# CHAPTER-1: INTRODUCTION

## 1.1. GENERAL

In this projectthe studyof behavior of a three storied building frame modelsubjected to harmonic base motions was carried out. This project also enables the understanding ofoccurrence of resonance phenomenon in simple multi-degree of freedom (MDOF) systems.

The frame is rectangular in plan with stiffness and mass properties distributeduniformly in plan as well as in elevation. The frame is designed to facilitate thevisualization of the first three mode shapes with bare eyes. Also, the frame is soconfigured such that a three degree of freedom model would serve as a reasonablemodel, at least to a first approximation.

The model shown in figure-7 can bethought of as a model for a building frame with three floors whichsuffers earthquake like base motions. The model however is an idealized demonstrationof this phenomenon since the building may not only be subjected to harmonic base motions.The frequency of the base motion can be varied by changing the RPM of the electric motor.It is also possible to vary the amplitude of the base motion by changing the clamp. By changing themotor RPM it would be possible to set the frame into resonant motions, which would enable us to visualize the first three normal modes of the frame.

This frame is then modeled in SAP2000 to get the similar results. Then this model is changed by certain parameters such as dimension, self weight, modulus of elasticity etc. to read the trend of change in their seismic parameters. Then based on those variations some relationships have been derived between modification ratio and the seismic parameters.

A realistic structure is also designed to meet the requirement of earthquake. For safety against earthquake, there is needed to keep in mind many points. All those points have also been discussed, which are based on codal provisions and past experiences.

## 1.2 ABOUT EARTHQUAKE, DAMAGES AND PAST OCCURRENCES

An earthquake is perceived as a sudden transient motion of the ground. This motion originates from a limited region inside the earth and spreads from there in all direction. This motion occurs on account of sudden release of elastic strain energy stored along active geological features.

Earthquakes have been an integral component of the geologic evolution of planet earth. Since the dawn of civilization, mankind has been continuously suffered due to their disastrous effects. Earthquakes usually strike without warning and have several direct effects (ground shaking and permanent crustal movement) and induced effects (landslides, avalanches, ground subsidence, liquefaction, ground fissuring, tsunamis and fires).

Globally the majority of earthquakes occur at plate boundaries due to plate deformations. These deformations results on account of slow plate movements of plate boundaries. Based on the distribution of epicenters of earthquakes it is revealed that almost all earthquakes occur in of one of three major seismic belt zones. These belts are:

1) The Circum Pacific Belt,
2) The Alpine Himalayan Belt or Alpide Belt,and
3) The Mid-Oceanic Rigid Belt.

The moderate to large earthquakes have occurred in China, Japan, India, Turkey, South and West of USSR, Palestine, Italy, Spain, Yugoslavia, Morocco, Parts of USA (California, Missouri), Central America, Alaska and New Zealand.

In order to evaluate strong ground motion characteristics and basic seismic coefficients in different parts of the country for earthquake resistant design of ordinary structures the first Indian Standard Seismic Zoning Map was published in 1962 (IS: 1893-1962). This map was prepared based on available earthquake intensity data and locations of moderate, large and greater earthquakes.

The Indian subcontinent has a history of devastating earthquakes. The major reason for the high frequency and intensity of the earthquakes is that the Indian plate is driving into Asia at a rate of approximately 47 mm/year. The following is a list of major earthquakes in India.

| Dates | Location | Deaths | Comments | Magnitude |
|---|---|---|---|---|
| March 5, 2012 | New Delhi | 5 | Strong tremors in Delhi, CBSE Physics board exam disrupted | 5.2 |
| September 18, 2011 | Gangtok, Sikkim | 118 | Strong earthquake in NE India, tremors felt in Delhi, Kolkata, Lucknow and Jaipur | 6.9 |
| August 10, 2009 | Andaman Islands | 26 | Tsunami Warning issued | 7.7 |
| April 6, 2006 | Gujarat | 0 | At least 36 injured in moderate-intensity tremor in Gujarat | 5.5 |
| October 8, 2005 | Kashmir | 130,000 | Affected 894,000 population of Islamabad, Pakistan,Jammu and Kashmir (India) | 7.6 |
| December 26, 2004 | off west coast northern Sumatra India Sri LankaMaldives | 283,106 | Third deadliest earthquake in the history of the world, the tsunami generated killed 15,000 people in India | 9.3 |
| January 26, 2001 | Bhuj, Gujarat | 20,000 | Indian Republic Day Gujarat earthquake, thousands killed | 7.6/7.7 |
| March 29, 1999 | Chamoli district, Uttarakhand | 103 Approx | | 6.8 |
| September 30, 1993 | Latur, Maharashtra | 9,748 | | 6.2 |
| October 20, 1991 | Uttarkashi, Uttarakhand | >2,000 | | 7.0 |

| | | | | |
|---|---|---|---|---|
| January 19, 1975 | Himachal Pradesh | 47 | | 6.8 |
| August 15, 1950 | Arunachal Pradesh | 1,526 | Largest earthquake recorded in mainland India since Independence. | 8.5 |
| June 26, 1941 | Andaman Islands | 7,000 | Triggered a tsunami that affected eastern India and Sri Lanka | 8.1 |
| May 31, 1935 | Quetta, Baluchistan | 30,000 / 60,000 | Deadliest earthquake recorded in modern-day Pakistan. | 7.7 |
| January 15, 1934 | Nepal, Epicenter lies 10 km south of Mt. Everest | 8,100 | Largest ever earthquake recorded in mainland Indian subcontinent. | 8.7 |
| April 4, 1905 | Himachal Pradesh | >20,000 | It was a major earthquake that occurred in the Kangra Valley and the Kangra region | 7.8 |
| June 12, 1897 | Shillong, India | 1,500 | | 8.1 |
| December 31, 1881 | Andaman Islands | 150,000 | Earliest earthquake for which rupture parameters have been estimated instrumentally (from tide gauges) | 7.9 |
| June 16, 1819 | Gujarat | 11,543 | Formed the Allah Bund and Lake Sindri | 8.2 |
| September 18, 1737 | Kolkata, West Bengal | 100,000 | | 7.6 |

## 1.3. AIMS AND BJECTIVES IN BRIEF

Detailed aims and objectives of this project work have been elaborated in chapter-3. A brief of those are as follows:

1.2.1. The objective of this project work is to analyze the seismic behavior of building frame model with the help of OROS NVGate software and shake table. And comparing their results with the values getting from:

1) Manual calculations
2) Excel programming
3) SAP2000 modeling

Here the following parameters have been analyzed:

1) Natural frequencies of deferent modes.
2) Damping ratio (ξ)
3) Displacement

1.2.2. Changing the model using SAP2000 to get the relationship between various kind of modification and some seismic behaviors. So as to establish direct relationship for dimension analysis of the structure for seismic analysis.

1.2.3. Design of real structure for seismic condition.

# CHAPTER-2: LITERATURE REVIEW

## 2.1. MODAL ANALYSIS

Modal analysis of a structure can be done in following ways depending upon the degree of freedoms of the structure.

### 2.1.1. SDOF Shear Building (Rigid Roof)

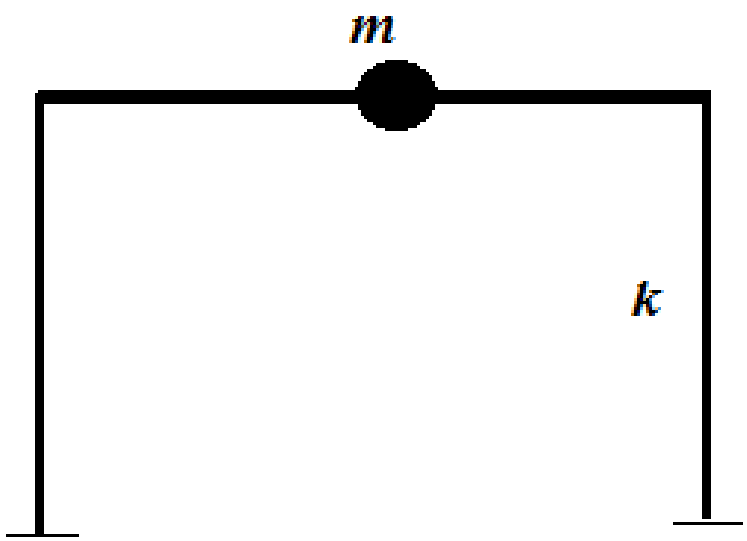



Figure- 1: SDOF System

$$ku + c\dot{u} + m\ddot{u} = -m\ddot{u}_g$$

$$m = \text{lumpedmass} = m_{roof} + 2\left(\frac{1}{2}m_{col}\right)$$

$$k = 2k_{col} = 2\frac{12EI_c}{h^3} = \frac{24EI_c}{h^3}$$

### 2.1.2. 3 Storied Frame (3 DOF System)

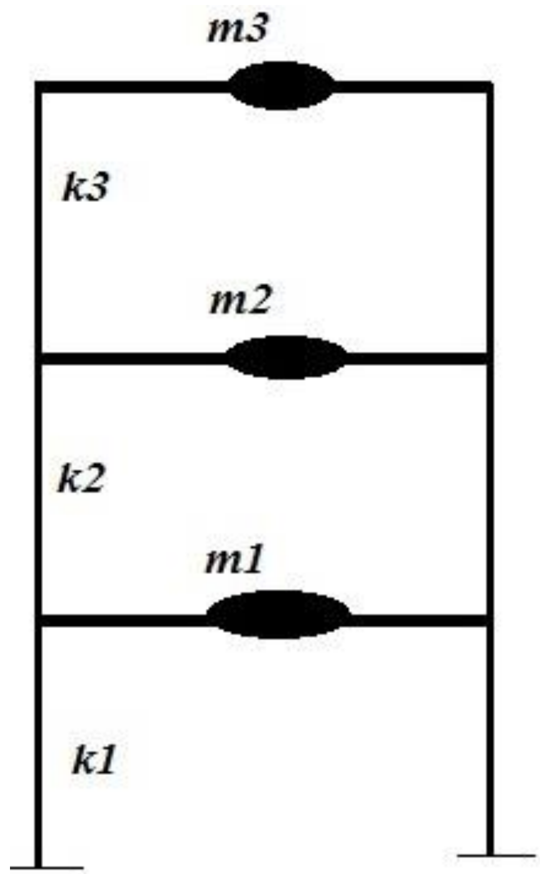



Figure- 2: 3 DOF System

The frame in figure-2 can be approximately modeled as a three degree of freedom shear beam as shown in figure-3.The free body diagram has also shown.

Say, if displacement imposed at the base of the structure = y

Expressing the floor displacements relative to the base motion:

$$x_{r1} = x_1 - y$$
$$x_{r2} = x_2 - y$$
$$x_{r3} = x_3 - y$$

---------- (1)

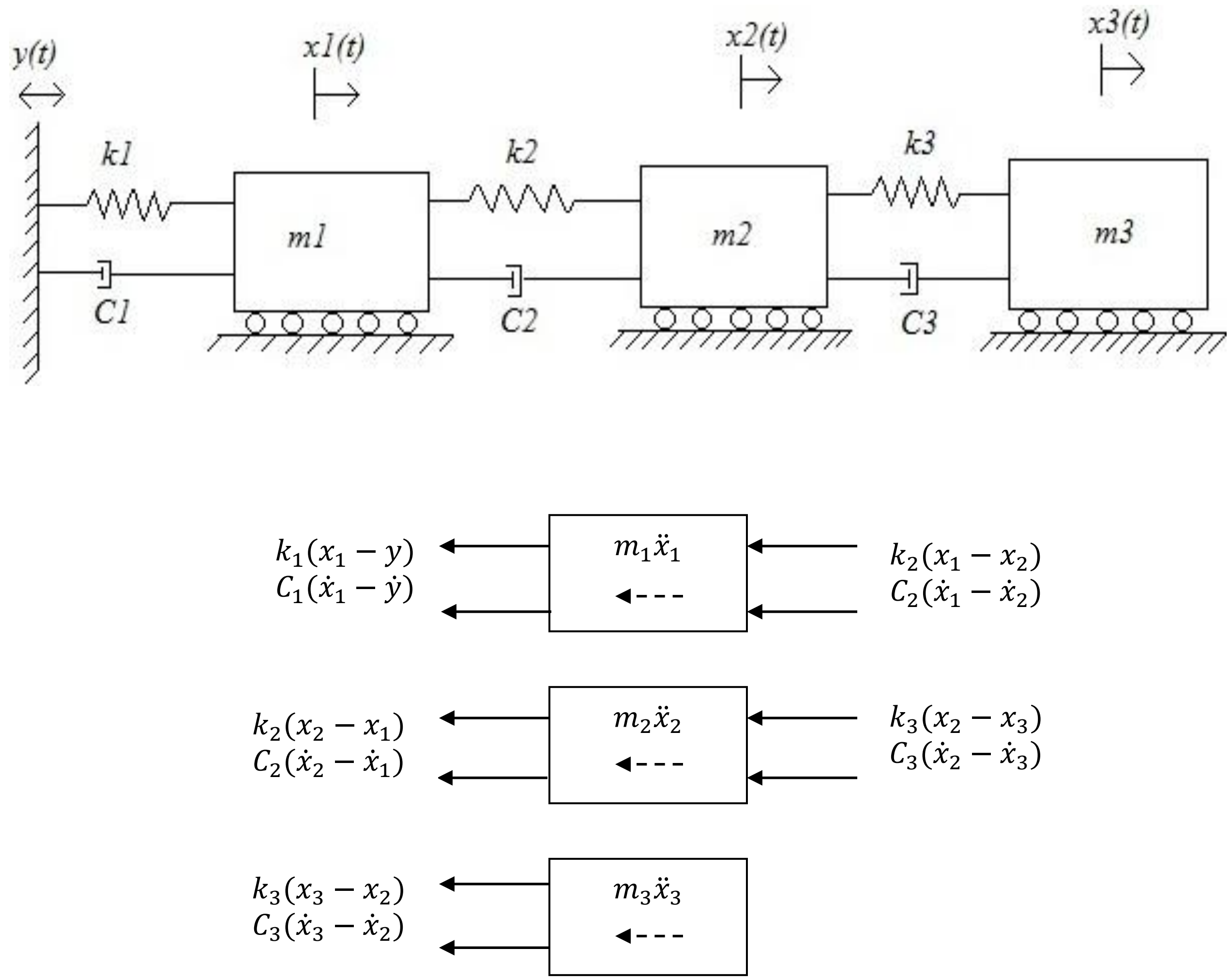



Figure- 3: Shear Beam Model and Free Body Diagram

Thus, theequation of motion for total displacement of three masses can be written asfollows:

$$m_1\ddot{x}_{r1} + c_1\dot{x}_{r1} + c_2(\dot{x}_{r1} - \dot{x}_{r2}) + k_1x_{r1} + k_2(x_{r1} - x_{r2}) = -m_1\ddot{y}$$

$$m_2\ddot{x}_{r2} + c_2(\dot{x}_{r2} - \dot{x}_{r1}) + c_3(\dot{x}_{r2} - \dot{x}_{r3}) + k_2(x_{r2} - x_{r1}) + k_3(x_{r2} - x_{r3}) = -m_2\ddot{y}$$

$$m_3\ddot{x}_{r3} + c_3(\dot{x}_{r3} - \dot{x}_{r2}) + k_3(x_{r3} - x_{r2}) = -m_3\ddot{y}$$

Rewriting this in matrix form:

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix}\begin{Bmatrix} \ddot{x}_{r1} \\ \ddot{x}_{r2} \\ \ddot{x}_{r3} \end{Bmatrix} + \begin{bmatrix} c_1 + c_2 & -c_2 & 0 \\ -c_2 & c_2 + c_3 & -c_3 \\ 0 & -c_3 & c_3 \end{bmatrix}\begin{Bmatrix} \dot{x}_{r1} \\ \dot{x}_{r2} \\ \dot{x}_{r3} \end{Bmatrix} + \begin{bmatrix} k_1 + k_2 & -k_2 & 0 \\ -k_2 & k_2 + k_3 & -k_3 \\ 0 & -k_3 & k_3 \end{bmatrix}\begin{Bmatrix} \dot{x}_{r1} \\ \dot{x}_{r2} \\ \dot{x}_{r3} \end{Bmatrix}$$

$$= (-)\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix}\begin{Bmatrix} 1 \\ 1 \\ 1 \end{Bmatrix}\ddot{y}$$

Thus, $$[m]\{\ddot{x}_r\} + [c]\{\dot{x}_r\} + [k]\{x_r\} = -[m]\{\Gamma\}\ddot{y} \qquad \text{---------- (2)}$$

Initial condition:

$$x_r = 0 \; and \; \dot{x}_r = 0 \;\; at \; t = 0$$

Here, $\{\Gamma\}$ is 3×1 vector of ones.

## 2.2. NATURAL FREQUENCY

Each material in the universe hasits own natural frequencies depending upon their different properties. In structures this frequency is dependent on their mass distribution and stiffness parameters. This is also called as the fundamental natural frequency of the structure. When the frequency of ground motion matches with the natural frequency of the structure, the structure becomes in resonance condition and it gets excessive deformation, theoretically infinite.

Similar to the SDOF, free vibration involves the system response in its natural frequencies. Thecorresponding Free Vibration Equation is (with no damping):

$$[m]\{\ddot{x}_r\} + [k]\{x_r\} = 0 \qquad \text{----------} \ (3)$$

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

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

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

Such that, $$\ddot{x} = -w^2 x$$

On solving above equations we will get,

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

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

For non- trivial solution,

$$|-mw^2 + k| = 0$$

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

$$\left| -\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix} w^2 + \begin{bmatrix} k_1 + k_2 & -k_2 & 0 \\ -k_2 & k_2 + k_3 & -k_3 \\ 0 & -k_3 & k_3 \end{bmatrix} \right| = 0 \qquad \text{---------- (4)}$$

By solving above expression, the values of natural frequencies at different modes can be determined. In this case thenumbers of non-trivial solutions are three, because matrix size is of 3x3, as it is a 3 degree of freedom system. For n degree of freedom system,there willbe“n” number of non-trivial solutions.

## 2.3. DAMPING RATIO

Suppose a pendulum is given a free vibration of certain amount and is left for few times. After some time the amplitude of oscillation of pendulum will be decreased, and then after a very long time it will be stopped. But Newton'sfirst law states that, a body moving with a constant velocity will keep on moving with the same constant velocity unless or until there will be no any external force. Then how that pendulum is stopped or slowed down? Surely, there is any force acting in the system which is gradually slowing down the velocity of motion of pendulum, leading to stop it. This force may be combination of many kinds of agencies such as air friction, material resistance, resistance due to abject shape, etc. Out of which, the dominating resistance is due to shape and material.

Thus the damping is an inhered property of the structure which depends mainly upon material of construction and structural configuration. Damping ratio is termed by certain percentage of the critical damping.For design purpose, the exact determination of damping ratio of a large structure is not possible or not so easy. Hence some specific valuesof damping ratio have been recommended, based on the material of construction used. There are some methods have been developed for exact determination of damping ratio. Out of which the method of logarithmic decrement is most popular. According to that,

Damping Ratio $\xi = \frac{\delta}{2\pi} \times 100\%$

Where, $\delta$ = logarithmic decrement

And, $\delta = ln\left(\frac{y_n}{y_{n+1}}\right)$

Where, $y_n$ and $y_{n+1}$ are two consecutive peak values of displacement vs. time graph of free vibration.

Using that expression, damping ratio of any structure can be determined by using time history graph of that structure.

## 2.4. REGRESSION ANALYSIS

Suppose if there are two or more kinds of data (say, X and Y) and if it is known that there is some correlation between them. Then their relationship can be determined by doing regression analysis. It can be done by manual calculations or by excel programming. A brief explanation is given here. Let's take an example,

| **X** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| **Y** | 20 | 65 | 110 | 155 | 200 | 245 | 290 | 340 | 380 |

To get the relationship between X and Y, regression result on excel programming is as follows,

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.999924829 |
| R Square | 0.999849663 |
| Adjusted R Square | 0.999828186 |
| Standard Error | 1.624465724 |
| Observations | 9 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 122853.75 | 122853.75 | 46555.10526 | 1.21251E-14 |
| Residual | 7 | 18.47222222 | 2.638888889 | | |
| Total | 8 | 122872.2222 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -25.69444444 | 1.180146988 | -21.77224083 | 1.08804E-07 | -28.48504863 | -22.90384026 | -28.48504863 | -22.90384026 |
| X | 45.25 | 0.209717623 | 215.766321 | 1.21251E-14 | 44.75409662 | 45.74590338 | 44.75409662 | 45.74590338 |

Figure- 4: Regression Analysis on Excel

a) "R Square" equals 0.99985, which is a very good fit. The closer to1 R Square value, the better the regression line.

b) To check if results are reliable, look at "Significance F". If this value is less than 0.05, it is OK. If it is greater than 0.05 then check "P-value". If any value in P-value is more than 0.05 then, stop correlating the parameter corresponding to that value.

c) The regression line is Y = 45.25*X – 25.694444

The Residuals and the predicted Y values based on regression line are also shown below. The lesser the residual value, the more closer the predicted value and actual value.

RESIDUAL OUTPUT

| Observation | Predicted Y | Residuals |
|---|---|---|
| 1 | 19.55555556 | 0.444444444 |
| 2 | 64.80555556 | 0.194444444 |
| 3 | 110.0555556 | -0.055555556 |
| 4 | 155.3055556 | -0.305555556 |
| 5 | 200.5555556 | -0.555555556 |
| 6 | 245.8055556 | -0.805555556 |
| 7 | 291.0555556 | -1.055555556 |
| 8 | 336.3055556 | 3.694444444 |
| 9 | 381.5555556 | -1.555555556 |

Figure- 5: Residual Output

But the drawback of this regression analysis is that it gives only linear relationship. To get the equation of power some modified expression can be used as explained below.

Say, the expression is in the form of, $y = a \times x^n$ ---------- (A)

Taking logarithm in both side, and rewriting,

$$log(y) = log(a) + n \times log(x)$$

Writing, $log(y) = Y,\ log(x) = X$ and $log(a) = A$ ,the expression will come out to be,

$$Y = A + nX \qquad \text{---------- (B)}$$

The above expression is in the form of a line. Thus using regression analysis the equation of powers can also be determined. This will help on determining direct relationship between magnification factor and seismic parameter for dimension analysis.

## 2.5. GENERAL CONSIDERATIONS FOR EARTHQUAKE RESISTANT DESIGN

Earthquake is a natural phenomenon. It occurs without any warning and mankind suffers a lot on its occurrence. A structure cannot be build to withstand completely against the earthquake, because economy will decrease by doing so. Hence it is tried to minimize the loss by keeping in mind various points while designing and planning the structure. Some basic points based on past experiences and codal provisions have been mentioned here, which will help in designing a multi-storey building, to well stand for earthquake.

a) The whole structure should be tied and connected properly, mainly at joints. So that the load can be distributed in structural frame properly, and structure can behave like a single unit.

b) Seismic lateral force and strength ratio throughout the structure should be approximately constant.

c) Strong column- weak beam is the most important aspect for ductility of structure. Because if there would be weak column- strong beam, then the structure will fail in brittle manner. i.e., sudden collapse.

d) Reduce the earthquake force by using light weight construction.

e) Try to avoid quasi- resonance condition. Tall buildings on soft soil are not suitable because will have lower frequencies of vibration and tall building is flexible in nature so its fundamental natural frequency will also be lower. In soft soil small and stiff building is advisable and tall building is suitable in rocky site.

f) Earthquake force is dependent on mass and stiffness distribution of the structure unlike to wind, gravity force, etc. thus we can control the earthquake force at very early stage in the structure.

g) Introducing base isolation or energy dissipating device or both in the structure to divert or absorb the earthquake energy.

h) Pounding action in two adjacent building should be avoided by providing sufficient clearance. The separation should be more than the sum of dynamic deflection of the two buildings. Pounding is more sever when the floor level of two adjacent buildings are at different level.

i) Sudden change in stiffness of frame element between storeys should be avoided. It becomes location of stress concentration. Sudden change in elevation should also be avoided.

j) Avoid use of stiff walls between flexible frames.

k) While damage of non-structural elements, a lot of energy gets absorbed.

l) Providing sufficient reinforcement to introduce ductility of the structure at critical locations and junctions.

m) Infill provides additional stiffness and causes brittle failure. So it should be connected to the structure such that its damage could be minimized at earthquake, as its repair is quite costly. Infill also causes bracing in the frame.Hence the beam-column joint should be well detailedas per IS: 13920- 1993 and should be laid carefully, for adequate strength and ductility. Confinement and proper anchorage of reinforcement provides proper ductility.

n) The design should be safe against reversible condition of earthquake force also.

o) Overturning effect should be considered for tension and compression at extreme ends.

p) Symmetric building plans should be provided. If there is any asymmetry, then use suitable separation in between to make it symmetric.

q) Large overhang and balconies should be avoided, as these portions are subjected to higher forces.

r) The parapet should be reinforced with a closed loop of bar at the coping level, so that it may not fall and could not cause injuries to the people.

s) Water tank should be properly anchored against overturning and sliding at the top of the structure. Large storage or swimming pool should be avoided at the roof of building as these cause mass irregularity in the structure.

t) When providing parking facility at the ground level of the building, we should increase the stiffness of that storey by using 2.5 times more strong columns than of above storey or by using shear walls, to avoid being ground floor as soft storey.

u) Typically, in earthquake ground motions, the frequency in the dynamic excitation can range from 0.5 Hz to 25.0 Hz.

v) Overhang and beams with floating column should be avoided.

## 2.6. SOME SPECIFICATIONS FROM IS: 1893 (PART 1): 2002

1) Load Combinations

For plastic design of steel structures:

A) 1.7 ( DL + IL )
B) 1.7 ( DL ± EL )
C) 1.3 ( DL + IL ± EL )

For limit state design of reinforced concrete and pre-stressed concrete structures:

A) 1.5 ( DL + IL )
B) 1.2 ( DL + IL ± EL )
C) 1.5 ( DL ± EL )
D) 0.9 DL ± 1.5 EL

2) Design Horizontal Seismic Coefficient

$$A_h = \frac{Z\,I\,S_a}{2\,R\,g} \times \eta$$

Where, $A_h$ = Design Horizontal Seismic Coefficient

$Z$ = Zone Factor

$I$ = Importance Factor

$R$ = Response Reduction Factor

$S_a/g$ = Average Response acceleration Coefficient (Figure-6)

$\eta$ = Factor to account for the damping of the structure

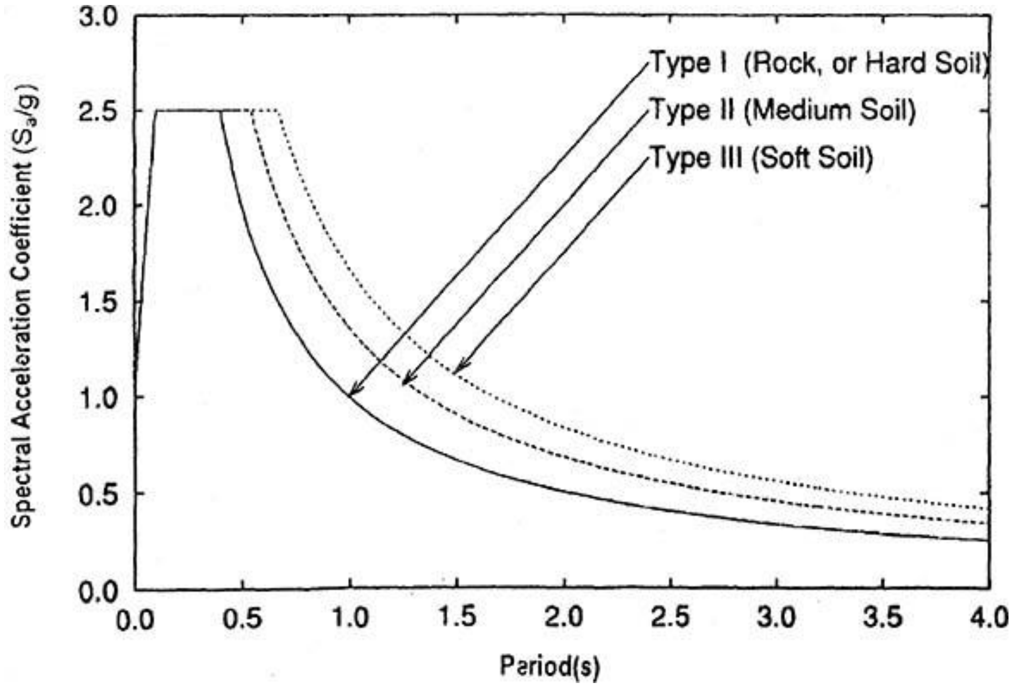



Figure- 6: Response Spectra for 5 % Damping

3) Dynamic analysis may be performed either by the Time History Method or by the Response Spectrum method. However, in either method, the design base shear $V_B$ shall be compared with a base shear calculated using fundamental period $T_a$ (as per clause 7.6 of IS: 1893- 2002). Then correction is to be applied for all the response quantities (for example member force, displacements, storey forces, storey shears and base reactions).

4) Modes to be considered

The number of modes to be used in the analysis should be such that the sum total of modal masses of all modes considered is at least 90% of the total seismic mass and missing mass correction beyond 33%. Modal combination shall be carried out only for modes up to 33 Hz.

## 2.7. CONCLUSIONS BASED ON LITERATURE SURVEY

A) The peak of response spectrum curve corresponds to time period of 0.1 to 0.4 sec in hard soil and 0.1 to 0.67 sec in soft soil. Hence soft soil more amplifies the earthquake of lower frequency (higher time period). And the structures, those have fundamental time periods lower or higher than this range attracts much smaller force.

B) Damping results in reduction of effective earthquake force on structure. It depends on material of construction and level of strains developed in the material.

C) Ductility depends on material of construction and structural configuration. Irregular buildings have low capacity to deform plastically without collapse.

D) Response reduction factor (R) takes account for ductility, which is a factor based on type of structural configuration, ductile detailing and material of construction.

E) EPGA (Effective Peak Ground Acceleration) or ZPA (Zero Period Acceleration) is peak acceleration of very rigid building, having time period almost zero.

F) The floor slabs are quite rigid in their plane and are responsible for distribution of lateral load among the various frames.

# CHAPTER-3: AIMS AND OBJECTIVES

Following are the aims and objectives of this project:

1) To setup the model in shake table.
2) To learn the programming of OROS NVGate for vibration measurement.
3) To study the occurrence of resonance condition in model.
4) To study the response behaviour of model.
5) To determine the damping ratio ($\xi$) of the model.
6) To perform theoretical calculation for natural frequency of the model.
7) To prepare a macro enabled excel programming for speedy calculation of natural frequencies, Eigen vector, mode shapes and modal mass participation ratios.
8) To model the experimental model in SAP2000 to match the results.
9) To change the model in SAP2000 by individually changing the dimension, self weight of material and elasticity of material.
10) To learn the regression analysis to find out the expression between two or more correlated quantities.
11) To deduce the relationships between those modifications and seismic parameters such as base shear, base moment, modal periods and modal frequencies, joint displacements for modal load case, total weight and modal mass participation ratios.
12) To study the principles and concepts of designing a building for earthquake resistance.
13) To study the IS: 1893 (Part-1) - 2002 for specifications of designing earthquake resistant structures.
14) To model a realistic multi-storey building for earthquake resistant design in SAP2000.
15) To deduce the conclusions.

# CHAPTER-4: MODEL STUDY

The following text in this chapter describes the study undertaken on a building modal shown in figure-5, for which structural parameters ware as following:

1) <u>Size Parameters</u>

Plate length (x-direction) = 300 mm

Plate width (y-direction) = 150 mm

Plate thickness (z-direction) = 12.44 mm

2) <u>Material Parameter</u>

Modulus of Elasticity of aluminium, $E = 0.69 \times 10^5 \; N/mm^2$

3) <u>Weight Parameter</u>

Mass of each slab = 1.54 kg

Mass of column 1 of all three storey = 0.2338 kg

Mass of column 2 of all three storey = 0.2341 kg

Mass of column 3 of all three storey = 0.2335 kg

Mass of column 4 of all three storey = 0.2322 kg

## 4.1. EXPERIMENTAL SETUP

Figures-7 shows the model setup. This consists of four aluminum columnsand four aluminum slabs each attached to the four columns at an interval of 400 mm. Theentire structure assemblyis placed on a shake table driven by an electricmotor. The RPM of the motor can be varied to achieve harmonic base motions atdifferent frequencies. In the set-up at laboratory, the amplitude of base motion can also be changed but this aspect is not crucial in the conduct of that work.

Figure-7: Experimental Setup

## 4.2. FLOOR DISPLACEMENTS BY EXPERIMENT

A) Unloaded Case:

| Guiding Frequency (Hz) | Ground Floor Displacement (μm) | First Floor Displacement (μm) | Second Floor Displacement (μm) | Third Floor Displacement (μm) |
|---|---|---|---|---|
| 1.1 | 804 | 654 | 762 | 1214 |
| 1.4 | 903 | 801 | 1070 | 1685 |
| 1.6 | 918 | 1047 | 1183 | 1784 |
| 1.8 | 942 | 1172 | 1409 | 2373 |
| 2 | 921 | 1486 | 1723 | 2652 |
| 2.1 | 921 | 1821 | 2160 | 3658 |
| 2.4 | 929 | 2296 | 3235 | 5560 |
| 2.6 | 1052 | 4879 | 7730 | 9120 |
| **2.7** | 1183 | 19320 | 34330 | 37020 |
| 2.9 | 824 | 5390 | 10390 | 13540 |
| 3.1 | 945 | 1843 | 4124 | 6620 |
| 3.2 | 945 | 1242 | 3094 | 5340 |
| 3.3 | 1009 | 708 | 2242 | 4217 |
| 3.5 | 1061 | 354 | 1679 | 3255 |
| 3.8 | 1006 | 76 | 1152 | 2377 |
| 4 | 998 | 61 | 914 | 1324 |
| 4.1 | 1074 | 167 | 837 | 1957 |
| 4.3 | 1106 | 267 | 721 | 1861 |
| 4.5 | 1106 | 337 | 621 | 1678 |
| 4.7 | 1162 | 440 | 550 | 1736 |
| 4.9 | 1182 | 513 | 479 | 1643 |
| 5.1 | 1153 | 579 | 392 | 1551 |
| 5.3 | 1099 | 622 | 314 | 1404 |
| 5.5 | 1152 | 725 | 279 | 1449 |
| 5.7 | 1196 | 817 | 245 | 1375 |
| 5.9 | 1210 | 932 | 188 | 1541 |

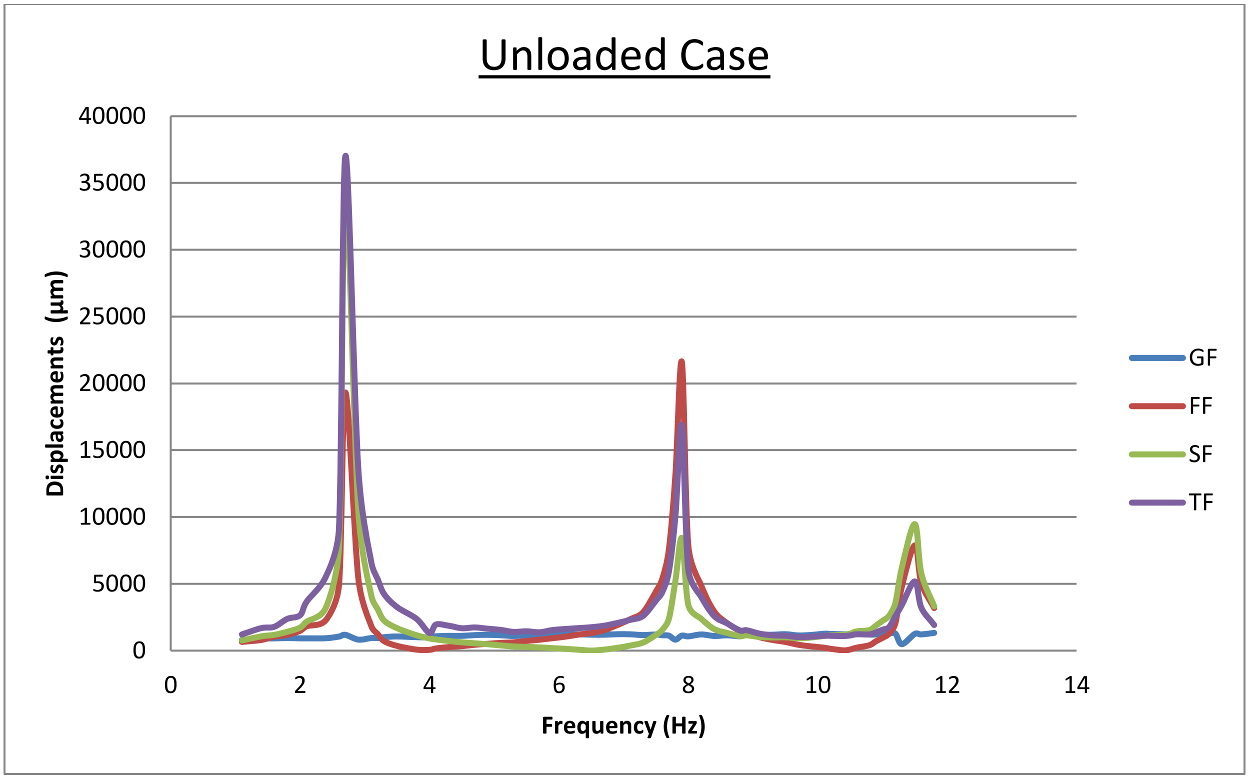
| | | | | |
|---|---|---|---|---|
| 6.1 | 1221 | 1046 | 134 | 1622 |
| 6.3 | 1225 | 1201 | 71 | 1686 |
| 6.5 | 1194 | 1323 | 5 | 1754 |
| 6.7 | 1192 | 1534 | 79 | 1866 |
| 6.9 | 1231 | 1910 | 208 | 2067 |
| 7.1 | 1224 | 2347 | 378 | 2302 |
| 7.3 | 1166 | 2870 | 604 | 2597 |
| 7.5 | 1209 | 4435 | 1177 | 3751 |
| 7.6 | 1153 | 5420 | 1570 | 4414 |
| 7.7 | 1119 | 7590 | 2395 | 5930 |
| 7.8 | 823 | 13150 | 5230 | 10070 |
| **7.9** | 1125 | 21580 | 8420 | 16850 |
| 8 | 1068 | 7840 | 3422 | 6050 |
| 8.2 | 1213 | 4864 | 2381 | 4017 |
| 8.4 | 1098 | 2930 | 1613 | 2585 |
| 8.6 | 1146 | 2061 | 1323 | 2037 |
| 8.8 | 1079 | 1469 | 1088 | 1508 |
| 8.9 | 1231 | 1372 | 1147 | 1528 |
| 9.1 | 1190 | 1009 | 1023 | 1274 |
| 9.3 | 1192 | 802 | 984 | 1148 |
| 9.5 | 1231 | 650 | 998 | 1114 |
| 9.7 | 1138 | 440 | 927 | 1021 |
| 9.9 | 1175 | 320 | 983 | 1042 |
| 10.1 | 1267 | 219 | 1104 | 1115 |
| 10.2 | 1251 | 137 | 1145 | 1109 |
| 10.4 | 1223 | 21 | 1186 | 1094 |
| 10.5 | 1236 | 85 | 1264 | 1137 |
| 10.6 | 1296 | 221 | 1439 | 1224 |
| 10.8 | 1203 | 410 | 1541 | 1216 |
| 10.9 | 1216 | 706 | 1879 | 1365 |
| 11 | 1294 | 951 | 2231 | 1569 |
| 11.1 | 1288 | 1263 | 2601 | 1751 |
| 11.2 | 1276 | 2051 | 3574 | 2578 |

| | | | | |
|---|---|---|---|---|
| 11.3 | 483 | 4785 | 6210 | 3420 |
| **11.5** | 1255 | 7880 | 9470 | 5180 |
| 11.6 | 1214 | 5060 | 5800 | 3225 |
| 11.8 | 1329 | 3185 | 3311 | 1917 |

B) Loaded Case:

| **Guiding Frequency (Hz)** | **Ground Floor Displacement (μm)** | **First Floor Displacement (μm)** | **Second Floor Displacement (μm)** | **Third Floor Displacement (μm)** |
|---|---|---|---|---|
| 1 | 875 | 589 | 755 | 1489 |
| 1.3 | 946 | 748 | 1005 | 1767 |
| 1.5 | 946 | 1013 | 1289 | 2282 |
| 1.7 | 1000 | 1282 | 1709 | 3110 |
| 1.9 | 991 | 1889 | 2318 | 4127 |
| 2.1 | 1081 | 2882 | 3884 | 6230 |
| 2.3 | 1145 | 5440 | 8600 | 11100 |
| **2.4** | 1167 | 34110 | 55100 | 59100 |
| 2.7 | 956 | 2758 | 4927 | 8340 |
| 2.8 | 934 | 1246 | 2619 | 4911 |
| 3.1 | 934 | 573 | 1604 | 3381 |
| 3.3 | 982 | 276 | 1224 | 2400 |
| 3.5 | 1029 | 87 | 981 | 2361 |
| 3.7 | 1099 | 89 | 809 | 2223 |
| 3.9 | 1129 | 211 | 700 | 2012 |
| 4.1 | 1077 | 289 | 571 | 1775 |
| 4.3 | 1075 | 428 | 470 | 1686 |
| 4.5 | 1084 | 511 | 418 | 1593 |
| 4.7 | 1154 | 633 | 387 | 1705 |
| 4.9 | 1185 | 753 | 380 | 1111 |
| 5.1 | 1187 | 887 | 316 | 1545 |
| 5.3 | 1139 | 1000 | 239 | 1797 |
| 5.5 | 1212 | 1229 | 211 | 2090 |

| | | | | |
|---|---|---|---|---|
| 5.7 | 1155 | 1388 | 155 | 2016 |
| 5.9 | 1169 | 1757 | 86 | 2241 |
| 6.1 | 1213 | 2492 | 32 | 2695 |
| 6.3 | 1232 | 4034 | 256 | 3715 |
| 6.5 | 1239 | 8230 | 888 | 6600 |
| **6.6** | 830 | 24060 | 3463 | 20380 |
| 6.7 | 1089 | 16790 | 3160 | 13450 |
| 6.9 | 1189 | 6200 | 1459 | 5030 |
| 7.1 | 1207 | 3332 | 984 | 2953 |
| 7.2 | 1088 | 2111 | 743 | 2037 |
| 7.5 | 1174 | 1592 | 700 | 1724 |
| 7.6 | 1152 | 1250 | 648 | 1447 |
| 7.8 | 1104 | 939 | 600 | 1207 |
| 8.1 | 1156 | 721 | 629 | 1135 |
| 8.3 | 1191 | 605 | 667 | 1098 |
| 8.6 | 1244 | 451 | 759 | 1121 |
| 8.8 | 1235 | 332 | 825 | 1110 |
| 9 | 1192 | 198 | 906 | 1101 |
| 9.2 | 1236 | 39 | 1147 | 1245 |
| 9.4 | 1249 | 259 | 1581 | 1474 |
| 9.6 | 1154 | 752 | 2321 | 1891 |
| **9.7** | 1246 | 8960 | 15900 | 10590 |
| 9.9 | 1169 | 4561 | 7430 | 5030 |
| 10 | 1292 | 2361 | 3338 | 2477 |
| 10.2 | 1290 | 1326 | 1522 | 1242 |
| 10.4 | 1216 | 959 | 951 | 788 |



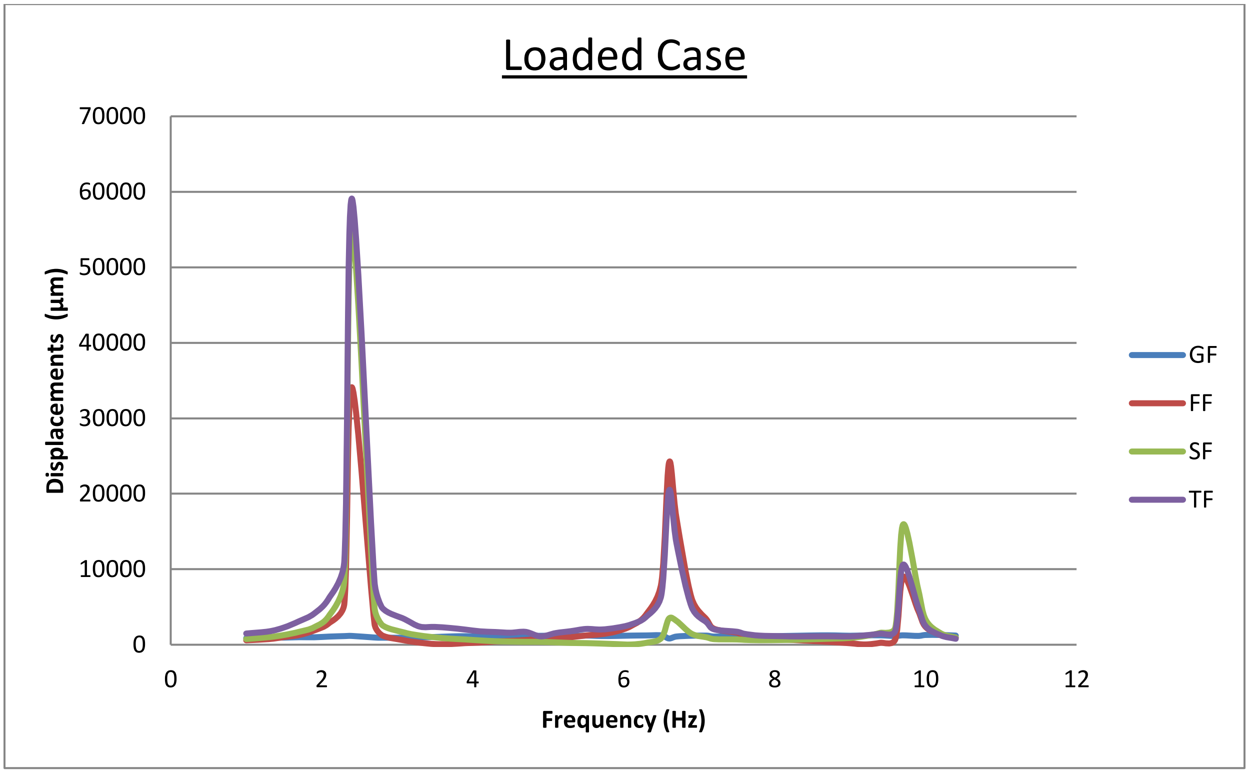




Figure- 8: Frequency vs. Displacement Graph

## 4.3. FREE DAMPED VIBRATION

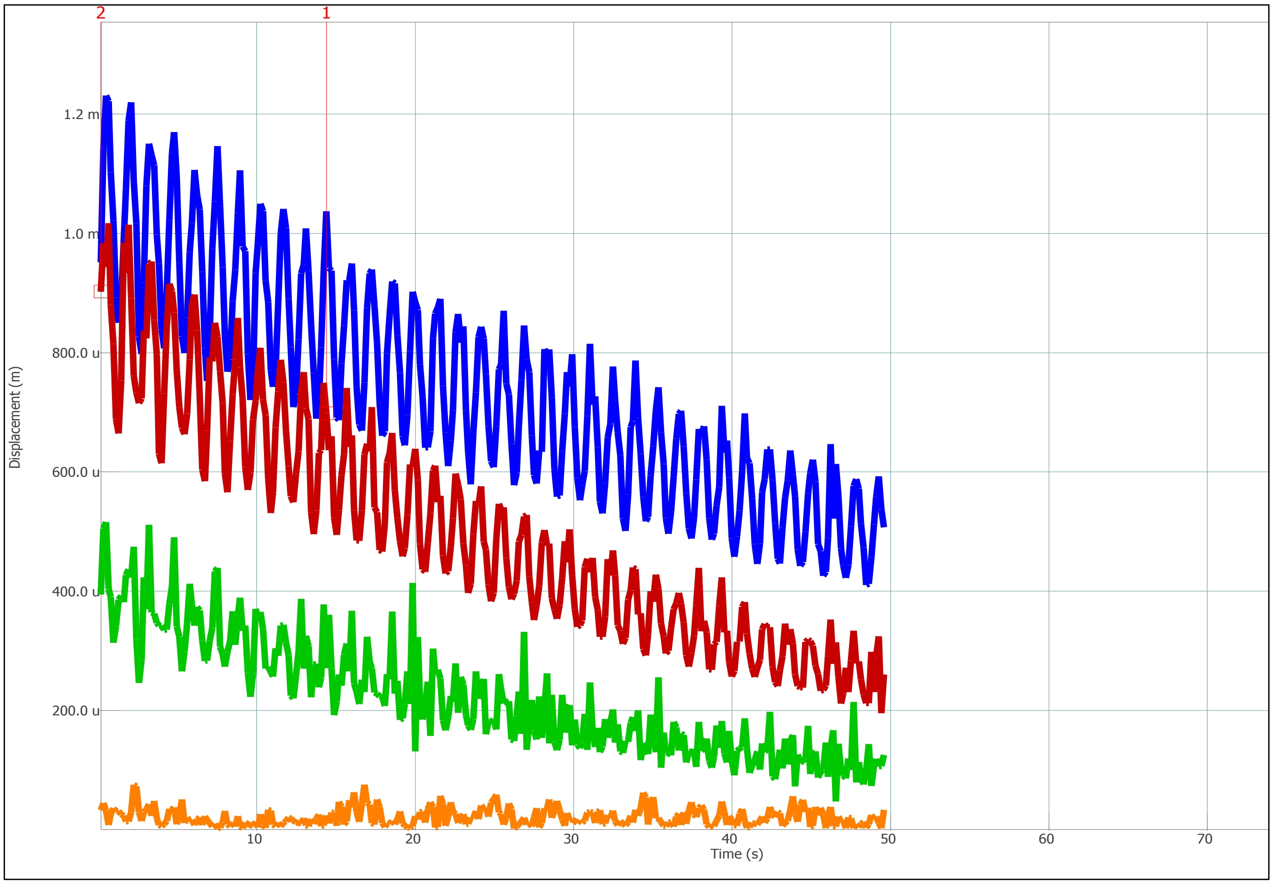



Figure- 9: Damped Free Vibration

RMS Displacement values of active trace (blue) have been recorded as:

| **Time** | **Displacement** | **Peak No.** | **Time** | **Displacement** | **Peak No.** | **Time** | **Displacement** | **Peak No.** |
|---|---|---|---|---|---|---|---|---|
| (sec) | (meter) | | (sec) | (meter) | | (sec) | (meter) | |
| 0.16 | 0.0009509 | | 1.12 | 0.0008918 | | 2.08 | 0.001219 | 2 |
| 0.32 | 0.001141 | | 1.28 | 0.0008493 | | 2.24 | 0.001087 | |
| 0.48 | 0.00123 | 1 | 1.44 | 0.0008841 | | 2.4 | 0.001016 | |
| 0.64 | 0.001221 | | 1.6 | 0.0009893 | | 2.56 | 0.000826 | |
| 0.8 | 0.001101 | | 1.76 | 0.001073 | | 2.72 | 0.0007972 | |
| 0.96 | 0.001021 | | 1.92 | 0.001188 | | 2.88 | 0.0009166 | |

| Time | Displacement | Peak No. | Time | Displacement | Peak No. | Time | Displacement | Peak No. |
|---|---|---|---|---|---|---|---|---|
| (sec) | (meter) | | (sec) | (meter) | | (sec) | (meter) | |
| 3.04 | 0.001079 | | 9.12 | 0.0009773 | | 15.2 | 0.0006859 | |
| 3.2 | 0.00115 | 3 | 9.28 | 0.0009692 | | 15.36 | 0.0007811 | |
| 3.36 | 0.00113 | | 9.44 | 0.0007972 | | 15.52 | 0.0008446 | |
| 3.52 | 0.001113 | | 9.6 | 0.0007202 | | 15.68 | 0.0009209 | |
| 3.68 | 0.0009976 | | 9.76 | 0.0007574 | | 15.84 | 0.0009205 | |
| 3.84 | 0.0009484 | | 9.92 | 0.000933 | | 16 | 0.000949 | 12 |
| 4 | 0.0008378 | | 10.08 | 0.0009824 | | 16.16 | 0.0008698 | |
| 4.16 | 0.0008065 | | 10.24 | 0.001049 | 8 | 16.32 | 0.0007412 | |
| 4.32 | 0.0009007 | | 10.4 | 0.001037 | | 16.48 | 0.0006788 | |
| 4.48 | 0.001022 | | 10.56 | 0.0009201 | | 16.64 | 0.0006687 | |
| 4.64 | 0.001133 | 4 | 10.72 | 0.0008836 | | 16.8 | 0.000749 | |
| 4.8 | 0.001169 | | 10.88 | 0.0007698 | | 16.96 | 0.0008743 | |
| 4.96 | 0.001094 | | 11.04 | 0.0007421 | | 17.12 | 0.0009319 | |
| 5.12 | 0.0009499 | | 11.2 | 0.00077 | | 17.28 | 0.000939 | 13 |
| 5.28 | 0.0008268 | | 11.36 | 0.0008817 | | 17.44 | 0.0008778 | |
| 5.44 | 0.0007984 | | 11.52 | 0.0009992 | | 17.6 | 0.0008162 | |
| 5.6 | 0.0008576 | | 11.68 | 0.00104 | 9 | 17.76 | 0.0007148 | |
| 5.76 | 0.0009678 | | 11.84 | 0.001008 | | 17.92 | 0.0006597 | |
| 5.92 | 0.001017 | | 12 | 0.0008895 | | 18.08 | 0.0006674 | |
| 6.08 | 0.001106 | 5 | 12.16 | 0.0008086 | | 18.24 | 0.000798 | |
| 6.24 | 0.001063 | | 12.32 | 0.0007079 | | 18.4 | 0.0008618 | |
| 6.4 | 0.001039 | | 12.48 | 0.0007303 | | 18.56 | 0.000919 | 14 |
| 6.56 | 0.0009347 | | 12.64 | 0.0008211 | | 18.72 | 0.0009153 | |
| 6.72 | 0.0008071 | | 12.8 | 0.0009318 | | 18.88 | 0.0008289 | |
| 6.88 | 0.0007522 | | 12.96 | 0.000947 | | 19.04 | 0.0007654 | |
| 7.04 | 0.0008304 | | 13.12 | 0.001007 | 10 | 19.2 | 0.0006591 | |
| 7.2 | 0.0009733 | | 13.28 | 0.000936 | | 19.36 | 0.0006439 | |
| 7.36 | 0.001053 | | 13.44 | 0.0008457 | | 19.52 | 0.0006944 | |
| 7.52 | 0.001146 | 6 | 13.6 | 0.0007655 | | 19.68 | 0.0008017 | |
| 7.68 | 0.001044 | | 13.76 | 0.0006885 | | 19.84 | 0.0009015 | 15 |
| 7.84 | 0.000942 | | 13.92 | 0.0007208 | | 20 | 0.0008843 | |
| 8 | 0.0008285 | | 14.08 | 0.0008082 | | 20.16 | 0.000871 | |
| 8.16 | 0.0007671 | | 14.24 | 0.000937 | | 20.32 | 0.0007795 | |
| 8.32 | 0.0007882 | | 14.4 | 0.001036 | 11 | 20.48 | 0.0007249 | |
| 8.48 | 0.0008859 | | 14.56 | 0.0009412 | | 20.64 | 0.0006402 | |
| 8.64 | 0.0009383 | | 14.72 | 0.0009365 | | 20.8 | 0.0006406 | |
| 8.8 | 0.001033 | | 14.88 | 0.0007889 | | 20.96 | 0.0006675 | |
| 8.96 | 0.001105 | 7 | 15.04 | 0.0006906 | | 21.12 | 0.0008234 | |

| Time | Displacement | Peak No. | Time | Displacement | Peak No. | Time | Displacement | Peak No. |
|---|---|---|---|---|---|---|---|---|
| (sec) | (meter) | | (sec) | (meter) | | (sec) | (meter) | |
| 21.28 | 0.0008648 | | 27.36 | 0.0006604 | | 33.44 | 0.0005611 | |
| 21.44 | 0.000875 | | 27.52 | 0.0005942 | | 33.6 | 0.0006749 | |
| 21.6 | 0.0008897 | 16 | 27.68 | 0.0005799 | | 33.76 | 0.0006846 | |
| 21.76 | 0.0007434 | | 27.84 | 0.000635 | | 33.92 | 0.0007857 | 25 |
| 21.92 | 0.0006654 | | 28 | 0.0006335 | | 34.08 | 0.0006902 | |
| 22.08 | 0.0006096 | | 28.16 | 0.000805 | 21 | 34.24 | 0.000629 | |
| 22.24 | 0.0006519 | | 28.32 | 0.0007959 | | 34.4 | 0.000557 | |
| 22.4 | 0.0007027 | | 28.48 | 0.0008044 | | 34.56 | 0.0005164 | |
| 22.56 | 0.0008336 | | 28.64 | 0.0007238 | | 34.72 | 0.000524 | |
| 22.72 | 0.0008639 | 17 | 28.8 | 0.0006049 | | 34.88 | 0.0005936 | |
| 22.88 | 0.0008158 | | 28.96 | 0.0005579 | | 35.04 | 0.0006417 | |
| 23.04 | 0.0008436 | | 29.12 | 0.0005601 | | 35.2 | 0.000703 | |
| 23.2 | 0.0007025 | | 29.28 | 0.0006345 | | 35.36 | 0.0007412 | 26 |
| 23.36 | 0.0006335 | | 29.44 | 0.0006975 | | 35.52 | 0.0006651 | |
| 23.52 | 0.0005785 | | 29.6 | 0.0007664 | | 35.68 | 0.0006128 | |
| 23.68 | 0.0006663 | | 29.76 | 0.0007425 | | 35.84 | 0.0005219 | |
| 23.84 | 0.0007324 | | 29.92 | 0.0007968 | 22 | 36 | 0.0004959 | |
| 24 | 0.0008255 | | 30.08 | 0.0006745 | | 36.16 | 0.0005328 | |
| 24.16 | 0.0008427 | 18 | 30.24 | 0.0005894 | | 36.32 | 0.0005913 | |
| 24.32 | 0.0008229 | | 30.4 | 0.0005519 | | 36.48 | 0.000655 | |
| 24.48 | 0.0007634 | | 30.56 | 0.0005764 | | 36.64 | 0.0006965 | |
| 24.64 | 0.0006766 | | 30.72 | 0.0006012 | | 36.8 | 0.0007019 | 27 |
| 24.8 | 0.0006173 | | 30.88 | 0.0006936 | | 36.96 | 0.0006417 | |
| 24.96 | 0.0006072 | | 31.04 | 0.0008143 | 23 | 37.12 | 0.0005641 | |
| 25.12 | 0.0006766 | | 31.2 | 0.0007121 | | 37.28 | 0.0005044 | |
| 25.28 | 0.0007715 | | 31.36 | 0.000726 | | 37.44 | 0.0004879 | |
| 25.44 | 0.0007799 | | 31.52 | 0.0006412 | | 37.6 | 0.0005228 | |
| 25.6 | 0.0008691 | 19 | 31.68 | 0.0005491 | | 37.76 | 0.0005866 | |
| 25.76 | 0.0007473 | | 31.84 | 0.0005296 | | 37.92 | 0.0006716 | |
| 25.92 | 0.0007295 | | 32 | 0.0005805 | | 38.08 | 0.000662 | |
| 26.08 | 0.0006461 | | 32.16 | 0.0006573 | | 38.24 | 0.0006757 | 28 |
| 26.24 | 0.0005774 | | 32.32 | 0.00068 | | 38.4 | 0.0006199 | |
| 26.4 | 0.0005978 | | 32.48 | 0.0007759 | 24 | 38.56 | 0.0005222 | |
| 26.56 | 0.0006757 | | 32.64 | 0.0007197 | | 38.72 | 0.0004861 | |
| 26.72 | 0.000753 | | 32.8 | 0.0006656 | | 38.88 | 0.000496 | |
| 26.88 | 0.0008446 | 20 | 32.96 | 0.000627 | | 39.04 | 0.0005433 | |
| 27.04 | 0.0007878 | | 33.12 | 0.000521 | | 39.2 | 0.0005741 | |
| 27.2 | 0.0007668 | | 33.28 | 0.0005003 | | 39.36 | 0.0007102 | 29 |

| Time | Displacement | Peak No. | Time | Displacement | Peak No. | Time | Displacement | Peak No. |
|---|---|---|---|---|---|---|---|---|
| (sec) | (meter) | | (sec) | (meter) | | (sec) | (meter) | |
| 39.52 | 0.0006319 | | 42.88 | 0.0004536 | | 46.24 | 0.0006461 | |
| 39.68 | 0.0006517 | | 43.04 | 0.0004457 | | 46.4 | 0.0005214 | |
| 39.84 | 0.0005898 | | 43.2 | 0.0005061 | | 46.56 | 0.0006124 | 34 |
| 40 | 0.0004879 | | 43.36 | 0.0005562 | | 46.72 | 0.0005587 | |
| 40.16 | 0.0004575 | | 43.52 | 0.0005845 | | 46.88 | 0.000471 | |
| 40.32 | 0.0004915 | | 43.68 | 0.0006355 | 32 | 47.04 | 0.0004435 | |
| 40.48 | 0.0005345 | | 43.84 | 0.000594 | | 47.2 | 0.000422 | |
| 40.64 | 0.0006013 | | 44 | 0.0005585 | | 47.36 | 0.0004432 | |
| 40.8 | 0.0006974 | 30 | 44.16 | 0.0004693 | | 47.52 | 0.0005076 | |
| 40.96 | 0.0006229 | | 44.32 | 0.0004416 | | 47.68 | 0.000576 | |
| 41.12 | 0.000614 | | 44.48 | 0.0004486 | | 47.84 | 0.0005871 | 35 |
| 41.28 | 0.0005548 | | 44.64 | 0.0004993 | | 48 | 0.0005716 | |
| 41.44 | 0.0004783 | | 44.8 | 0.0005629 | | 48.16 | 0.0005127 | |
| 41.6 | 0.0004455 | | 44.96 | 0.0005972 | | 48.32 | 0.0004725 | |
| 41.76 | 0.0004795 | | 45.12 | 0.0006203 | 33 | 48.48 | 0.00041 | |
| 41.92 | 0.0005654 | | 45.28 | 0.0005829 | | 48.64 | 0.0004122 | |
| 42.08 | 0.0005879 | | 45.44 | 0.0004786 | | 48.8 | 0.000456 | |
| 42.24 | 0.000637 | | 45.6 | 0.0004664 | | 48.96 | 0.0005115 | |
| 42.4 | 0.0006376 | 31 | 45.76 | 0.0004252 | | 49.12 | 0.000557 | |
| 42.56 | 0.0005856 | | 45.92 | 0.000432 | | 49.28 | 0.0005916 | 36 |
| 42.72 | 0.0005139 | | 46.08 | 0.0004889 | | | | |

As we know that, Damping Ratio $\xi = \frac{\delta}{2\pi} \times 100\%$

Where, δ = logarithmic decrement

And, $\delta = ln\left(\frac{y_n}{y_{n+1}}\right)$

Where, $y_n$ and $y_{n+1}$ are two consecutive peak values of displacement vs. time graph of free vibration.

Corresponding to 36 peak values, we will get 35 values of damping ratio. Averaging them by leaving first and last values, as they may have some error then we will get final value of damping ratio as,

ξ = 0.352 %

# CHAPTER-5: THEORETICAL STUDY

## 5.1. MATHEMATICAL CALCULATIONS

Since all the columns at each storey have same dimensions, hence stiffness will be same for all floors. Hence assuming, $k_1 = k_2 = k_3 = k$

Then by solving equation (4), we will get

$$-m_1m_2m_3(w^2)^3 + k(m_1m_2 + 2m_2m_3 + 2m_3m_1)(w^2)^2 - k^2(m_1 + 2m_2 + 3m_3)w^2 + k^3 = 0$$

---------- (5)

This is a cubic equation in the form of: $a\,x^3 + b\,x^2 + c\,x + d = 0$

Where, $w^2$is the variable and,

$$a = -m_1m_2m_3$$
$$b = k(m_1m_2 + 2m_2m_3 + 2m_3m_1)$$
$$c = -k^2(m_1 + 2m_2 + 3m_3)$$
$$d = k^3$$

Dimension Parameters:

Plate length (x-direction) = 300 mm

Plate width (y-direction) = 150 mm

Plate thickness (z-direction) = 12.44 mm

Column thickness (x-direction) = 2.92 mm

Column width (y-direction) = 24.95 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 = 24.95 mm and d = 2.92 mm)

Stiffness of each column, $k_c = \frac{12EI}{l^3}$ (Here, $l$ = 400 mm)

Modulus of Elasticity of aluminium, $E = 0.69\times10^5\ N/mm^2$

Thus, stiffness of each storey,

$$k = 4k_c = 4\times\frac{12\times(0.69\times10^5)\times\frac{24.95\times2.92^3}{12}}{400^3}$$

$$= 2.67885\ N/mm \quad \text{(or, 2678.85 N/m)}$$

<u>Weight Parameters:</u>

Mass of each slab = 1.54 kg

Mass of column 1 of all three storey = 0.2338 kg

Mass of column 2 of all three storey = 0.2341 kg

Mass of column 3 of all three storey = 0.2335 kg

Mass of column 4 of all three storey = 0.2322 kg

Hence, mass of all columns at each storey level = $\frac{0.2338+0.2341+0.2335+0.2322}{3}$

= 0.3112 kg

Case-1: without additional load on floor levels.

$$m_1 = 1.54 + 0.3112 = 1.8512\ kg$$

$$m_2 = 1.54 + 0.3112 = 1.8512\ kg$$

$$m_3 = 1.54 + \frac{0.3112}{2} = 1.6956\ kg$$

And, $k = 2678.85$ N/m

On substituting these values in equation (5), we will get,

$w_1{}^2 = 300.25\ (rad/s)^2$ Hence, $f_1 = 2.7578\ Hz$ $\left(As,\ f = \frac{w}{2\pi}\right)$

$w_2{}^2 = 2321.39\ (rad/s)^2$ $f_2 = 7.6683\ Hz$

$w_3{}^2 = 4746.58\ (rad/s)^2$ $f_3 = 10.9651\ Hz$

Case-2: with additional load on floor levels.

Additional load on slab of F1= 1.0 kg

Additional load on slab of F2= 0.6 kg

Additional load on slab of F3= 0.2 kg

Then,

$$m_1 = 1.54 + 0.3112 + 1.0 = 2.8512\ kg$$

$$m_2 = 1.54 + 0.3112 + 0.6 = 2.4512\ kg$$

$$m_3 = 1.54 + \frac{0.3112}{2} + 0.2 = 1.8956\ kg$$

And, $k = 2678.85$ N/m

On substituting these values in equation (5), we will get,

$w_1{}^2 = 241.14\ (rad/s)^2$ Hence, $f_1 = 2.471\ Hz$ $\left(As,\ f = \frac{w}{2\pi}\right)$

$w_2{}^2 = 1702.64\ (rad/s)^2$ $f_2 = 6.567\ Hz$

$w_3{}^2 = 3534.26\ (rad/s)^2$ $f_3 = 9.462\ Hz$

## 5.2. MODAL CALCULATION BY EXCEL PROGRAMMING

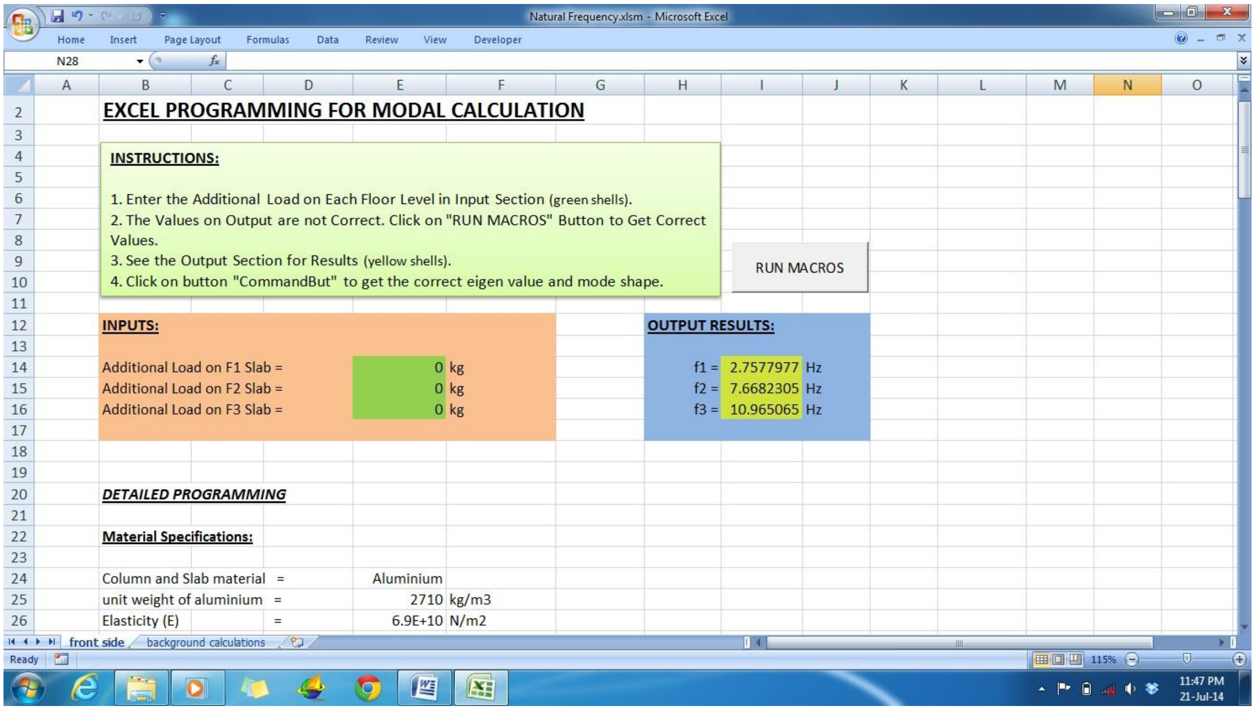



Figure- 10(a)

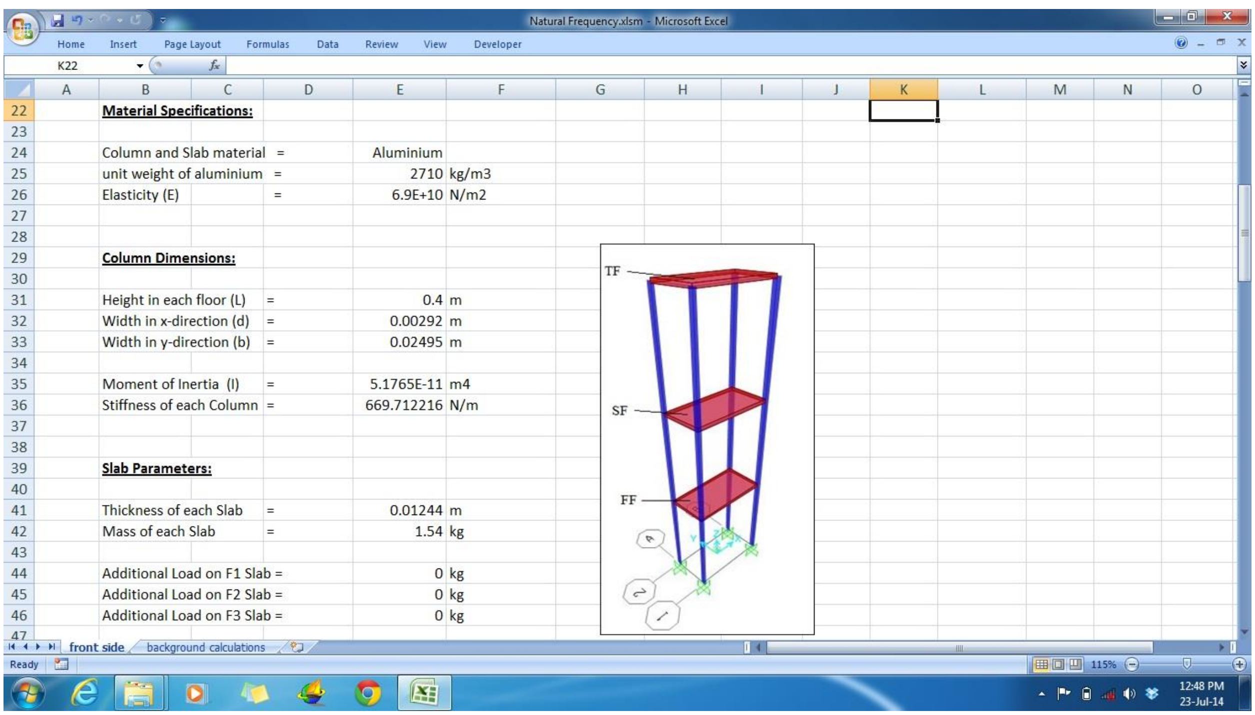



Figure- 10(b)

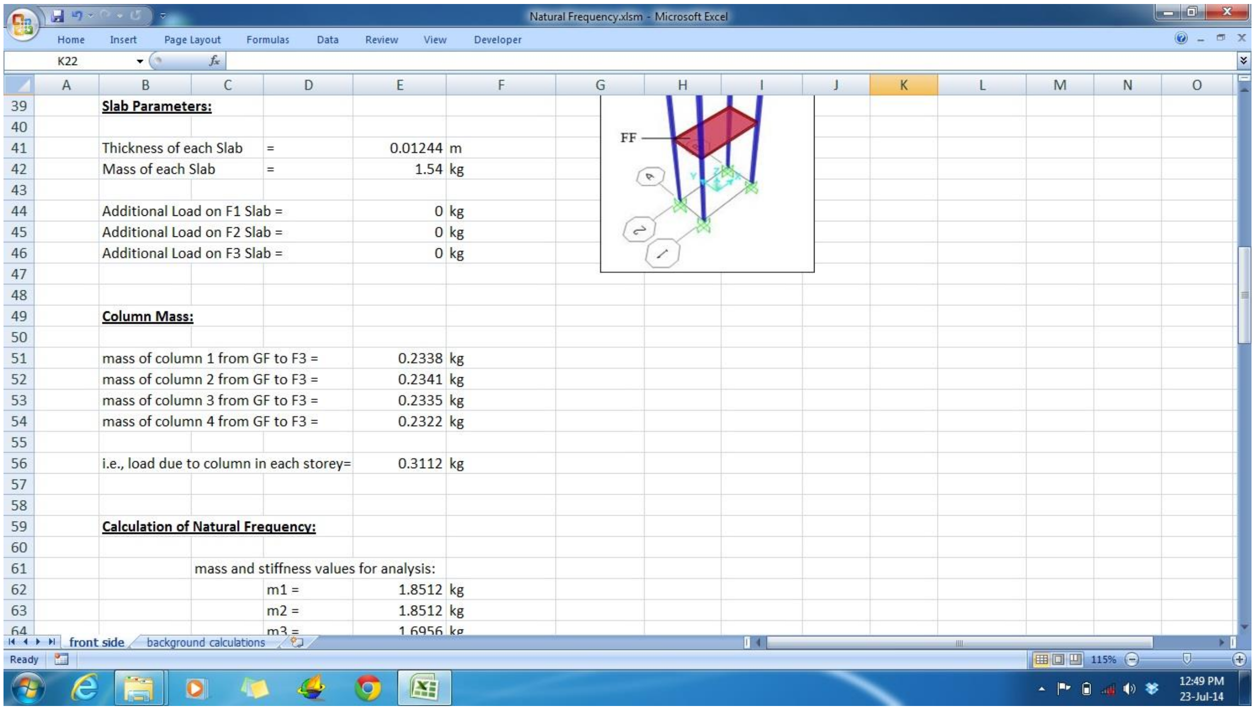



Figure- 10(c)

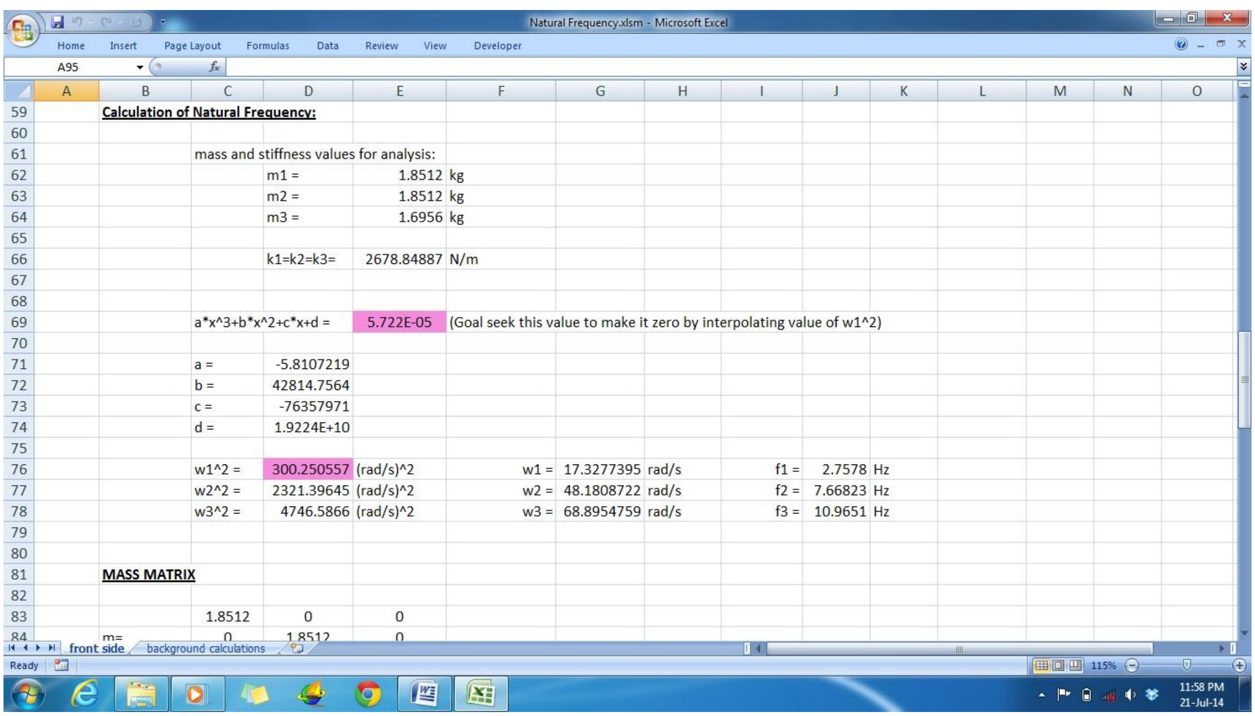



Figure- 10(d)

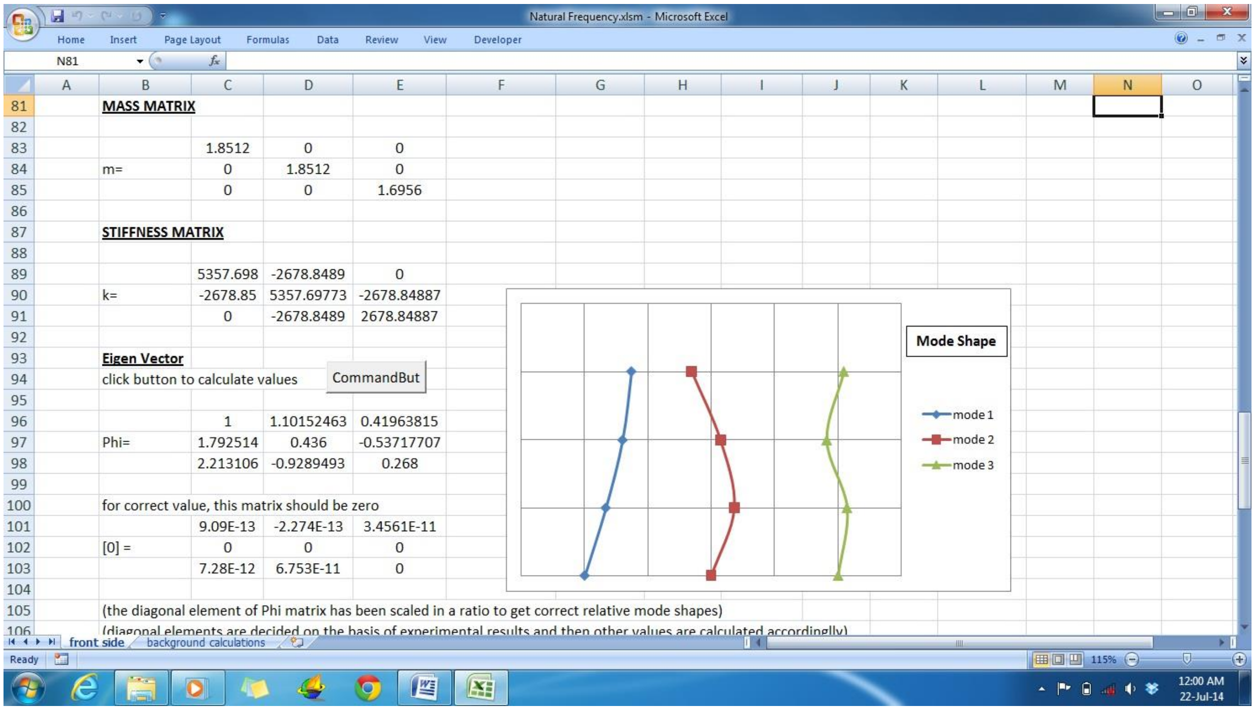



Figure- 10(e)

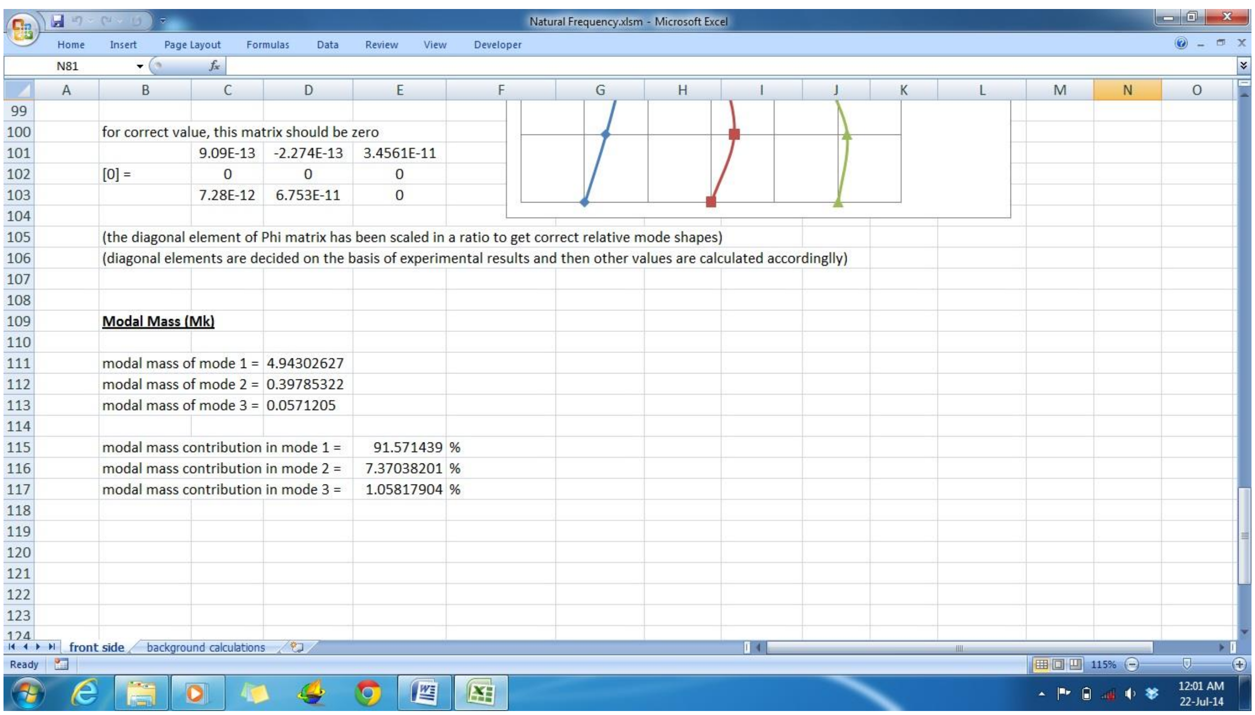



Figure- 10(f)

Figure- 10: Excel Programming for Modal Calculation

## 5.3. DIMENSIONAL ANALYSIS

The experimental model was modelled in SAP2000 and the various observations getting from experiments were matched. Then the model was changed by some scale by changing some parameters. Then the variations in those results were observed to get the trend of variation by doing regression analysis. The following parameters were changed:

1) Size of elements in three dimensions.
2) Only unit weight of material.
3) Only elasticity of material.

### 5.3.1. Changing Size of Elements in Three Dimensions

Various parameters were noted down from SAP2000 results to analyse the trend of variations. They are as follows:

A) Base Shear in X- direction (N)

| **Magnification Ratio** | **0.5** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|---|
| mode 1 | -30.11 | -21.29 | -15.06 | -12.29 | -10.65 | -9.52 | -8.69 | -8.05 |
| mode 2 | -66.31 | -46.89 | -33.15 | -27.07 | -23.44 | -20.97 | -19.14 | -17.72 |
| mode 3 | 51.55 | 36.45 | 25.78 | 21.05 | 18.23 | 16.3 | 14.88 | 13.78 |

B) Base Moment in Y-direction (N-mm)

| **Magnification Ratio** | **0.5** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|---|
| mode 1 | -13328 | -18849 | -26656 | -32647 | -37697 | -42147 | -46169 | -49869 |
| mode 2 | 11094 | 15689 | 22188 | 27174 | 31378 | 35082 | 38430 | 41509 |
| mode 3 | 6596 | 9327 | 13191 | 16156 | 18655 | 20857 | 22848 | 24678 |

C) Modal Period (sec)

| **Magnification Ratio** | **0.5** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|---|
| mode 1 | 0.1801 | 0.3602 | 0.7204 | 1.0806 | 1.4408 | 1.8010 | 2.1612 | 2.5213 |
| mode 2 | 0.0647 | 0.1294 | 0.2589 | 0.3884 | 0.5178 | 0.6473 | 0.7767 | 0.9062 |
| mode 3 | 0.0452 | 0.0904 | 0.1809 | 0.2713 | 0.3618 | 0.4522 | 0.5427 | 0.6331 |

D) Modal Frequency (Hz)

| Magnification Ratio | 0.5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| mode 1 | 5.5525 | 2.7763 | 1.3881 | 0.92542 | 0.69407 | 0.55525 | 0.46271 | 0.39661 |
| mode 2 | 15.449 | 7.7247 | 3.8624 | 2.5749 | 1.9312 | 1.5449 | 1.2875 | 1.1035 |
| mode 3 | 22.113 | 11.057 | 5.5283 | 3.6855 | 2.7641 | 2.2113 | 1.8428 | 1.5795 |

E) Joint Displacements (mm)

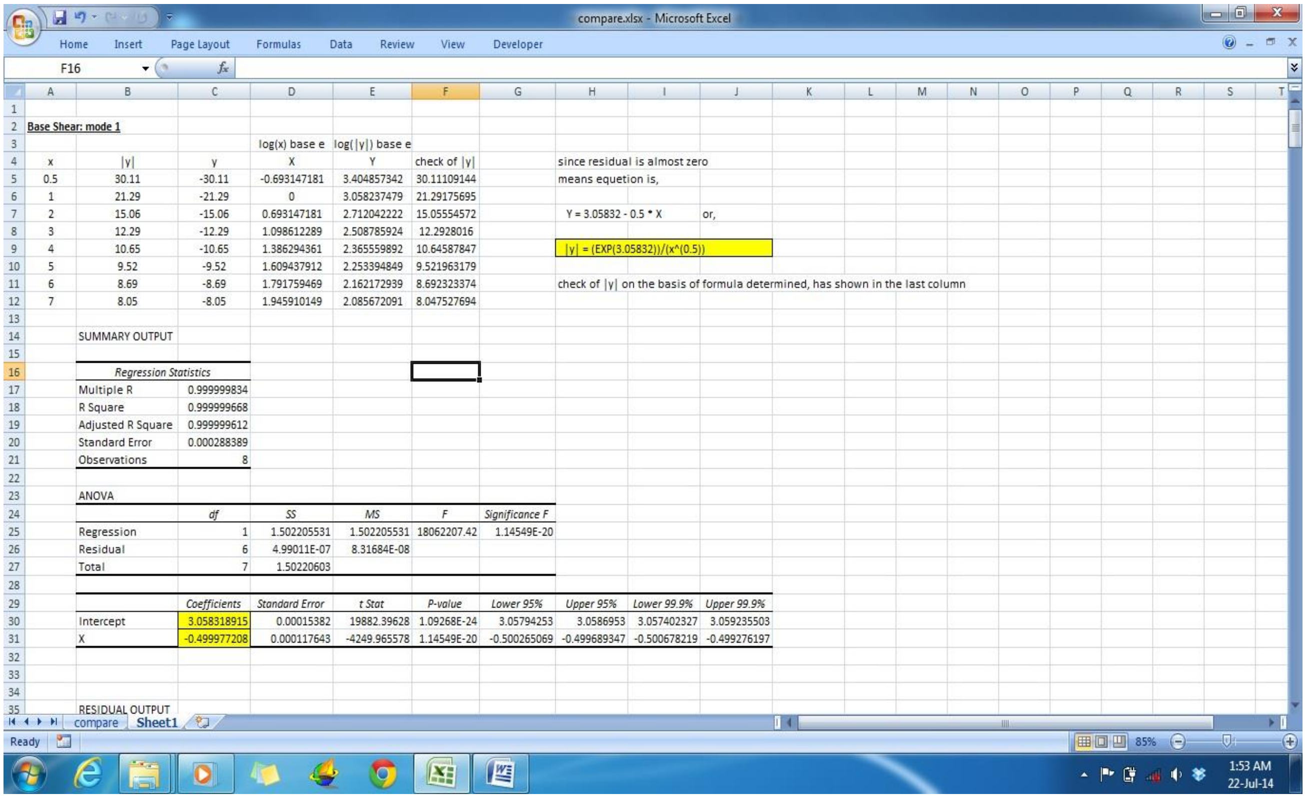
| | Magnification Ratio | 0.5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| GF | mode 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FF | mode 1 | 22.351 | 7.902 | 2.794 | 1.521 | 0.988 | 0.706 | 0.537 | 0.426 |
| SF | mode 1 | 40.138 | 14.191 | 5.017 | 2.731 | 1.774 | 1.269 | 0.965 | 0.766 |
| TF | mode 1 | 49.584 | 17.530 | 6.198 | 3.373 | 2.191 | 1.567 | 1.192 | 0.946 |
| GF | mode 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FF | mode 2 | 49.080 | 17.352 | 6.135 | 3.339 | 2.169 | 1.552 | 1.180 | 0.937 |
| SF | mode 2 | 19.458 | 6.879 | 2.432 | 1.324 | 0.860 | 0.615 | 0.468 | 0.371 |
| TF | mode 2 | -41.447 | -14.653 | -5.181 | -2.820 | -1.832 | -1.310 | -0.997 | -0.791 |
| GF | mode 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FF | mode 3 | -38.064 | -13.457 | -4.758 | -2.59 | -1.682 | -1.203 | -0.915 | -0.726 |
| SF | mode 3 | 48.658 | 17.203 | 6.082 | 3.311 | 2.150 | 1.538 | 1.170 | 0.928 |
| TF | mode 3 | -24.326 | -8.600 | -3.041 | -1.655 | -1.075 | -0.769 | -0.585 | -0.464 |

F) Modal Participation Mass Ratio

| Magnification Ratio | 0.5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| mode 1 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 |
| mode 2 | 0.07405 | 0.07405 | 0.07405 | 0.07405 | 0.07405 | 0.07405 | 0.07405 | 0.07405 |
| mode 3 | 0.01066 | 0.01066 | 0.01066 | 0.01066 | 0.01066 | 0.01066 | 0.01066 | 0.01066 |

G) Total Weight (N)

| Magnification Ratio | 0.5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Total Weight | 6.75 | 53.98 | 431.82 | 1457.4 | 3454.58 | 6747.22 | 11659.19 | 18514.36 |



compare.xlsx - Microsoft Excel

**Base Shear: mode 1**

| x | \|y\| | y | log(x) base e X | log(\|y\|) base e Y | check of \|y\| |
|---|---|---|---|---|---|
| 0.5 | 30.11 | -30.11 | -0.693147181 | 3.404857342 | 30.11109144 |
| 1 | 21.29 | -21.29 | 0 | 3.058237479 | 21.29175695 |
| 2 | 15.06 | -15.06 | 0.693147181 | 2.712042222 | 15.05554572 |
| 3 | 12.29 | -12.29 | 1.098612289 | 2.508785924 | 12.2928016 |
| 4 | 10.65 | -10.65 | 1.386294361 | 2.365559892 | 10.64587847 |
| 5 | 9.52 | -9.52 | 1.609437912 | 2.253394849 | 9.521963179 |
| 6 | 8.69 | -8.69 | 1.791759469 | 2.162172939 | 8.692323374 |
| 7 | 8.05 | -8.05 | 1.945910149 | 2.085672091 | 8.047527694 |

since residual is almost zero
means equetion is,

Y = 3.05832 - 0.5 * X    or,

|y| = (EXP(3.05832))/(x^(0.5))

check of |y| on the basis of formula determined, has shown in the last column

SUMMARY OUTPUT

| Regression Statistics | |
|---|---|
| Multiple R | 0.999999834 |
| R Square | 0.999999668 |
| Adjusted R Square | 0.999999612 |
| Standard Error | 0.000288389 |
| Observations | 8 |

ANOVA

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 1 | 1.502205531 | 1.502205531 | 18062207.42 | 1.14549E-20 |
| Residual | 6 | 4.99011E-07 | 8.31684E-08 | | |
| Total | 7 | 1.50220603 | | | |

| | Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 99.9% | Upper 99.9% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 3.058318915 | 0.00015382 | 19882.39628 | 1.09268E-24 | 3.05794253 | 3.0586953 | 3.057402327 | 3.059235503 |
| X | -0.499977208 | 0.000117643 | -4249.965578 | 1.14549E-20 | -0.500265069 | -0.499689347 | -0.500678219 | -0.499276197 |

RESIDUAL OUTPUT

Figure- 11: Regression Analysis and Check of First Set

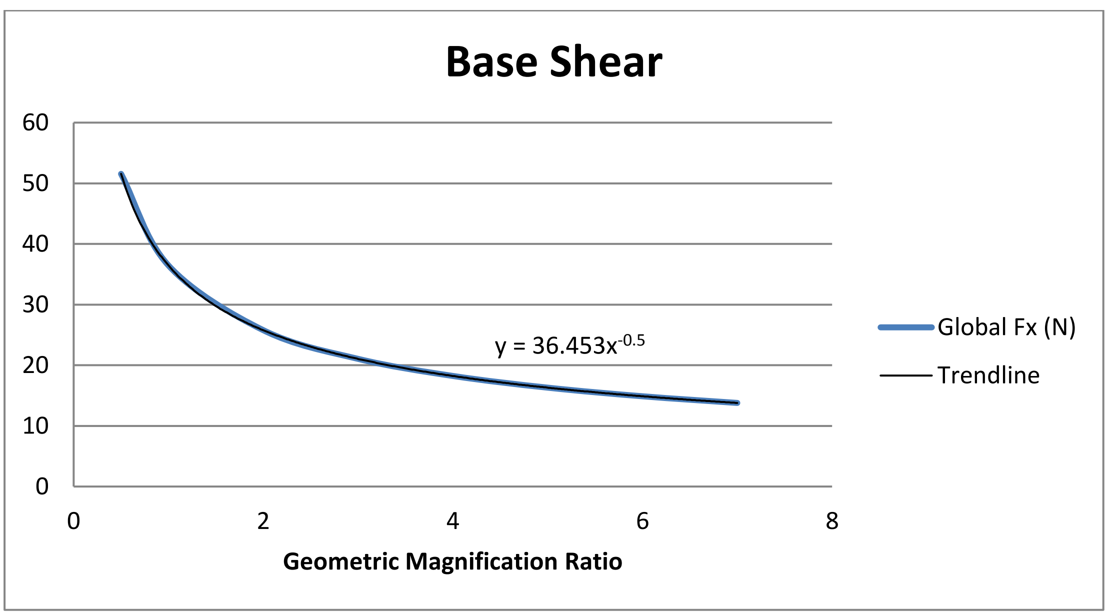



Figure- 12: Magnification Ratio vs. Base Shear Graph

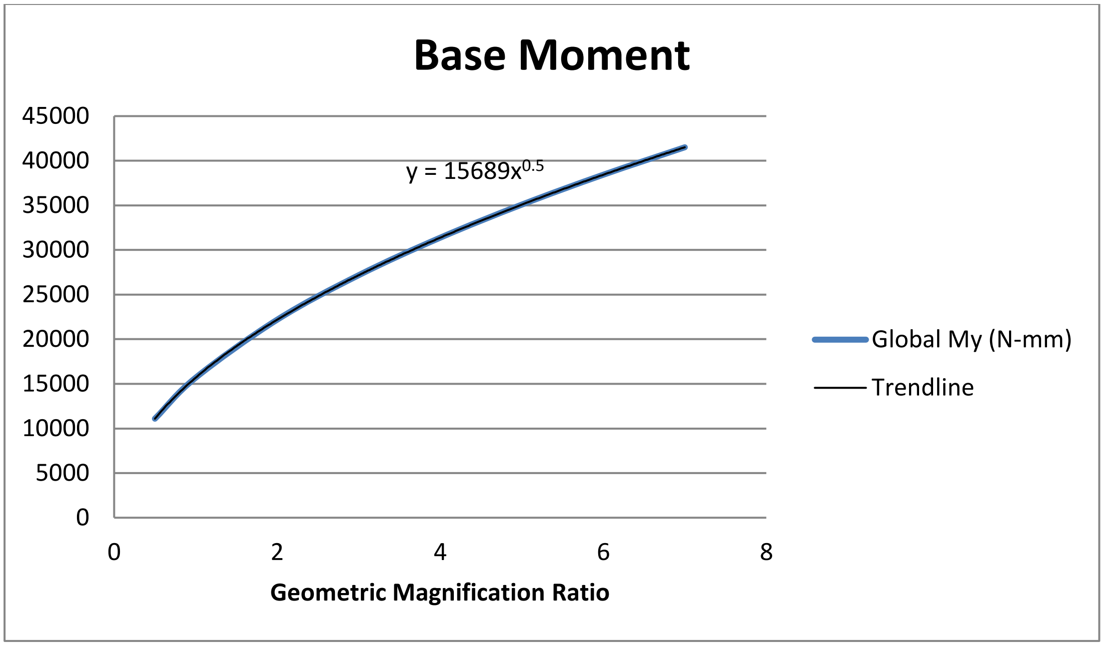



Figure- 13: Magnification Ratio vs. Base Moment Graph

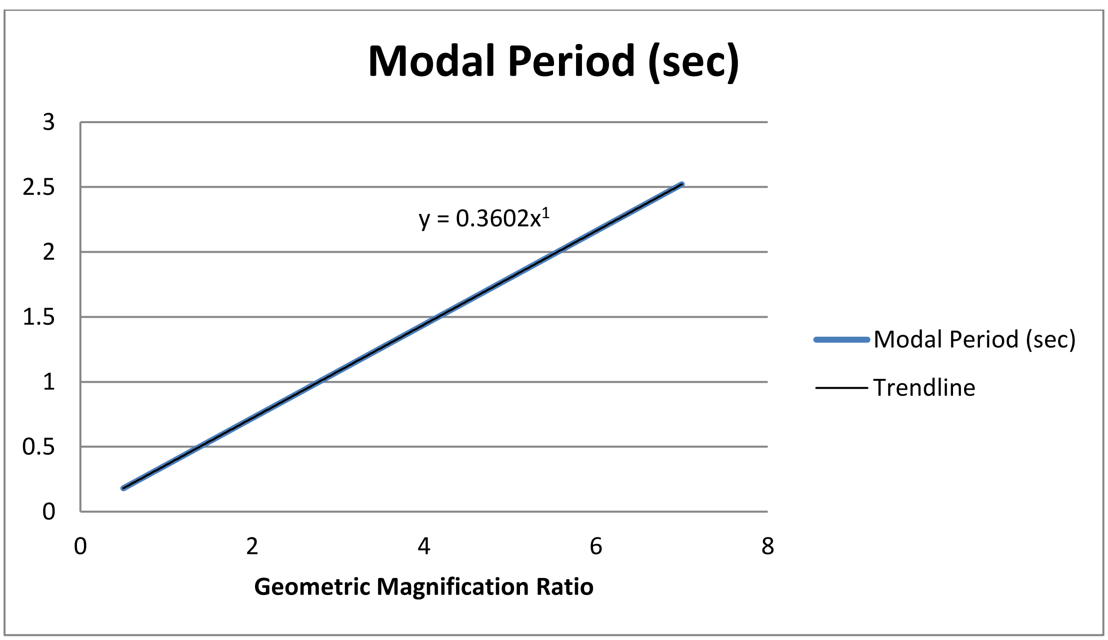



Figure- 14: Magnification Ratio vs. Modal Period Graph

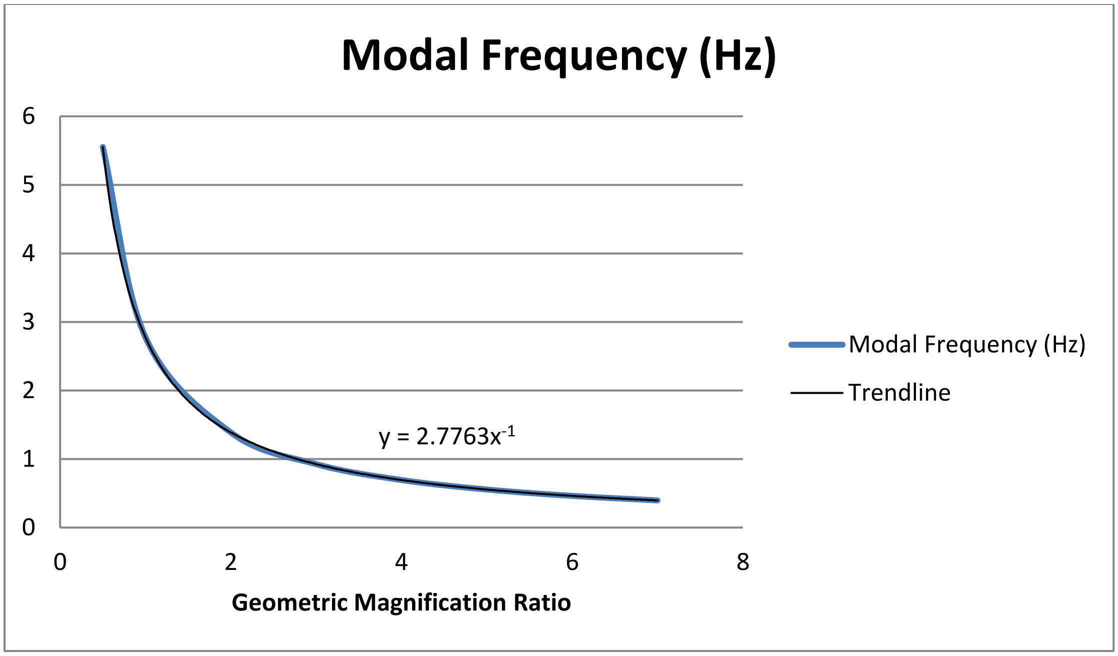



Figure- 15: Magnification Ratio vs. Modal Frequency Graph

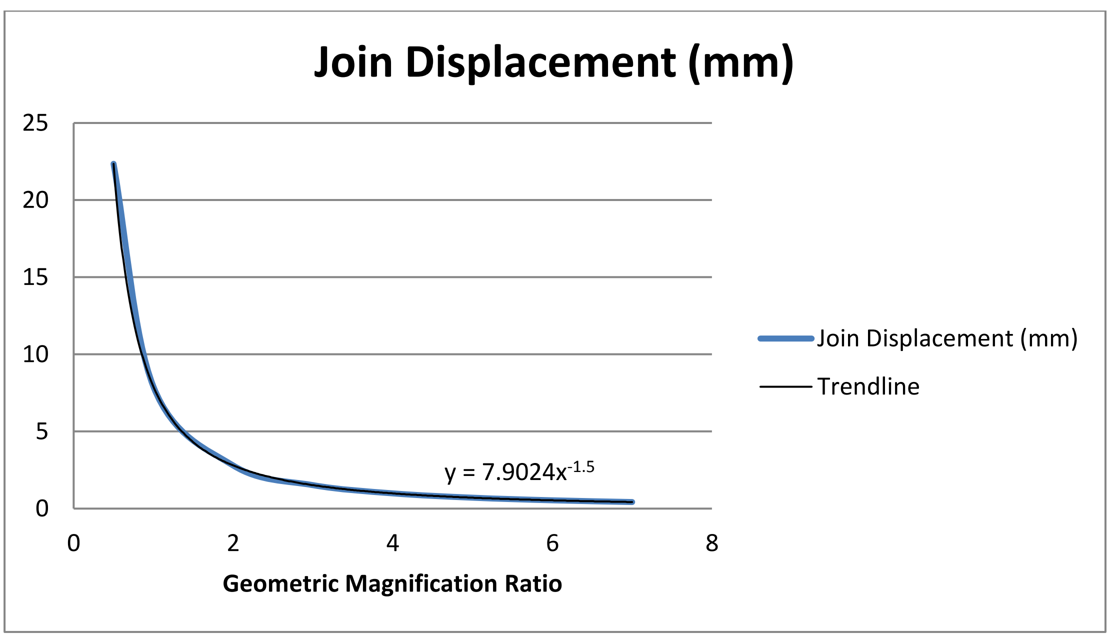



Figure- 16: Magnification Ratio vs. Joint Displacement Graph

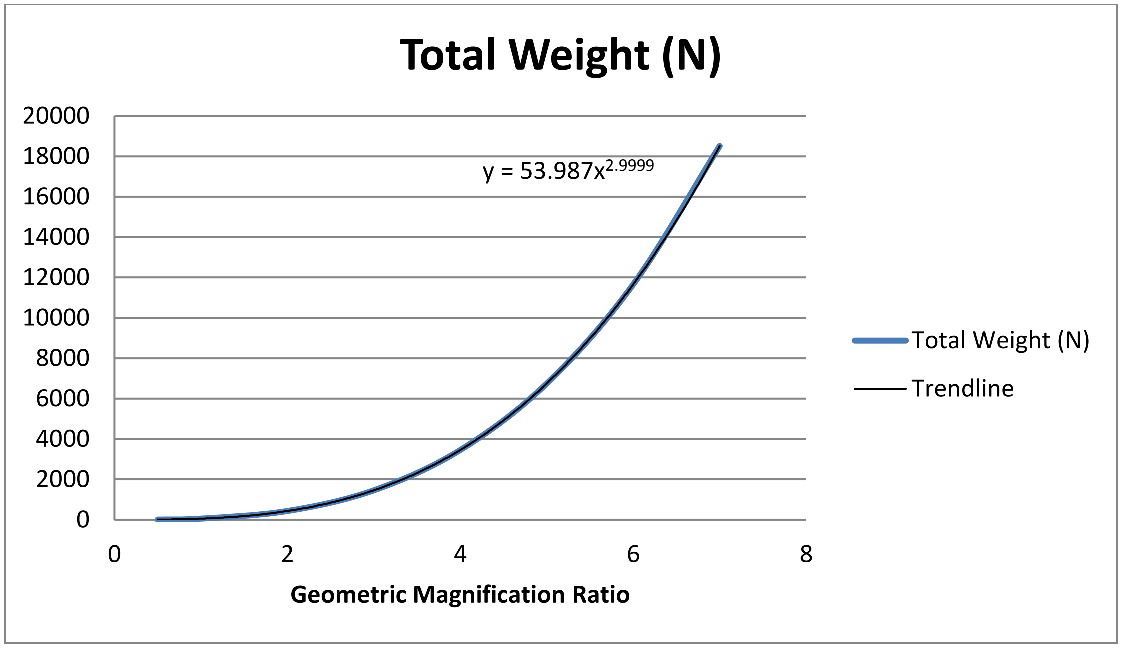



Figure- 17: Magnification Ratio vs. Total Weight Graph

By looking all these trend lines and regression analysis results, it can be concluded that if only dimension is varied and rest all parameters are kept same than by this effect following relationship will come out:

Say, if modification factor is being represented by "*x*" then ,

Base Shear $\propto \frac{1}{\sqrt{x}}$

Base Moment $\propto \sqrt{x}$

Modal Period$\propto x$

Modal Frequency $\propto \frac{1}{x}$

Joint Displacement $\propto \frac{1}{x\sqrt{x}}$

Total Weight $\propto x^3$

Here mass of structure is also being changed by changing geometric dimensions, which is resulting in change in total weight of structure by cubically to the magnification factor. It means if the material is kept same or unit weight of material of structure is unchanged then the mass of various structural element is changing by cube of magnification factor. In this modelling no external force is applied. Only the self weight of structural element is the mass source for modal analysis. Hence if we want to get relationship for loaded structure also then all these relations will be valid, but we will have to change the external load, mass or weight by cube of change in magnification factor, having unit of force. If it is distributed load then the power will be changed accordingly. For linearly distributed load change it by square of magnification factor, and for areal distributed load change will be directly proportional to the magnification factor.

### 5.3.2. Changing Only Unit Weight of Material

It has been seen that by changing dimensions, weight is also changing. Thus, in previous case all the relationships derived have effect of both, change in size and mass also. Hence to understand both kinds of variations individually, we will now change the unit weight of the structural element only so that mass can be changed by keeping the dimension unchanged.

A) Base Shear, Base Moment and Total Weight

| Base Shear (N) | | | |
|---|---|---|---|
| **Magnification By** | **Mode - 1** | **Mode - 2** | **Mode - 3** |
| 1 | -21.29 | -46.89 | 36.45 |
| 3 | -12.3 | -27.08 | 21.05 |
| Base Moment (N-mm) | | | |
| **Magnification By** | **Mode - 1** | **Mode - 2** | **Mode - 3** |
| 1 | -18848.6 | 15689.03 | 9327.56 |
| 3 | -10886.3 | 9061.45 | 5387.28 |
| Total Weight(N) | | | |
| **Magnification By 1** | | **Magnification By 3** | |
| 53.98 | | 161.92 | |

B) Modal Period, Modal Frequency and Modal Participation Mass Ratio

| Modal Period (sec) | | | |
|---|---|---|---|
| **Magnification By** | **Mode-1** | **Mode-2** | **Mode-3** |
| 1 | 0.360196 | 0.129455 | 0.090444 |
| 3 | 0.623644 | 0.224138 | 0.156596 |
| Modal Frequency (Hz) | | | |
| **Magnification By** | **Mode-1** | **Mode-2** | **Mode-3** |
| 1 | 2.7763 | 7.7247 | 11.057 |
| 3 | 1.6035 | 4.4615 | 6.3859 |
| Modal Participation Mass Ratio | | | |
| **Magnification By** | **Mode-1** | **Mode-2** | **Mode-3** |
| 1 | 0.92 | 0.07405 | 0.01066 |
| 3 | 0.92 | 0.07405 | 0.01066 |

C) Joint Displacements (mm)

| **Magnification** | **Mode** | **GF** | **FF** | **SF** | **TF** |
|---|---|---|---|---|---|
| 1 | 1 | 0 | 7.90244 | 14.19093 | 17.53055 |
| | 2 | 0 | 17.35249 | 6.879535 | -14.6539 |
| | 3 | 0 | -13.4578 | 17.20345 | -8.60077 |
| 3 | 1 | 0 | 4.56418 | 8.196195 | 10.12505 |
| | 2 | 0 | 10.02221 | 3.973385 | -8.46358 |
| | 3 | 0 | -7.77275 | 9.936125 | -4.96751 |

If magnification factor is being represented by "$x$" then following relations can be derived from observing above table:

Base Shear $\propto \frac{1}{\sqrt{x}}$

Base Moment $\propto \frac{1}{\sqrt{x}}$

Total Weight $\propto x$

Modal Period $\propto \sqrt{x}$

Modal Frequency $\propto \frac{1}{\sqrt{x}}$

Joint Displacement $\propto \frac{1}{\sqrt{x}}$

### 5.3.3. Changing Only Elasticity (E) of Material

When real structure is to be modelled, then it is not necessary to provide the same material. Thus it is also needed to take care of that parameter so that we can use different material for model can be used as per convenience. Hence a trial is made by changing elasticity of material also.

A) Base Reactions

| Base Shear (N) | | | |
|---|---|---|---|
| **Magnification By** | **Mode - 1** | **Mode - 2** | **Mode - 3** |
| 1 | -21.29 | -46.89 | 36.45 |
| 3 | -63.88 | -140.66 | 109.36 |
| Base Moment (N-mm) | | | |
| **Magnification By** | **Mode - 1** | **Mode - 2** | **Mode - 3** |
| 1 | -18848.6 | 15689.03 | 9327.56 |
| 3 | -56545.8 | 47067.09 | 27982.68 |

B) Modal Period, Modal Frequency and Modal Participation Mass Ratio

| Modal Period (sec) | | | |
|---|---|---|---|
| **Magnification By** | **Mode-1** | **Mode-2** | **Mode-3** |
| 1 | 0.360196 | 0.129455 | 0.090444 |
| 3 | 0.207959 | 0.074741 | 0.052218 |
| Modal Frequency (Hz) | | | |
| **Magnification By** | **Mode-1** | **Mode-2** | **Mode-3** |
| 1 | 2.7763 | 7.7247 | 11.057 |
| 3 | 4.8086 | 13.38 | 19.15 |
| Modal Participation Mass Ratio | | | |
| **Magnification By** | **Mode-1** | **Mode-2** | **Mode-3** |
| 1 | 0.92 | 0.07405 | 0.01066 |
| 3 | 0.92 | 0.07405 | 0.01066 |

C) Joint Displacements and Total Weight

| Joint Displacements (mm) | | | | | |
|---|---|---|---|---|---|
| **Magnification** | **Mode** | **GF** | **FF** | **SF** | **TF** |
| 1 Times | 1 | 0 | 7.90244 | 14.19093 | 17.53055 |
| | 2 | 0 | 17.35249 | 6.879535 | -14.6539 |
| | 3 | 0 | -13.4578 | 17.20345 | -8.60077 |
| 3 Times | 1 | 0 | 7.90244 | 14.19093 | 17.53055 |
| | 2 | 0 | 17.35249 | 6.879535 | -14.6539 |
| | 3 | 0 | -13.4578 | 17.20345 | -8.60077 |

| Total Weight (N) | |
|---|---|
| **Magnification By 1** | **Magnification By 3** |
| 53.98 | 53.98 |

If magnification factor is being represented by "$x$" then following relations can be derived from observing above table:

Base Shear $\propto x$

Base Moment $\propto x$

Total Weight $\propto x$

Modal Period $\propto \frac{1}{\sqrt{x}}$

Modal Frequency $\propto \sqrt{x}$

Joint displacements, total weight, and modal participation mass ratio areremaining unchanged.

# CHAPTER-6: DESIGN OF MULTI-STOREY BUILDING

Design of multi-storey building is carried out for seismic condition. The inputs,basic parameters and the output file from SAP2000are as follows.

## 6.1. BASIC PARAMETERS

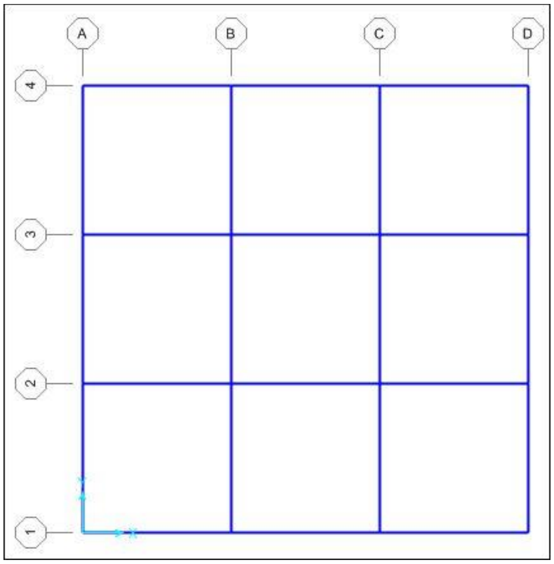



Figure- 18: Plan

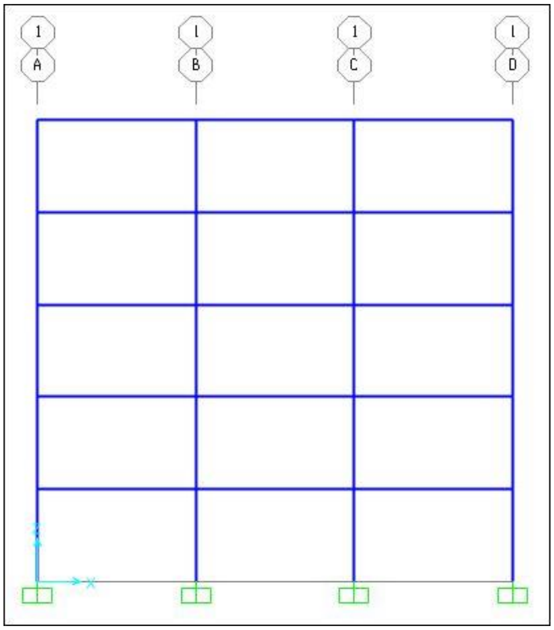



Figure- 19: Elevation

a) Building is regular and symmetric in plan and elevation.
b) 3 bays of 6 meters, total 18 meters in plan.
c) Storey height 3.5 meters having 5 numbers of stories in elevation.
d) Grade of concrete used is M-30.
e) Grade of steel used for rebar is Fe-415.
f) Parapet height = 1.5 m
g) Slab thickness = 150 mm
h) Wall thickness = 150 mm
i) Column size is 480 mm x 480 mm with 4 bars on each direction and 200 mm c/c confinement bar.
j) Top storey beams are 200 mm x 300 mm and floor level beams are 300 mm x 450 mm.
k) Live load on floor = 3 $kN/m^2$
l) Live load on roof = 1.5 $kN/m^2$
m) Floor finishes = 1 $kN/m^2$
n) Roof treatment = 1.5 $kN/m^2$
o) Site location in seismic zone-v (Z = 0.36)
p) Soil condition = medium
q) Importance factor = 1
r) Density of concrete = 25 $kN/m^3$
s) Density of masonry wall = 20 $kN/m^3$

## 6.2. LOAD CASES

A) Dead Load

1) Dead=Self weight of the structural element

2) Dead Wall = 0.15x(3.5-0.45)x20 (up to 3rd floor)
   = 9.15 kN/m (UDL)

   and, = 0.15x(3.5-0.3)x20 (at 4th floor)
   = 9.6 kN/m (UDL)

3) Dead Parapet = 0.15x1.5x20
   = 4.5 kN/m (UDL)

4) Dead Slab + Floor Finish = 0.15x3x25 + 1x3
   = 14.25 kN/m (triangular)

5) Dead Slab + Roof Treatment = 0.15x3x25 + 1.5x3
   = 15.75 kN/m (triangular)

B) Live load

1) Live Floor = 3x3
   = 9 kN/m (triangular)

2) Live Roof = 1.5x3
   = 4.5 kN/m (triangular)

C) <u>Response Spectrum (Earthquake Load)</u>

Scale Factor $= \frac{Z}{2}\frac{I}{R}g$

$= \frac{0.36}{2} \times \frac{1}{5} \times 9.81$

= 0.3532 (SI unit)

## 6.3. DESIGN LOAD COMBINATIONS

1) 1.5 ( DL + IL )
2) 1.2 ( DL + IL ± EL )
3) 1.5 ( DL ± EL )
4) 0.9 DL ± 1.5 EL

## 6.4. SAP2000 OUTPUT FILE

### 6.4.1. Modal Periods and Frequencies

| StepType | StepNum | Period | Frequency |
|---|---|---|---|
| Text | Unitless | Sec | Cyc/sec |
| Mode | 1 | 0.507702 | 1.9697 |
| Mode | 2 | 0.507702 | 1.9697 |
| Mode | 3 | 0.472396 | 2.1169 |
| Mode | 4 | 0.165043 | 6.059 |
| Mode | 5 | 0.165043 | 6.059 |
| Mode | 6 | 0.154011 | 6.493 |
| Mode | 7 | 0.091707 | 10.904 |
| Mode | 8 | 0.091707 | 10.904 |
| Mode | 9 | 0.086486 | 11.563 |
| Mode | 10 | 0.058793 | 17.009 |
| Mode | 11 | 0.058793 | 17.009 |
| Mode | 12 | 0.055891 | 17.892 |
| Mode | 13 | 0.043914 | 22.772 |
| Mode | 14 | 0.043914 | 22.772 |
| Mode | 15 | 0.041901 | 23.866 |

### 6.4.2. Modal Participation Mass Ratio

| StepType | StepNum | Period | UX | UY | SumUX | SumUY | RZ | SumRZ |
|---|---|---|---|---|---|---|---|---|
| Text | Unitless | Sec | Unitless | Unitless | Unitless | Unitless | Unitless | Unitless |
| Mode | 1 | 0.507702 | 0.00053 | 0.80667 | 0.00053 | 0.80667 | 0 | 0 |
| Mode | 2 | 0.507702 | 0.80667 | 0.00053 | 0.8072 | 0.8072 | 0 | 0 |
| Mode | 3 | 0.472396 | 0 | 0 | 0.8072 | 0.8072 | 0.81098 | 0.81098 |
| Mode | 4 | 0.165043 | 0.05903 | 0.0489 | 0.86624 | 0.8561 | 0 | 0.81098 |
| Mode | 5 | 0.165043 | 0.0489 | 0.05903 | 0.91514 | 0.91514 | 0 | 0.81098 |
| Mode | 6 | 0.154011 | 0 | 0 | 0.91514 | 0.91514 | 0.10598 | 0.91696 |
| Mode | 7 | 0.091707 | 0.02425 | 0.02529 | 0.93939 | 0.94042 | 0 | 0.91696 |
| Mode | 8 | 0.091707 | 0.02529 | 0.02425 | 0.96467 | 0.96467 | 0 | 0.91696 |
| Mode | 9 | 0.086486 | 0 | 0 | 0.96467 | 0.96467 | 0.04837 | 0.96532 |
| Mode | 10 | 0.058793 | 0.02309 | 0.00339 | 0.98776 | 0.96806 | 0 | 0.96532 |
| Mode | 11 | 0.058793 | 0.00339 | 0.02309 | 0.99115 | 0.99115 | 0 | 0.96532 |
| Mode | 12 | 0.055891 | 0 | 0 | 0.99115 | 0.99115 | 0.02599 | 0.99132 |
| Mode | 13 | 0.043914 | 0.00543 | 0.00342 | 0.99658 | 0.99457 | 0 | 0.99132 |
| Mode | 14 | 0.043914 | 0.00342 | 0.00543 | 1 | 1 | 0 | 0.99132 |
| Mode | 15 | 0.041901 | 0 | 0 | 1 | 1 | 0.00868 | 1 |

### 6.4.3. Modal Load Participation Ratio

| OutputCase | ItemType | Item | Static | Dynamic |
|---|---|---|---|---|
| Text | Text | Text | Percent | Percent |
| MODAL | Acceleration | UX | 100 | 100 |
| MODAL | Acceleration | UY | 100 | 100 |
| MODAL | Acceleration | UZ | 0 | 0 |

### 6.4.4. Base Reaction for Various Load Cases

| OutputCase | StepType | GlobalFX | GlobalFY | GlobalFZ | GlobalMX | GlobalMY | GlobalMZ |
|---|---|---|---|---|---|---|---|
| Text | Text | KN | KN | KN | KN-m | KN-m | KN-m |
| 1.2 ( DL + LL + EQX ) | Max | 114.776 | 0 | 23662.8 | 212965.2005 | -211614.8 | 1032.988 |
| 1.2 ( DL + LL + EQX ) | Min | -114.776 | 0 | 23662.8 | 212965.1995 | -214315.5 | -1032.988 |
| 1.2 ( DL + LL - EQX ) | Max | 114.776 | 0 | 23662.8 | 212965.2005 | -211614.8 | 1032.988 |
| 1.2 ( DL + LL - EQX ) | Min | -114.776 | 0 | 23662.8 | 212965.1995 | -214315.5 | -1032.988 |
| 1.2 ( DL + LL - EQY ) | Max | 0 | 114.776 | 23662.8 | 214315.5563 | -212965.2 | 1032.988 |
| 1.2 ( DL + LL - EQY ) | Min | 0 | -114.776 | 23662.8 | 211614.8437 | -212965.2 | -1032.988 |
| 1.2 ( DL + LL + EQY ) | Max | 0 | 114.776 | 23662.8 | 214315.5563 | -212965.2 | 1032.988 |
| 1.2 ( DL + LL + EQY ) | Min | 0 | -114.776 | 23662.8 | 211614.8437 | -212965.2 | -1032.988 |
| 1.5 ( DL + EQY ) | Max | 0 | 143.471 | 22855.5 | 207387.4454 | -205699.5 | 1291.235 |
| 1.5 ( DL + EQY ) | Min | 0 | -143.471 | 22855.5 | 204011.5546 | -205699.5 | -1291.235 |
| 1.5 ( DL + EQX ) | Max | 143.471 | 0 | 22855.5 | 205699.5007 | -204011.5 | 1291.235 |
| 1.5 ( DL + EQX ) | Min | -143.471 | 0 | 22855.5 | 205699.4993 | -207387.4 | -1291.235 |
| 1.5 ( DL - EQX ) | Max | 143.471 | 0 | 22855.5 | 205699.5007 | -204011.5 | 1291.235 |
| 1.5 ( DL - EQX ) | Min | -143.471 | 0 | 22855.5 | 205699.4993 | -207387.4 | -1291.235 |
| 1.5 ( DL - EQY ) | Max | 0 | 143.471 | 22855.5 | 207387.4454 | -205699.5 | 1291.235 |
| 1.5 ( DL - EQY ) | Min | 0 | -143.471 | 22855.5 | 204011.5546 | -205699.5 | -1291.235 |
| 0.9 DL + 1.5 EQX | Max | 143.471 | 0 | 13713.3 | 123419.7007 | -121731.7 | 1291.235 |
| 0.9 DL + 1.5 EQX | Min | -143.471 | 0 | 13713.3 | 123419.6993 | -125107.6 | -1291.235 |
| 0.9 DL - 1.5 EQX | Max | 143.471 | 0 | 13713.3 | 123419.7007 | -121731.7 | 1291.235 |
| 0.9 DL - 1.5 EQX | Min | -143.471 | 0 | 13713.3 | 123419.6993 | -125107.6 | -1291.235 |
| 0.9 DL - 1.5 EQY | Max | 0 | 143.471 | 13713.3 | 125107.6454 | -123419.7 | 1291.235 |
| 0.9 DL - 1.5 EQY | Min | 0 | -143.471 | 13713.3 | 121731.7546 | -123419.7 | -1291.235 |
| 0.9 DL + 1.5 EQY | Max | 0 | 143.471 | 13713.3 | 125107.6454 | -123419.7 | 1291.235 |
| 0.9 DL + 1.5 EQY | Min | 0 | -143.471 | 13713.3 | 121731.7546 | -123419.7 | -1291.235 |

# CHAPTER-7: ANALYSIS & DISCUSSION OF RESULTS

## 7.1. MODAL RESULTS

Estimate of the natural frequencies of three-storey building frame has compared below along with the mode shape.

a) For unloaded case:

| Mode | Natural frequencies in Hz | |
|---|---|---|
| | By Excel Programming | By Experiment |
| 1 | 2.75 | 2.7 |
| 2 | 7.66 | 7.9 |
| 3 | 10.96 | 11.5 |

b) For loaded case:

| Mode | Natural frequencies in Hz | |
|---|---|---|
| | By Excel Programming | By Experiment |
| 1 | 2.47 | 2.4 |
| 2 | 6.56 | 6.6 |
| 3 | 9.46 | 9.7 |

Mode Shape:

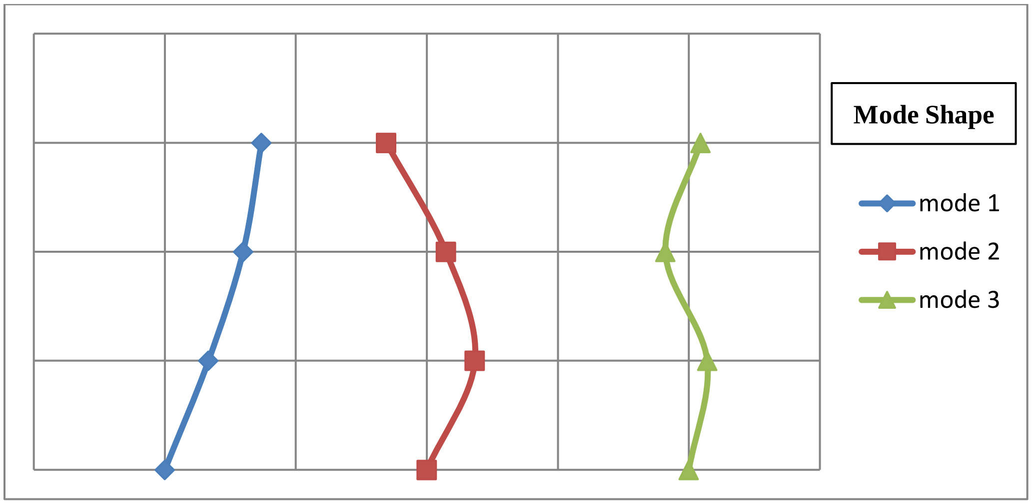



Figure- 20: Mode Shape

## 7.2. DAMPING RATIO

Damping Ratio of aluminum frame model is coming out to be 0.352% of the critical.

## 7.3. DIMENSIONAL ANALYSIS RESULTS

If *"x"* is the magnification factor, then following relations have been derived.

### 7.3.1. Changing Size of Elements in Three Dimensions

Base Shear $\propto \frac{1}{\sqrt{x}}$

Base Moment $\propto \sqrt{x}$

Modal Period $\propto x$

Modal Frequency $\propto \frac{1}{x}$

Joint Displacement $\propto \frac{1}{x\sqrt{x}}$

Total Weight $\propto x^3$

### 7.3.2. <u>Changing Only Unit Weight of Material</u>

Base Shear $\propto \frac{1}{\sqrt{x}}$

Base Moment $\propto \frac{1}{\sqrt{x}}$

Total Weight $\propto x$

Modal Period $\propto \sqrt{x}$

Modal Frequency $\propto \frac{1}{\sqrt{x}}$

Joint Displacement $\propto \frac{1}{\sqrt{x}}$

### 7.3.3. <u>Changing Only Elasticity of Material</u>

Base Shear $\propto x$

Base Moment $\propto x$

Total Weight $\propto x$

Modal Period $\propto \frac{1}{\sqrt{x}}$

Modal Frequency $\propto \sqrt{x}$

Joint displacements, total weight, and modal participation mass ratio are remaining unchanged.

## 7.4. DESIGN RESULTS

The reinforcement detailing in each memberof the frame has shown below. Since the structure is symmetric and regular, hence one outer frame and one inner frame are sufficient to understand the entire structure. The figures for reinforcement detailing are as follows:

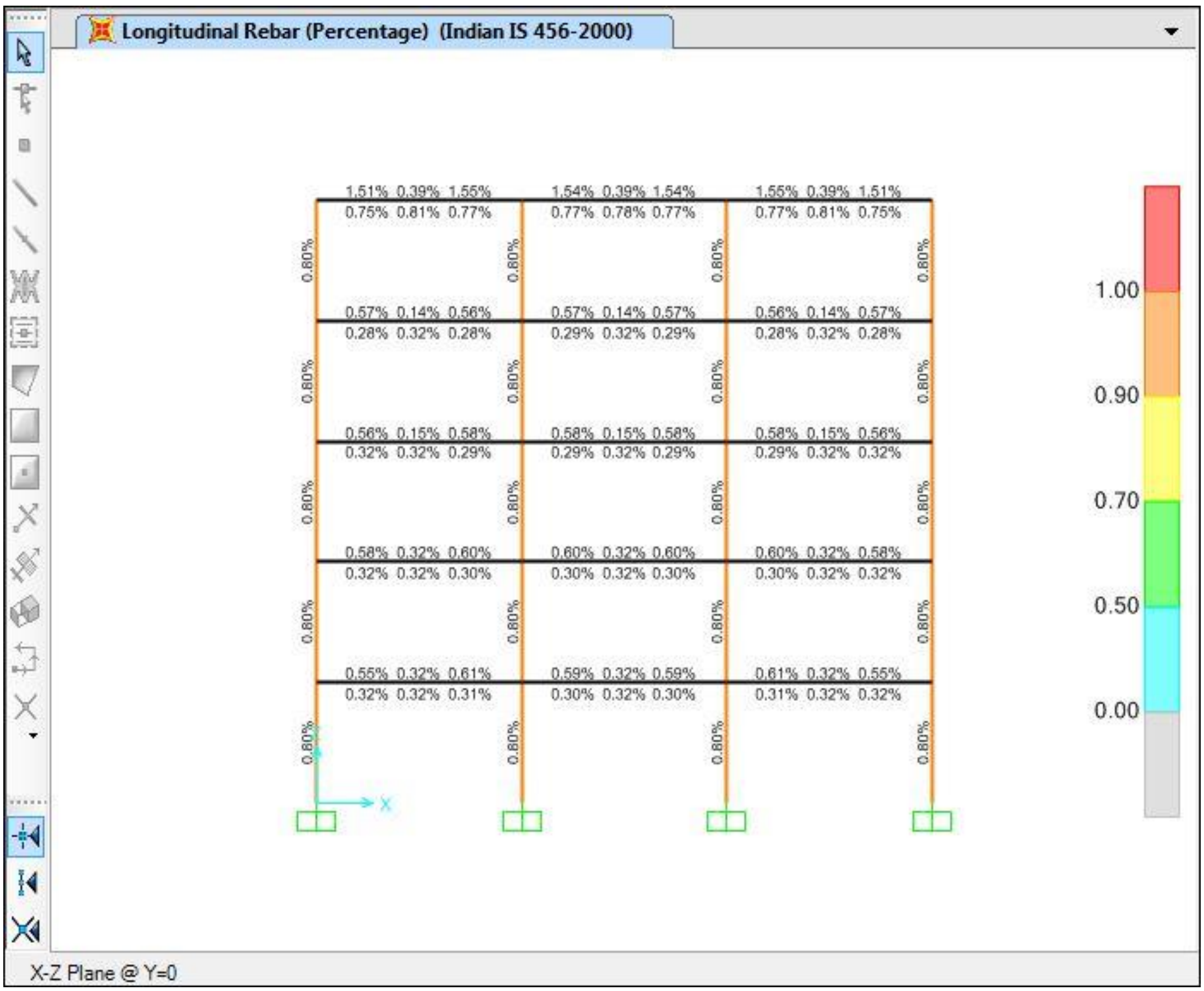



Figure- 21: Reinforcement Distribution in Outer Frame

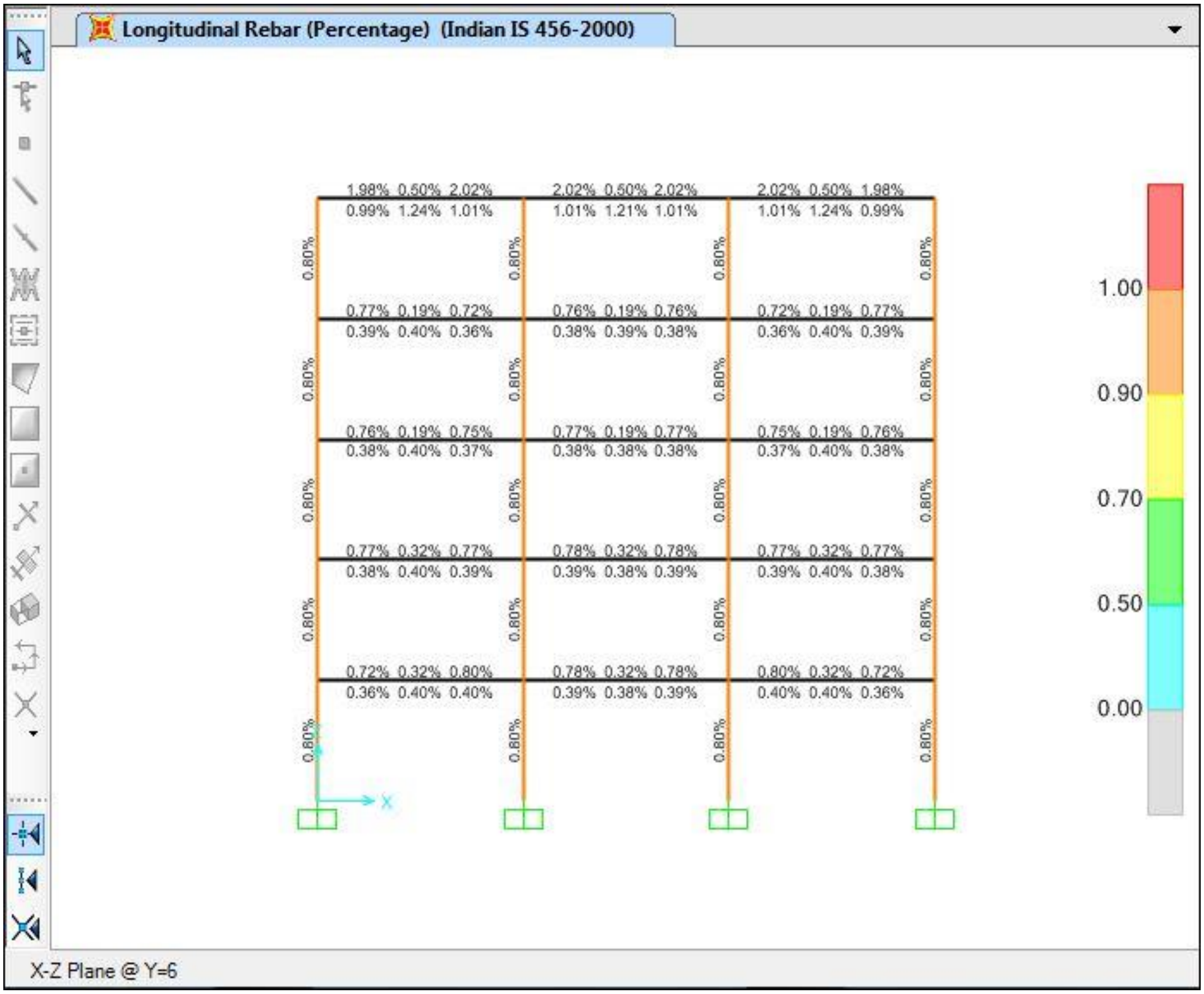



Figure- 22: Reinforcement Distribution in Inner Frame

For this design, the column/beam strength ratios have also been shown below with the figure.

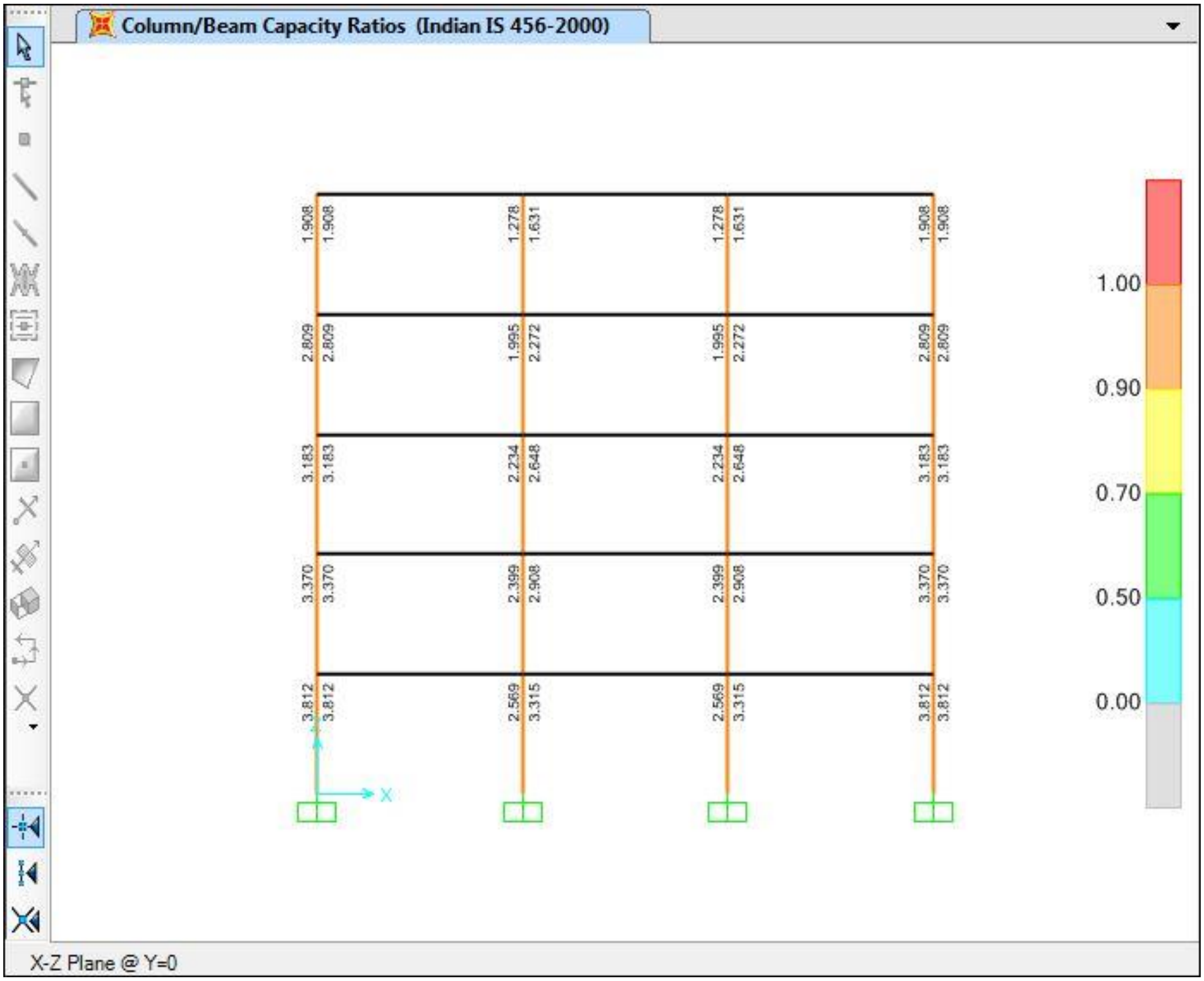



Figure- 23: Column/Beam Strength Ratio for Outer Frame

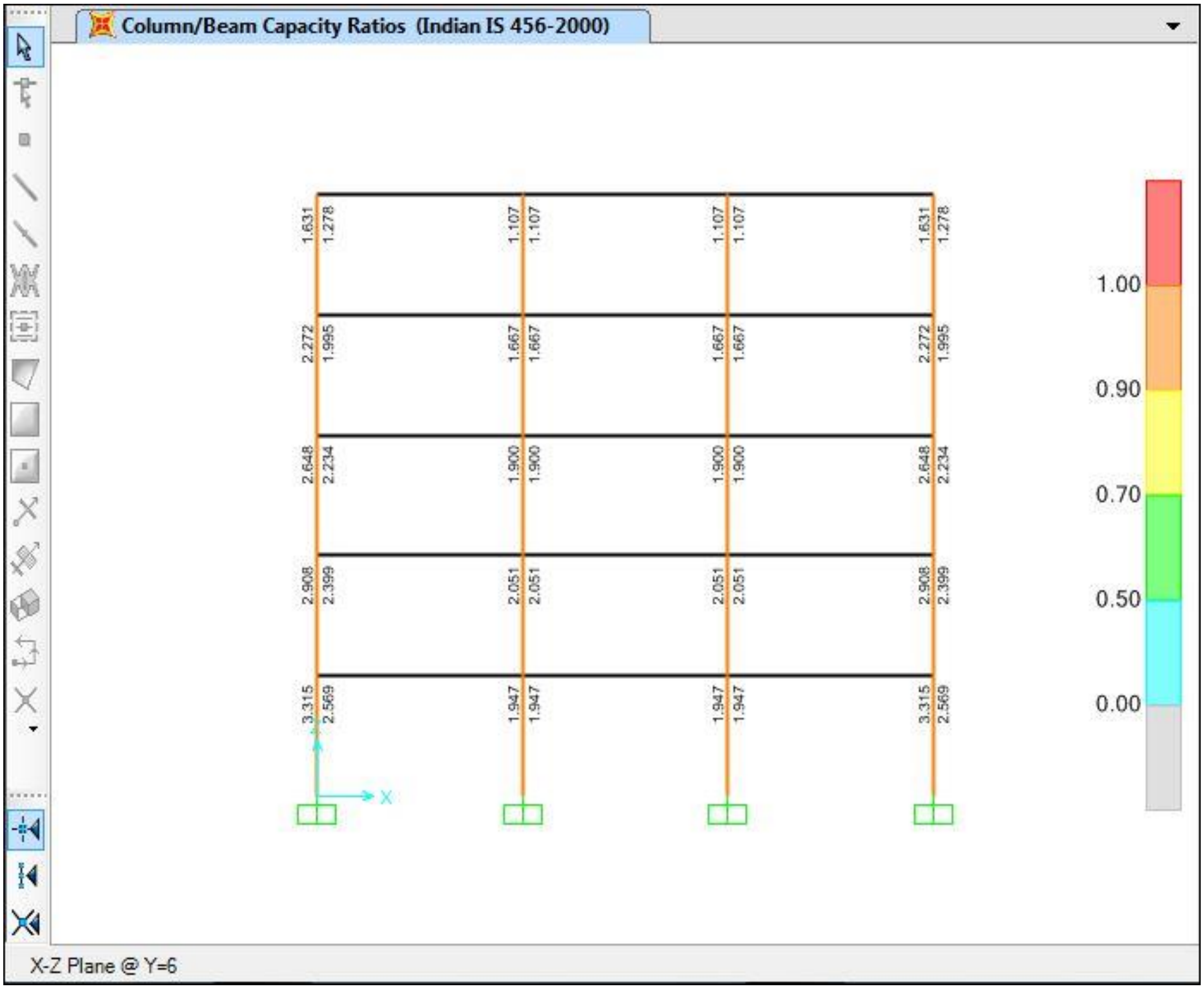



Figure- 24: Column/Beam Strength Ratio for Inner Frame

# CHAPTER-8: CONCLUSION

After performing all these trials and experiments, it can be concluded that the results getting from OROS NVGateare correct in all aspects. On seeing the graph of displacement vs. frequency, we can conclude that the displacement at the time of resonance state in the structure is very high. Hence, at that state the structure is most sever to collapse. Hence to counterpart that situationthere is needed to design the structure in ductile point of view to resist earthquake.

It has also beenobserved that the variation in natural frequencies in different results is very less in lower mode. The variation is increasing with the increasing mode. The value getting for damping ratio (ξ) of aluminum frame is also in range. This value is approximately 0.4 % for aluminum. On later stage damping ratio of an asbestos chimney model is also determined. It was coming around 35 %, which is a realistic result. However that part has not been included in this work.

The mode shapes that has been generated from the excel programming is realistic in nature. It looks like the same asobserved shapes in the experiment. The excel programming is too much handy in use as well. Hence it may become a good tool for further work.

The relationships derived for dimensional analysis may become helpful for analyzing real structures for dynamic condition, because it gives direct relations between the parameters.There will not be needed to have large calculations.

In design result, the reinforcement distribution is clearly shown by the figure. For instance, column/beam strength ratios have also been shown. At all the joints the columns are stronger than the beams, which is most important for ductile failure of structure at the time of earthquake.

# CHAPTER-9: SCOPE OF FUTURE WORK

By seeing the accuracy of results getting in this model, it can be said that the experiment can also be performed in different models. And also the experiment can be performed in same model by varying amplitude of shacking table. By doing so, maybe there will be any change in graph pattern.It can be further find out the damping ratio of any material, asit gives very accurate results.

As the future work on excel programming, further programming for calculation of base reactions or any other seismic parameter can be made. This sheet can be extended as beyond as possible.

The dimensional analysis can be made more helpful by analysing for more parameters.Thusit can further be related to a real building to create a model for analysis purpose. This will help in easy understanding of behaviour of the structure.

Some more kind of analysis can also be performed for the designed building, such as:

1) P-Δ analysis.
2) Modal time history analysis.
3) Non-linear analysis for staged construction.
4) Analysing by taking effect of infill.
5) Static pushover analysis, etc.

By doing so, a good knowledge of behaviour of that structure can be achieved.

# ***References***


[1] IS 1893 (Part-1): 2002, “Criteria for Earthquake Resistant Design of Structures”.

[2] Book, Dynamics of Structures, by Mario Paz.

[3] Manual of National Program on Earthquake Engineering Education MHRD, Government of India, by IISc Bangalore.

[4] FEMA454, Chapter-4, “Earthquake Effects on Buildings”, by Christopher Arnold.

[5] “Introduction to Theory of Vibration”, by Manish Shrikhande, IIT Roorkee.

[6] Journal of theoretical and applied mechanics, “factors affecting internal damping in aluminum” by Mehmet Colakoglu.

[7] Multi degree of freedom (MDOF) systems and modal analysis, byAhmed Algamal.

[8] “Philosophy and Principals of Earthquake Resistant Design”, by Professor D. K. Paul.

[9] “Architectural Considerations and Guidelines for Earthquake Resistant Design of Buildings”, by Dr. Yogendra Singh, IIT Roorkee.

[10] MTS Tabletop Earthquake System Manual.

[11] Reference manual and user’s manual provided by OROS NVGate software.

[12] Microsoft Excel user help manual.

[13] SAP2000 manual.