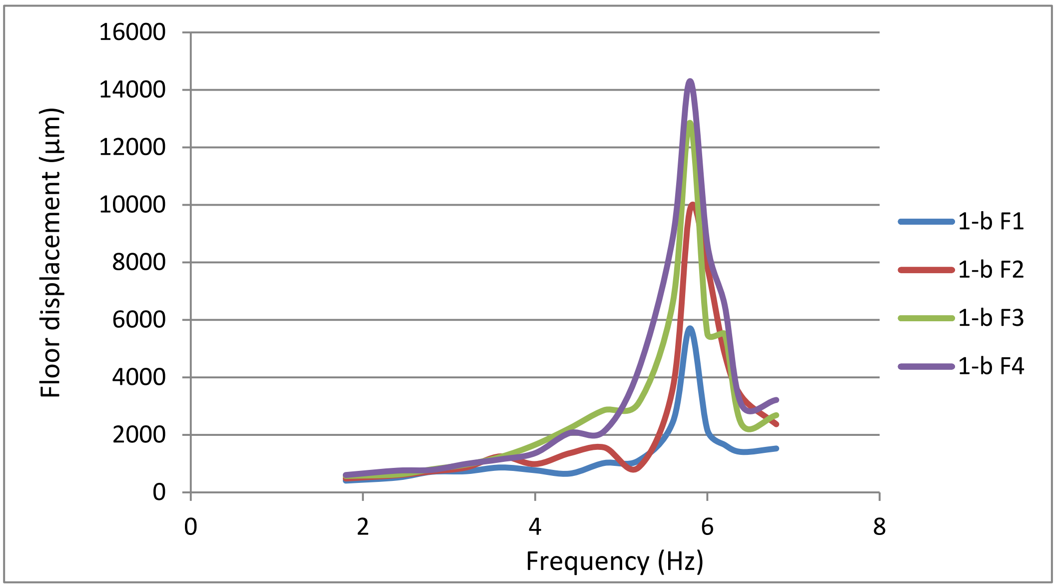


Fig. 5.9 floor displacement corresponding to guiding frequency with mass variation on 1st floor

The graph shows above in figure 5.9 gives the details of displacement of floor with increase in the frequency. The floor displacement is maximum for the top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 5.8 Hz.

Case-1 (c): Additional mass on slab of 2nd floor = 3.0 kg

In this case additional load of 3 kg is applied on 2nd floor of frame as shown in the figure;

Figure 5.10 bare frame model with mass variation on 2nd floor

The record of frequency vs. floor displacement is presented in table 5.4 and the frequency vs. floor displacement graph is plotted in figure 5.11

Table 5.4 floor displacement corresponding to guiding frequency (additional mass on 2nd floor)

Frequency (Hz)	Floor Displacement (µm)			
	F1	F2	F3	F4
1.4	334	556	589	571
1.8	495	555	675	715
2.4	723	713	763	795
2.8	776	1035	1048	1081
3.2	887	1041	1098	1144
3.6	938	1269	1347	1239
4.0	1048	1405	1605	1860
4.4	865	1676	1861	1919
4.8	1256	2760	2315	2352
5.2	2980	3560	5120	6230
5.4	4980	9470	11771	12885
5.6	2230	4215	8625	6332
5.9	2762	3456	3586	4560
6.2	2205	2756	3456	5423

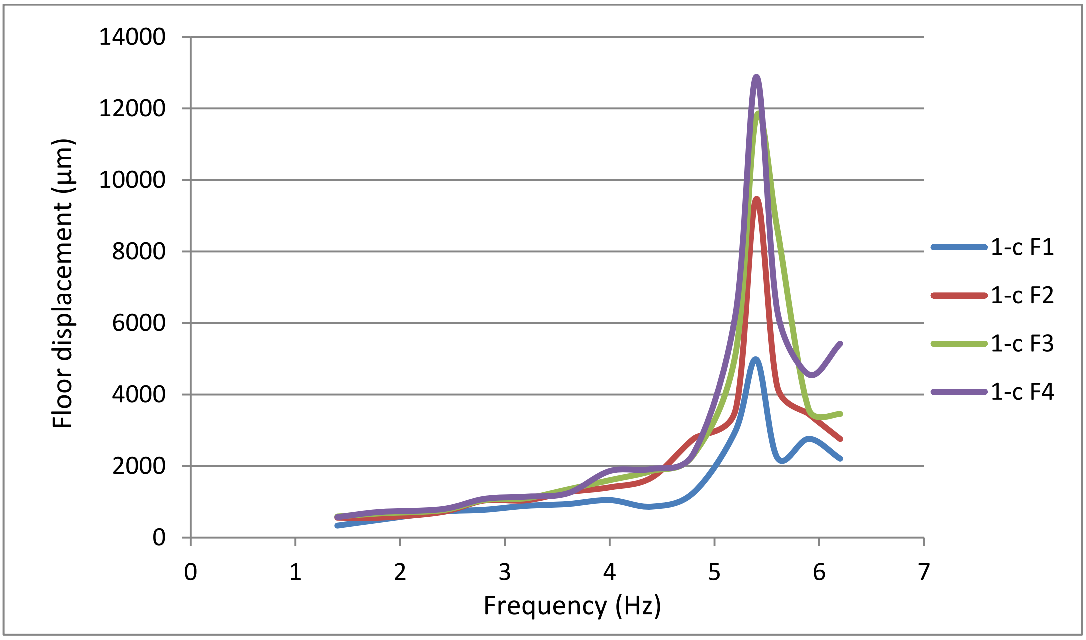


Fig. 5.11 floor displacement corresponding to guiding frequency with mass variation on 2nd floor

The graph shows above in figure 5.11 gives the details of displacement of floor with increase in the frequency. The floor displacement is maximum for the top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 5.4 Hz

Case-1 (d): Additional mass on slab of 3rd floor = 3.0 kg

In this case additional load of 3 kg is applied on 3rd floor of frame as shown in the figure;

Figure 5.12 bare frame model with mass variation on 3rd floor

The record of frequency vs. floor displacement is presented in table 5.5 and the frequency vs. floor displacement graph is plotted in figure 5.13.

Table 5.5 floor displacement corresponding to guiding frequency (additional mass on 3rd floor)

Frequency (Hz)	Floor Displacement (µm)			
	F1	F2	F3	F4
1.4	346	395	495	456
1.8	406	531	605	549
2.4	729	755	784	763
2.8	735	978	950	900
3.2	900	1010	935	1035
3.6	756	1050	1144	1160
4.0	1233	1901	2258	1325
4.4	1456	2465	2690	1910
4.8	1653	3012	3365	4012
5.2	4266	8171	11370	12294
5.6	1856	3662	5632	6352
5.8	1120	1869	2362	4865
6.0	1246	1125	1965	2456

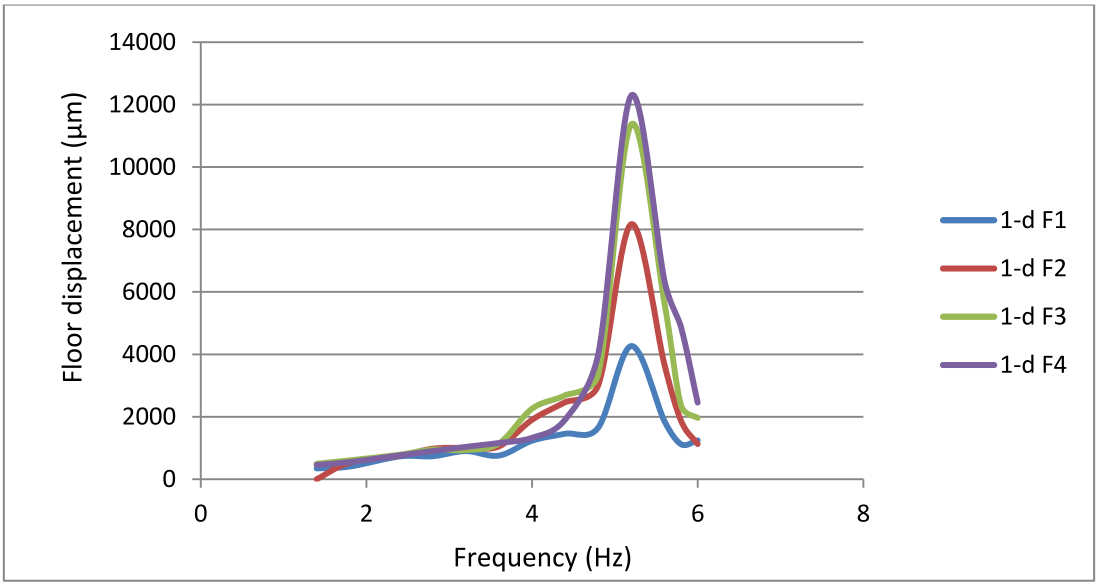


Fig. 5.13 floor displacement corresponding to guiding frequency with mass variation on 3rd floor

The graph shows above in figure 5.13 gives the details of displacement of floor with increase in the frequency. The floor displacement is maximum for the top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 5.2 Hz.

5.4.2 Case-2: frame with all story closed by walls

In this case a four storied frame model where all story are closed with walls is used to study effect of mass irregularity. Here cases with no mass variation and then with variation of mass at different floor level is studied and corresponding natural frequency is found in laboratory.

In this case the stiffness of the frame is so high that even 1st mode is obtained at frequency of 18.49Hz as calculated analytically and such high frequency cannot be achieved experimentally.

Hence no displacement variations with frequency are shown for this case.

Figure 5.14 model with all story closed by walls

5.4.3 Case-3: frame with 1st story as soft story

In this case a four storied bare frame model with ground(1st) story with no walls(soft story) is used to study effect of mass irregularity. Here cases with no mass variation and then with variation of mass at different floor level is studied and corresponding natural frequency is found in laboratory.

Case-3 (a): without mass variation on floor levels.

In this case no additional load is applied on floor of frame as shown in the figure;

Figure 5.15 frame with 1st soft story model without mass variation on floor

The record of frequency vs. floor displacement is presented in table 5.6 and the frequency vs. floor displacement graph is plotted in figure 5.16.

Table 5.6 floor displacement corresponding to guiding frequency without additional mass

Frequency (Hz)	**Floor Displacement (μm)**			
	F1	F2	F3	F4
1.4	506	630	698	756
1.8	605	744	731	856
2.4	664	802	871	923
3.0	774	822	997	1046
3.6	801	882	972	1026
4.0	865	896	965	1120
4.2	974	1084	1419	1903
4.4	1056	1335	1503	2296
4.8	1456	1663	1882	1901
5.2	1623	2040	1839	1562
5.8	2863	3496	2963	3125
6.4	2350	2923	3460	3896
6.6	3925	4996	5102	5467
6.8	9607	10085	10356	10516
7.0	3962	4533	4663	5369
7.2	2230	2625	2998	3265
7.4	2405	2220	2345	3320

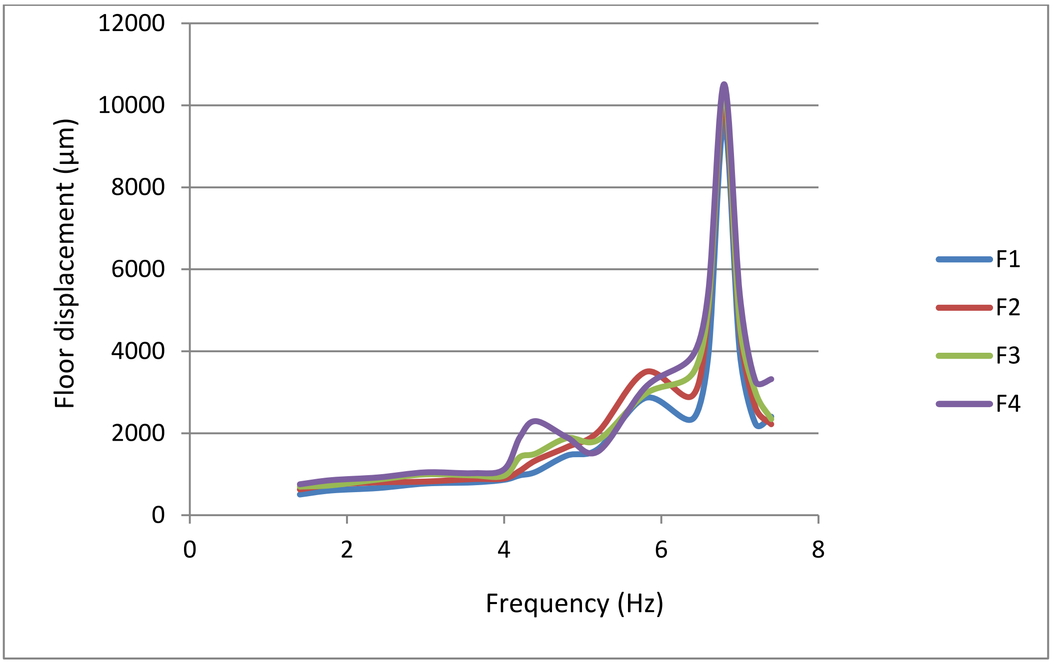


Fig. 5.16 floor displacement corresponding to guiding frequency without mass variation

The graph shows above in figure 5.16 gives the details of displacement of floor with increase in the frequency. The floor displacement is less for first floor and almost same for the second, third and top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 6.8

Case-3 (b): Additional mass on slab of 1st floor = 3.0 kg

In this case additional load of 3 kg is applied on 1^{st} floor of frame as shown in the figure;

Figure 5.17 frame with 1^{st} soft story model with mass variation on 1st floor

The record of frequency vs. floor displacement is presented in table 5.7 and the frequency vs. floor displacement graph is plotted in figure 5.18.

Table 5.7 floor displacement corresponding to guiding frequency (additional mass on 1st floor)

Frequency (Hz)	Floor Displacement (μm)			
	F1	F2	F3	F4
1.4	392	422	424	496
1.8	422	470	446	573
2.4	506	630	698	756
3.0	605	744	731	856
3.6	664	802	871	923
4.0	774	822	997	1046
4.2	801	882	872	1226
4.4	965	896	965	1655
4.8	1025	1123	1396	1965
5.2	1489	1882	3382	2552
5.8	2065	2352	3562	2923
6.4	3252	3430	3883	4302
6.6	8718	9039	9262	9378
6.8	3636	3965	4022	4088
7	3772	3789	3898	4056
7.2	4236	4110	3963	4256
7.4	4056	4220	4056	4112

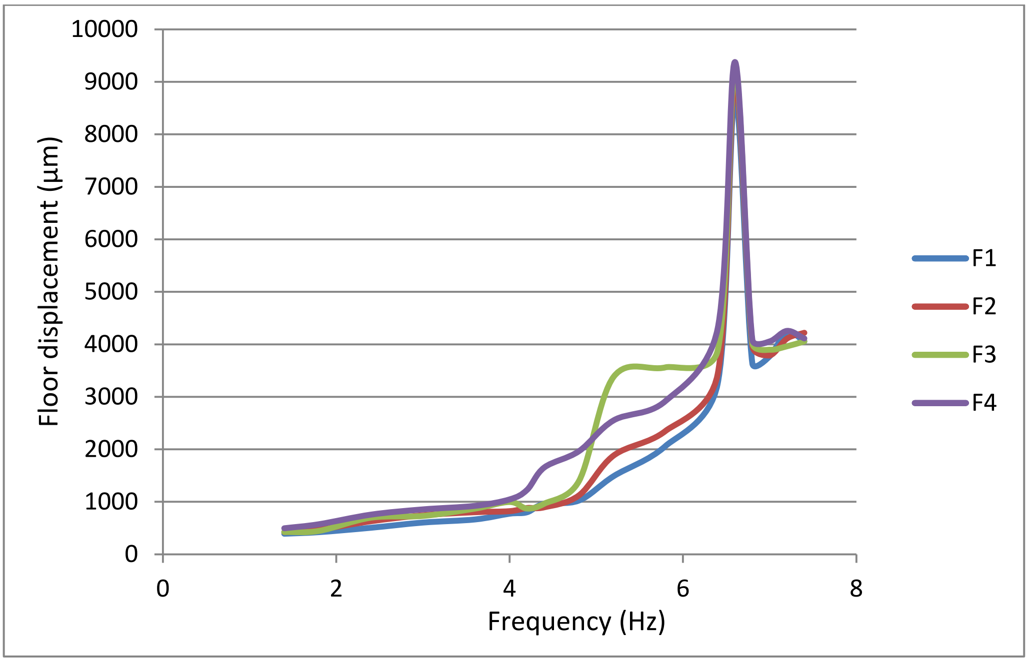


Fig. 5.18 floor displacement corresponding to guiding frequency with mass variation on 1st floor

The graph shows above in figure 5.16 gives the details of displacement of floor with increase in the frequency. The floor displacement is less for first floor and almost same for the second, third and top floor in fundamental mode of vibration.

.Resonance is achieved at frequency of 6.6 Hz

Case-3 (c): Additional mass on slab of 2nd floor = 3.0 kg

In this case additional load of 3 kg is applied on 2nd floor of frame as shown in the figure;

Figure 5.19 frame with 1st soft story model with mass variation on 2nd floor

The record of frequency vs. floor displacement is presented in table 5.8 and the frequency vs. floor displacement graph is plotted in figure 5.20.

Table 5.8 floor displacement corresponding to guiding frequency (additional mass on 2nd floor)

Frequency (Hz)	Floor Displacement (μm)			
	F1	F2	F3	F4
1.4	325	426	559	535
1.8	423	459	597	688
2.4	465	502	656	786
3.0	663	696	712	804
3.6	846	905	998	1056
4.0	963	1023	1112	1196
4.0	1205	1144	1344	1263
4.4	1652	1526	1656	1754
5.0	2125	2365	1853	1903
5.8	2635	2963	2639	2888
6.2	3326	3556	3692	3516
6.4	8576	8991	9212	9330
6.6	4456	4632	4562	4662
6.8	4652	4763	4689	4765
7.0	4562	4852	4887	4925
7.2	4726	4775	4996	5021

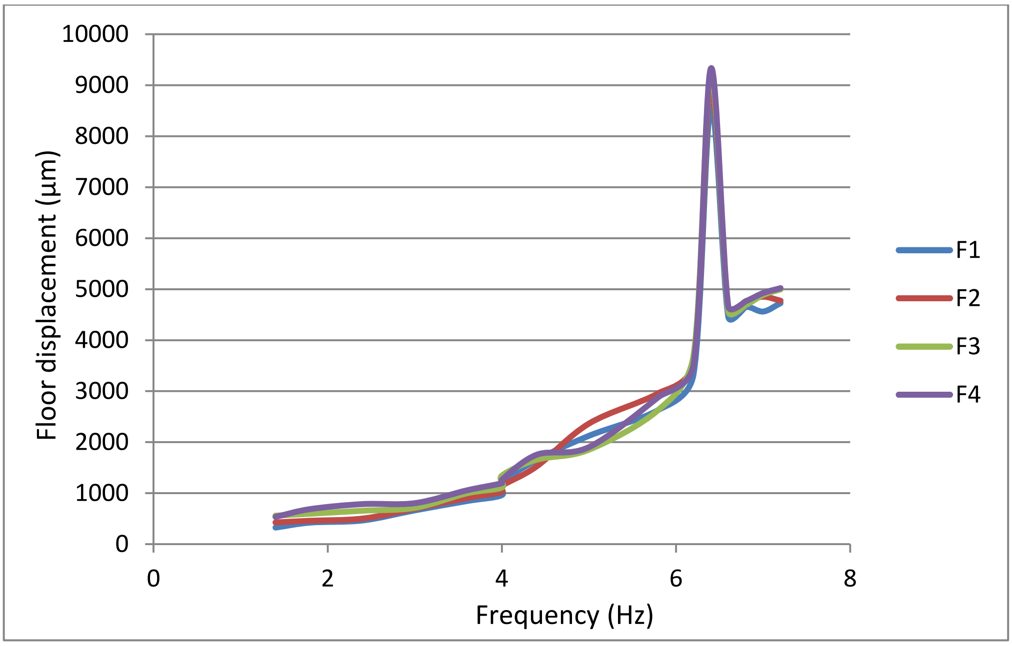


Fig. 5.20 floor displacement corresponding to guiding frequency with mass variation on 2nd floor

The graph shows above in figure 5.20 gives the details of displacement of floor with increase in the frequency. The floor displacement is less for first floor and almost same for the third and top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 6.4 Hz

Case-3 (d): Additional mass on slab of 3rd floor = 3.0 kg

In this case additional load of 3 kg is applied on 3rd floor of frame as shown in the figure;

Figure 5.21 frame with 1st soft story model with mass variation on 3rd floor

The record of frequency vs. floor displacement is presented in table 5.9 and the frequency vs. floor displacement graph is plotted in figure 5.22.

Table 5.9 floor displacement corresponding to guiding frequency (additional mass on 3rd floor)

Frequency (Hz)	Floor Displacement (μm)			
	F1	F2	F3	F4
1.4	362	444	521	620
1.8	456	496	568	644
2.4	604	665	705	695
3	798	800	963	1036
3.6	936	1104	1040	1254
4	1009	1296	1454	1365
4	1059	1339	1535	1757
4.4	1453	1963	1339	1635
5	1856	1693	2455	2756
5.8	2325	3652	3456	2223
6.2	3256	3644	3856	3443
6.4	4032	4432	5026	5126
6.5	8469	8883	9205	9327
6.6	4456	4115	3965	4126
6.9	2633	2773	2951	3301
7.2	1744	1854	2020	2263
7.4	1203	1456	1556	1866

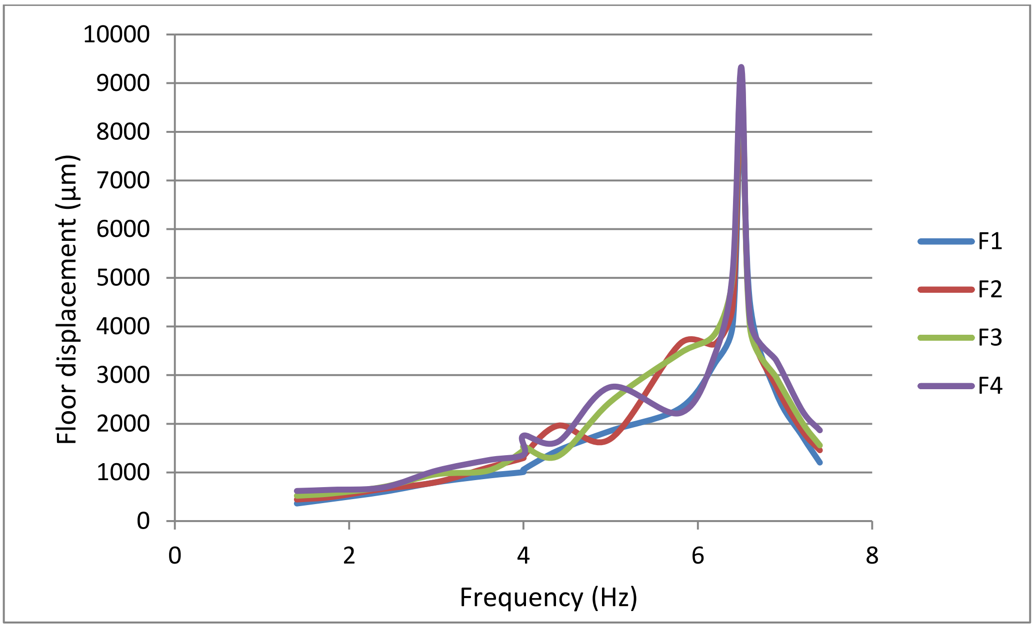


Figure 5.22 floor displacement corresponding to guiding frequency with mass variation on 3rd floor

The graph shows above in figure 5.22 gives the details of displacement of floor with increase in the frequency. The floor displacement is less for first floor and almost same for the third and top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 6.5 Hz

5.4.4 Case-4: frame with 2nd story as soft story

In this case a four storied bare frame model with 2nd story with no walls(soft story) is used to study effect of mass irregularity. Here cases with no mass variation and then with variation of mass at different floor level is studied and corresponding natural frequency is found in laboratory.

Case-4 (a): without mass variation on floor levels.

In this case no additional load is applied on floor of frame as shown in the figure;

Figure 5.23 frame with 2^{nd} soft story model without mass variation on floor

The record of frequency vs. floor displacement is presented in table 5.10 and the frequency vs. floor displacement graph is plotted in figure 5.24.

Table 5.10 floor displacement corresponding to guiding frequency with no additional mass

Frequency (Hz)	Floor Displacement (µm)			
	F1	F2	F3	F4
1.4	275	408	456	512
1.8	326	512	496	526
2.4	386	695	604	656
2.8	424	804	744	833
3.4	452	865	963	1069
4	469	953	1066	1203
4.6	481	1103	1365	1562
5.4	505	1265	1466	1956
6	530	1456	1862	1722
6.6	545	1988	1536	2456
7	575	2356	2755	2693
7.5	590	4562	6523	6362
7.8	594	7562	7789	7963
7.9	624	11535	12002	12241
8	574	8562	9663	10452
8.2	504	6523	7223	6932
8.4	536	5523	5963	5226

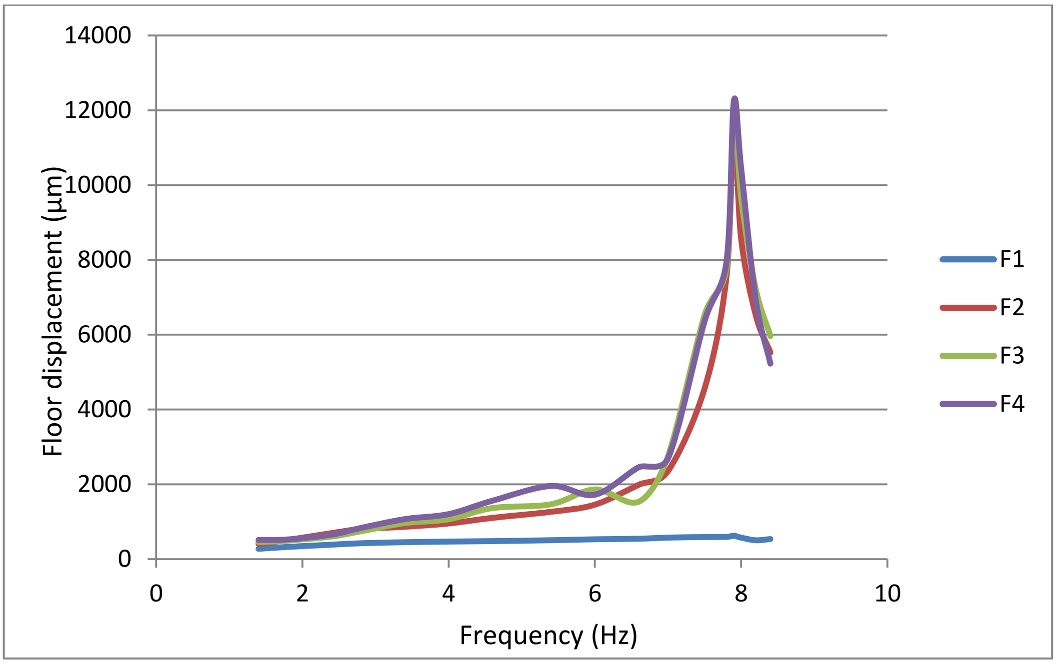


Fig. 5.24 floor displacement corresponding to guiding frequency without mass variation

The graph shows above in figure 5.24 gives the details of displacement of floor with increase in the frequency. Displacement of first floor is very less and almost same for second, third and top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 7.9 Hz.

Case-4 (b): Additional mass on slab of 1st floor = 3.0 kg

In this case additional load of 3 kg is applied on 1st floor of frame as shown in the figure;

Fig. 5.25 frame with 2nd soft story model with mass variation on 1st floor

The record of frequency vs. floor displacement is presented in table 5.11 and the frequency vs. floor displacement graph is plotted in figure 5.26.

Table 5.11 floor displacement corresponding to guiding frequency (additional mass on 1st floor)

Frequency (Hz)	Floor Displacement (μm)			
	F1	F2	F3	F4
1.4	292	456	354	504
2	321	496	556	654
2.8	546	723	865	962
3.6	886	1456	1236	1050
4.4	986	1863	1756	2026
5.2	1223	2256	2465	3056
6	1365	2639	2230	3625
6.4	1235	3212	3125	3456
6.8	1456	2963	3456	3962
7.2	1774	4420	3856	4456
7.5	1853	5652	5126	5326
7.8	2456	6623	7625	7456
8	3000	11533	11998	12239
8.2	2115	6235	6330	7256
8.6	1963	5569	5696	6632

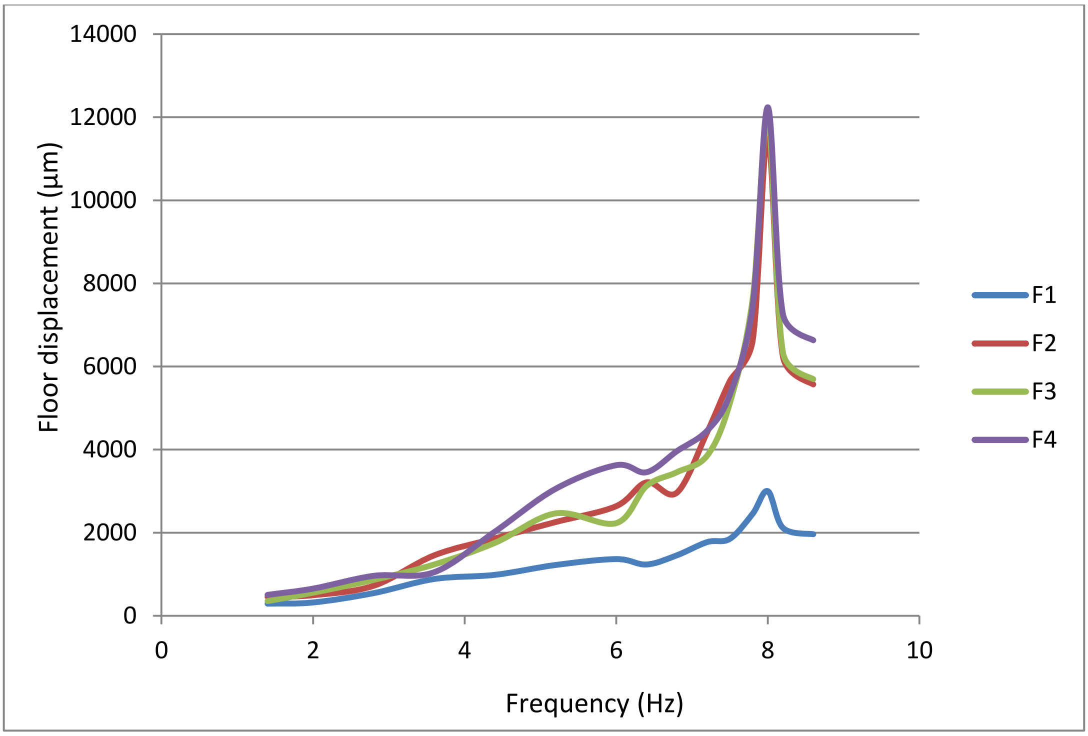


Fig. 5.26 floor displacement corresponding to guiding frequency with mass variation on 1st floor.

The graph shows above in figure 5.26 gives the details of displacement of floor with increase in the frequency. The floor displacement is very less for first floor and almost same fore above floors with maximum for the top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 8 Hz.

Case-4 (c): Additional mass on slab of 2nd floor = 3.0 kg

In this case additional load of 3 kg is applied on 2nd floor of frame as shown in the figure;

Fig. 5.27 frame with 2nd soft story model with mass variation on 2nd floor

The record of frequency vs. floor displacement is presented in table 5.12 and the frequency vs. floor displacement graph is plotted in figure 5.28.

Table 5.12 floor displacement corresponding to guiding frequency (additional mass on 2nd floor)

Frequency (Hz)	Floor Displacement (μm)			
	F1	F2	F3	F4
1.4	242	321	426	523
2	296	411	552	625
2.8	349	541	775	865
3.6	584	986	1052	963
4.4	774	1011	1263	1362
5	995	1456	1662	1896
5.8	1196	1235	1996	2260
6.4	1294	3362	3966	4652
6.6	1856	6953	7562	7965
6.8	2597	10031	10336	10496
7	2041	8456	8501	8652
7.5	1652	5562	6022	7623
7.6	1362	3669	4096	5623
7.8	1420	4025	4263	4425

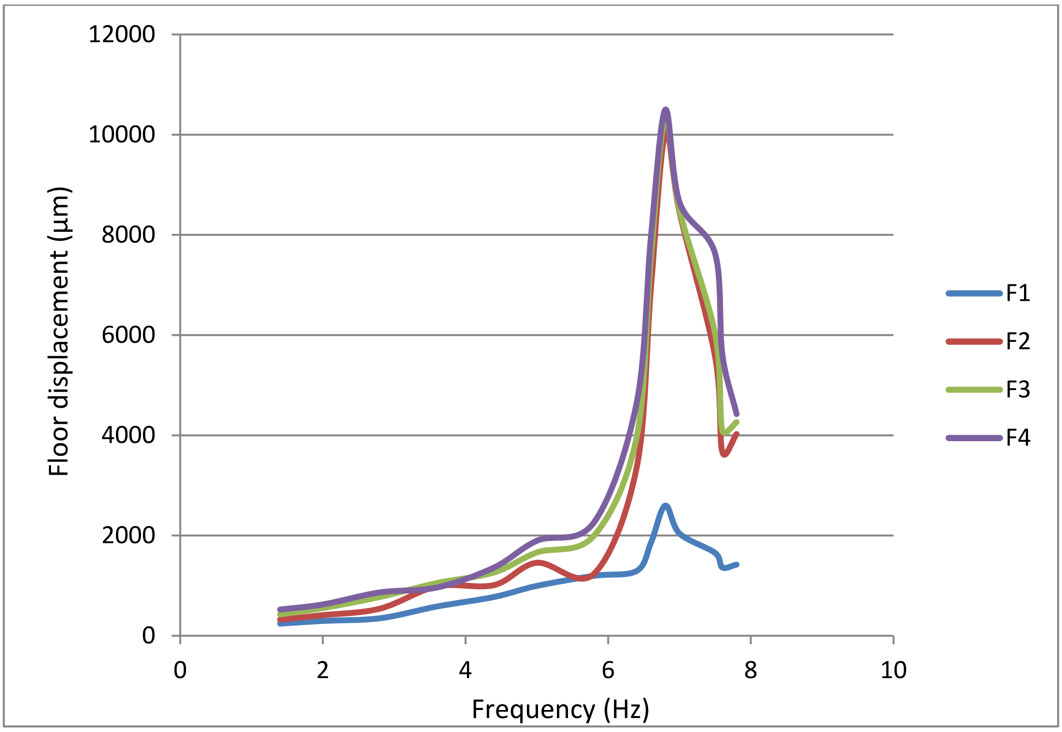


Fig. 5.28 floor displacement corresponding to guiding frequency with mass variation on 2nd floor

The graph shows above in figure 5.28 gives the details of displacement of floor with increase in the frequency. The floor displacement is almost same for second, third and top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 6.8 Hz.

Case-4 (d): Additional mass on slab of 3rd floor = 3.0 kg

In this case additional load of 3 kg is applied on 3rd floor of frame as shown in the figure;

Fig. 5.29 frame with 2nd soft story model with mass variation on 3rd floor

The record of frequency vs. floor displacement is presented in table 5.13 and the frequency vs. floor displacement graph is plotted in figure 5.30.

Table 5.13 floor displacement corresponding to guiding frequency (additional mass on 3rd floor)

Frequency (Hz)	Floor Displacement (μm)			
	F1	F2	F3	F4
1.4	496	596	695	765
2	601	672	756	962
2.8	711	804	876	1253
3.6	864	1052	1026	1896
4.4	921	1456	1965	2156
5	1056	1652	1445	2456
5.6	1123	1865	2165	2256
6.4	1322	2456	2364	3269
6.8	1665	3632	3906	4986
7	2256	4806	5102	5698
7.1	2549	10092	10286	10450
7.4	1896	5623	5564	5693
7.8	1356	4963	5123	5226

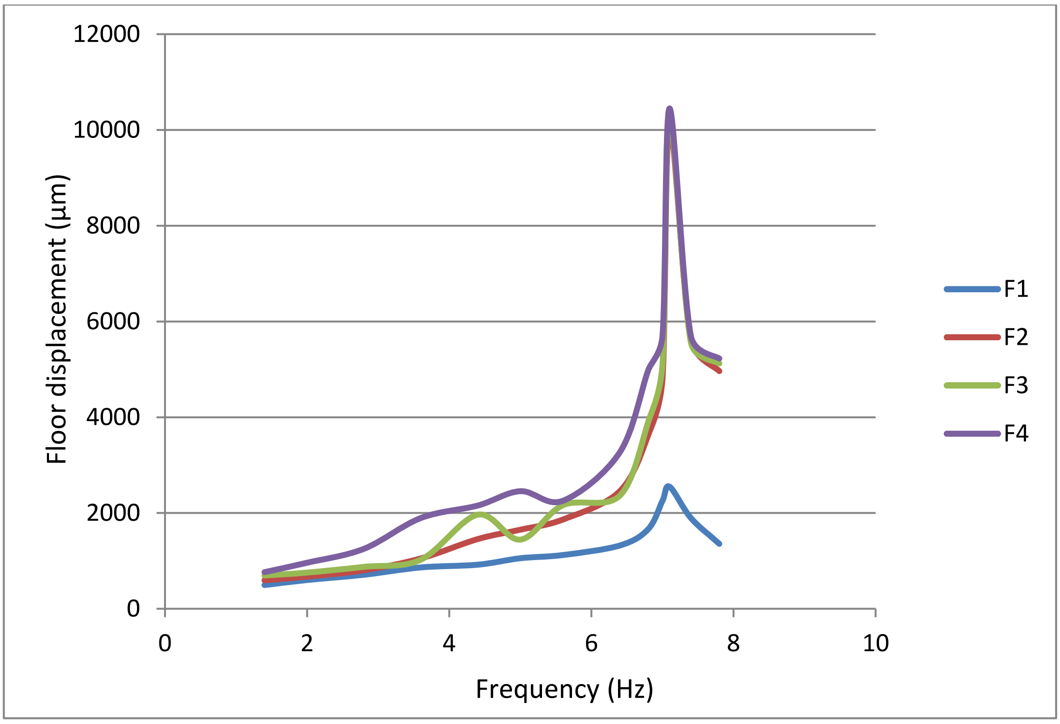


Fig. 5.30 floor displacement corresponding to guiding frequency with mass variation on 3rd floor

The graph shows above in figure 5.30 gives the details of displacement of floor with increase in the frequency. The floor displacement is almost same for second, third and top floor in fundamental mode of vibration.

Resonance is achieved at frequency of 7.1 Hz.

5.4.5 Case-5: frame with 3rd story as soft story

In this case the stiffness of the frame is so high that even 1st mode is obtained at frequency of 10.98Hz as calculated analytically and such high frequency cannot be achieved experimentally.

Hence no displacement variations with frequency are shown for this case.

Figure 5.31 frame with 3rd story as soft story

5.4.6 Case-6: frame with 4th story as soft story

In this case the stiffness of the frame is so high that even 1st mode is obtained at frequency of 18.49Hz as calculated analytically and such high frequency cannot be achieved experimentally.

Hence no displacement variations with frequency are shown for this case.

Fig. 5.32 frame with 4th story as soft story

CHAPTER 6

ETABS MODELLING

6.1 Introduction

The frame is modelled in ETABS software to validate the result that I have obtained from the analytical and experimental analysis. The model is analysed with no additional mass on the floor level and with additional mass on different floor level. The time period and frequency is calculated for every case, with or without additional mass. The mass is varied along the height of the frame. The properties of the model are taken from the analytical and experimental analysis.

Following cases were adopted while carrying out analysis in ETABS:

Case 1: bare frame with no walls

Case 2: frame with all story closed by walls

Case 3: frame with 1st story as soft story

Case 4: frame with 2nd story as soft story

Case 5: frame with 3rd story as soft story

Case 6: frame with 4thstory as soft story

All the above cases are further divided into four sub cases as follow:

a) Without mass variation on floor level

b) With additional mass on 1st floor = 3 kg

c) With additional mass on 2nd floor = 3 kg

d) With additional mass on 3rd floor = 3 kg

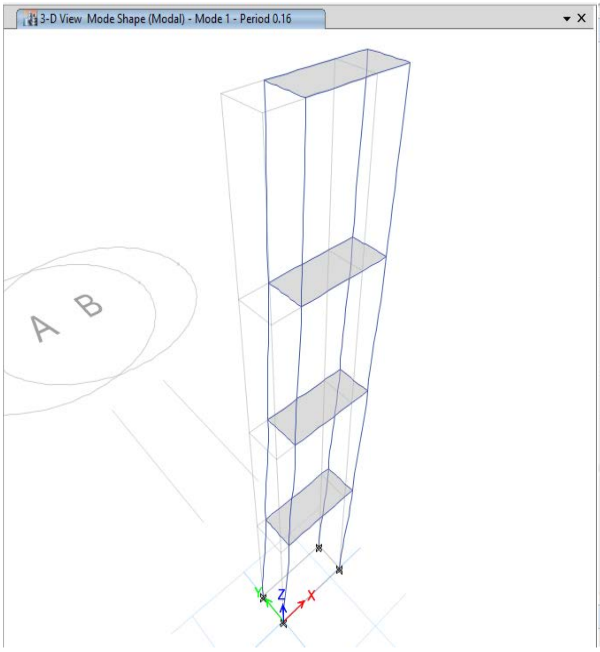
6.2 Dynamic analysis

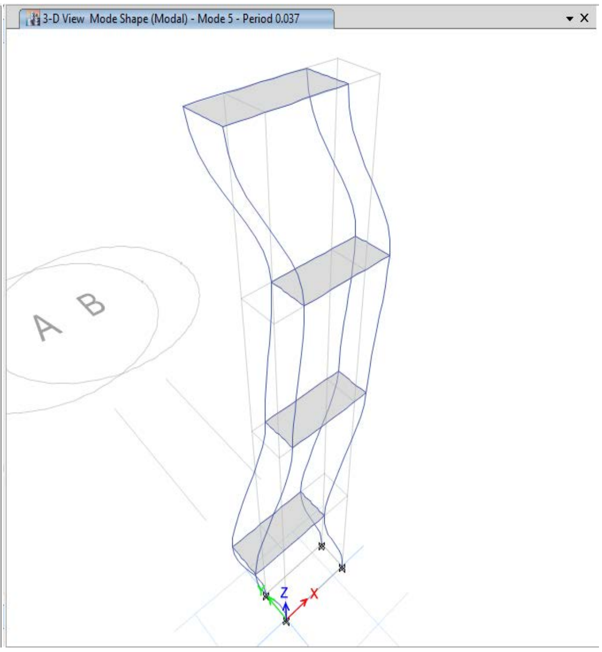
The dynamical analysis is carried out for the above cases. The time periods and frequencies are obtained for different modes. The frequencies and time periods obtained for various cases are plotted in tables below

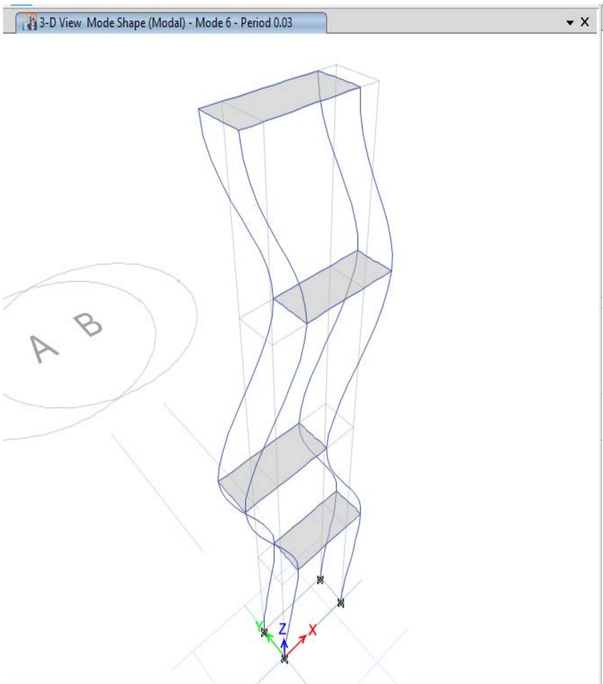
6.2.1 Case-1: bare frame with no walls

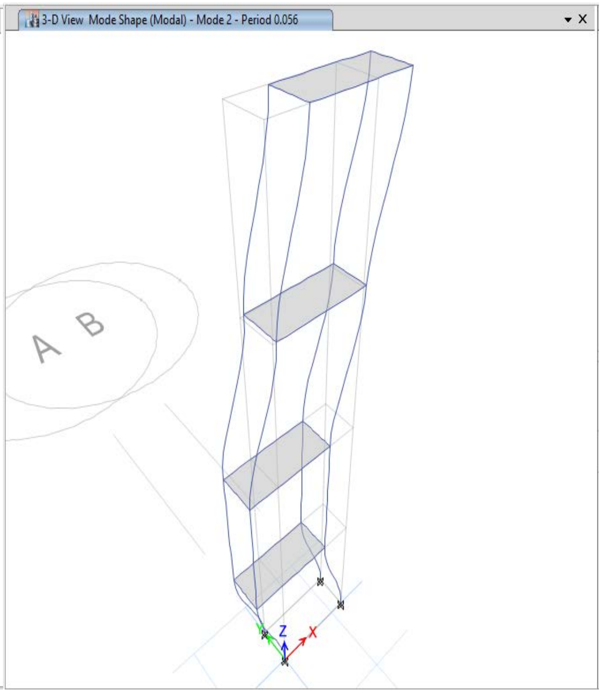
Case-1 (a): without mass variation on floor levels.

Modes	1	2	3	4
Time period (sec)	0.16	0.056	0.037	0.030
Frequency (Hz)	6.25	17.85	27.02	33.33
Angular frequency(rad/sec)	39.26	112.15	169.77	209.41



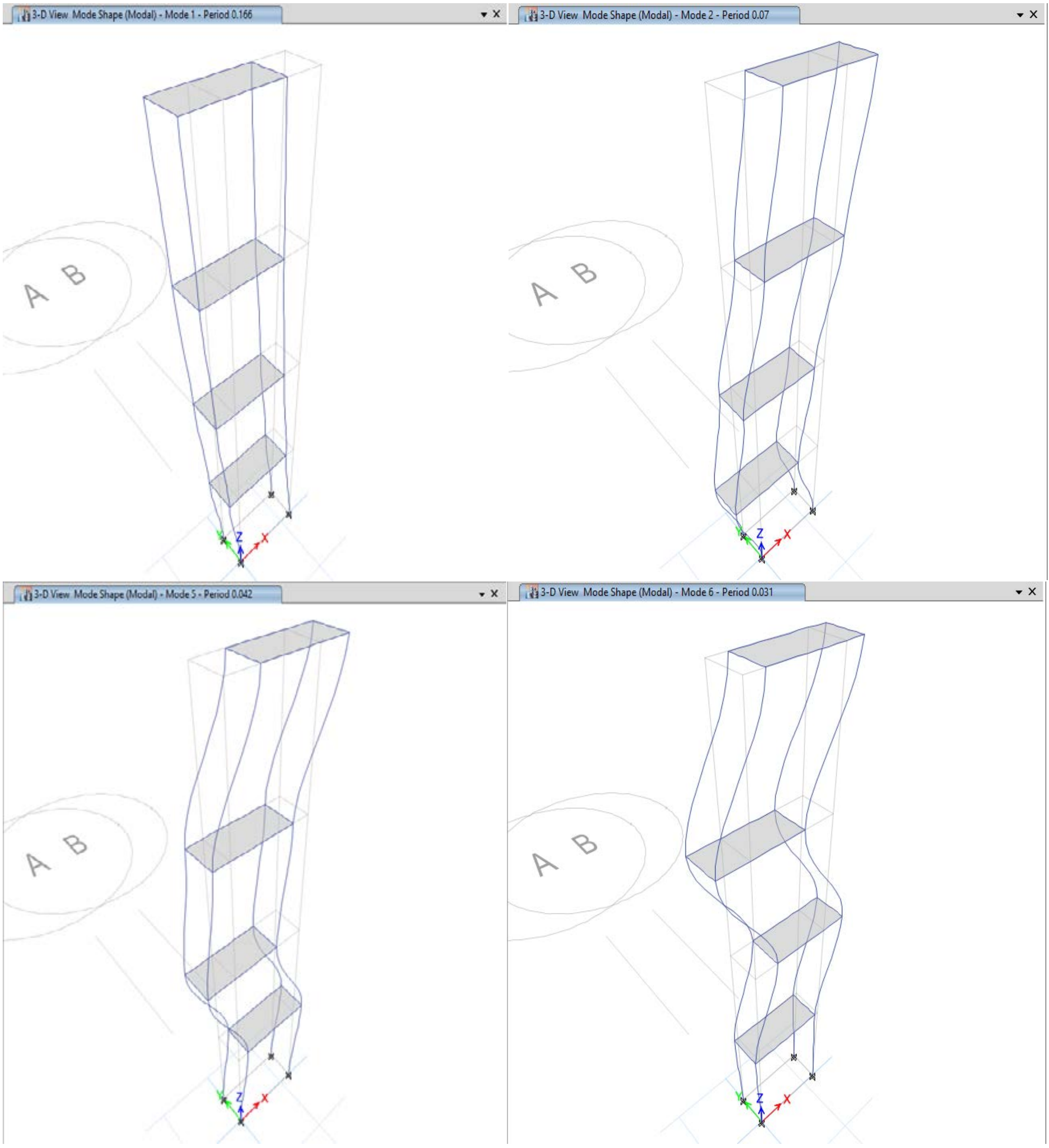






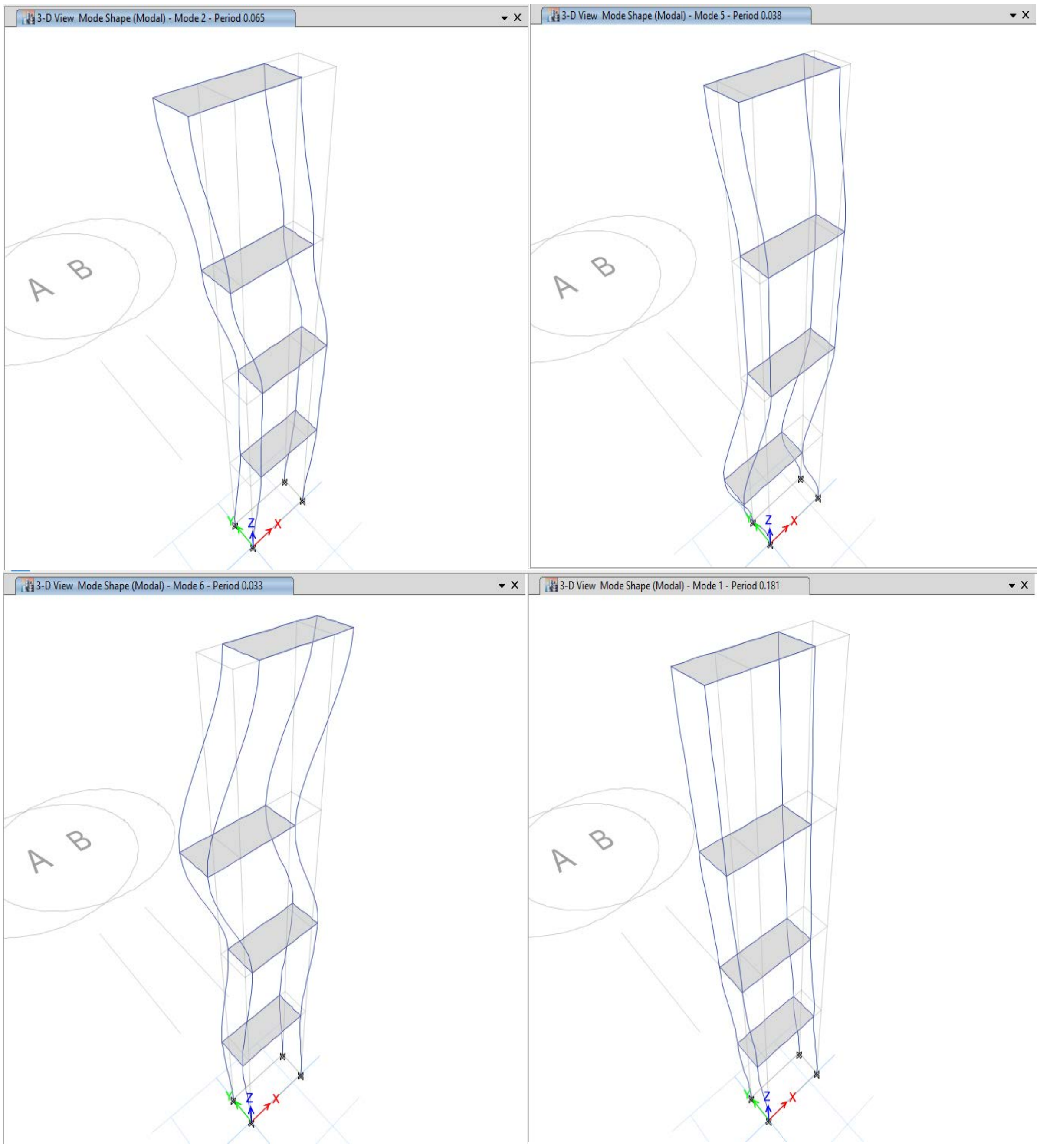
Case-1 (b): Additional mass on slab of 1st floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	.166	.07	.042	.031
Frequency (Hz)	6.02	14.28	23.80	32.25
Angular frequency(rad/sec)	36.28	89.72	149.53	202.63



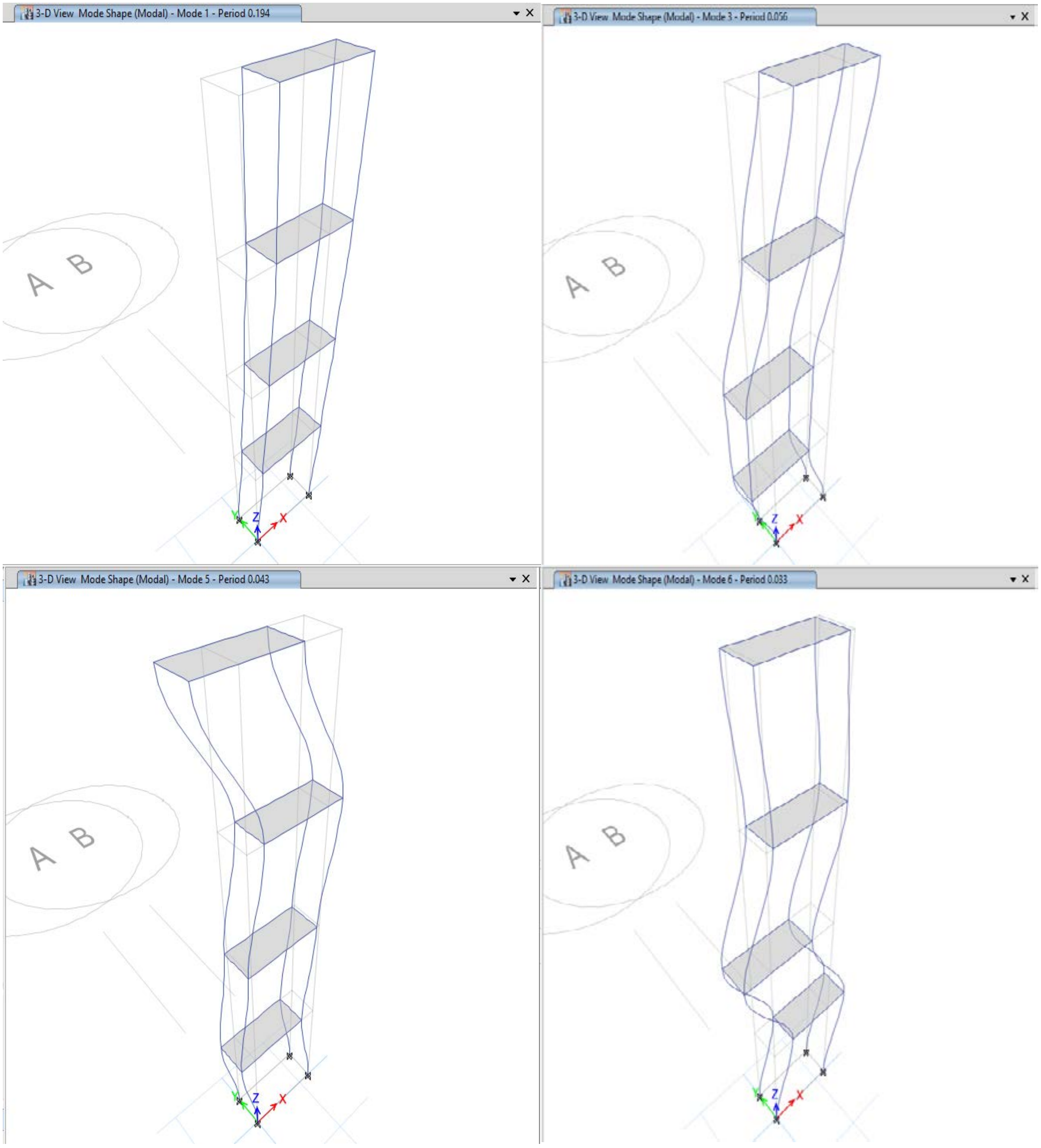
Case-1 (c): Additional mass on slab of 2nd floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	0.181	.065	0.038	0.033
Frequency (Hz)	5.52	15.38	26.31	30.30
Angular frequency(rad/sec)	30.52	96.63	165.32	190.38



Case-1 (d): Additional mass on slab of 3rd floor = 3.0 kg

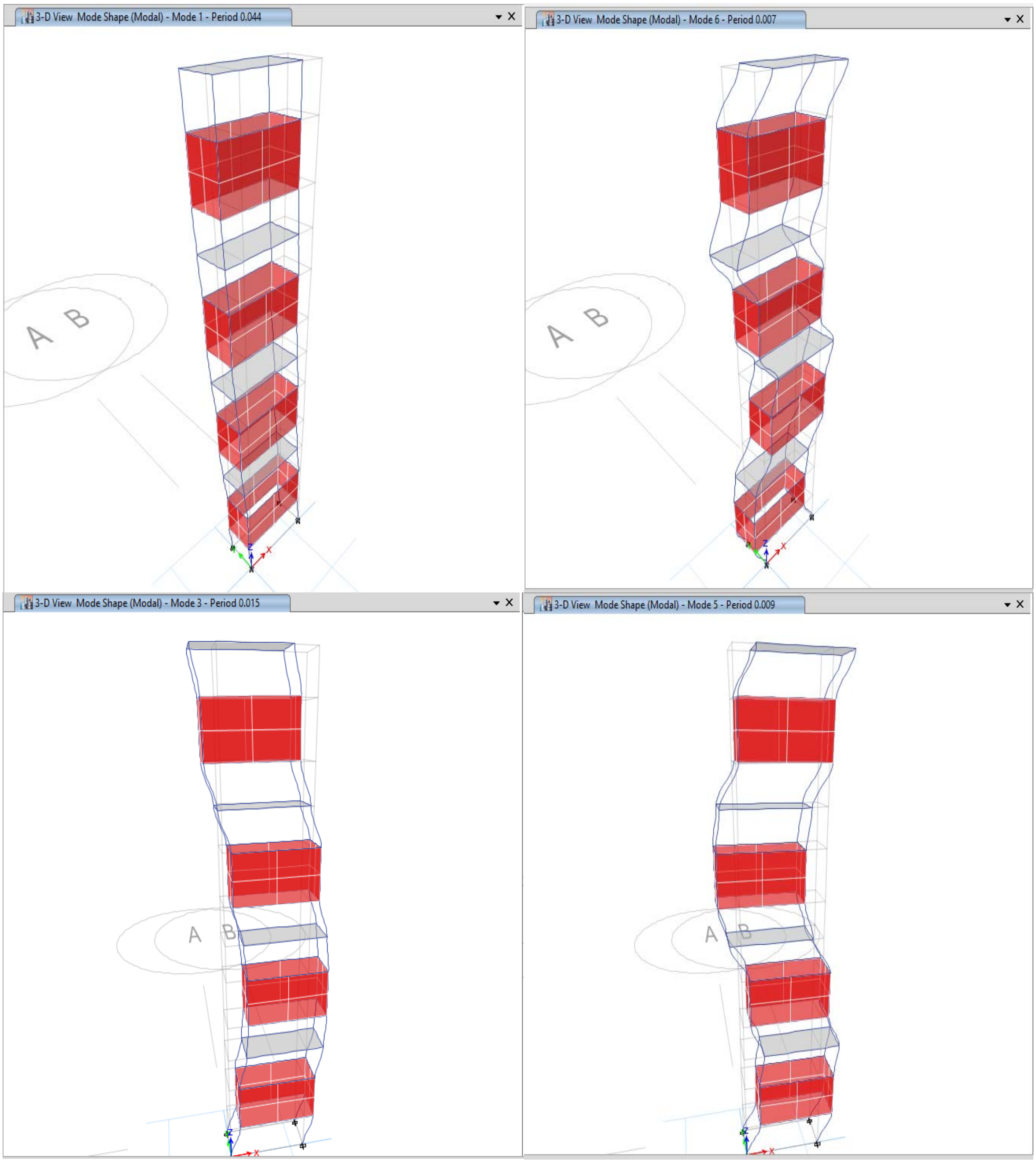
Modes	1	2	3	4
Time period (sec)	0.194	0.056	0.043	0.033
Frequency (Hz)	5.15	17.85	23.25	30.30
Angular frequency(rad/sec)	32.35	112.17	146.13	190.38



6.2.2 Case-2: frame with all story closed by walls

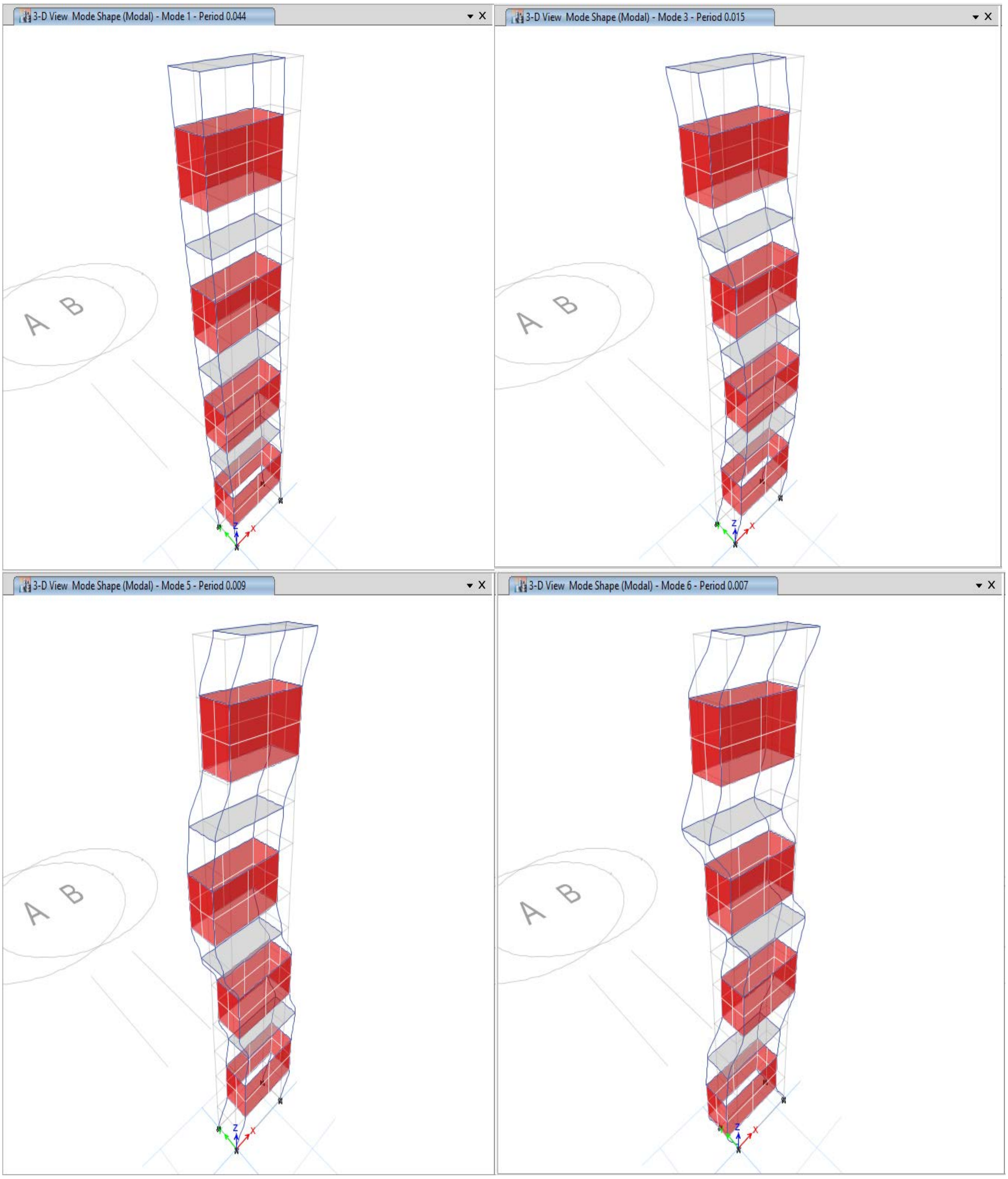
Case-2 (a): without mass variation on floor levels.

Modes	1	2	3	4
Time period (sec)	0.044	0.015	0.0098	0.0079
Frequency (Hz)	22.72	66.67	102.04	126.55
Angular frequency(rad/sec)	142.75	418.89	641.14	795.34



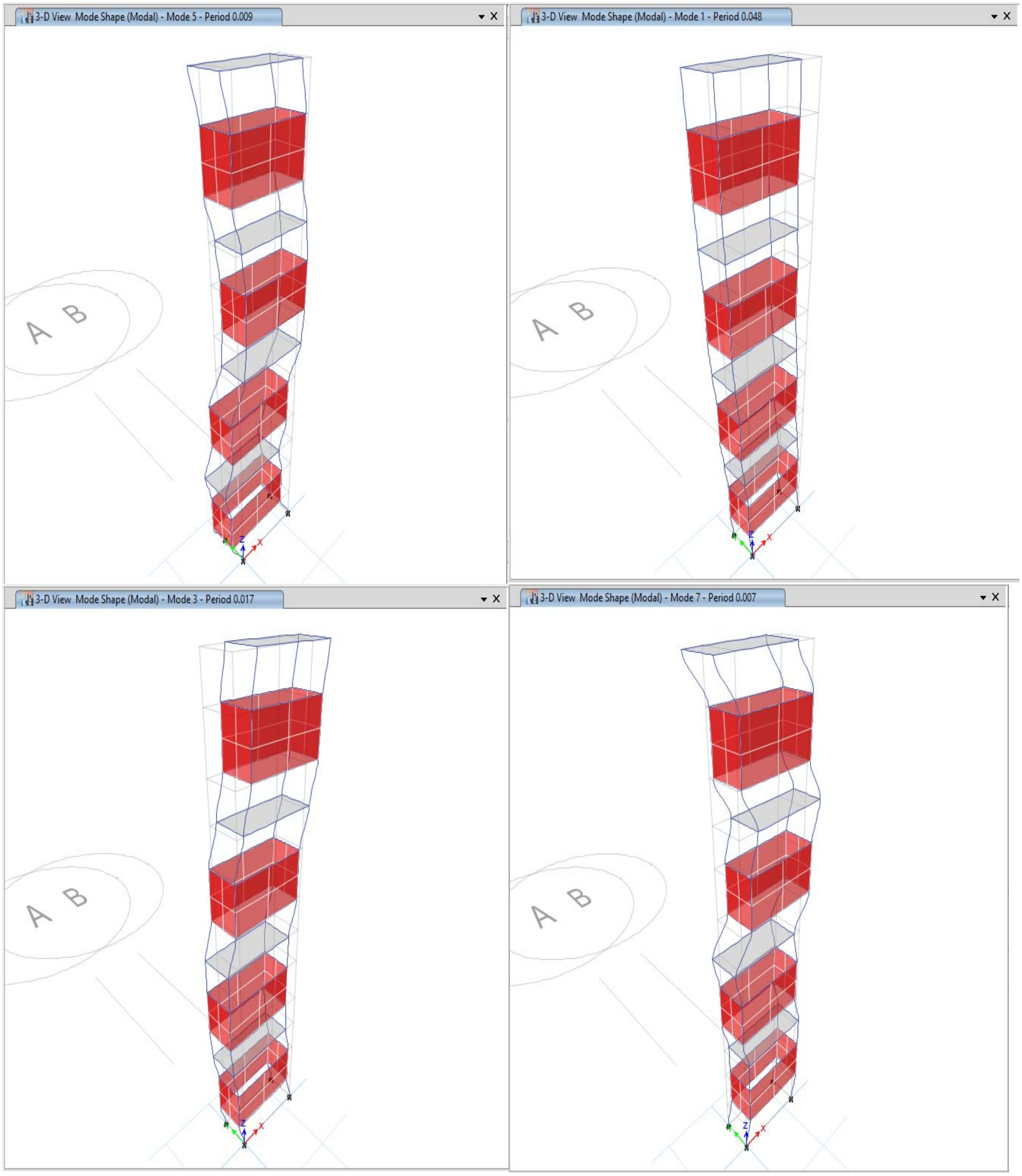
Case-2 (b): Additional mass on slab of 1st floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	0.045	.018	.0112	.0088
Frequency (Hz)	22.23	55.55	89.28	113.63
Angular frequency(rad/sec)	139.67	349.02	560.96	713.99



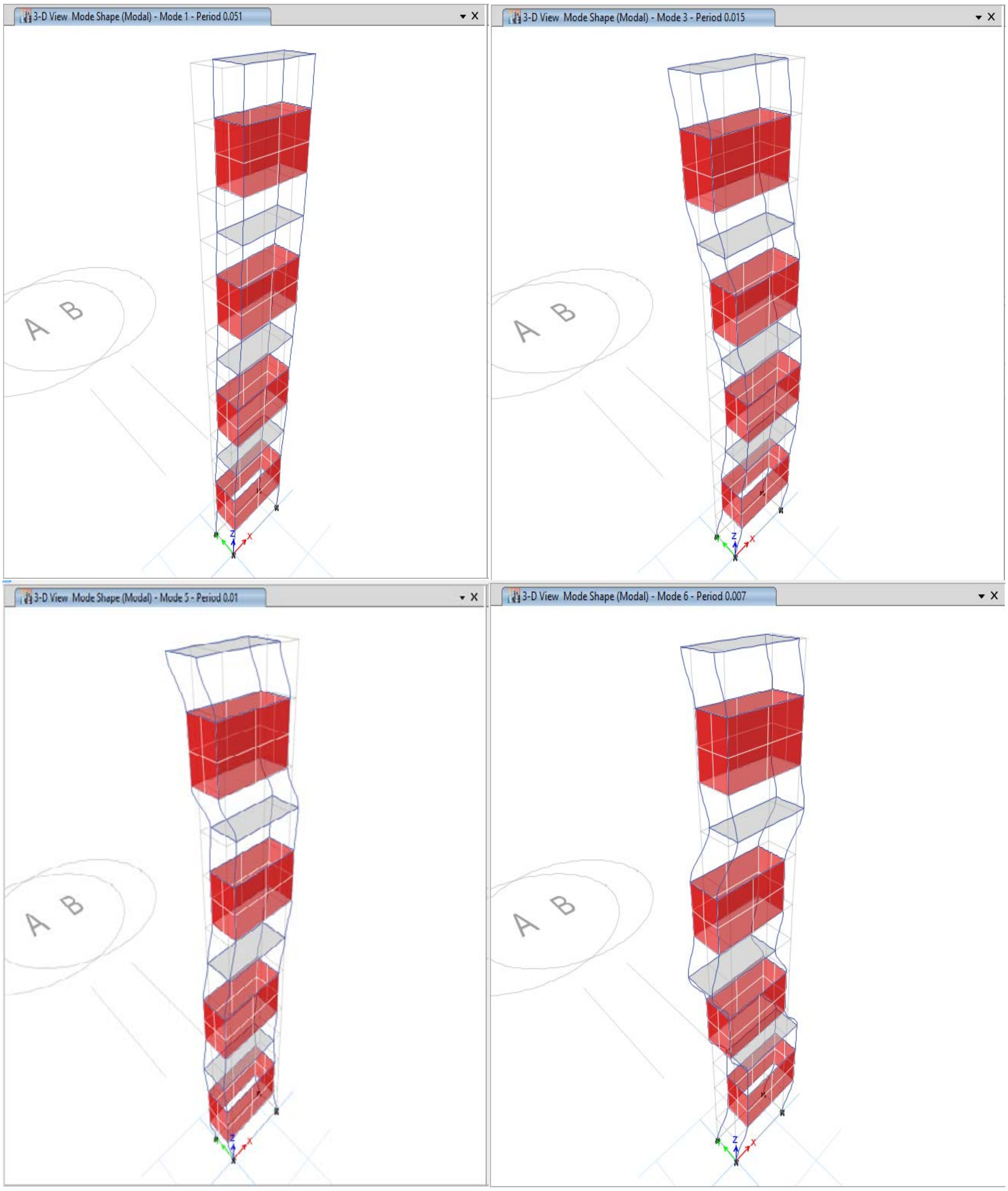
Case-2 (c): Additional mass on slab of 2nd floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	0.048	0.017	.0098	0.0079
Frequency (Hz)	20.83	58.82	102.01	126.55
Angular frequency(rad/sec)	130.82	369.57	641.15	795.34



Case-2 (d): Additional mass on slab of 3rd floor = 3.0 kg

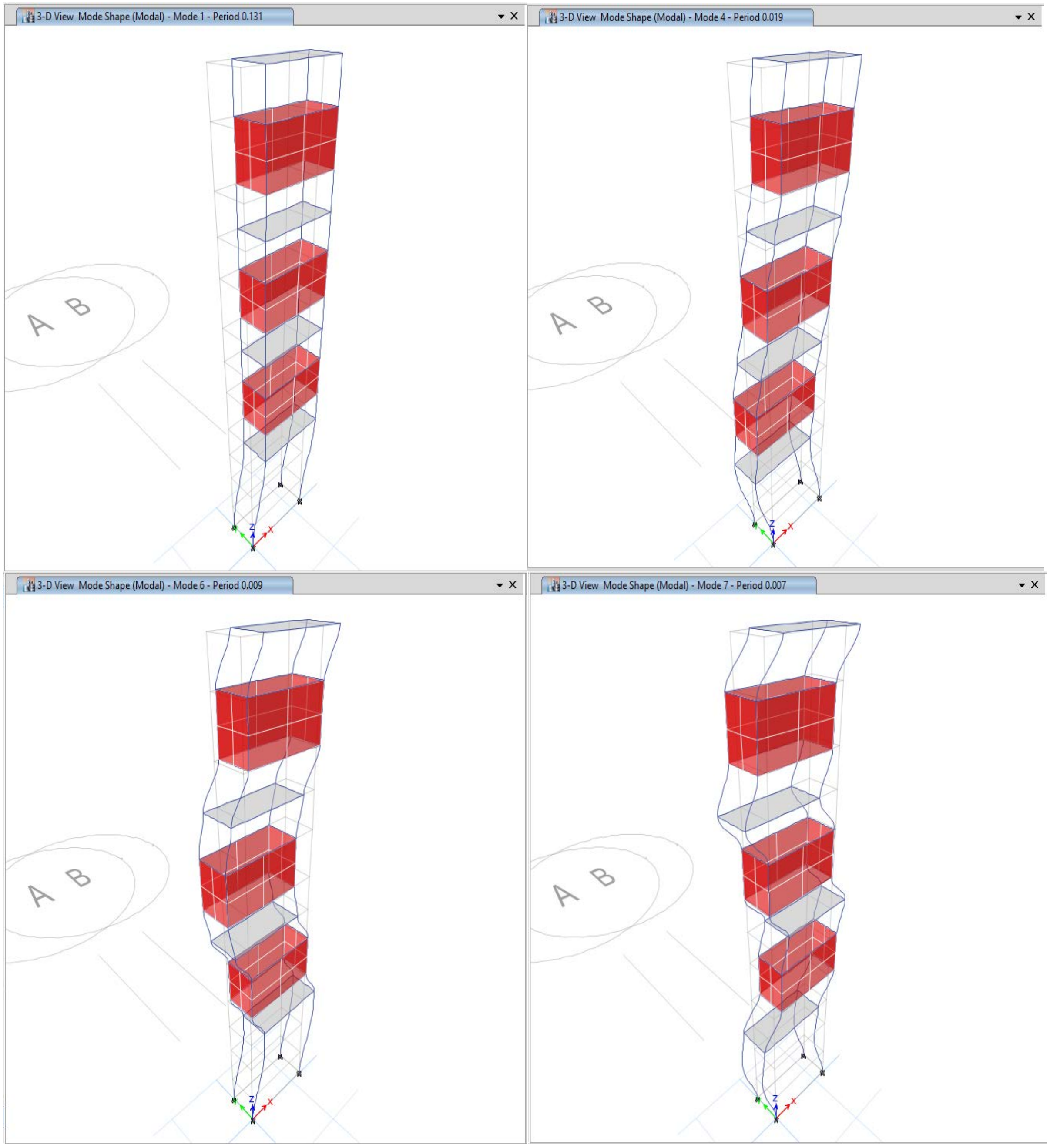
Modes	1	2	3	4
Time period (sec)	.051	.015	.0108	.0079
Frequency (Hz)	19.60	66.67	92.59	126.55
Angular frequency(rad/sec)	123.15	418.89	581.77	795.34



6.2.3 Case-3: frame with 1st story as soft story

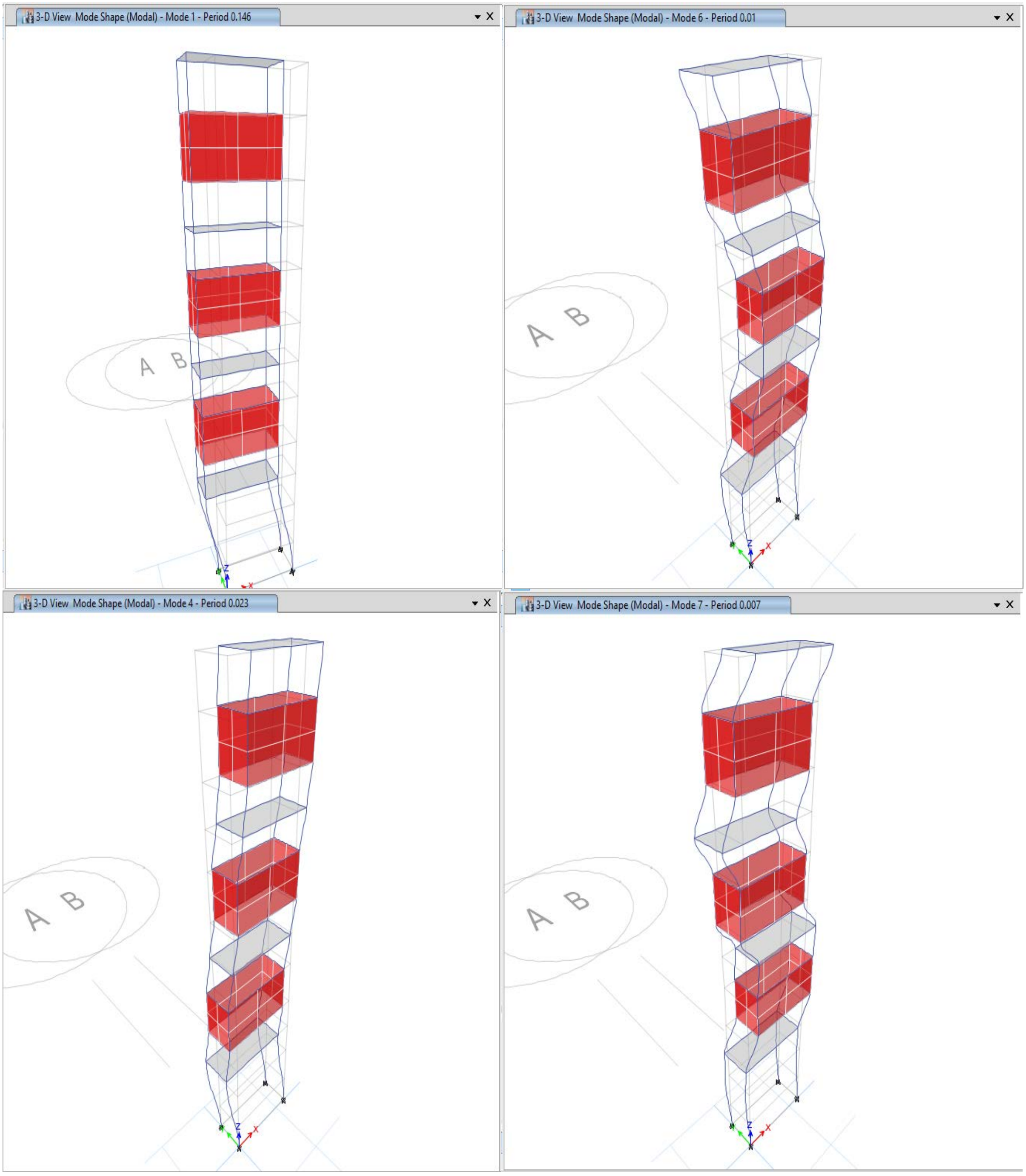
Case-3 (a): without mass variation on floor levels.

Modes	1	2	3	4
Time period (sec)	.131	.019	.0098	.0079
Frequency (Hz)	7.63	52.63	102.04	126.58
Angular frequency(rad/sec)	47.96	330.69	641.14	795.34



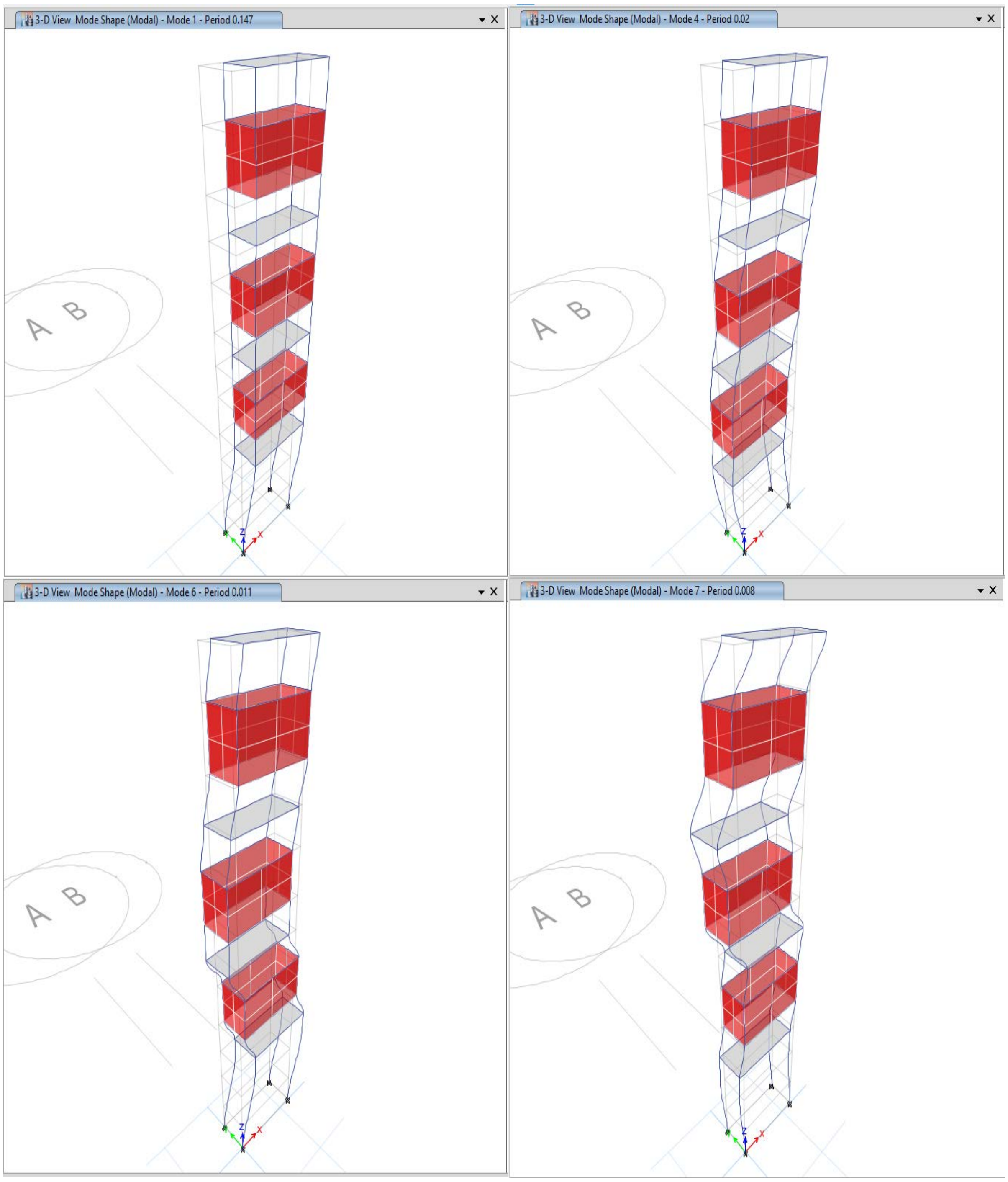
Case-3 (b): Additional mass on slab of 1st floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	.146	.023	0.0109	0.0079
Frequency (Hz)	6.84	43.47	91.74	126.58
Angular frequency(rad/sec)	43.03	273.18	576.43	795.34



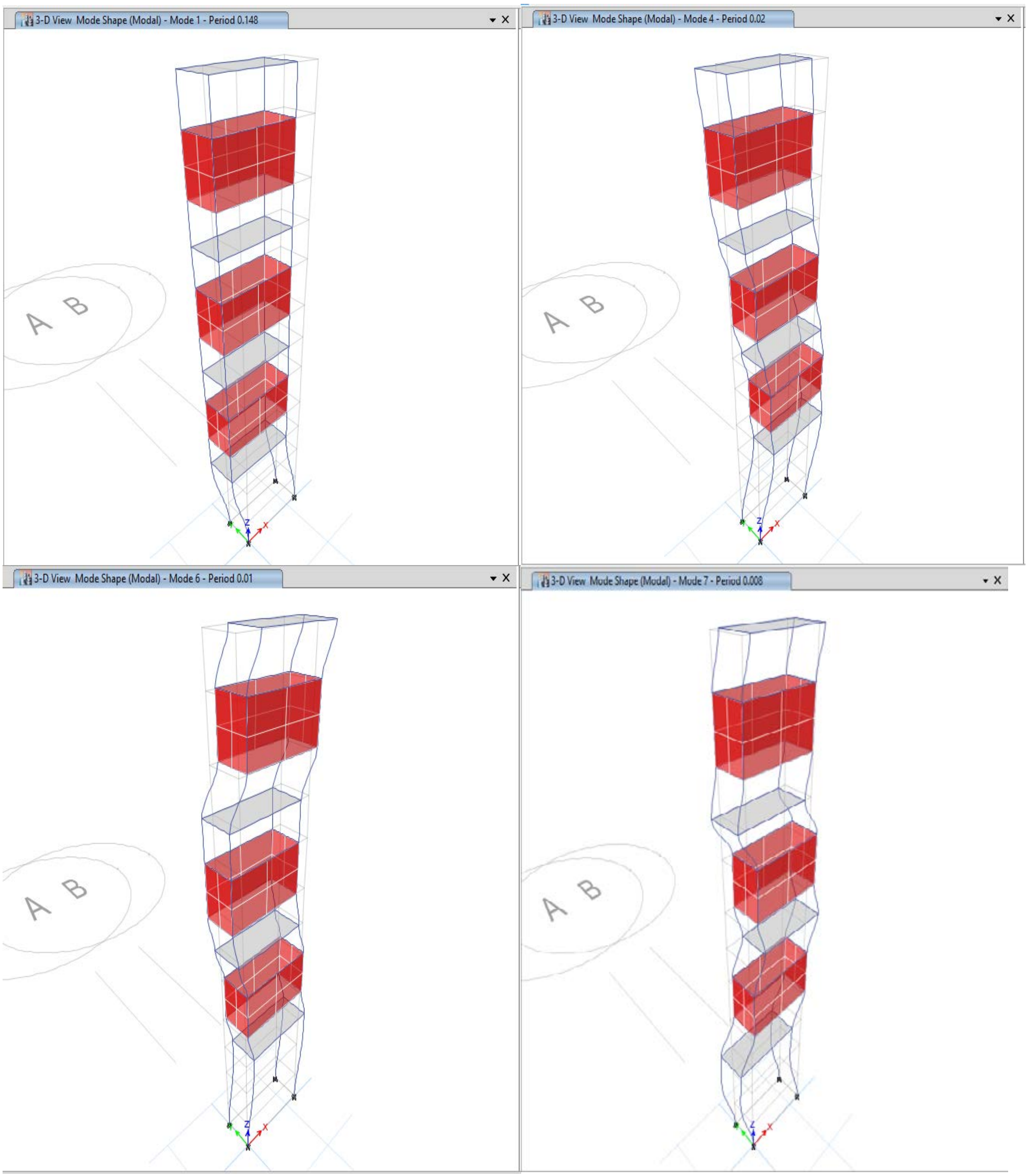
Case-3 (c): Additional mass on slab of 2nd floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	.147	.0202	.0118	.0088
Frequency (Hz)	6.80	49.50	84.74	113.63
Angular frequency(rad/sec)	42.74	311.05	532.47	713.99



Case-3 (d): Additional mass on slab of 3rd floor = 3.0 kg

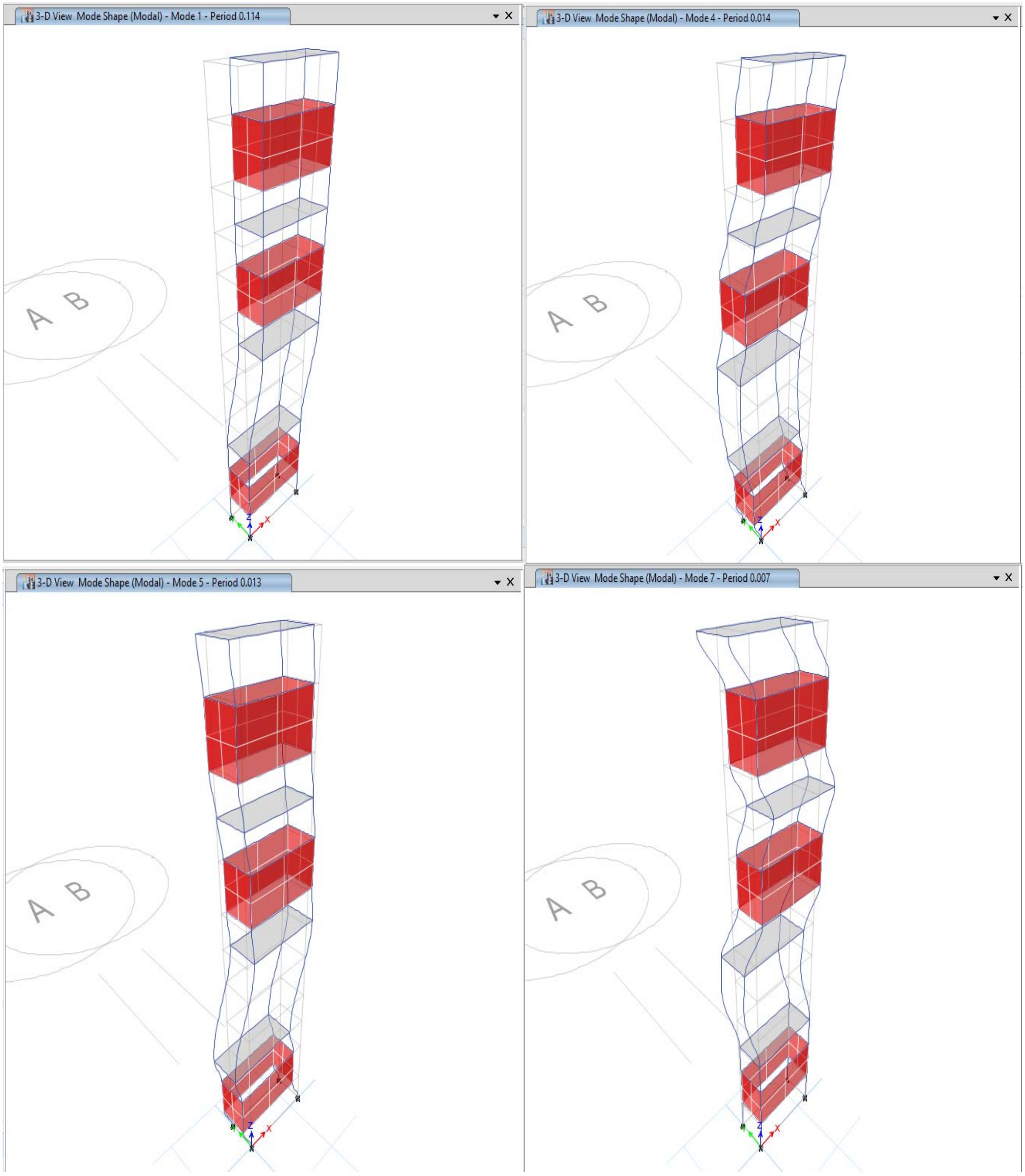
Modes	1	2	3	4
Time period (sec)	.148	.029	0.019	.0089
Frequency (Hz)	6.75	34.48	52.63	112.35
Angular frequency(rad/sec)	42.45	216.67	330.69	705.97



6.2.4 Case-4: frame with 2nd story as soft story

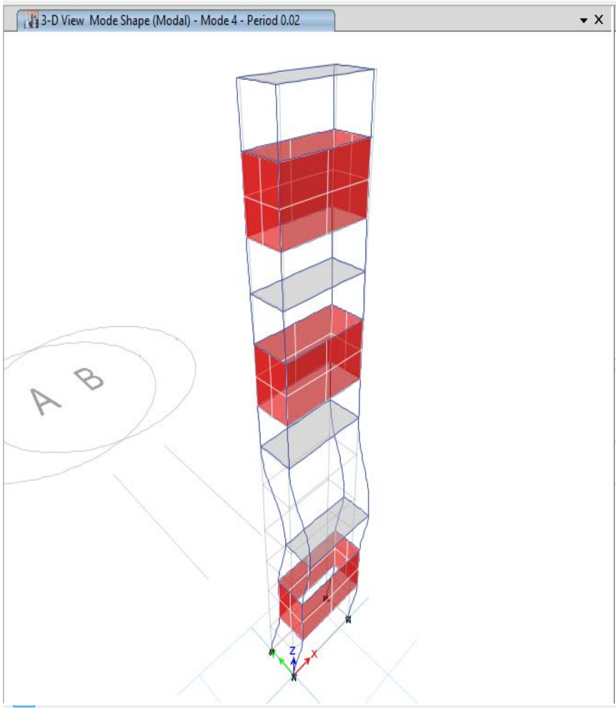
Case-4 (a): without mass variation on floor levels.

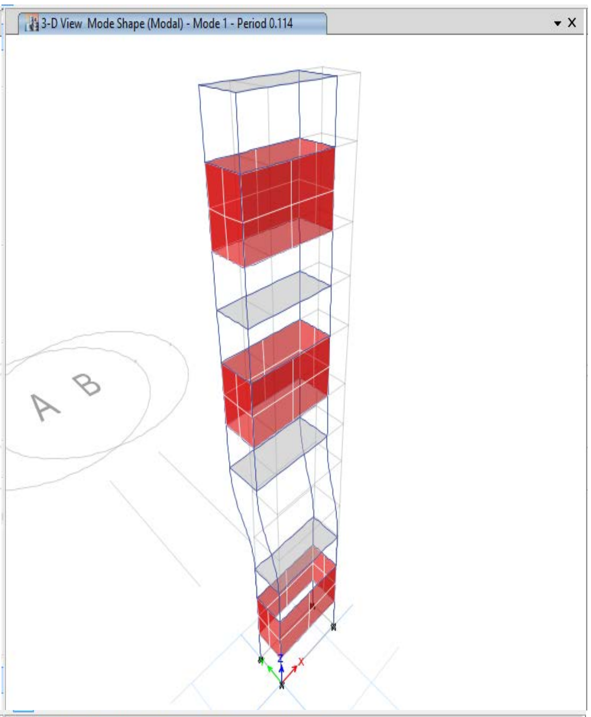
Modes	1	2	3	4
Time period (sec)	.114	0.0148	0.0136	0.0078
Frequency (Hz)	8.77	67.56	73.52	128.20
Angular frequency(rad/sec)	55.11	424.53	461.99	805.53

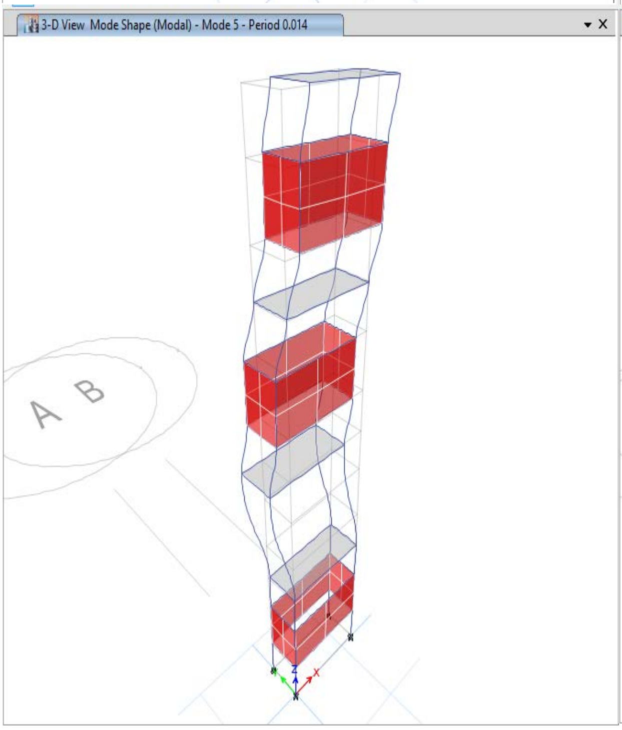


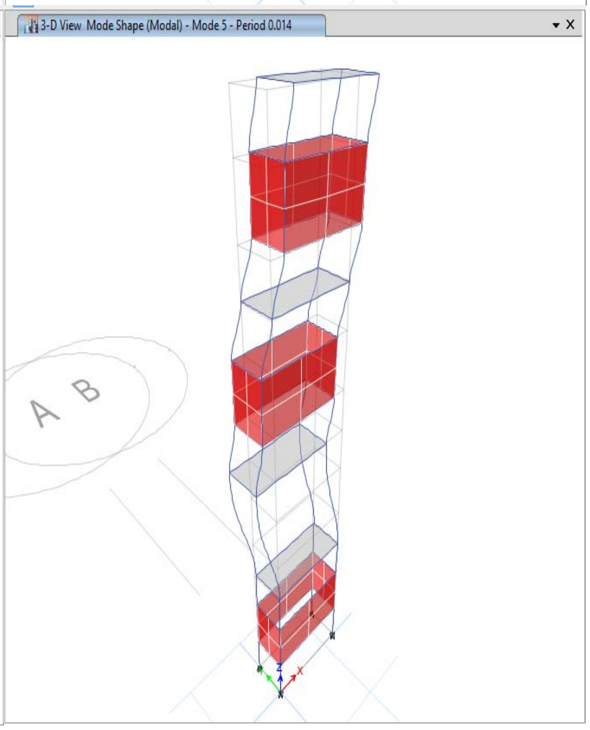
Case-4 (b): Additional mass on slab of 1st floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	.1148	.021	0.0145	.0091
Frequency (Hz)	8.71	47.61	68.96	109.81
Angular frequency(rad/sec)	54.73	299.19	433.32	690.46



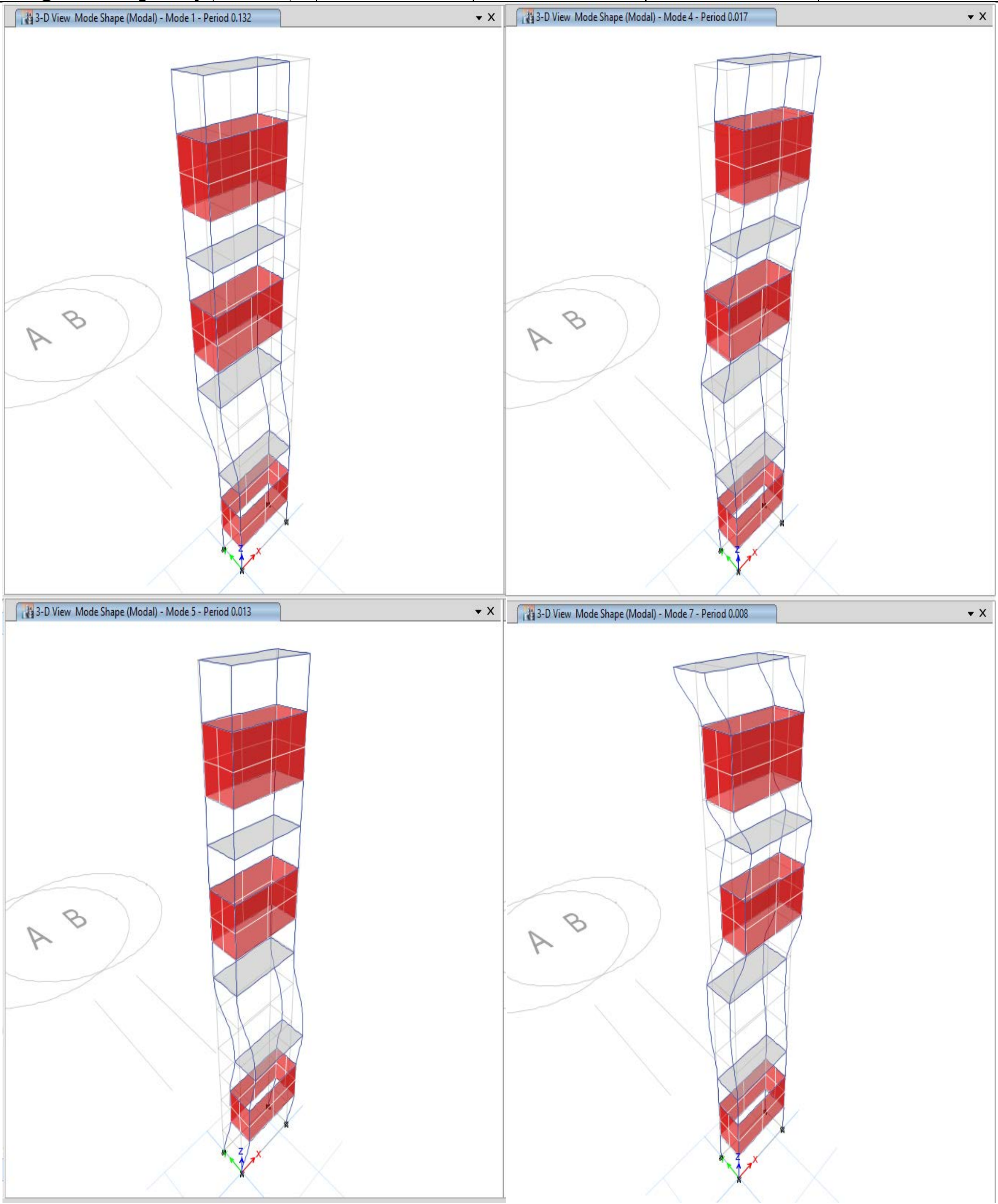






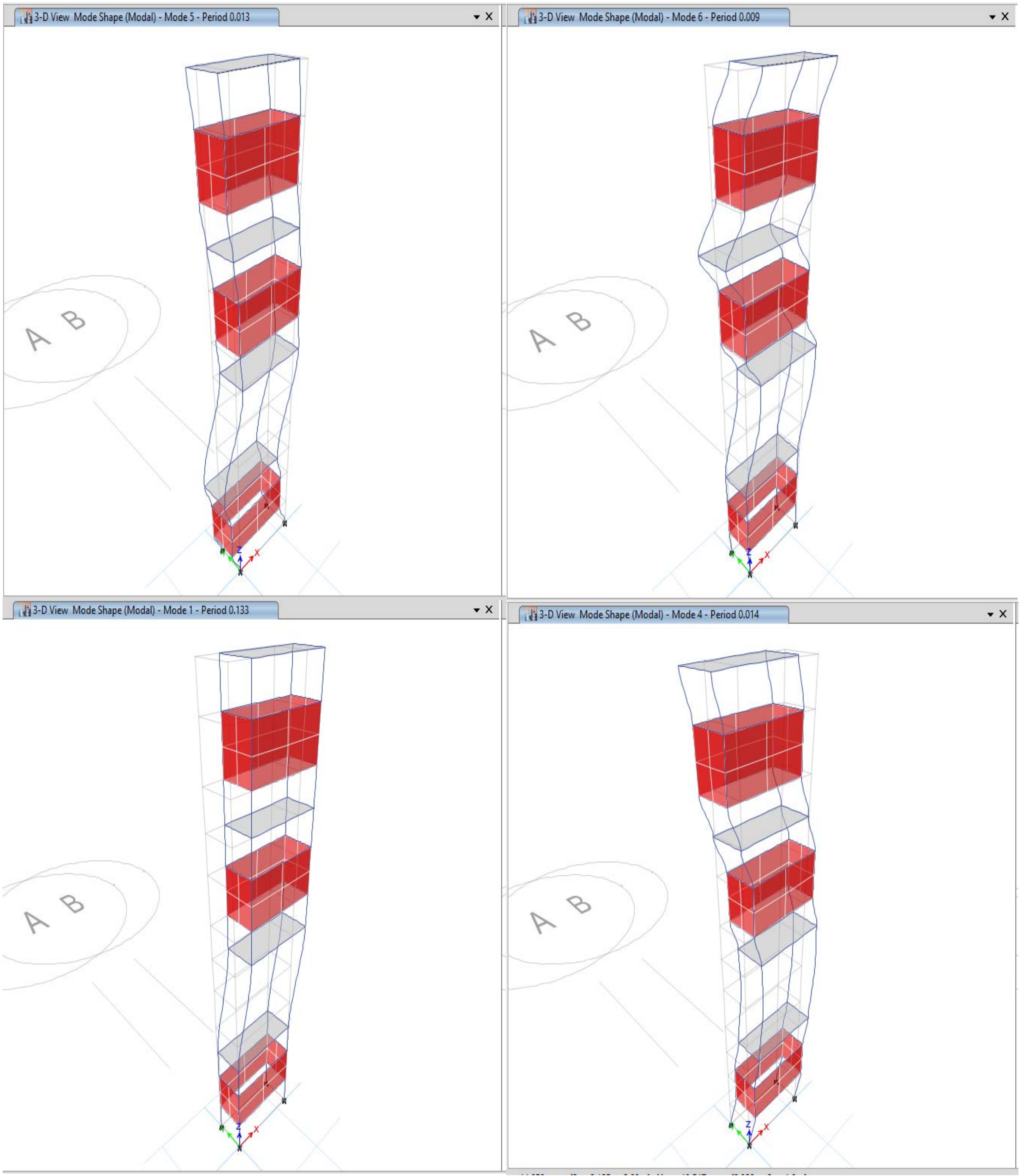
Case-4 (c): Additional mass on slab of 2nd floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	.132	.017	.013	.0088
Frequency (Hz)	7.57	58.82	72.46	133.63
Angular frequency(rad/sec)	47.59	369.60	455.28	713.99



Case-4 (d): Additional mass on slab of 3rd floor = 3.0 kg

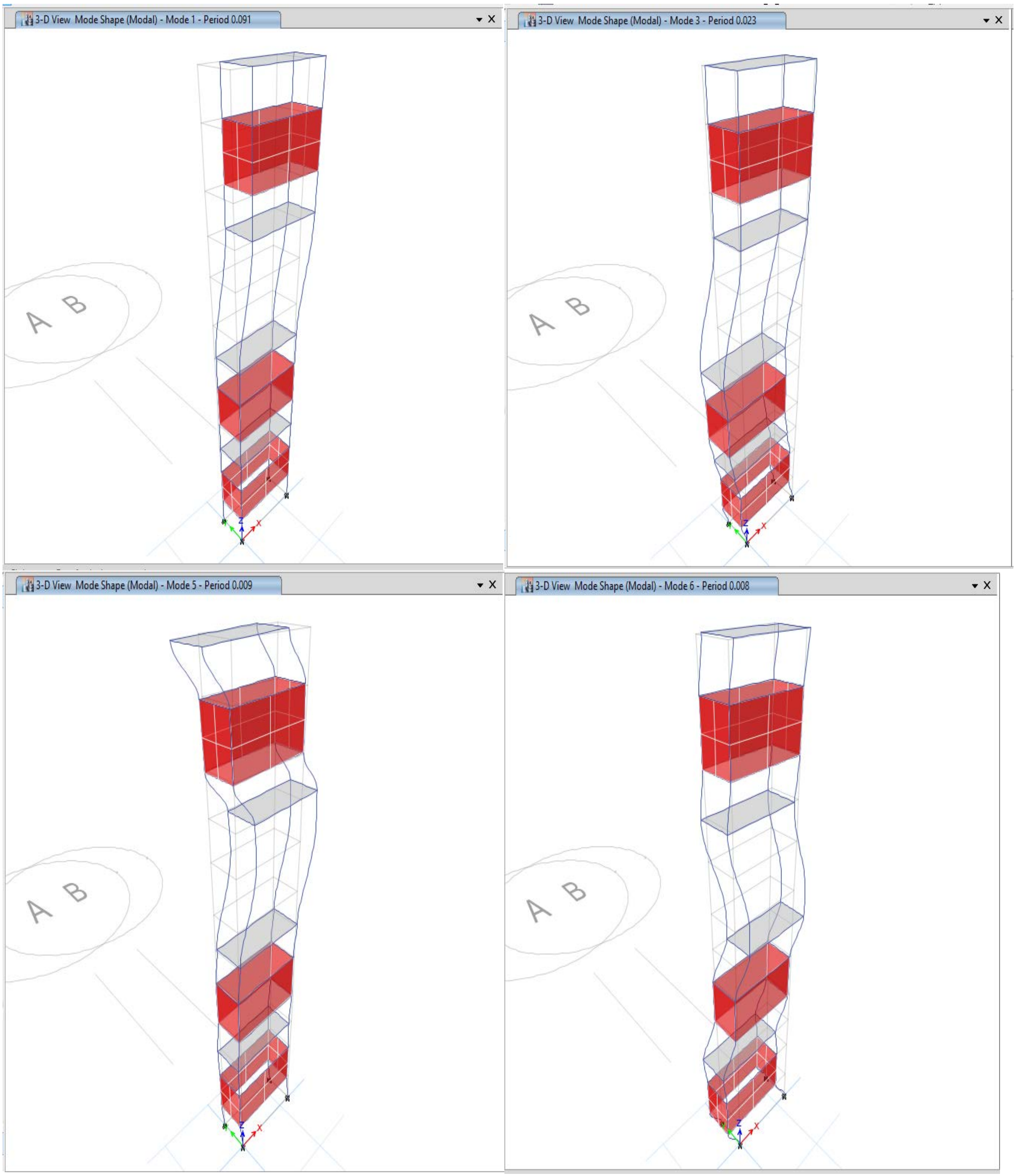
Modes	1	2	3	4
Time period (sec)	.133	.0149	.0138	.0098
Frequency (Hz)	7.51	67.56	72.46	102.04
Angular frequency(rad/sec)	47.24	421.69	455.30	641.14



6.2.5 Case-5: frame with 3rd story as soft story

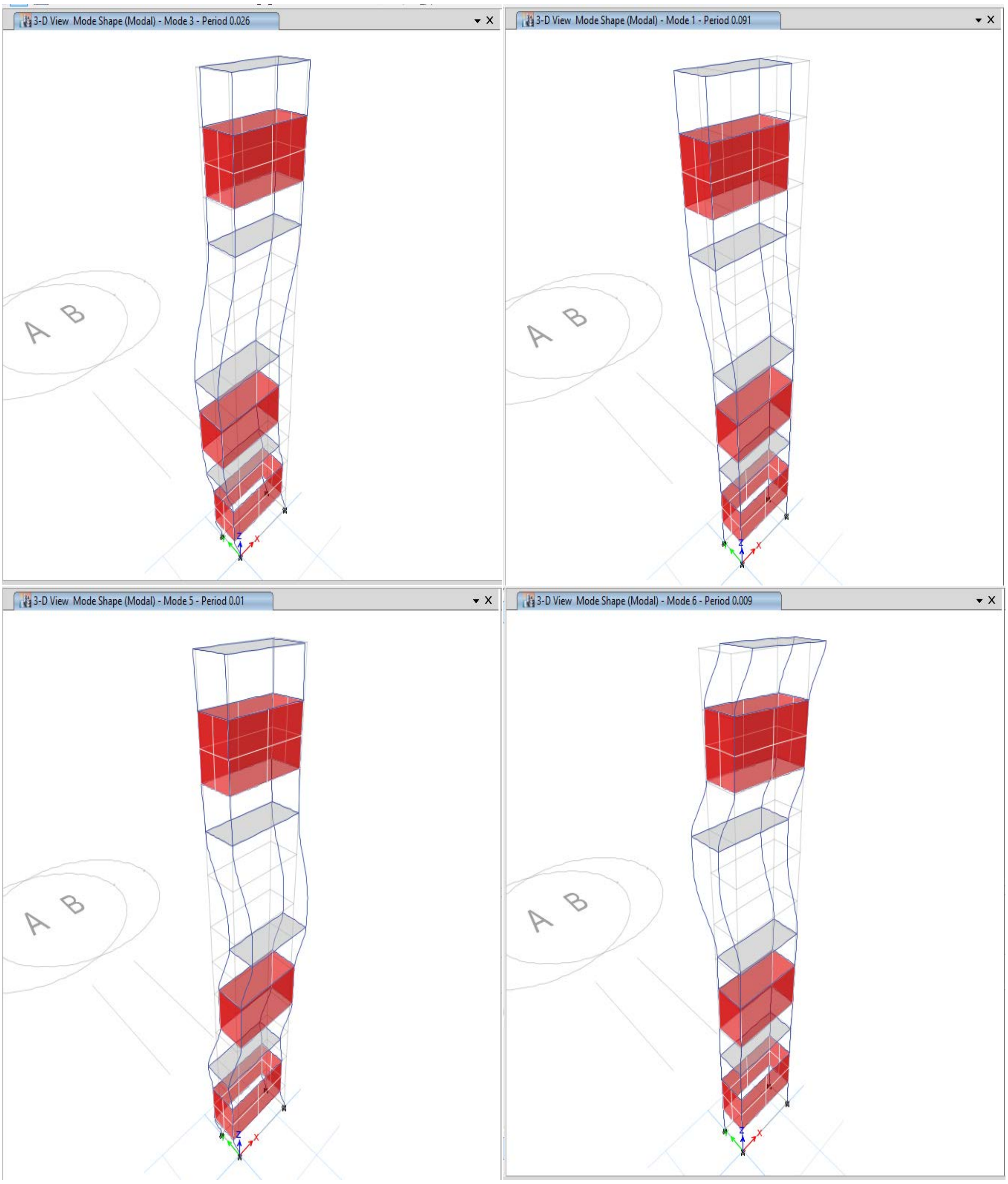
Case-5 (a): without mass variation on floor levels.

Modes	1	2	3	4
Time period (sec)	.091	.0239	.0098	.0088
Frequency (Hz)	10.98	41.84	102.04	133.63
Angular frequency(rad/sec)	69.045	263.98	641.14	713.99



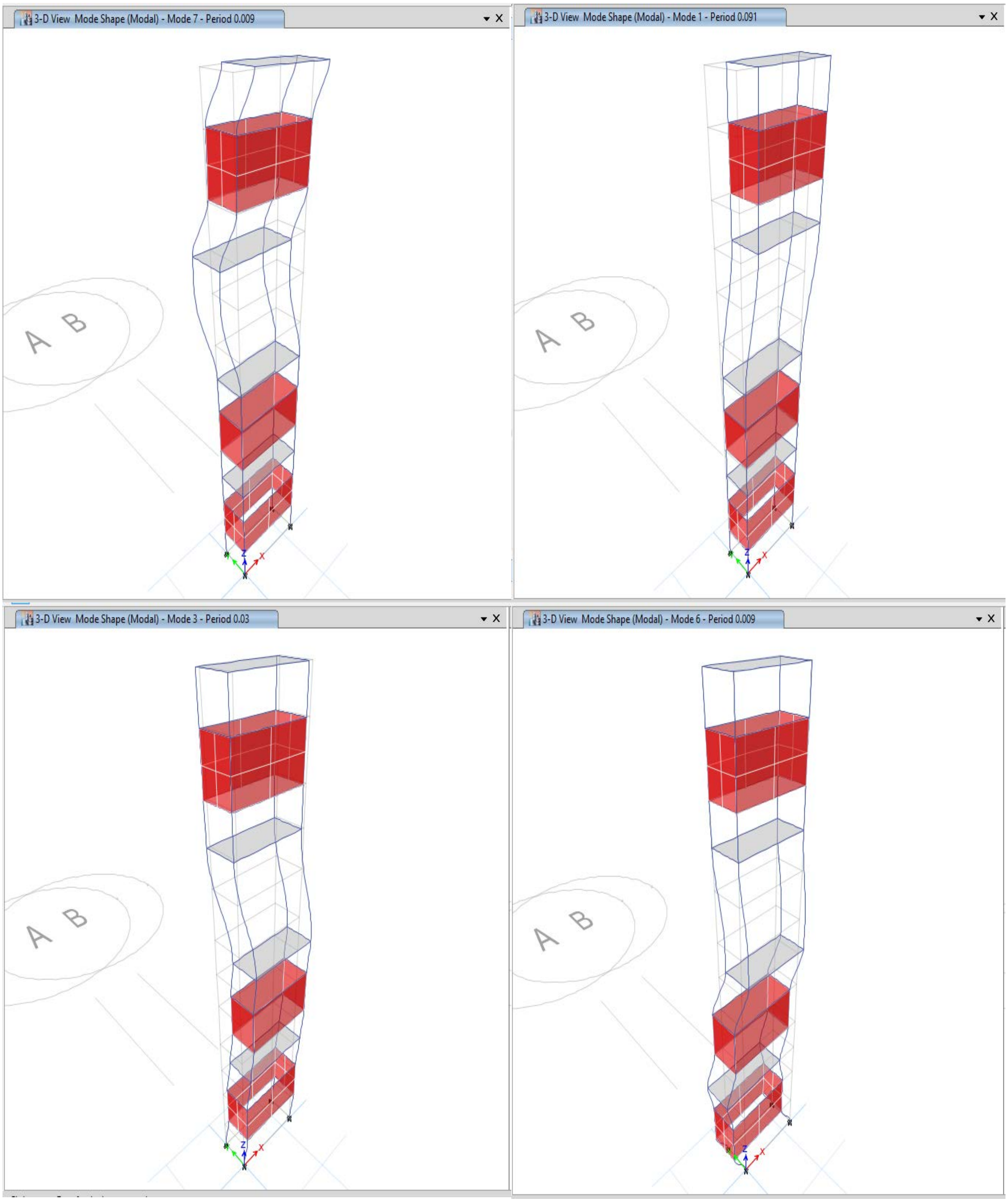
Case-5 (b): Additional mass on slab of 1st floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	0.091	.0268	.011	.0098
Frequency (Hz)	10.98	37.31	90.90	102.04
Angular frequency(rad/sec)	69.04	234.44	571.20	641.14



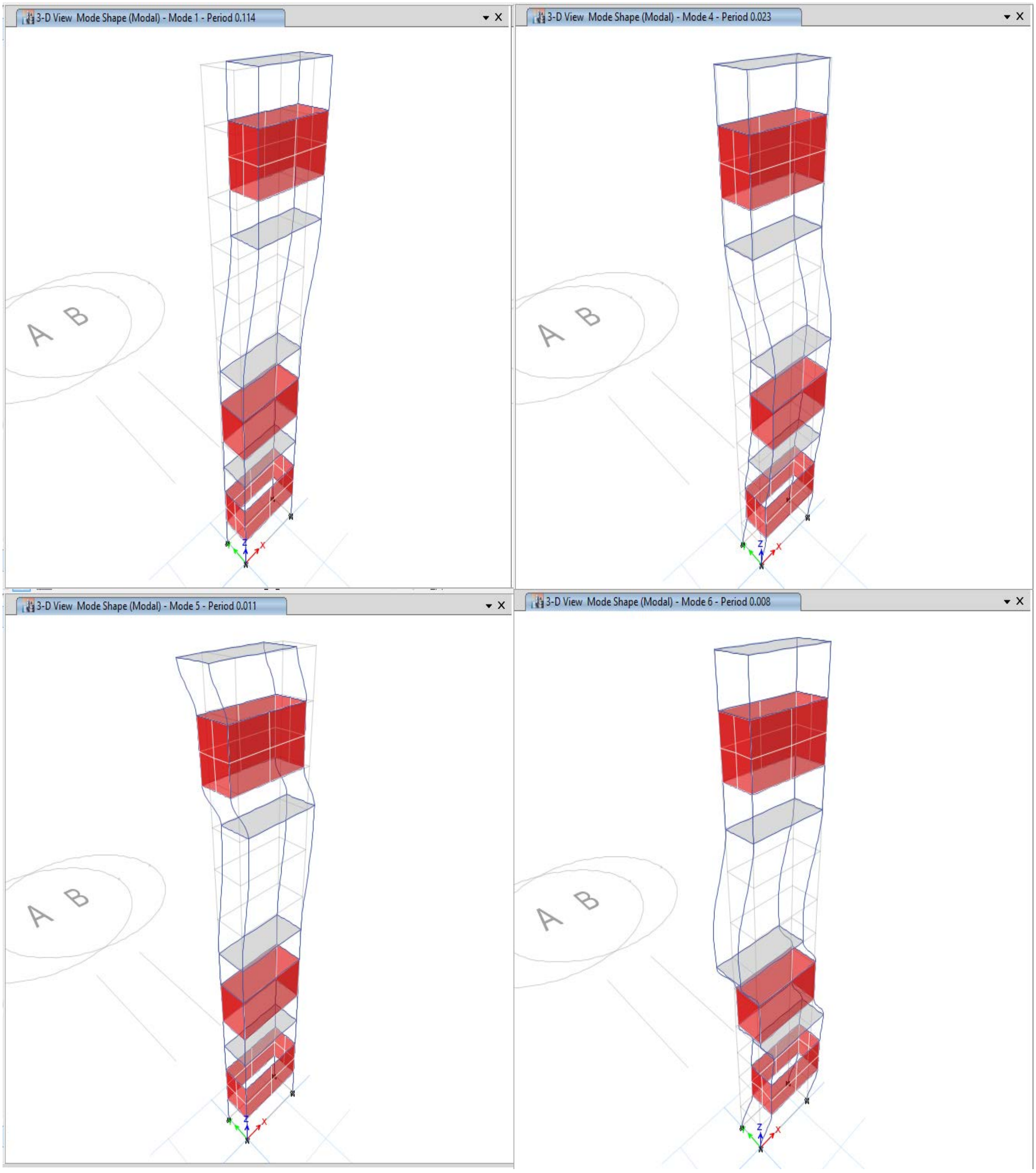
Case-5 (c): Additional mass on slab of 2nd floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	.091	.030	.0098	.0092
Frequency (Hz)	10.98	33.33	102.04	108.69
Angular frequency(rad/sec)	69.04	209.43	641.14	682.95



Case-5 (d): Additional mass on slab of 3rd floor = 3.0 kg

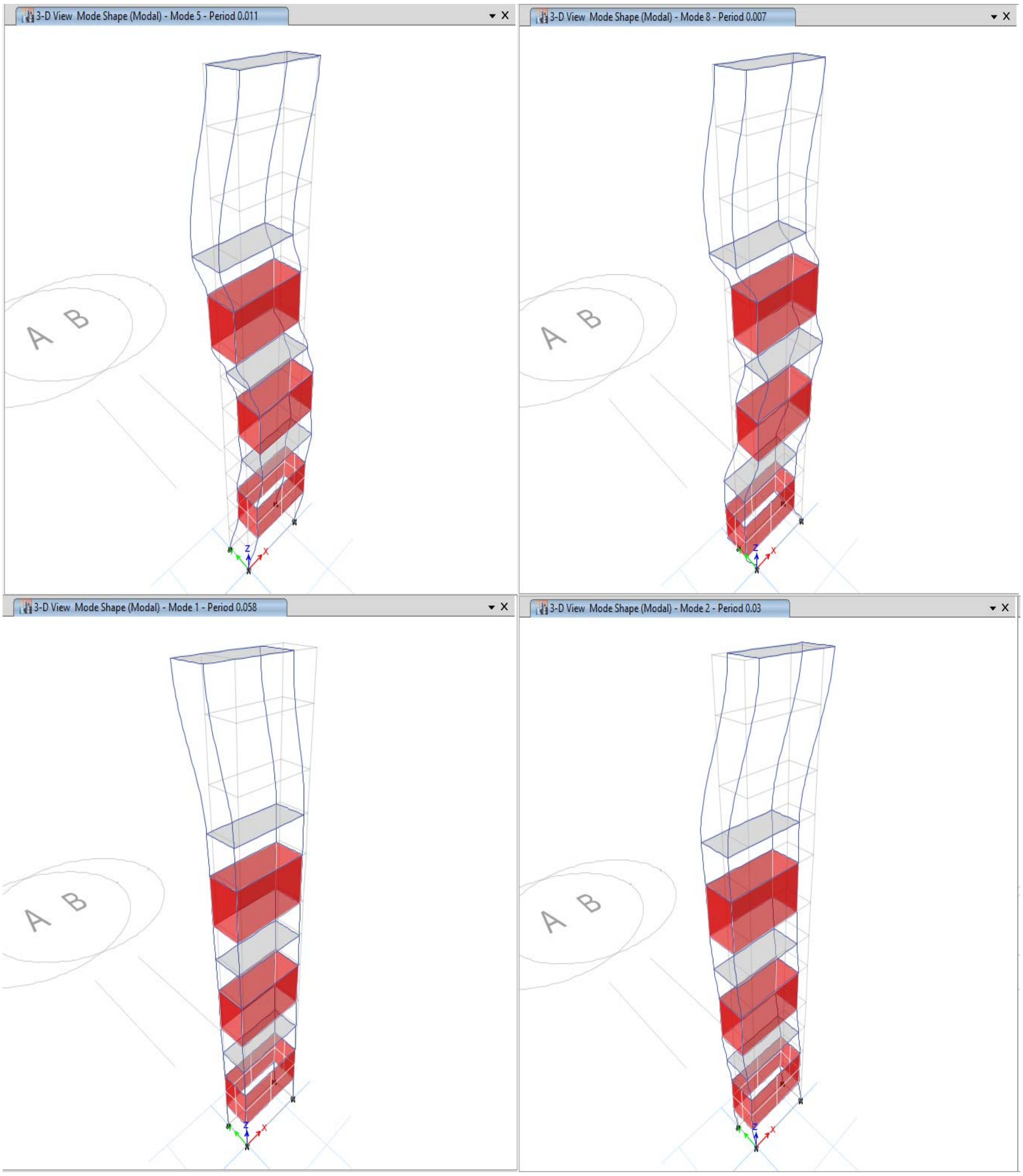
Modes	1	2	3	4
Time period (sec)	.114	.023	.011	.008
Frequency (Hz)	8.77	43.47	90.90	133.63
Angular frequency(rad/sec)	55.11	273.18	571.20	713.99



6.2.6 Case-6: frame with 4th story as soft story

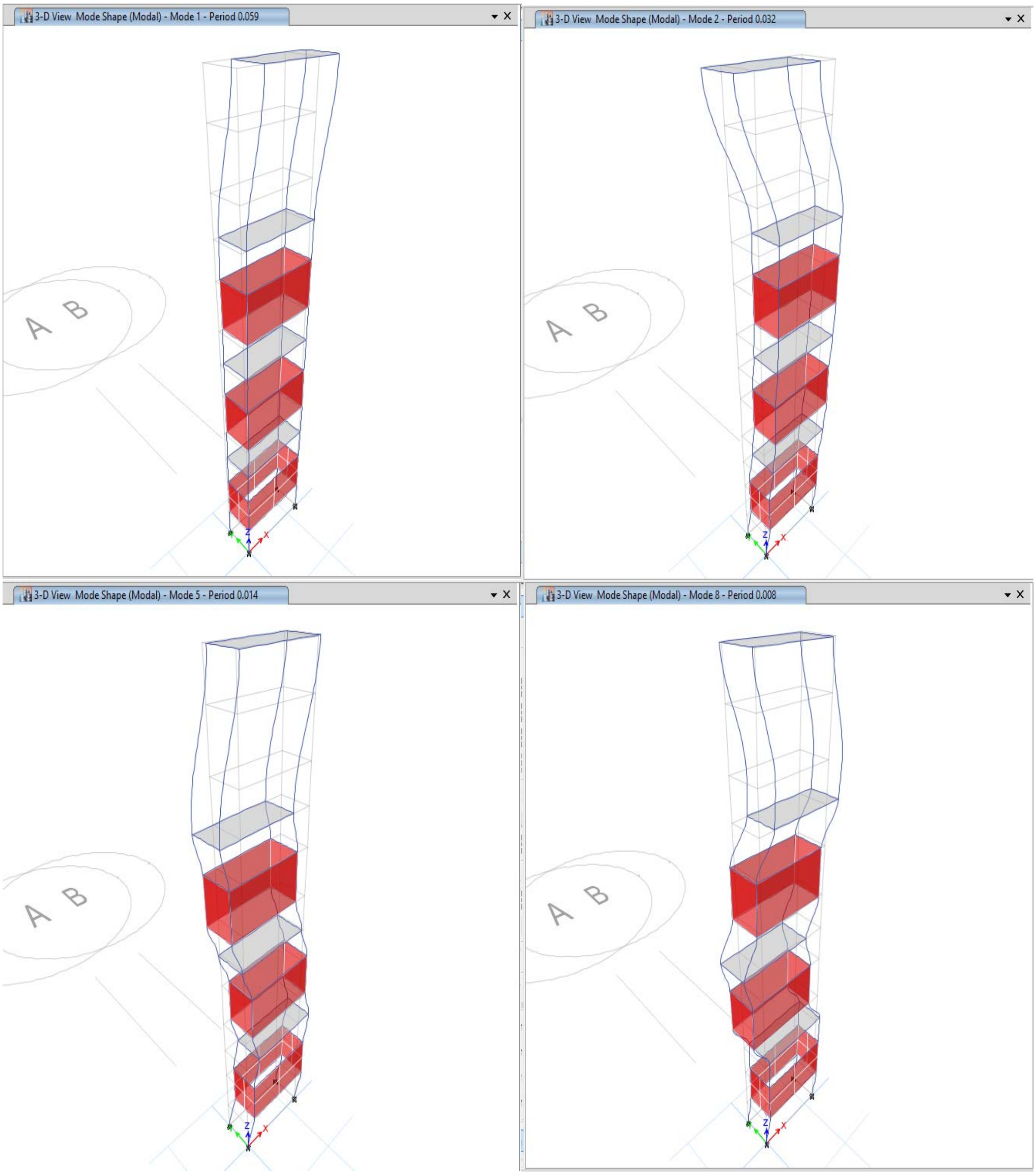
Case-6 (a): without mass variation on floor levels.

Modes	1	2	3	4
Time period (sec)	.058	.032	.0118	.0079
Frequency (Hz)	17.24	31.25	84.74	126.58
Angular frequency(rad/sec)	108.33	196.35	532.47	795.33



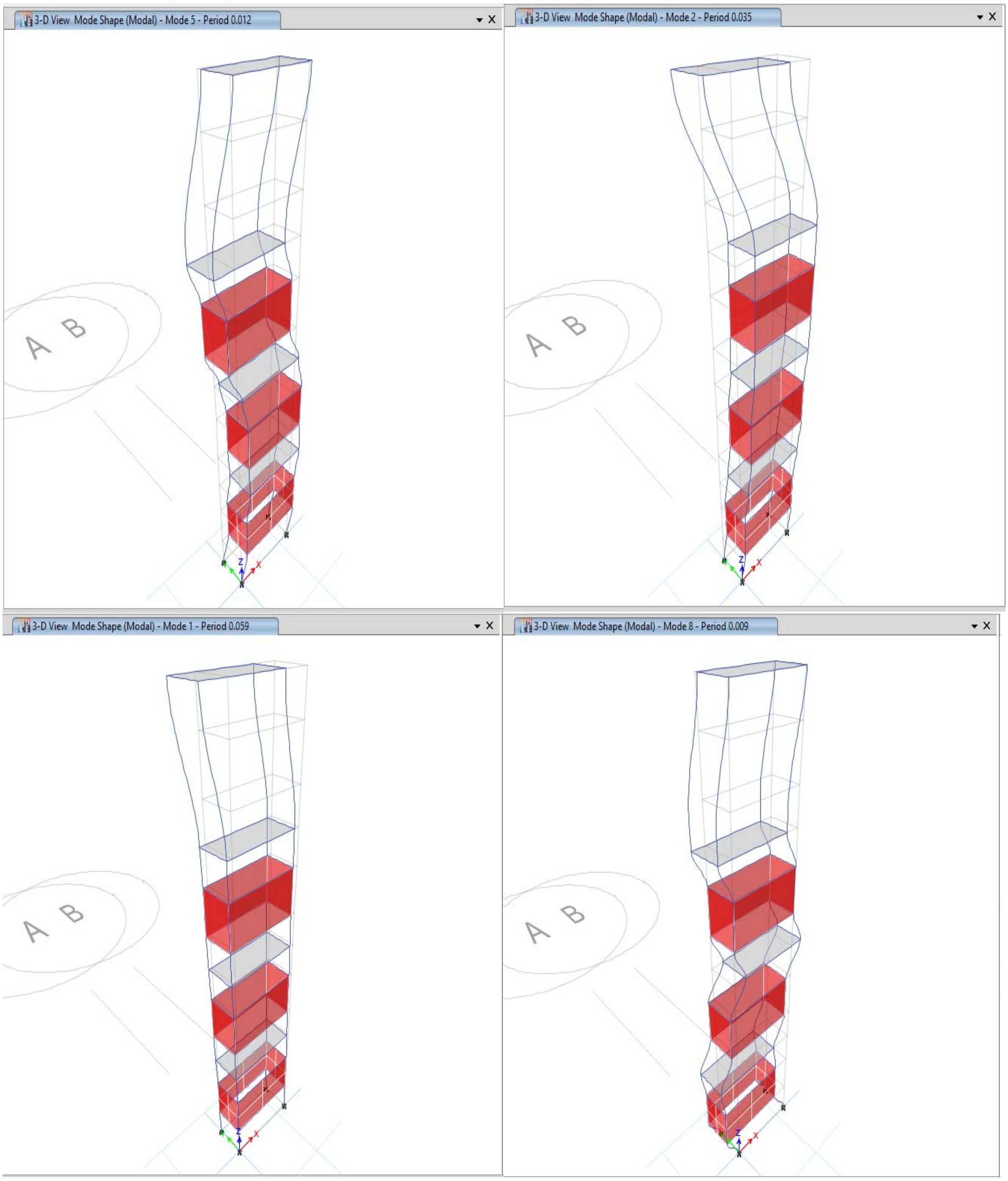
Case-6 (b): Additional mass on slab of 1st floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	.059	.0328	.0148	.0089
Frequency (Hz)	16.95	30.48	67.56	112.35
Angular frequency(rad/sec)	106.5	191.56	424.53	705.98



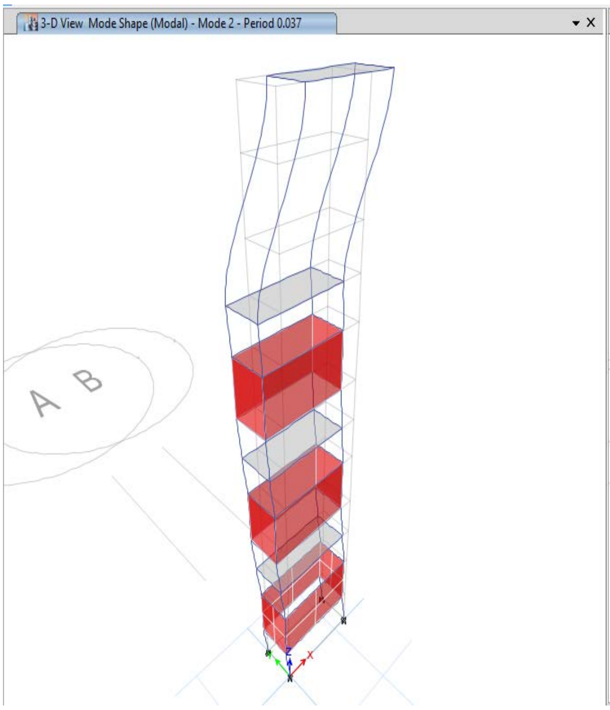
Case-6 (c): Additional mass on slab of 2nd floor = 3.0 kg

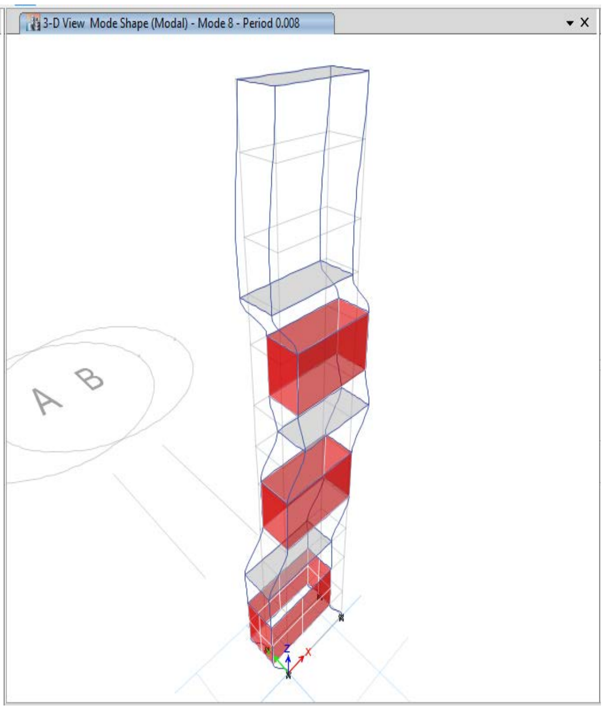
Modes	1	2	3	4
Time period (sec)	.0595	.035	.0128	.0099
Frequency (Hz)	16.80	28.57	78.12	101.01
Angular frequency(rad/sec)	105.60	179.51	490.87	634.66

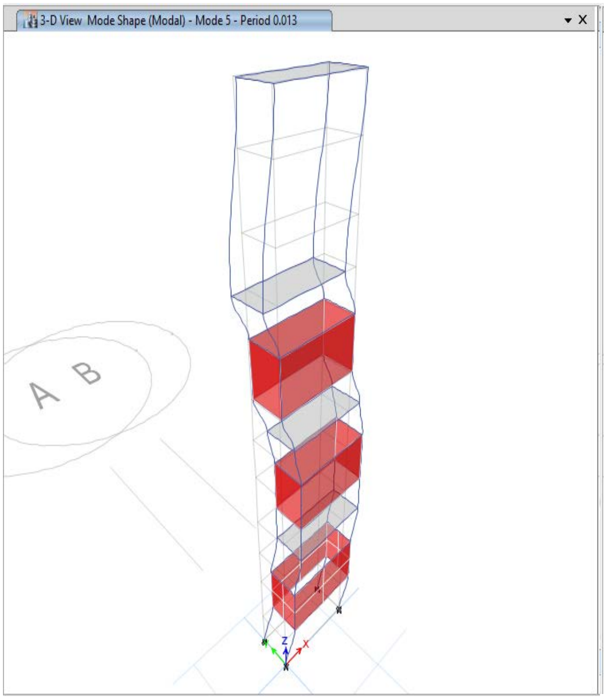


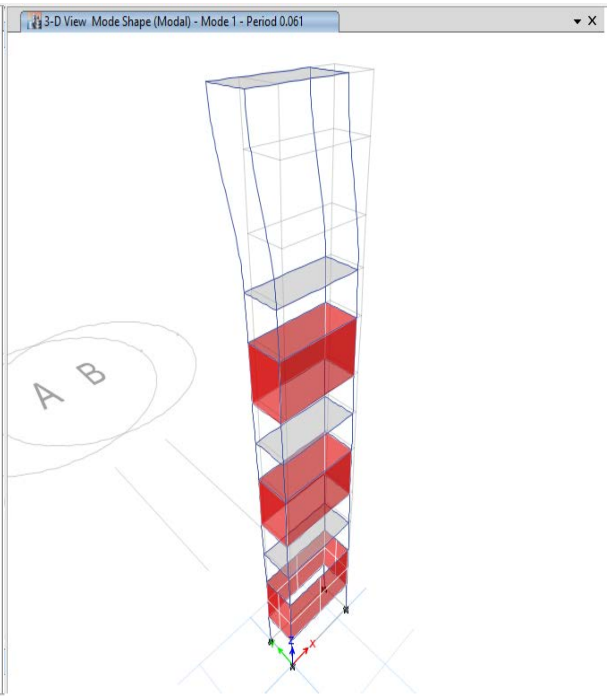
Case-6 (d): Additional mass on slab of 3rd floor = 3.0 kg

Modes	1	2	3	4
Time period (sec)	.061	.037	.013	.0089
Frequency (Hz)	16.39	27.02	76.92	112.36
Angular frequency(rad/sec)	268.74	730.46	5917.16	705.98









CHAPTER 7

RESULTS AND ANALYSIS

In this chapter the frequencies and time periods obtained from analytical, experimental and ETABS software in the previous chapters is compared for different cases and results are shown in tables below:

7.1 Results: frequency, time period and angular frequency.

Case-1: Bare frame with no walls

In this case a four storied bare frame model with no walls is used to study effect of mass irregularity. Here cases with no mass variation and then with variation of mass at different floor level is studied.

Case-1 (a): without mass variation on floor levels.

In this case four storied regular frame with same mass at all story is studied. The frequency and time period are presented in table 7.1

Table 7.1 Frequencies, and time period without mass variation

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	37.05	37.68	39.25	106.00	_	112.098	167.29	_	169.68	195.622	_	209.312
Frequency (Hz)	5.90	6.0	6.25	16.88	_	17.85	25.64	_	27.02	31.15	_	33.33
Time Period (sec)	0.169	.166	.160	.0592	_	.0560	.0375	_	.0370	.0321	_	.0300

b) With additional mass on 1st floor = 3 kg

In this case four storied frame with additional mass on 1st story is studied. The frequency and time period are presented in table 7.2

Table 7.2 Frequencies, and time period with additional mass on 1st floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	Practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	35.544	36.424	37.805	84.214	_	89.678	141.04	_	149.46	189.46	_	202.53
Frequency (Hz)	5.66	5.8	6.02	13.41	_	14.28	22.46	_	23.80	30.17	_	32.25
Time Period (sec)	0.176	.0172	.0166	.0745	_	.0700	.0445	_	.0420	.0331	_	.0310

c) With additional mass on 2nd floor = 3 kg

In this case four storied frame with additional mass on 2nd story is studied. The frequency and time period are presented in table.7.3

Table 7.3 Frequencies, and time period with additional mass on 2nd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	32.530	33.912	34.665	90.180	_	96.586	160.39	_	165.22	176.71	_	190.28
Frequency (Hz)	5.18	5.4	5.52	14.36	_	15.38	25.54	_	26.31	28.14	_	30.30
Time Period (sec)	.193	.185	.181	.0696	_	.0650	.0391	_	0380	.0355	_	.0330

d) With additional mass on 3rd floor = 3 kg

In this case four storied frame with additional mass on 3rd story is studied. The frequency and time period are presented in table.7.4

Table 7.4 Frequencies, and time period with additional mass on 3rd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	Practical	ETAB
Angular Frequency (rad/sec)	30.20	32.656	32.342	105.62	_	112.09	137.46	_	146.01	182.12	_	190.284
Frequency (Hz)	4.81	5.2	5.15	16.82	_	17.85	21.89	_	23.25	29.00	_	30.30
Time Period (sec)	.207	.192	.194	.0594	_	.0560	.0456	_	.0430	.0344	_	.0330

Case 2: frame with all story closed by walls

In this case a four storied frame model where all story are closed with walls is used to study effect of mass irregularity. Here cases with no mass variation and then with variation of mass at different floor level is studied.

a) Without mass variation on floor level

In this case four storied regular frame with same mass at all story is studied. The frequency and time period are presented in table 7.5

Table 7.5 Frequencies, and time period without mass variation

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	Practical	ETAB
Angular Frequency (rad/sec)	136.65	_	142.68	390.05	_	418.68	587.80	_	640.81	707.12	_	794.73
Frequency (Hz)	21.76	_	22.72	62.11	_	66.67	93.60	_	102.04	112.60	_	126.55
Time Period (sec)	.0459	_	.044	.0161	_	.0149	.0106	_	.0098	.0088	_	.0079

b) With additional mass on 1st floor = 3 kg

In this case four storied frame with additional mass on 1st story is studied. The frequency and time period are presented in table 7.6

Table 7.6 Frequencies, and time period with additional mass on 1st floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	Practical	ETAB
Angular Frequency (rad/sec)	132.31	_	139.60	325.49	_	348.85	526.13	_	560.67	690.67	_	713.59
Frequency (Hz)	21.07	_	22.23	51.83	_	55.55	83.78	_	89.28	109.98	_	113.63
Time Period (sec)	.0474	_	.044	.0192	_	.0180	.0119	_	.0112	.0090	_	.0088

c) With additional mass on 2nd floor = 3 kg

In this case four storied frame with additional mass on 2nd story is studied. The frequency and time period are presented in table 7.7

Table 7.7 Frequencies, and time period with additional mass on 2nd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	Practical	ETAB	Analytic	practical	ETAB	Analytic	Practical	ETAB
Angular Frequency (rad/sec)	123.46	_	130.81	344.77	_	369.38	563.25	_	640.62	652.68	_	794.73
Frequency (Hz)	19.66	_	20.83	54.90	_	58.82	89.69	_	102.01	103.93	_	126.55
Time Period (sec)	0.0508	_	.0480	.0182	_	.0170	.0115	_	.0098	.0096	_	.0079

d) With additional mass on 3rd floor = 3 kg

In this case four storied frame with additional mass on 3rd story is studied. The frequency and time period are presented in table 7.8

Table 7.8 Frequencies, and time period with additional mass on 3rd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	Practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	116.11	_	123.08	387.85	_	418.89	525.69	_	581.77	660.65	_	795.34
Frequency (Hz)	18.49	_	19.60	61.76	_	66.67	83.71	_	92.59	105.2	_	126.55
Time Period (sec)	.0540	_	.0510	.0161	_	.015	.0119	_	.0108	.0095	_	.0079

Case 3: frame with 1st story as soft story

a) Without mass variation on floor level

In this case four storied regular frame with same mass at all story is studied. The frequency and time period are presented in table 7.9

Table 7.9 Frequencies, and time period without mass variation

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	45.34	42.704	47.916	317.95	-	330.51	559.48	_	640.81	701.60	_	794.92
Frequency (Hz)	7.22	6.8	7.63	50.53	_	52.63	89.09	_	102.04	111.72	_	126.58
Time Period (sec)	.138	.147	.131	.0197	_	.190	.0112	_	.0098	.0089	_	.0079

b) With additional mass on 1st floor =3 kg

In this case four storied frame with additional mass on 1st story is studied. The frequency and time period are presented in table 7.10

Table 7.10 Frequencies, and time period with additional mass on 1st floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	40.44	41.44	42.95	265.26	-	272.99	518.60	_	576.12	690.10	_	794.92
Frequency (Hz)	6.44	6.6	6.84	42.24	_	43.47	82.58	_	91.74	109.89	_	126.58
Time Period (sec)	.155	.151	.146	.0236	_	.230	.0121	_	.0109	.0091	_	.0079

c) With additional mass on 2nd floor = 3 kg

In this case four storied frame with additional mass on 2nd story is studied. The frequency and time period are presented in table 7.11

Table 7.11 Frequencies, and time period with additional mass on 2nd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	40.06	40.192	42.704	304.83	_	310.86	500.89	_	532.16	650.85	_	713.59
Frequency (Hz)	6.38	6.4	6.80	48.54	_	49.50	79.76	_	84.74	103.64	_	113.63
Time Period (sec)	.156	.156	.147	.0206	_	.0202	.0125	_	.0118	.0096	_	.0088

d) With additional mass on 3rd floor = 3 kg

In this case four storied frame with additional mass on 3rd story is studied. The frequency and time period are presented in table 7.12

Table 7.12 Frequencies, and time period with additional mass on 3rd floor

Mode	1			2			3			4		
	Analytic	**practical**	**ETAB**	**Analytic**	**practical**	**ETAB**	**Analytic**	**practical**	**ETAB**	**Analytic**	**practical**	**ETAB**
Angular Frequency (rad/sec)	39.94	40.82	42.39	203.158	_	216.53	303.73	_	330.51	512.198	_	705.558
Frequency (Hz)	6.36	6.5	6.75	32.35	_	34.48	48.365	_	52.63	81.56	_	112.35
Time Period (sec)	.157	.153	.148	.0309	_	.0290	.206	_	.190	.122	_	.0089

Case 4: frame with 2nd story as soft story

a) Without mass variation on floor level

In this case four storied regular frame with same mass at all story is studied. The frequency and time period are presented in table 7.13

Table 7.13 Frequencies, and time period without mass variation

Mode	1			2			3			4		
	Analytic	**practical**	**ETAB**	**Analytic**	**practical**	**ETAB**	**Analytic**	**practical**	**ETAB**	**Analytic**	**practical**	**ETAB**
Angular Frequency (rad/sec)	52.312	49.612	55.075	381.44	-	424.27	421.01	_	461.70	672.33	_	805.09
Frequency (Hz)	8.33	7.9	8.77	60.74	_	67.56	67.04	_	73.52	107.06	_	128.20
Time Period (sec)	.120	.126	.114	.0164	_	.0148	.0149	_	.0136	.0093	_	.0078

b) With additional mass on 1st floor =3 kg

In this case four storied frame with additional mass on 1st story is studied. The frequency and time period are presented in table 7.14

Table 7.14 Frequencies, and time period with additional mass on 1st floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	52.312	50.24	54.69	270.41	_	298.99	419.81	_	433.06	671.96	_	689.60
Frequency (Hz)	8.33	8.0	8.71	43.06	_	47.61	66.85	_	68.96	107.00	_	109.81
Time Period (sec)	.120	.125	.1148	.0232	_	.0210	.0149	_	.0145	.0093	_	.0091

c) With additional mass on 2nd floor = 3 kg

In this case four storied frame with additional mass on 2nd story is studied. The frequency and time period are presented in table 7.15

Table 7.15 Frequencies, and time period with additional mass on 2nd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	44.807	42.704	47.539	346.15	_	369.38	383.70	_	455.04	644.20	_	839.196
Frequency (Hz)	7.135	6.8	7.57	55.12	_	58.82	61.10	_	72.46	102.85	_	133.63
Time Period (sec)	.140	.147	.132	.0181	_	.0170	.0163	_	.0138	.0097	_	.0074

d) With additional mass on 3rd floor = 3 kg

In this case four storied frame with additional mass on 3rd story is studied. The frequency and time period are presented in table 7.16

Table 7.16 Frequencies, and time period with additional mass on 3rd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	44.33	44.588	47.162	381.25	_	424.276	420.822	_	455.04	559.98	_	640.81
Frequency (Hz)	7.06	7.1	7.51	60.71	_	67.56	67.01	_	72.46	89.17	_	102.04
Time Period (sec)	.1416	.1408	.1331	.0164	_	.0148	.0149	_	.0138	.0112	_	.0098

Case 5: frame with 3rd story as soft story

a) Without mass variation on floor level

In this case four storied regular frame with same mass at all story is studied. The frequency and time period are presented in table 7.17

Table 7.17 Frequencies, and time period without mass variation

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	65.123	_	68.954	242.91	_	262.75	589.629	_	640.8112	605.07	_	839.196
Frequency (Hz)	10.37	_	10.98	38.68	_	41.84	93.89	_	102.04	96.35	_	133.63
Time Period (sec)	.0964	_	.0910	.0258	_	.0239	.0106	_	.0098	.0103	_	.0074

b) With additional mass on 1st floor =3 kg

In this case four storied frame with additional mass on 1^{st} story is studied. The frequency and time period are presented in table 7.18

Table 7.18 Frequencies, and time period with additional mass on 1st floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	65.06	_	68.954	211.69	_	211.69	490.530	_	570.85	590.194	_	640.81
Frequency (Hz)	10.36	_	10.98	33.71	_	37.31	78.11	_	90.90	93.98	_	102.04
Time Period (sec)	.0965	_	.0910	.0296	_	.0296	.0128	_	.0110	.0106	_	.0098

c) With additional mass on 2nd floor = 3 kg

In this case four storied frame with additional mass on 2^{nd} story is studied. The frequency and time period are presented in table 7.19

Table 7.19 Frequencies, and time period with additional mass on 2nd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	64.872	_	68.954	185.00	_	209.312	563.00	_	640.811	606.96	_	682.573
Frequency (Hz)	10.33	_	10.98	29.46	_	33.33	89.65	_	102.04	96.65	_	108.69
Time Period (sec)	.0968	_	.0910	.0339	_	.0300	.0111	_	.0098	.0103	_	.0092

d) With additional mass on 3rd floor = 3 kg

In this case four storied frame with additional mass on 3rd story is studied. The frequency and time period are presented in table 7.20

Table 7.20 Frequencies, and time period with additional mass on 3rd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	51.433	_	55.075	242.65	_	272.99	508.99	_	570.85	604.63	_	839.19
Frequency (Hz)	8.19	_	8.77	38.64	_	43.47	81.05	_	90.90	96.28	_	133.63
Time Period (sec)	.1221	_	.1140	.0258	_	.0230	.0123	_	.0110	.0103	_	.0074

Case 6: frame with 4thstory as soft story

a) Without mass variation on floor level

In this case four storied regular frame with same mass at all story is studied. The frequency and time period are presented in table 7.21

Table 7.21 Frequencies, and time period without mass variation

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	99.789	_	108.267	184.694	_	196.25	468.61	_	532.167	671.96	_	794.92
Frequency (Hz)	15.89	_	17.24	29.41	_	31.25	74.62	_	84.74	107.00	_	126.58
Time Period (sec)	.0629	_	.0580	.0340	_	.032	.0134	_	.0118	.0093	_	.0079

b) With additional mass on 1st floor =3 kg

In this case four storied frame with additional mass on 1st story is studied. The frequency and time period are presented in table 7.22

Table 7.22 Frequencies, and time period with additional mass on 1st floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	99.286	_	106.446	174.2	_	191.414	376.23	_	424.27	627.24	_	705.55
Frequency (Hz)	15.81	_	16.95	27.75	_	30.48	59.91	_	67.56	99.88	_	112.35
Time Period (sec)	.0632	_	.0589	.0360	_	.0328	.0166	_	.0148	.01001	_	.0089

c) With additional mass on 2nd floor = 3 kg

In this case four storied frame with additional mass on 2nd story is studied. The frequency and time period are presented in table 7.23

Table 7.23 Frequencies, and time period with additional mass on 2nd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	98.030	_	105.504	159.826	_	179.419	446.570	_	490.593	583.663	_	634.342
Frequency (Hz)	15.61	_	16.80	25.45	_	28.57	71.11	_	78.12	92.94	_	101.01
Time Period (sec)	.0640	_	.0595	.0392	_	.0350	.0140	_	.0128	.0107	_	.0099

d) With additional mass on 3rd floor = 3 kg

In this case four storied frame with additional mass on 3rd story is studied. The frequency and time period are presented in table 7.24

Table 7.24 Frequencies, and time period with additional mass on 3rd floor

Mode	1			2			3			4		
	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB	Analytic	practical	ETAB
Angular Frequency (rad/sec)	96.272	_	102.929	153.608	_	169.685	421.325	_	483.057	656.134	_	705.620
Frequency (Hz)	15.33	_	16.39	24.46	_	27.02	67.09	_	76.92	104.48	_	112.36
Time Period (sec)	.0652	_	.0610	.0408	_	.0370	.0149	_	.0130	.0095	_	.0089

7.2 Analysis:

Case-1: bare frame with no walls

a) Without mass variation on floor levels.

b) With additional mass on 1st floor =3 kg

c) With additional mass on 2nd floor = 3 kg

d) With additional mass on 3rd floor = 3 kg

Table 7.25 comparison of frequencies of bare frame with no walls

Mode	Case 1(a)	Case 1(b)	Case 1(c)	Case 1(d)
1	5.90	5.66	5.18	4.81
2	16.88	13.41	14.36	16.82
3	25.64	22.46	25.54	21.89
4	31.15	30.17	28.14	29.00

In this case the natural frequency is maximum for regular frame with no mass variation and as the mass is varied frequency is greater when mass irregularity is present on first story as compared to top story. Thus the time period is greater when the mass irregularity is present on top floor in the first mode.

Time period thus is maximum when mass irregularity is present on first floor in 2nd mode, top floor in 3rd mode and third floor in 4th mode.

Case 2: frame with all story closed by walls

a) Without mass variation on floor levels.

b) With additional mass on 1st floor =3 kg

c) With additional mass on 2nd floor = 3 kg

d) With additional mass on 3rd floor = 3 kg

Table 7.26 comparison of frequencies of frame with all story closed by walls

Mode	Case 2(a)	Case 2(b)	Case 2(c)	Case 2(d)
1	21.76	21.07	19.66	18.49
2	62.115	51.83	54.90	61.76
3	93.60	83.78	89.69	83.71
4	112.60	109.98	103.93	105.2

In this case the natural frequency is maximum for regular frame with no mass variation and as the mass is varied frequency is greater when mass irregularity is present on first story as compared to top story. Thus the time period is greater when the mass irregularity is present on top floor in the first mode.

Time period thus is maximum when mass irregularity is present on first floor in 2nd mode, top floor in 3rd mode and third floor in 4th mode.

Case 3: frame with 1st story as soft story

a) Without mass variation on floor levels.

b) With additional mass on 1st floor =3 kg

c) With additional mass on 2nd floor = 3 kg

d) With additional mass on 3rd floor = 3 kg

Table 7.27 comparison of frequencies of frame with 1st story as soft story

Mode	Case 3(a)	Case 3(b)	Case 3(c)	Case 3(d)
1	7.22	6.44	6.38	6.36
2	50.53	42.24	48.54	32.25
3	89.09	82.58	79.76	48.36
4	111.72	109.89	103.64	81.56

In this case the natural frequency is maximum for regular frame with no mass variation and as the mass is varied frequency is greater when mass irregularity is present on first story as compared to top story. Thus the time period is greater when the mass irregularity is present on top floor in the first mode.

Time period thus is maximum when mass irregularity is present on fourth floor in 2nd mode, 3rd mode and 4th mode.

Case 4: frame with 2nd story as soft story

a) Without mass variation on floor levels.

b) With additional mass on 1st floor =3 kg

c) With additional mass on 2nd floor = 3 kg

d) With additional mass on 3rd floor = 3 kg

Table 7.28 comparison of frequencies of frame with 2nd story as soft story

Mode	Case 4(a)	Case 4(b)	Case 4(c)	Case 4(d)
1	8.33	8.33	7.135	7.06
2	60.74	43.06	55.12	60.71
3	67.04	66.85	61.10	67.01
4	107.06	107.00	102.85	89.17

In this case the natural frequency is maximum for regular frame with no mass variation and as the mass is varied frequency is greater when mass irregularity is present on first story as compared to top story. Thus the time period is greater when the mass irregularity is present on top floor in the first mode.

Time period thus is maximum when mass irregularity is present on first floor in 2nd mode, third floor in 3rd mode and fourth floor in 4th mode.

Case 5: frame with 3rd story as soft story

a) Without mass variation on floor levels.

b) With additional mass on 1st floor =3 kg

c) With additional mass on 2nd floor = 3 kg

d) With additional mass on 3rd floor = 3 kg

Table 7.29 comparison of frequencies of frame with 3rd story as soft story

Mode	Case 5(a)	Case 5(b)	Case 5(c)	Case 5(d)
1	10.37	10.36	10.33	8.19
2	38.68	33.71	29.46	38.64
3	93.89	78.11	89.65	81.05
4	96.35	93.98	96.65	96.28

In this case the natural frequency is maximum for regular frame with no mass variation and as the mass is varied frequency is greater when mass irregularity is present on first story as compared to top story. Thus the time period is greater when the mass irregularity is present on top floor in the first mode.

Time period thus is maximum when mass irregularity is present on second floor in 2nd mode, first floor in 3rd mode and 4th mode.

Case 6: frame with 4^{th} story as soft story

a) Without mass variation on floor levels.

b) With additional mass on 1st floor =3 kg

c) With additional mass on 2nd floor = 3 kg

d) With additional mass on 3rd floor = 3 kg

Table 7.30 comparison of frequencies of frame with 4th story as soft story

Mode	Case 6(a)	Case 6(b)	Case 6(c)	Case 6(d)
1	15.89	15.81	15.61	15.33
2	29.41	27.75	24.45	24.46
3	74.62	59.91	71.11	67.09
4	107.00	99.88	92.94	104.48

In this case the natural frequency is maximum for regular frame with no mass variation and as the mass is varied frequency is greater when mass irregularity is present on first story as compared to top story. Thus the time period is greater when the mass irregularity is present on top floor in the first mode.

Time period thus is maximum when mass irregularity is present on second floor in 2nd mode, first floor in 3rd mode and second floor in 4th mode.

CHAPTER 8

CONCLUSIONS

8.1 Main conclusions

a) Location of irregularity affects the dynamic characteristics of the building under seismic excitation to a large extent. Therefore, while considering irregularity, both extent and location of irregularity should be considered.

b) This study shows that the time period and deformation demand depends on the mass irregularities.

c) The time period calculate as per IS 1893:2002 (Part I) is same for dimensions in plan and elevation. The eigenvalue analysis shows that time period differs by varying mass along the height of the building. Also the previous studies shown that the time period depends on the type of irregularity and location of irregularity.

d) It may be appreciated that the time period estimated from eigenvalue analysis is different from that prescribed by codes as former one consider effect of mass irregularity.

e) The time period estimated by the commercial Etabs software may provide result difference for higher modes as compared to eigenvalue analysis.

f) The deformation of the building also varies with varying mass along the height of the building.

g) it is seen that the fundamental time period is maximum when mass irregularity present at top storey.

h) The time period changes considerably by varying mass at different floor along the height of the buildings.

i) The behaviour of the frame seen to be affected by the extent and location of mass irregularity.

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