"STUDY THE BEHAVIOR OF A MULTI-STOREY BUILDING UNDER SEISMIC CONDITIONS"

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

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

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CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled **"STUDY THE BEHAVIOR OF A MULTI-STOREY BUILDING UNDER SEISMIC CONDITIONS"** in the partial fulfilment of the requirements for the award of the degree of "Master of Technology" in structural engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of my own work carried out under the supervision of Mr. Alok Verma (Associate Professor), Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Date: 30th July 2014

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

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ABSTRACT

Structures on the earth are generally subjected to two types of load: Static load and Dynamic load. Static loads are unvarying with time while dynamic loads are time – varying. The majority of Civil Engineering structures are designed with the assumption that all applied loads are static in nature. The effect of dynamic load is not taken into account because the structure is rarely subjected to dynamic loads, considering it in the analysis makes the solution more complicated and time consuming. This feature of neglecting the dynamic forces may sometimes become the cause of disaster, in case of earthquake. Therefore seismic analysis and design is required to make the structure earthquake resistant and dynamic analysis of building structures by Response Spectrum Method is most suitable.

In the present work, the various aspects of dynamic analysis are considered. Seismic analysis according to Indian codes is studied and an overview of the topic is developed. Modelling of a multi storyed building is done in STAAD Pro software. The material property, loading details and soil types are assigned to the model, and then its dynamic analysis is carried out. Then displacement and peak storey shear at each floor for different zone factor and soil type are obtained from output file of STAAD pro. Also, the base shear for different modes is obtained for different zone factor and soil type. Then comparison of base shear, peak storey shear and displacement between different response reduction factor while keeping the zone factor and soil type constant is carried out and % variations of output parameters with variation of response reduction factor are plotted. Then finally the outcomes and results are stated, comparisons are made.

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1. INTRODUCTION

1.1 GENERAL

With the increasing population of the world, the need for residential and commercial buildings, dams, bridges etc. is exponentially increasing. This has put extra pressure on the existing infrastructure which has resulted in an accelerated rate of building construction. The buildings are expanding in vertical direction as there is less space to expand in horizontal direction which requires special care of seismic safety at the design stage itself.

When an earthquake occurs, it produces serious consequences, such as infrastructure damage, socio economic impact, or even loss of life. The consequences can be noticeably observed as damage to physical facilities, such as damage to buildings and residences, collapse of bridges, indoor property loss, and break down of utility systems. Earthquakes are one of nature's greatest hazards to life on this planet. The impact of these phenomena is sudden with little or no warning to take preventive measures against damages and collapse of buildings or structures. The hazards to life in case of earthquake are almost entirely associated with manmade structures such as buildings, dams, tunnels, bridges etc. Prevention of disasters caused by earthquake has become increasingly important in recent years. The new structure can be built sufficiently earthquake resistant by adopting proper design methodology and construction quality control. [1]

Also it must be noted that in every construction practice, economy plays an important role. Hence its role in seismic risk assessment of buildings also cannot be ignored. The building must be constructed considering the economic factor as well as strength factor.

There are two sources of mistakes which would seriously cause danger to our structures. The first come from ignoring the ways the earthquake affects the structures; the other is the inadequate construction practices. [2]

After each major earthquake, one discusses the damages which affected the structures during the disaster, and possible means of prevention against the damages. From these discussions, many ideas usually come out on changes which should be introduced into the traditional construction ways. But human nature is such that, as soon as the first fears are over, nobody considers any further changes; and the feeling of security prevails, moreover, even those ideas get forgotten which have been accepted just after an earthquake. During construction no one does take care about the quality of work, but the only aim is that a building as large as possible is built with expenses as low as possible. It is clear that such buildings cannot be strong enough to resist an earthquake which shows that the buildings are seismically vulnerable. [2]

Earthquake damage depends on several parameters, such as intensity, duration & frequency content of ground motion, geological & soil condition, quality of construction, etc. Building design must ensure that the building has sufficient strength, high ductility, and will remain as single unit, even when subjected to very large deformation. Seismic analysis is a subset of structural analysis which involves the calculation of the behaviour of a structure subjected to earthquake excitation. This is important to carry out the structural design, structural assessment and retrofitting of the structures in the areas which are seismically critical. Several seismic parameters are necessary to perform the seismic analysis of the structures. [3]

For the purpose of achieving seismic resistance at economical cost, three parameters are considered to be significant in categorization of buildings [4]:

a) Seismic intensity zone,
b) The importance of the building, and
c) Stiffness of the foundation soil.

A combination of these parameters will determine the extent of appropriate seismic strengthening of the building.

Methods of 3-Dimensional dynamic analysis of structures have become more efficient in use along with the development of technology. The Response spectrum analysis method for seismic analysis can give more accurate results than an equivalent static approach. The major advantage of using the forces obtained from a dynamic analysis as the basis for a structural design is that the vertical distribution of lateral forces may be significantly different from the lateral forces obtained from an equivalent static load analysis. Consequently, the use of dynamic analysis will produce structural designs that are more seismically resistant than structures designed using static load analysis.

2. LITERATURE REVIEW

This chapter helps us in understanding the basic parameters which are needed used in the dynamic analysis of building. It mainly focuses on definitions and explanations of those basic terminologies which help us in defining various methodologies for the dynamic analysis of building frames.

2.1 EARTHQUAKE EFFECTS

There are four basic causes of earthquake induced damages [3]:

- Ground Shaking,
- Ground Failure,
- Tsunamis and
- Fire

2.1.1 Ground Shaking

The main cause of earthquake-induced damages is ground shaking. As earth vibrates, all buildings on the ground surface will act in response to that vibration in varying degrees. Earthquake induced velocities, displacements and accelerations, can damage a building unless it is designed and constructed or strengthened to be earthquake resistant. Hence, the effect of ground shaking on buildings is a major area of consideration in the design of earthquake resistant buildings. Seismic design loads are tremendously difficult to determine due to the random nature of earthquake motions. On the other hand, experiences from past strong earthquakes have shown that reasonable practices can keep a building safe during an earthquake.

2.1.2 Ground Failure

Earthquake-induced ground failure has been observed in the form of ground rupture along the fault zone, settlement, landslides, and soil liquefaction. Ground rupture along a fault zone may be very inadequate or may extend over hundreds of kilo-meters. Ground displacement along the fault zone may be vertical, horizontal, or both, and also it can be measured in centimetres or even metres. Evidently, a building directly spanning such a rupture will be severely damaged or collapsed.

While the settlement can only damage the building but landslide may destroy a building. Soil liquefaction can occur only in low density saturated sands of having relatively uniform size. The phenomenon of liquefaction is particularly important for bridges, underground pipelines, dams, and buildings standing on such ground.

2.1.3 Tsunamis

Tsunamis or seismic sea waves are produced by a sudden movement of the ocean floor. As the sea waves approach land, their velocity decreases and their height increases from 5 to 8 m, or even more. Evidently, tsunamis can be disturbing for buildings built in coastal areas.

2.1.4 Fire

When the fire subsequent an earthquake starts, it becomes difficult to turn off it, because of a strong earthquake is accompanied by traffic jams and the loss of water supply. Hence, the earthquake damage increases with the earthquake-induced fire as well as the damage to buildings directly due to the earthquakes. An example of an earthquake induced fire is the case of the 1923 Kanto earthquake 50% of Tokyo and 70% of the total number of houses were burnt and more than 100,000 people were killed by the fire.

2.2 NEED FOR DYNAMIC ANALYSIS

The behaviour of structure or building during an earthquake is basically a problem of vibration. The structure vibrates due to the seismic movement of the ground and causes structural deformity in the building. Several parameters regarding this deformity like time period, frequency of vibration, and amplitude are of considerable importance and defines the overall response of the structure. These responses also depend on the distribution of seismic forces within the structure which further depends on the methodology which is used to calculate this distribution. Various methods of 3-Dimensional dynamic analysis of structures have become more efficient in use along with the advancement of technology. The Response spectrum analysis method for seismic analysis is one of them which also can give more precise results than an equivalent static approach. The major advantage of using the lateral forces obtained from a dynamic analysis as the basis for a structural design is that the vertical distribution of lateral forces may be considerably different from the lateral forces obtained from an equivalent static load analysis. As a result, the use of dynamic analysis will produce structural designs that are more earthquake resistant than structures designed using static load analysis. [5]

2.3 FACTORS GOVERNING DYNAMIC BEHAVIOUR

The factors which governs the dynamic behaviour of a building are stated below [6]

2.3.1 Effect of Mass and Height

The earthquake load acting on the buildings is called as lateral loads since their effect is observed mainly in the horizontal direction. This is in contrast to the weights of the building (and occupants) which act vertically downward due to gravity. The earthquake force is also called seismic force. These forces are induced in a building because of the heavy masses present at various floor levels such forces are called inertial forces. Inertial forces are calculated by the products of the accelerations and their respective masses. The accelerations which are generated by the seismic waves in the ground are transmitted through the vibrating structure to the masses at various floor levels, thereby producing the horizontal seismic forces. The building behaves like a vertical cantilever and horizontally swings like an inverted pendulum such that masses at higher levels swing more because of the cantilever action of the building the forces accumulate from top to bottom. Total horizontal force acting on the ground storey columns is the sum of the seismic forces acting at all the levels above. This is defined as the base shear.

2.3.2 Effect of Stiffness

Under service loads, buildings are expected to behave elastically. Elasticity is that property by virtue of which a structure displaced by a load regains its original shape when unloading. Because of this property, those buildings which are pushed horizontally by mild earthquake loads regained to its original vertical configuration after the vibration has passed. The deflection of the building under the given load is measured by a property called stiffness which may be defined as the force required producing unit deflection. The stiffer the building, the less it will deflect. The lateral stiffness and mass of the building contribute to another important structural property, termed as the natural period of vibration. The value of which governs the magnitude of seismic force that the building will attract.

2.3.3 Effect of Ductility

The capability of a structure to deform with damages & without sudden break down is termed as ductility. Due to ductility a building can continue to resist seismic forces without sudden collapse.

If the structural components in a building can "hold on" through ductile behaviour, without breaking during the short period of the major earthquake the building will not collapse. It may get damaged; such ductile buildings attract lesser load with increasing deformation. Due to the earthquake, a considerable amount of the input energy in the building gets dissipated through the yielding of the ductile materials or else the entire input energy will to be stored as elastic strain energy. If the required ductility can be provided in the building, the design seismic force can be much lower (up to 20%) than that of in an elastic building.

2.3.4 Effect of Layout and Configuration

The building should have a simple plan and geometrical shape, like rectangular or circular. If the building is too long in one direction or too large in plan, it is possible to be damaged during earthquake. Buildings which have, 'U', 'H' 'V', 'L' or 'Y' shapes in plan are also undesirable attracting severe stresses at the interior corners called as re entrant corners. Buildings which are not symmetrical in plan are bound to twist under an earthquake, attracting further damages. If the complex geometries are utterly required, then it is desirable to break up the building plan into simple rectangular segments with proper separation joints such that they behave as individual units under an earthquake load.

2.3.5 Effect of Soil

The accelerations which occur in the rock layer of the crust during an earthquake get transmitted to the building through the soil strata over the rock layer. If the soil is relatively soft, the accelerations tend to get exaggerated, which results in the structure attracting higher seismic loads. In the presence of subsoil water, buildings located in loose granular soils, have another severe and potential danger which can occur during an earthquake. The granular soil will behave like quicksand through a phenomenon called liquefaction. Buildings which are located in those soils may sink or afloat, and tilt extensively and collapse.

2.3.6 Effect of Strength and Integrity

The strength of every structural component is the magnitude of the maximum internal force such as bending moment or axial force or shear force, which can resist under a certain type of loading. When this strength is exceeded by the applied load, the material tends to fail (or collapse). The strength depends upon not only on the size of the cross section, but also on other factors, such as type of material.

During an earthquake the load attracted by a structural component depends upon the lateral stiffness and mass of the building. If the building is designed not to “yield”, and to behave in a ductile manner, it will be required to resist higher loads during an earthquake to avoid a sudden failure of a building. A structural component should be designed to have a strength which is not less than the maximum internal force, associated with ductility and with the overall seismic load on the building.

2.4 BASIC TERMINOLOGIES

The basic parameters which are considered in the dynamic analysis of a building are defined as below. The dynamic analysis compliances with the methodologies used in IS: 1893 (Part-I)-2002 "Criteria for Earthquake Resistant Design of Structures (Fifth Revision)”. The following literature has been taken from this code with due acknowledgements. [7]

2.4.1 Damping

If a structure vibrates, the amplitude of the vibration will decay with due course of time and eventually come to an end. Damping is a measure of this decay in amplitude of the vibration. It is due to absorbed energy and internal friction. Damping is affected by the nature of the structure and its connections. A heavy concrete structure will provide more damping than a light steel frame. Also architectural features such as partitions and exterior facade construction contribute to the damping. Damping is measured by a theoretical damping level termed critical damping. This is the least amount of damping that will allow the structure to regain its original position without any continuous vibration. The effect of internal friction, imperfect elasticity of material, slipping, sliding, etc in reducing the amplitude of vibration and is expressed as a percentage of critical damping. For most structures, the amount of damping in the system will vary from 3 to 10% of critical.

2.4.2 Design Acceleration Spectrum

Design acceleration spectrum refers to an average smoothened plot of maximum acceleration as a function of frequency or time period of vibration for a specified damping ratio for earthquake excitations at the base of a single degree of freedom system.

2.4.3 Design Horizontal Acceleration (A_h)

It is a horizontal acceleration coefficient that shall be used for design of structures.

2.4.4 Design Lateral Force

It is the horizontal seismic force that shall be used to design a structure.

2.4.5 Importance Factor (I)

It is a factor used to get the design seismic force depending on the functional use of the structure, characterized by dangerous consequences of its failure, its post-earthquake functional need, historic value, or economic importance. The importance of the building should be a factor in grading it for strengthening purposes.

2.4.6 Modal Mass (M_k)

Modal mass of a structure subjected to vertical or horizontal, as the case may be, ground motion is a part of the total seismic mass of the structure that is effective in mode k of vibration. The modal mass for a given mode has a sole value irrespective of scaling of the mode shape.

2.4.7 Modal Participation Factor (P_k)

Modal participation factor of mode k of vibration is the amount through which mode k contributes to the overall vibration of the structure under vertical and horizontal earthquake ground motions. Since the amplitudes of 95% mode shapes can be scaled randomly, the value of this modal participation factor depends on the scaling used for mode shapes.

2.4.8 Mode Shape

Mode shape of oscillation related with a natural period of vibration of a building is the deformed shape of the building when shaken at the natural period. Hence, a building has as mode shapes as the number of natural periods. There are infinite numbers of natural period for a building. But, in the mathematical modelling of building, the building is discredited into a number of elements. The junctions of these elements are called nodes. Each & every node is free to translate in all the three directions and rotate about the three axes. Therefore, if the number of nodes of discretisation is N, then there would be 6N modes of oscillation, and related with these are 6N natural periods and mode shapes of oscillation. The deformed shape of the building related with oscillation at fundamental natural period is termed as its first mode shape. Similarly, the deformed shapes associated with oscillations at second, third, and other higher natural periods are termed as second mode shape, third mode shape, and so on, respectively.

Factors influencing Mode Shapes [8]

- Effect of Building Height
- Effect of Flexural Stiffness of Structural Elements
- Effect of Unreinforced Masonry Infill Walls in RC Frames
- Effect of Degree of Fixity at Member Ends
- Effect of Axial Stiffness of Vertical Members

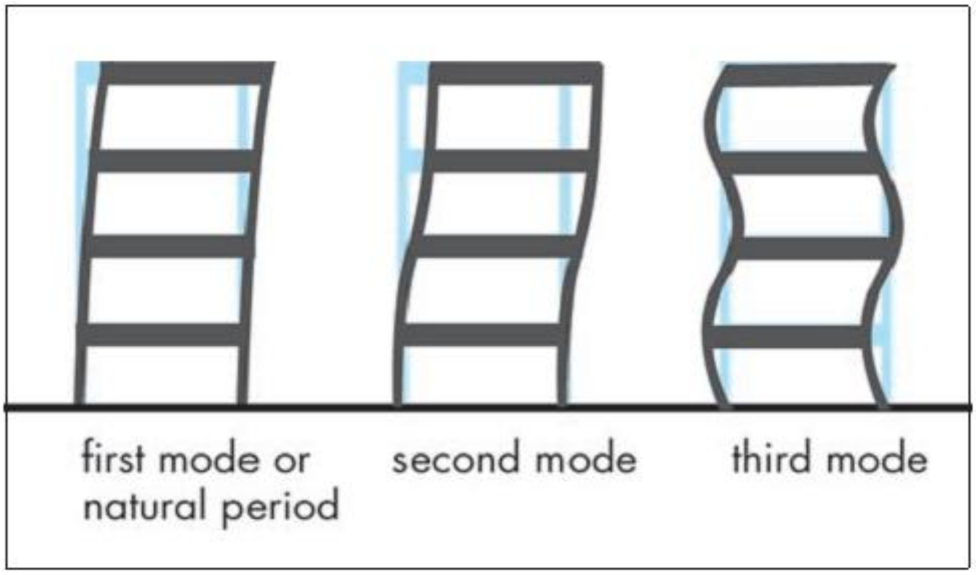

Figure 2.1*[9] Modes of vibrations

2.4.9 Mode Shape Coefficient (φ_{ik})

When a system is vibrating in normal mode k, at any instant of time, the amplitude of mass articulated as a ratio of the amplitude of one of the masses of the system, is recognized as mode shape coefficient (φ_{ik})

2.4.10 Natural Period (T)

Another important characteristic of earthquake waves is their period or frequency; that is, whether the waves are quick and sudden or slow and rolling. This phenomenon is important for determining building seismic forces. All objects have a natural or fundamental period; this is the rate at which they will move back and forth if they are given a horizontal thrust. Without pulling and pushing it back and forth, it is impossible to make an object vibrate at anything other than its natural period. When earthquake motion starts a building vibrating, it will tend to sway back and forth at its natural period. Natural period of a structure is its time period of un-damped free vibration. Period is the time in seconds (or fractions of a second) that is needed to complete one cycle of a seismic wave. Frequency is the inverse of natural period, the number of cycles that will occur in a second and is measured in "Hertz". One Hertz is defined as one cycle per second. [9]

Factors influencing Natural Period [8]

- Effect of Cracked Sections on Analysis of RC Frames
- Effect of Stiffness
- Effect of Mass
- Effect of Column Orientation
- Effect of Unreinforced Masonry Infill Walls in RC Frames
- Effect of Building Height

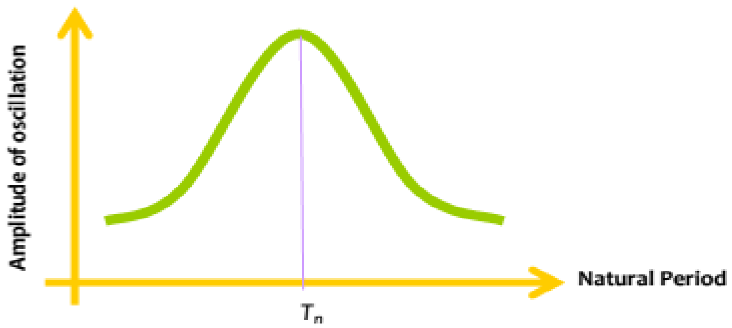

Figure 2.2*[8] Natural frequency of a building

Natural periods of buildings depend on the distribution of mass and stiffness along the building (in all directions). Some major trends related to natural periods of buildings of regular geometries are [8]:

- Building tends to oscillate in the directions in which they are most flexible and have larger translational natural periods.
- Natural period of buildings reduces with increase in stiffness.
- Natural period of buildings increases with increase in mass.
- Natural period of buildings depends on amount and extent of spatial distribution of unreinforced masonry infill walls.
- Tall buildings have larger fundamental translational natural periods.

2.4.11 Fundamental Natural Period (T_1)

Every building has a many number of natural frequencies, at which it offers minimum resistance to shaking induced by external effects and internal effects. Each of these natural frequencies and the related deformation shape of a building constitute a Natural Mode of Oscillation. The mode of oscillation corresponds to smallest natural frequency is called the Fundamental Mode; and the associated natural period T_1 is called the Fundamental Natural Period and the associated natural frequency f_1 is called the Fundamental Natural Frequency. Further, regular buildings restrained their base from translation in the three directions, have

- Three fundamental translational natural periods, T_{x1}, T_{y1} and T_{z1}, related with its translational oscillation along X, Y and Z directions respectively, and
- One fundamental rotational natural period $T_{\theta 1}$ related with its rotation about an axis parallel to Z axis.

In reality, the number of natural modes of a building is infinity. But, practically, the number of modes is finite. When the finite element model of the building is prepared, the buildings are discretised into members meeting at nodes. Each node has a maximum of 6 degrees of freedom. Therefore, a building with many nodes, the maximum degrees of freedom can be counted to be finite, say N, which shows N natural modes of oscillation. [8]

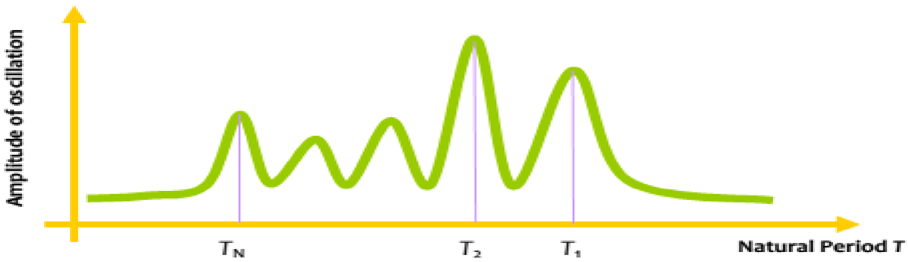

Figure 2.3*[8] Multiple natural periods

The approximate fundamental natural period of vibration (T_a), in seconds, of a moment-resisting frame building without brick in-fill panels may be estimated by the empirical expression:

$$T_a = 0.075\ h^{0.75} \quad \text{for RC frame building}$$

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

Where,

h= Height of building, in m.

This excludes the basement storeys, where basement walls are connected with the ground floor deck between the building columns. But, it includes the basement storeys, when they are not so connected.

The approximate fundamental natural period of vibration (Ta), in seconds, of all other buildings, including moment-resisting frame buildings with brick infill panels, may be estimated by the empirical expression:

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

h= Height of building, in m, and

b= Base dimension of the building at the plinth level, in m, along the considered direction of the lateral force.

2.4.12 Modal Natural Period (T_k)

The modal natural period of mode k is the time period of vibration corresponding to mode k.

2.4.13 Response Reduction Factor (R)

It is the factor by which the actual base shears forces that would be generated if the structure were to remain elastic during its response to the Design Basis – Earthquake (DBE) shaking shall be reduced to obtain the design lateral force.

2.4.14 Response Spectrum

It can be seen that buildings with different periods (or frequency responses) will respond in different ways to the same earthquake ground motion. On the other hand, any building will perform differently during different earthquakes, so for the design purposes it is necessary to represent the building's range of responses to ground motion of different frequency content. Such a representation is called as a site response spectrum. A site response spectrum is a graph in which the maximum response values of displacements, acceleration, or relative velocity are plotted against undamped natural period (and frequency) arid for various damping values. Site response spectra are very important tools in earthquake engineering. [8]

2.4.15 Structural Response Factors (S_a/g)

It is a factor denoting the acceleration response spectrum of the structure subjected to earthquake ground vibrations, and depends on natural period of vibration and damping of the structure.

2.4.16 Zone Factor (Z)

It is a factor to obtain the design spectrum depending on the perceived maximum seismic risk characterized by Maximum Considered Earthquake (MCE) in the zone in which the structure is located. The basic zone factors included in this standard are reasonable estimate of effective peak ground acceleration.

Table 2.1*[7] Zone factors

Seismic Zone	II	III	IV	V
Seismic Intensity	Low	Moderate	Severe	Very severe
Z	0.10	0.16	0.24	0.36

2.4.17 Design Seismic Base Shear (V_B)

The Total horizontal force acting on the ground storey columns is the sum of the seismic forces acting at all the levels above. This is defined as the seismic base shear. The total design lateral force or design seismic base shear (V_B) along any principal direction shall be determined by the following expression:

$$V_B = A_h * W$$

Where,

A_h = Design horizontal acceleration spectrum value using the fundamental natural period Ta in the considered direction of vibration; and

W= Seismic weight of the building

2.4.18 Moment-Resisting Frame

Moment resisting frames carry lateral loads primarily by flexure in the members and joints. Joints are designed and constructed in such a way so that they are theoretically completely rigid therefore any lateral deflection of the frame occurs from the bending of columns and beams. These are more flexible than braced frames or shear wall structures; the horizontal deflection, or drift, is greater.

2.4.19 Ordinary Moment-Resisting Frame

It is a steel or concrete moment-resisting frame that does not meet the special detailing requirements for ductile behaviour. Ordinary steel frames may be used in any seismic zones while ordinary concrete frames cannot be used in zones III or IV.

2.4.20 Special Moment-Resisting Frame

It is a moment-resisting frame specially detailed to provide ductile behaviour and comply with the requirements given in IS 4326 or IS 13920 or SP 6 (6).

2.4.21 Storey Drift

Drift is the lateral movement of a building under the influence of earthquake induced vibrations. It is the displacement of one level relative to the other level above or below. Drift as a limiting factor is important in order to ensure that exterior facades do not break off or crack excessively. When the two buildings or portions of buildings are isolated by a seismic joint, they must be separated by at least the sum of the drifts to avoid pounding during an earthquake.

2.4.22 Storey Shear (V_i)

The Total lateral force acting on the storey under consideration is the sum of the seismic forces acting at all the levels above. This is defined as the seismic storey shear.

2.4.23 Soil Types

Three soil types are considered here [4]:

- Hard soil (Firm soil)- Those soils which have an allowable bearing capacity of more than 10 t/m^2
- Medium Soil - Those soils, which have allowable bearing capacity less than or equal to 10 t/m^2
- Soft Soil - Those soils, which are liable to large Differential settlement or liquefaction during an earthquake.

  Appropriate soil investigations should be carried out to establish the allowable bearing capacity and nature of soil. Soft soils must be avoided or compacted to improve them so as to qualify as hard or medium soil.

2.4.24 Design Spectrum

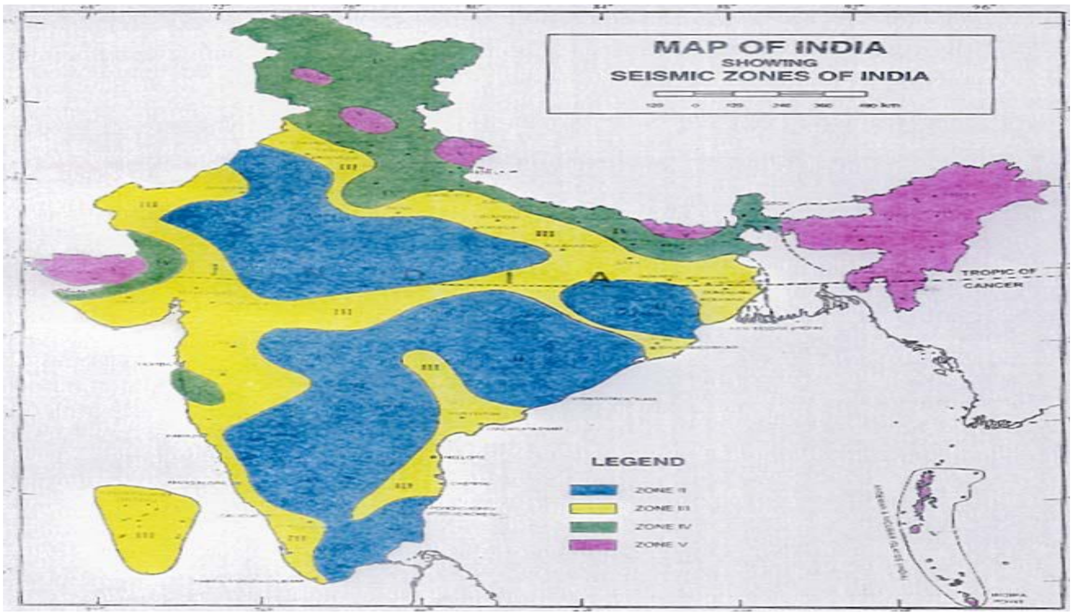

Figure 2.4*[12] Seismic Zones of India as per IS 1893:2002

For the purpose of determining seismic forces, the country is classified into four seismic zones as shown in Fig. 2.4.

As per IS1893:2002 (Part 1), India has been divided into 4 seismic hazard zones (*see* Fig. 2.4). The details of different seismic zones are given below:

Zone II Low seismic hazard (damage during earthquake may be of MSK Intensity VI or lower)

Zone III Moderate seismic hazard (maximum damage during earthquake may be up to MSK Intensity VII)

Zone IV High seismic hazard (maximum damage during earthquake may be up to MSK Intensity VIII)

Zone V Very high seismic hazard (maximum damage during earthquake may be of MSK Intensity IX or greater)

The design horizontal seismic coefficient for a structure shall be determined by the following mathematical expression [7]:

$$A_h = \frac{ZIS_a}{2Rg}$$

Provided that for any structure with T ≤ 0.1s, the value of A_h will not be taken less than Z/2 whatever be the value of where

Z= Zone factor given in Table 2.1, is for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Maximum Considered Earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE).

I= Importance factor, depending upon the functional use of the structures, characterised by hazardous consequences of its failure, post earthquake functional needs, historical value, or economic importance (Table 2.2).

R= Response reduction factor, depending on the perceived seismic damage performance of the structure, characterised by ductile or brittle deformations. However, the ratio (I/R) shall not be greater than 1.0 (Table 2.3). The values of R for buildings are given in Table 2.3.

S_a/g= Average response acceleration Coefficient

Figure 2.5 shows the proposed 5 percent spectra for rocky and soils sites

For rocky, or hard soil sites

$$\frac{S_a}{g} = \begin{cases} 1 + 15T & 0.00 \le T \le 0.10 \\ 2.50 & 0.10 \le T \le 0.40 \\ \frac{1}{T} & 0.40 \le T \le 4.00 \end{cases}$$

For medium soil sites

$$\frac{S_a}{g} = \begin{cases} 1 + 15T & 0.00 \leq T \leq 0.10 \\ 2.50 & 0.10 \leq T \leq 0.55 \\ \dfrac{1.36}{T} & 0.55 \leq T \leq 4.00 \end{cases}$$

For soft soil sites

$$\frac{S_a}{g} = \begin{cases} 1 + 15T & 0.00 \leq T \leq 0.10 \\ 2.50 & 0.10 \leq T \leq 0.67 \\ \dfrac{1.67}{T} & 0.67 \leq T \leq 4.00 \end{cases}$$

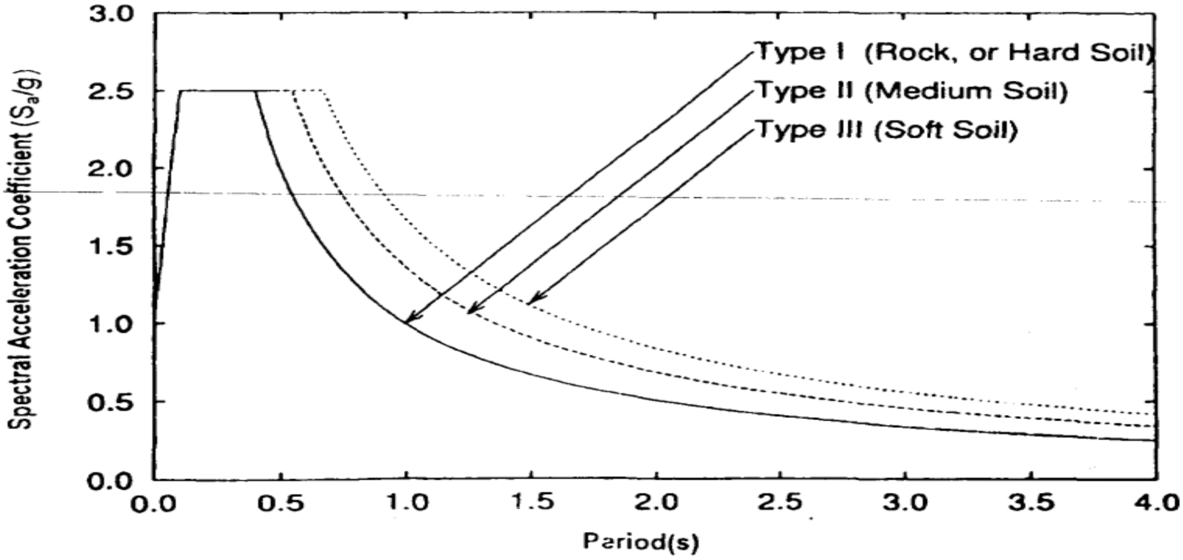

Figure 2.5*[7] Spectral Acceleration Coefficient Vs Period

Table 2.2*[7] Importance Factor, I

SI. No. (1)	Structure (2)	Importance Factor (3)
i)	Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, tire station buildings; large community halls like cinemas, assembly halls and subway stations, power stations	1.5
ii)	All other buildings	1.0

Table 2.3*[7] Response Reduction Factor, R, for Building Systems

SI. NO. (1)	Lateral Load Resisting System (2)	R (3)
	Building Frame Systems	
(i)	Ordinary RC moment –resisting frame(OMRF)	3.0
(ii)	Special RC moment-resisting frame(SMRF)	5.0
(iii)	Steel frame with a) Concentric braces b) Eccentric braces	 4.0 5.0
(iv)	Steel moment resisting frame building with shear walls	5.0
(v)	Load bearing masonry wall buildings a) Unreinforced b) Reinforced with horizontal RC bands c) Reinforced with horizontal RC bands and vertical bars at corners of rooms and	 1.5 2.5 3.0
(vi)	Ordinary reinforced concrete shear walls	3.0
(vii)	Ductile shear walls	4.0
	Buildings with Dual System	
(viii)	Ordinary shear wall with OMRF	3.0
(ix)	Ordinary shear wall with SMRF	4.0
(x)	Ductile shear wall with OMRF	4.5
(xi)	Ductile shear wall with SMRF	5.0

Table 2.4*[7] Percentage of Imposed Load to be considered in seismic weight calculation

Imposed Uniformity Distributed Floor Loads (kN/m^2) (1)	Percentage of Imposed Load (2)
Upto and including 3.0	2.5
Above	50

2.4.25 Dynamic Analysis

Dynamic analysis shall be performed to get the design seismic force and its distribution to various levels along the height of the building and to the different lateral load resisting elements, for the following buildings:

- Regular buildings —those greater than 40 m in height in Zones IV and V, and those greater than 90 m in height in Zones II and III.
- Irregular buildings -All framed buildings higher than 12 m in Zones IV and V, and those greater than 40 m in height in Zones II and III.

The damping values for the buildings may be taken as 2 and 5 % of the critical, for the purposes of dynamic analysis of steel and reinforced concrete buildings, respectively.

2.5 METHODS OF DYNAMIC ANALYSIS

Following are the methods of dynamic analysis

2.5.1 Time History Analysis

It is an analysis of the dynamic response of the structure at each increment of time, when its base is subjected to a specific ground motion time history. Accelerograms at the ground surface are needed for input into the analyses. All accelerograms selected for the analyses must be compatible with the design earthquake scenario, the seismic-tectonic environment of the region, the geology of the area and geotechnical details in relation to the overlying soil particles of the sites. [13]

2.5.2 Response Spectrum Analysis

The representation of the maximum response of idealized single degree freedom system having certain period and damping, during different earthquake ground motions. Such a representation is called as a site response spectrum. A site response spectrum is a graph in which the maximum response values of displacements, acceleration, or relative velocity are plotted against un-damped natural period (and frequency) arid for various damping values. Site response spectra are very important tools in earthquake engineering. [9]

2.6 DYNAMIC ANALYSIS BY RESPONSE –SPECTRUM METHOD

The response spectrum represents an envelope of upper bound responses, which are based on several different ground motion records. For the purpose of seismic analysis, the design spectrum given in figure 2.5 is used. This response spectrum is based on strong motion records of eight Indian earthquakes. This spectrum method is an elastic dynamic analysis approach that relies on the assumption that dynamic response of the structure may be found by considering the individual response of each natural mode of vibration and then combining the response of each in the same way. This is the fact that generally only few of the lowest modes of vibration have importance while calculating deflections, moments, and shear at various levels of the building. [15]

Following procedure is used for the spectrum analysis [15]:

1) The design spectrum is selected
2) The mode shapes and periods of vibration to be included in the analysis to be determined
3) The level of response from the spectrum for the period of each of the modes considered is noted down.
4) Participation of each mode corresponding to the single-degree-of-freedom response obtained from the curve is calculated.
5) The effect of modes is added to obtain combined maximum response.
6) The combined maximum response are converted into shears and moments for use in design of the structure.

Analysis of the building is done for the resulting moments and shears in the same manner as the static loads. In response reduction method, by a free vibration analysis, natural frequencies and mode shapes are obtained. The design lateral force at each floor level for each mode of vibration is given by the following equation. The peak shear force acting in storey i in mode k is given by the equation.

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

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

The peak storey shear force in storey i due to all modes considered is obtained by combining those due to each mode in accordance with using Square Root of Sum of Square (SRSS) combination given by equation. So the lateral force at each storey due to all modes considered is calculated by the equation

$$F_{roof} = V_{roof}$$

$$F_i = V_i - V_{i+1}$$

In response spectrum method the peak response of the structure is calculated from combination of the model, the following two methods can be used.

- Square Root of Sum of Square (SRSS) Method

$$\lambda = \sqrt{\sum_{k=1}^{r} \lambda_k^2}$$

Where,

k = Absolute value of quantity in mode k

r = Number of modes being considered.

- Complete Quadratic Combination Method:

$$\lambda = \sqrt{\sum_{i=1}^{r} \sum_{j=1}^{r} \lambda_i \rho_{ij} \lambda_j}$$

Where, λ_i = Response quantity in mode

ρ_{ij} = Cross modal coefficient

λ_j = Response quantity in mode j

$$\rho_{ij} = \frac{8\zeta^2(1+\beta)\beta^{1.5}}{(1-\beta^2)^2 + 4\zeta^2\beta(1+\beta)^2}$$

Where, ζ = Modal damping ratio in fraction

β = Frequency ratio = ω_j / ω_i

ω_i = Circular Frequency in i^{th} mode

ω_j = Circular frequency in j^{th} mode

2.7 PROCEDURE FOR DYNAMIC ANALYSIS IN STAAD PRO

This is precise method of analysis. The design lateral force at each floor for each mode is computed by STAAD Pro in compliance with IS: 1893 (Part 1)-2002. The software gives result for design values, storey wise base shear and modal masses.

Methodology: The design lateral shear force at each floor for each mode is computed by STAAD Pro in accordance with the IS: 1893 (Part 1) - 2002 by following equation.

$$Q_{ik} = A_k*\Phi_{ik}*P_k*W_k, \text{ and}$$

$$V_{ik} = Q_{ik}$$

STAAD Pro utilizes the following procedure to produce the lateral seismic loads. [15]

- The value for (Z/2)*(I/R) as factors for input spectrum are provided.
- Software program calculates time periods for various modes.
- Software program calculates Sa/g for each mode utilizing damping and time period for each mode.
- The software program calculates design horizontal acceleration spectrum A_k for various modes.
- The software program calculates mode participation factor for various modes.
- The peak lateral seismic force is calculated at each floor for each mode.
- All response quantities are calculated for each mode.
- The peak response quantities are then combined as per method (CQC or SRSS) as defined to get the final results.

3. AIMS AND OBJECTIVES

3.1 OBJECTIVES

The objectives of the present study are mentioned below

1. Study of fundamental of seismic dynamic analysis of a building and factors governing dynamic behaviours.
2. Modelling and dynamic analysis of a building (response factor method) using STAAD PRO.
3. Study of variation of certain parameters which affect dynamic behaviours (like Spectral acceleration coefficient, Zone factor, response reduction factor) and their effects on building response parameter (like base shear, peak storey shear, storey drift etc.) of the building being considered.
4. Plotting of graphs and drawing suitable inferences and conclusions.

3.2 METHODOLOGY

The methodology for the project can easily explained by the following flowchart-

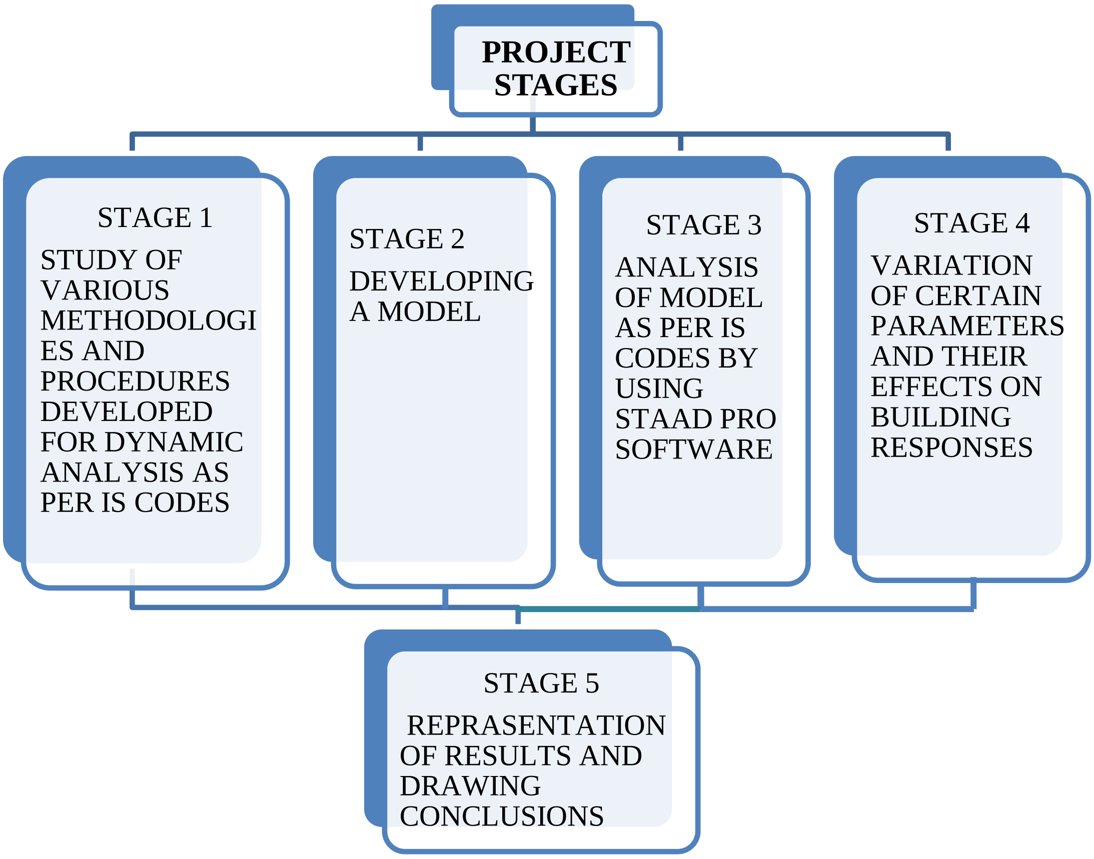

Figure 3.1 Flowchart of project overview

4. MODELLING

4.1 OVERVIEW

This project includes modelling and dynamic analysis of multi-storeyed building [G + 4 (3 dimensional frame)] and study of its dynamic behaviour with variation in different parameters (like zone factor, response reduction factor, soil types) using STAAD Pro.

From model generation, analysis and result verification, STAAD. Pro is the professional's choice. STAAD Pro has a very interactive user interface which allows the users to draw the frame and input the load values and dimensions. Then according to the specified criteria assigned it analyses the structure and designs the members with reinforcement details for RCC frames.

Initially, an irregular multi-storeyed building (3-D RCC frame) with the dimensions of 5 bays in z-axis and 3 bays in x-axis is modelled in STAAD Pro and analysed for all possible load combinations [dead, live and seismic loads] as per Indian Standard Code of practice. Then building responses like base shear, peak storey shear and storey drift has been analysed while changing various parameters (like zone factor, response reduction factor, soil types). Then percentage variation of base shear, peak storey shear and storey drift is plotted with respect to zone factor and soil type.

4.2 MODEL DETAILS

4.2.1Physical Parameters:-

The model consists of 4 bays in z-axis and 3 bays in x-axis forming an irregular configuration as shown in the figure. The height of the building is 15.45 m

BEAMS

- Plinth beams: 0.45 m× 0.50 m (prismatic)
  0.6 m × 0.30 m (prismatic)

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

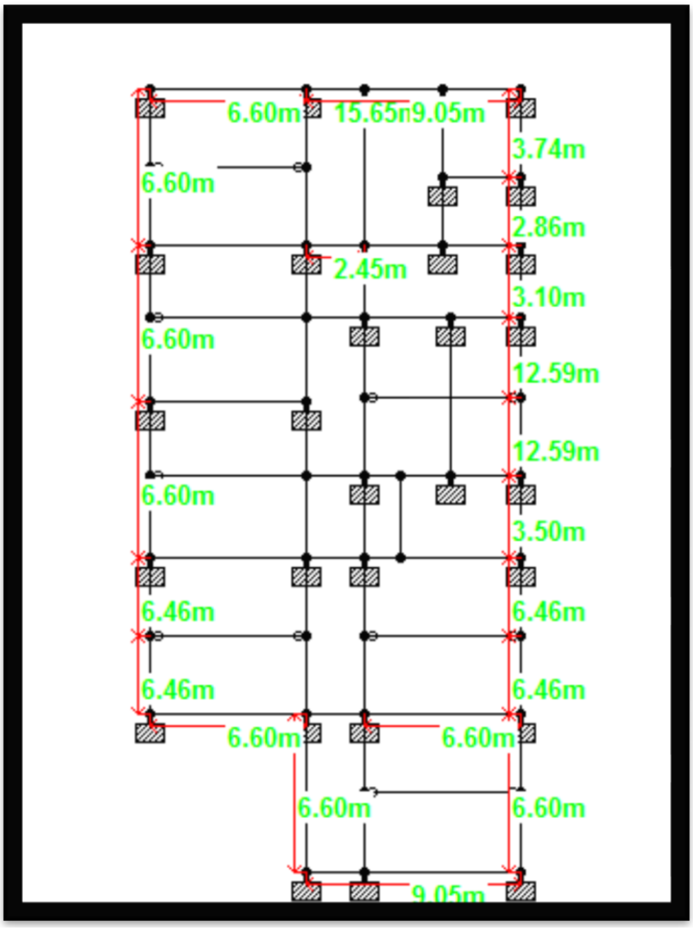

Figure 4.1 Plan of the Model generated by STAAD Pro

Columns-

Columns are rectangular in section with dimensions as described below-

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

Characteristics of the framed building-

Length = 15.65 m (3 bays along x-axis)

Width = 33.0 m (4 bays along z-axis @6.6m)

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

Wall load

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

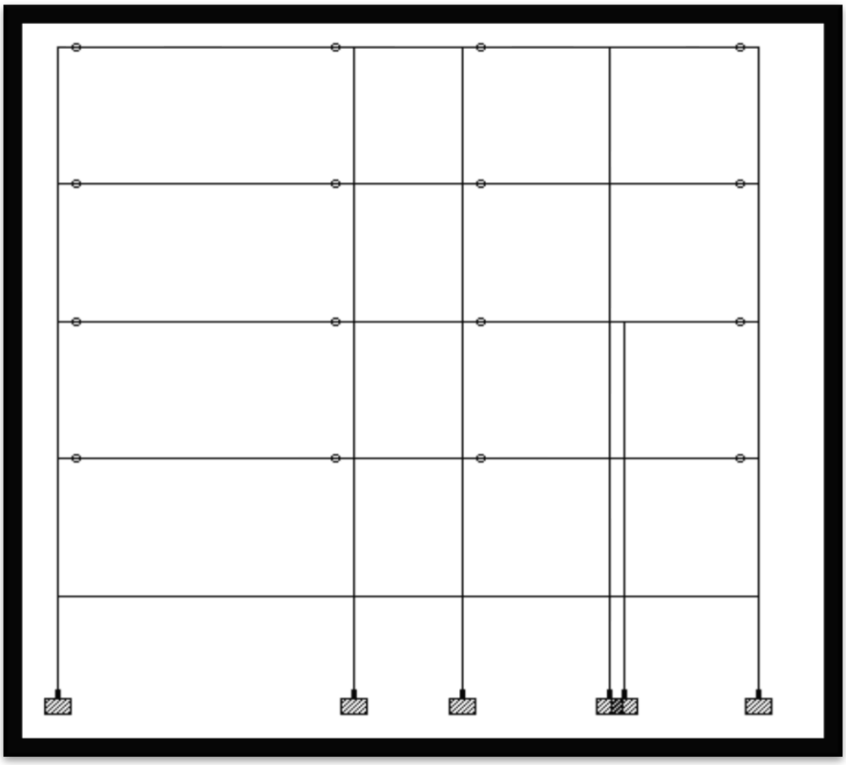

Figure 4.2 Elevation of the Model generated by STAAD Pro

Dead Load on the building-

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

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

b) Dead load acting as the member load-

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

Live load on the building-

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

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

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

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

4.2.2 Supports:

The base of the building is provided with a fixed support. This fixed support is assigned to the building. The supports are generated and allocated to the base of the building

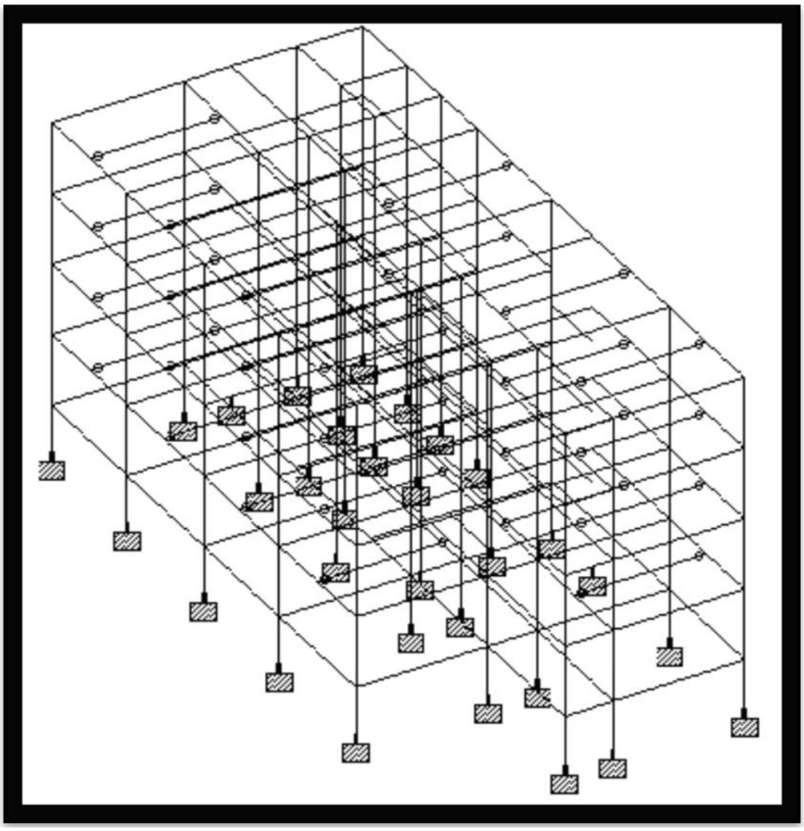

Figure 4.3 Fixing supports of the structure generated by STAAD Pro

4.3 INPUT PARAMETERS

Following parameters are considered in analysis [16]

4.3.1 Materials for the structure

The materials for the building are specified as concrete with their various constants as per standard IS code of practice.

4.3.2 Loading Details

The loadings are calculated partially manually and rest was produced by STAAD Pro load generator. The loading cases are considered as:

- Self-weight
- Dead load from slab
- Live load
- Seismic load
- Load combinations

4.3.2.1 Self-weight

The self weight of the structure is generated by STAAD Pro itself with the self weight command in the load case column.

4.3.2.2 Dead load from slab

Dead load from slab is also produced using STAAD Pro by specifying the thickness of the floor and the load on the floor per sq m. The Calculation of the load per sq m is done considering the weight of beam, weight of column, weight of walls, and weight of RCC slab.

4.3.2.3 Live load

The live load applied on the framed building is of different intensities.

- Live load on roof is -1.5 kN/m^2
- Live load as a floor load is of intensities -1 kN/m^2, -2 kN/m^2,and -3 kN/m^2
- Live load as a member load is of magnitude -10 kN/m , -13.2 kN/m

The live loads are produced in a similar manner as done in the earlier case for dead load for each floor. This may be done from the member load button from the load case column.

4.3.2.4 Seismic load

The seismic load values are calculated as per IS 1893-2002. STAAD Pro has a seismic load generator in compliance with the IS code mentioned above. [16]

Description

The seismic load generator is used to produce lateral loads in the X and Z directions only. Y is the direction of gravity loads. This feature has not been developed for cases where the Z axis is set to be the vertical direction using the "SET Z UP" command.

Methodology

The design base shear is calculated by STAAD Pro in compliance with the IS: 1893(Part 1)-2002.

$$V = A_h*W$$

Where, $A_h = (Z*I*S_a)/ (2*R*g)$

STAAD Pro utilizes the following procedure to produce the lateral seismic loads.

- Seismic zone co-efficient is provided and desired "1893(Part 1)-2002 specification" through the DEFINE 1893 LOAD command.
- The software program calculates the structure period (T).
- The software program calculates Sa/g utilizing structure period (T).
- The software program calculates Base shear (V) from the above equation. Weight (W) is obtained from the weight data provided through the DEFINE 1893 LOAD command.
- The total lateral seismic load (base shear) is distributed by the software program among various levels of the structure as per the IS: 1893(Part 1)-2002 procedures.

4.4 VARIATIONS OF INPUT PARAMETERS

For the building model, changes have been made in the values of response reduction factor, zone factor, and type of soil. Different values of response reduction factor may cover different types of structure while different values of zone factor may cover different areas/seismic zones of the country. Different types of soil may be covered by considering hard/medium/soft soils.

For a particular soil type (like hard soil or medium soil or soft soil), the changes have been made in response reduction factor for each zone. Then corresponding changes in output parameters are obtained.

For a particular zone (like Zone II or Zone III or Zone IV or Zone V), the changes have been made in soil type for each response reduction factor. Then corresponding changes in output parameters are obtained.

For a particular soil type (like hard soil or medium soil or soft soil), the changes have been made in zone factor for each response reduction factor. Then the corresponding changes in output parameters are obtained.

4.5 OUTPUT PARAMETERS

Following are the output parameters considered in analysis

4.5.1 Modal Participation Factor (P_k)

Modal participation factor of mode k of vibration is the amount by which mode k contributes to the overall vibration of the structure under horizontal and vertical earthquake ground motions. Since the amplitudes of 95 percent mode shapes can be scaled arbitrarily, the value of this factor depends on the scaling used for mode shapes.

4.5.2 Storey Drift

Drift is the lateral movement of a building under the influence of earthquake induced vibrations. It is the displacement of one level relative to the other level above or below. Drift as a limiting factor is important in order to ensure that exterior facades do not break off or crack excessively. When the two buildings or portions of buildings are isolated by a seismic joint, they must be separated by at least the sum of the drifts to avoid pounding during an earthquake.

4.5.3 Design Seismic Base Shear

The total design lateral force or design seismic base shear (V_B) along any principal direction shall be determined by the following expression:

$$V_B = W^* A_h$$

Where

A_h = Design horizontal acceleration spectrum value

W = Seismic weight of the building

4.5.4 Peak Storey Shear

It is the Storey Shear Forces due to all modes considered is obtained by combining those due to each Mode.

4.5.5 Frequency

Natural Period T_n of a building is the time taken by it to complete one cycle of oscillation. This property of a building is controlled by its mass m and stiffness k. These three quantities are related by

$$T_n = 2\pi\sqrt{\frac{m}{k}}$$

Its units are seconds (s).

The reciprocal ($1/T_n$) of natural period of a building is called the Natural Frequency f_n; its unit is Hertz (Hz)

4.6 VARIATIONS IN BUILDING RESPONSES

The analysis consists of variation of displacements, base shear and peak storey shear with respect to response reduction factor at each zone for different types of soil. The displacements due to seismic forces at each floor is calculated in mm, peak storey shear at each floor is calculated in kN and base shear for each mode is calculated in kN.

Here R = 3 represents response reduction factor corresponds to ordinary moment resisting frame and R = 5 represents response reduction factor corresponds to special moment resisting frame as given in Table 2.3

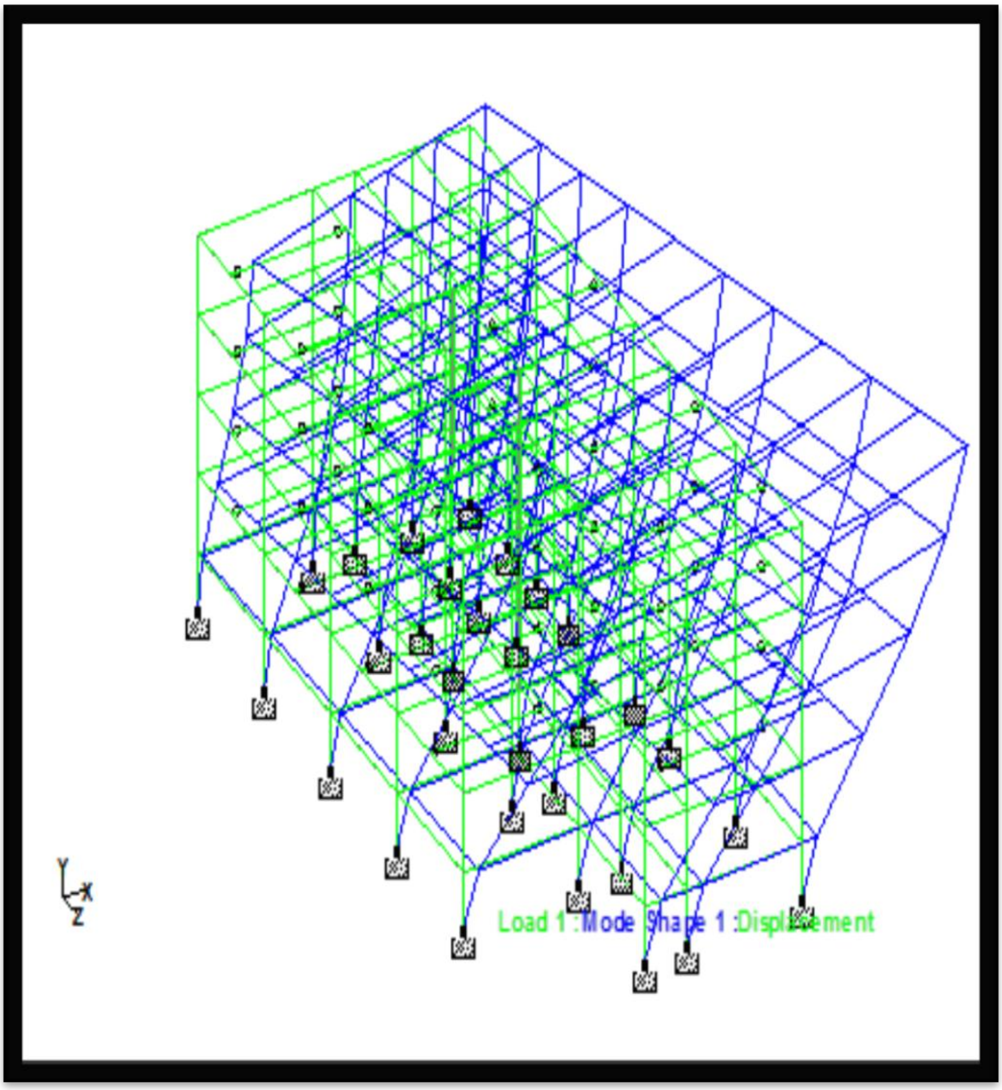

Figure 4.4 Deflected shape of the building generated by STAAD Pro

5. ANALYSIS & DISCUSSIONS OF RESULTS

5.1 DISPLACEMENTS

The displacements due to seismic forces at each floor in x direction for different response reduction factors are taken from output file of the model generated above in STAAD pro. These displacements correspond to hard soil strata for various zone factors.

Table 5.1 Displacements corresponding to hard soil for R=3

Floor	Displacement in mm (Zone II)	Displacement in mm (Zone III)	Displacement in mm (Zone IV)	Displacement in mm (Zone V)
1	0.74	1.18	1.76	2.64
2	3.28	5.28	7.95	11.95
3	5.7	9.21	13.91	20.94
4	7.62	12.36	18.69	28.18
5	8.63	14.08	21.35	32.26

Table 5.2 Displacements corresponding to hard soil for R=5

Floor	Displacement in mm (Zone II)	Displacement in mm (Zone III)	Displacement in mm (Zone IV)	Displacement in mm (Zone V)
1	0.44	0.71	1.06	1.59
2	1.94	3.15	4.75	7.15
3	3.35	5.46	8.28	12.50
4	4.46	7.30	11.10	16.79
5	4.99	8.26	12.62	19.17

Table 5.3 Percentage variations in Displacement for hard soil

Floor	% Variation in Displacement	% Variation in Displacement	% Variation in Displacement	% Variation in Displacement
	Zone II	Zone III	Zone IV	Zone V
1	39.86	39.91	39.95	39.97
2	40.70	40.44	40.29	40.19
3	41.19	40.73	40.48	40.32
4	41.51	40.93	40.61	40.41
5	42.14	41.32	40.87	40.58

The percentage change is calculated as change in displacement corresponds to R=3 and R=5 with displacement corresponds to R=3 response reduction factor. The percentage variation of displacement in x direction with variation of R for different zones (Zone II, Zone III, Zone IV, and Zone V) for hard soil has been plotted graphically as shown below

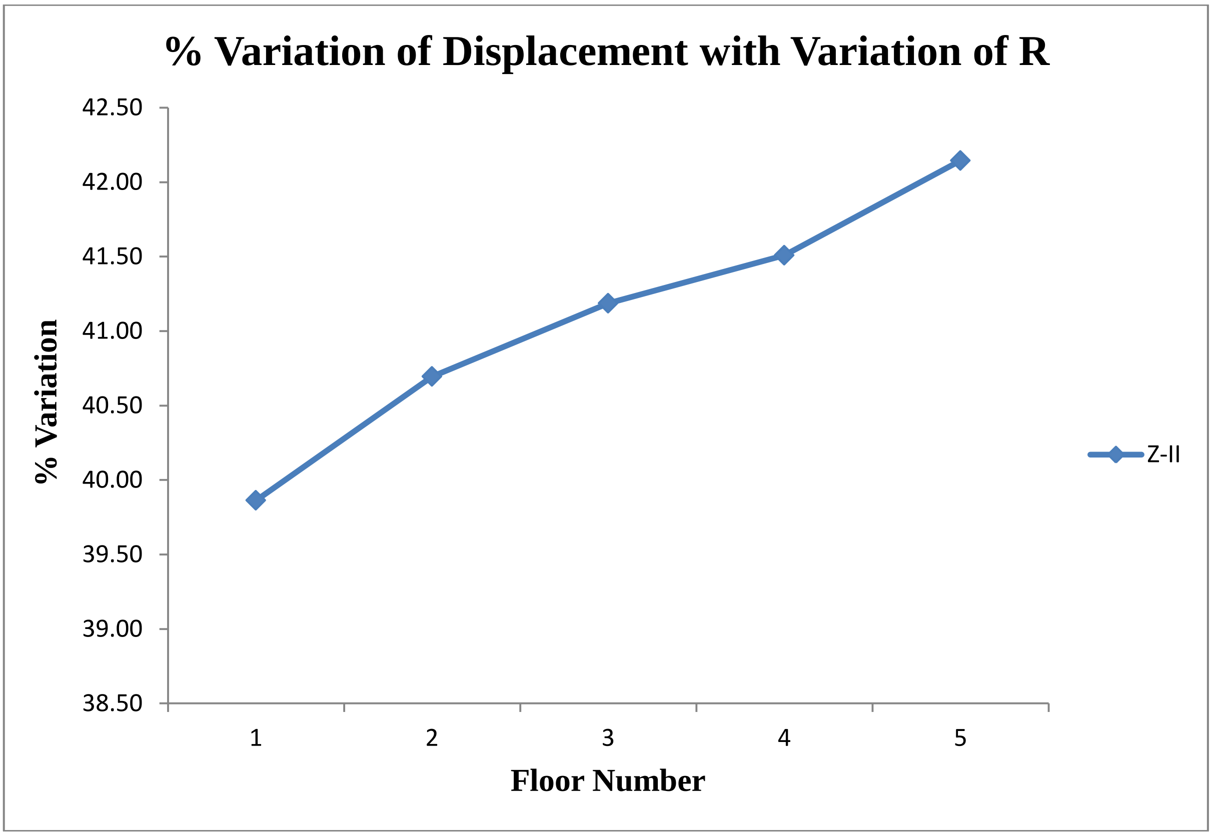

Figure 5.1 Percentage variation of Displacement for Zone II for hard soil

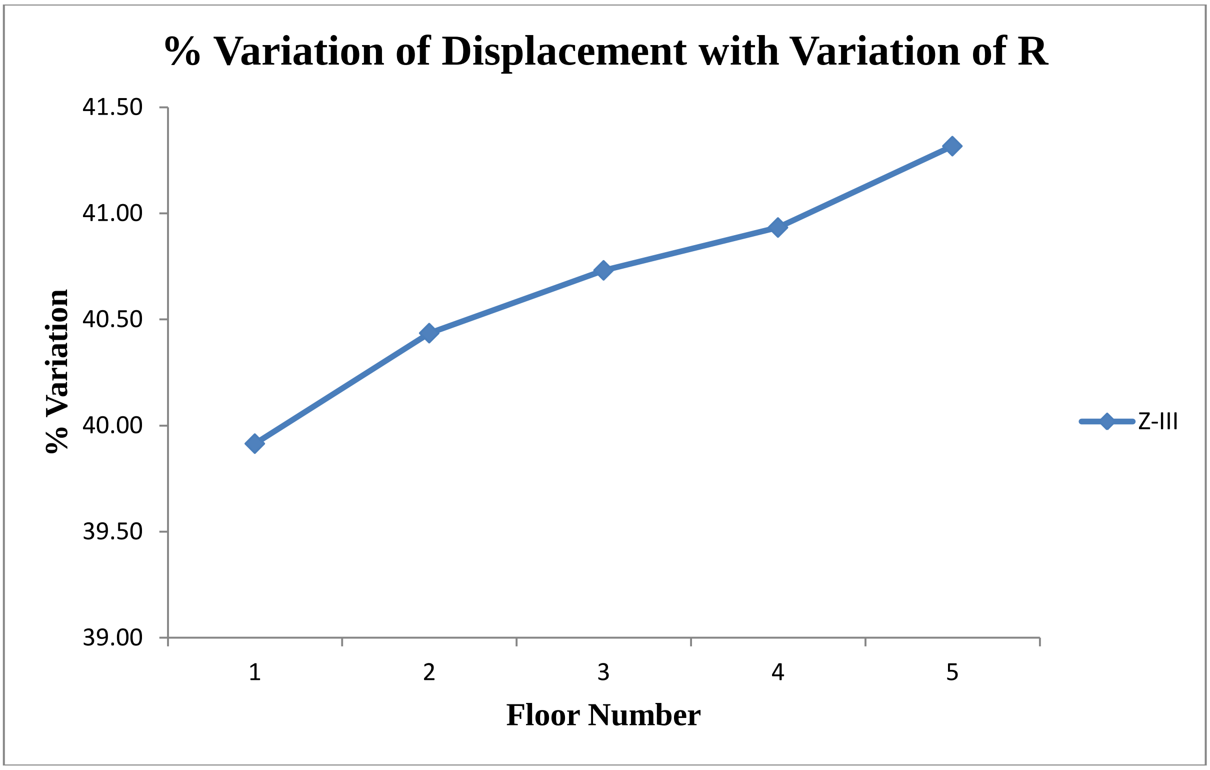

Figure 5.2 Percentage variation of Displacement for Zone III for hard soil

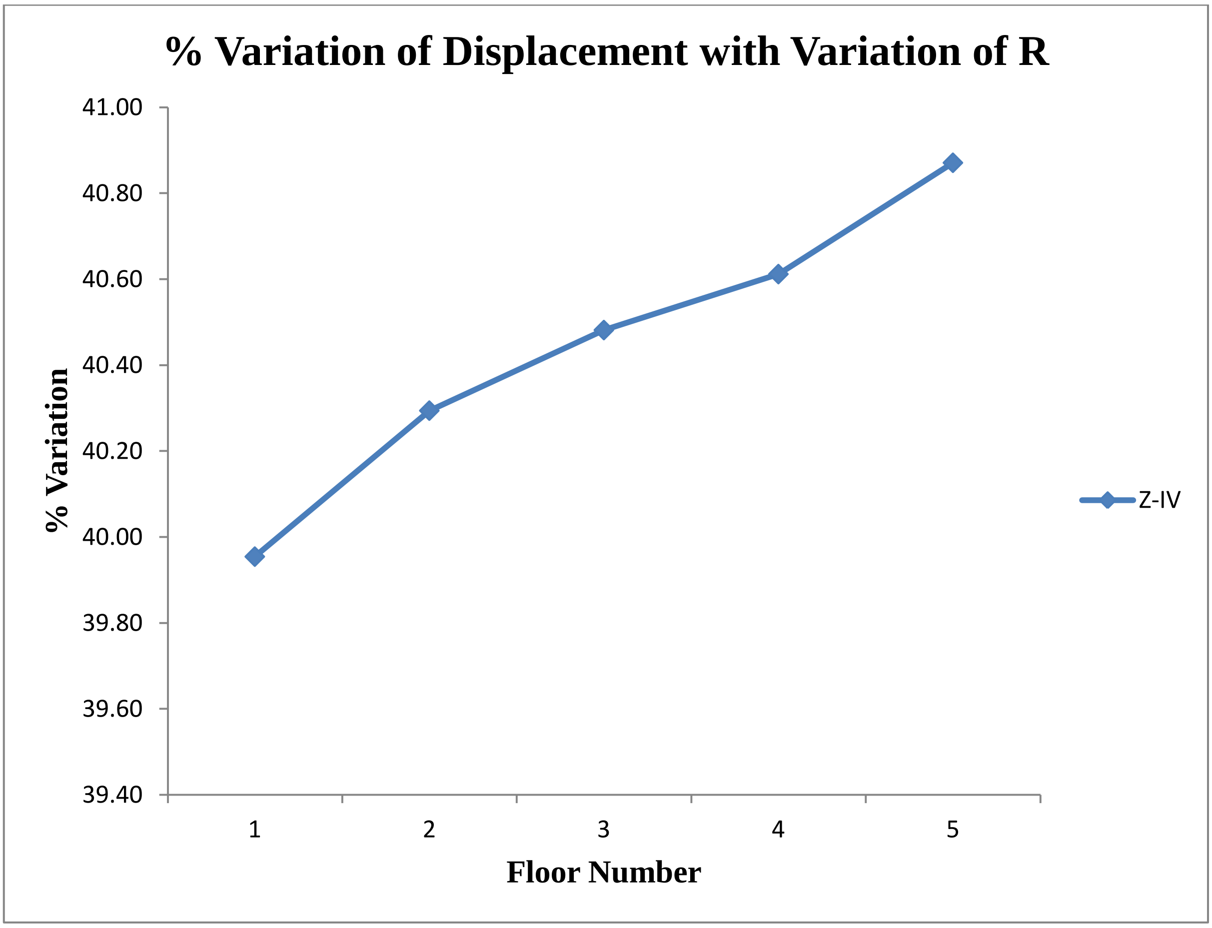

Figure 5.3 Percentage variation of Displacement for Zone IV for hard soil

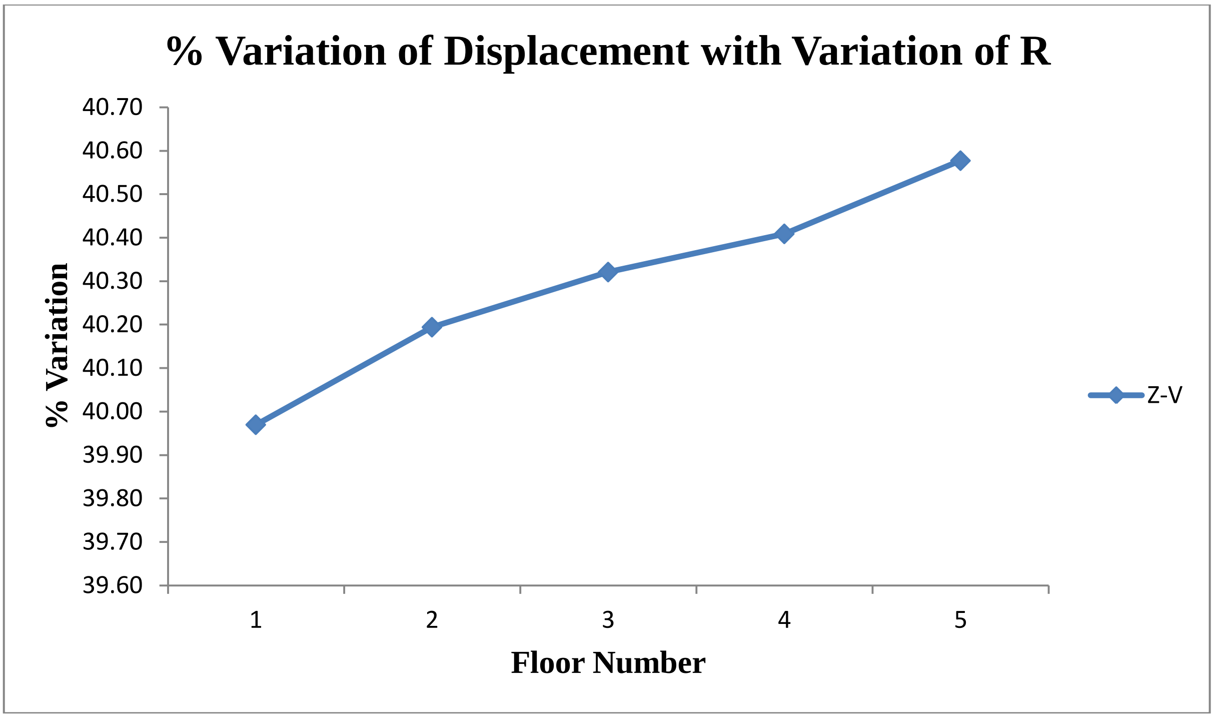

Figure 5.4 Percentage variation of Displacement for Zone V for hard soil

The displacements due to seismic forces at each floor in x direction for different response reduction factors are shown below. These displacements correspond to medium soil strata for various zone factors.

Table 5.4 Displacements corresponding to medium soil for R=3

Floor	Displacement in mm (Zone II)	Displacement in mm (Zone III)	Displacement in mm (Zone IV)	Displacement in mm (Zone V)
1	0.99	1.58	2.37	3.55
2	4.45	7.15	10.75	16.15
3	7.79	12.57	18.93	28.48
4	10.47	16.92	25.52	38.42
5	11.88	19.29	29.17	43.98

Table 5.5 Displacements corresponding to medium soil for R=5

Floor	Displacement in mm (Zone II)	Displacement in mm (Zone III)	Displacement in mm (Zone IV)	Displacement in mm (Zone V)
1	0.59	0.95	1.42	2.13
2	2.64	4.27	6.43	9.67
3	4.61	7.47	11.29	17.02
4	6.16	10.04	15.20	22.94
5	6.94	11.39	17.32	26.20

Table 5.6 Percentage variations in Displacement for medium soil

Floor	% Variation in Displacement	% Variation in Displacement	% Variation in Displacement	% Variation in Displacement
	Zone II	Zone III	Zone IV	Zone V
1	39.92	39.95	39.96	39.96
2	40.52	40.32	40.22	40.14
3	40.86	40.53	40.35	40.24
4	41.10	40.68	40.45	40.30
5	41.56	40.96	40.63	40.42

The percentage change is calculated as change in displacement corresponds to R=3 and R=5 with displacement corresponds to R=3 response reduction factor. The percentage variation of displacement in x direction with variation of R for different zones (Zone II, Zone III, Zone IV, and Zone V) for medium soil has been plotted graphically as shown below

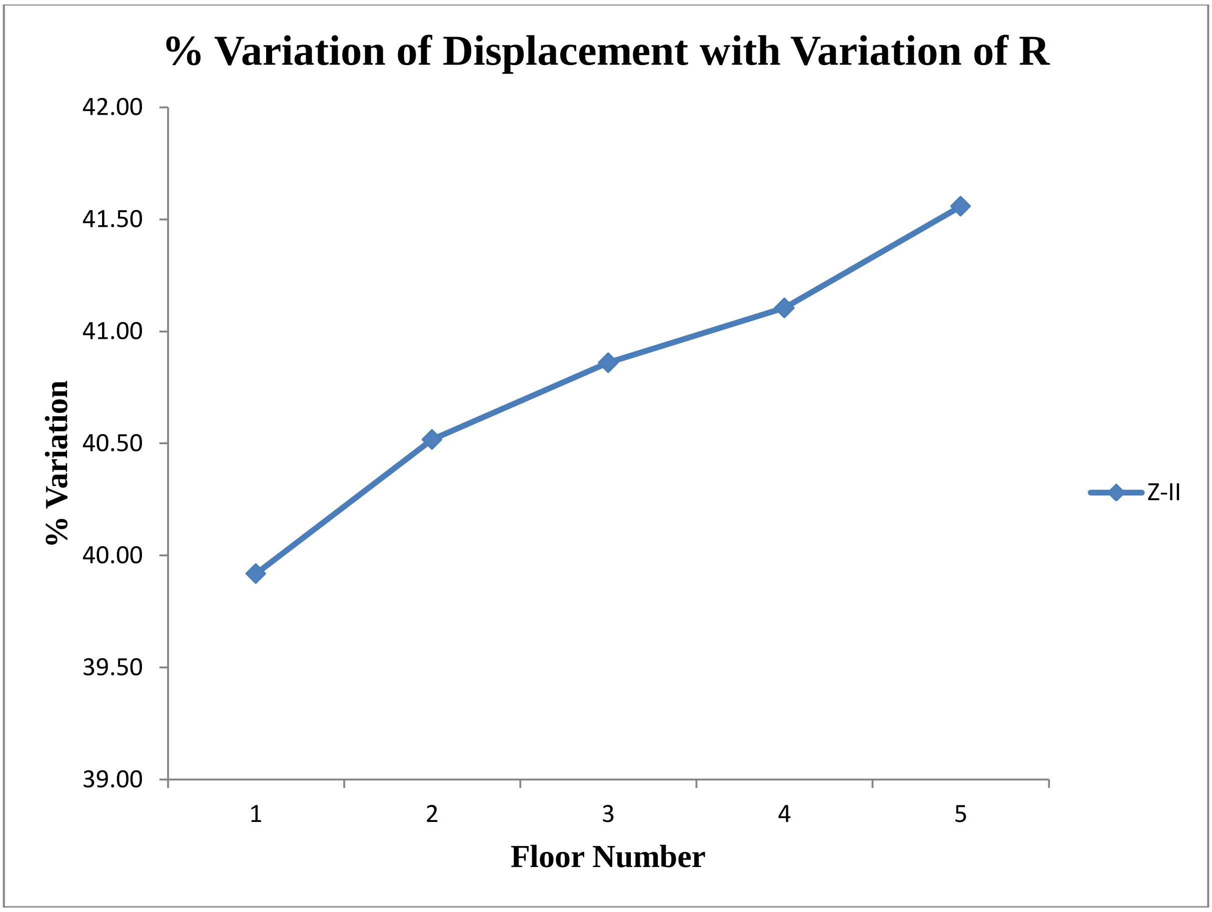

Figure 5.5 Percentage variation of Displacement for Zone II for medium soil

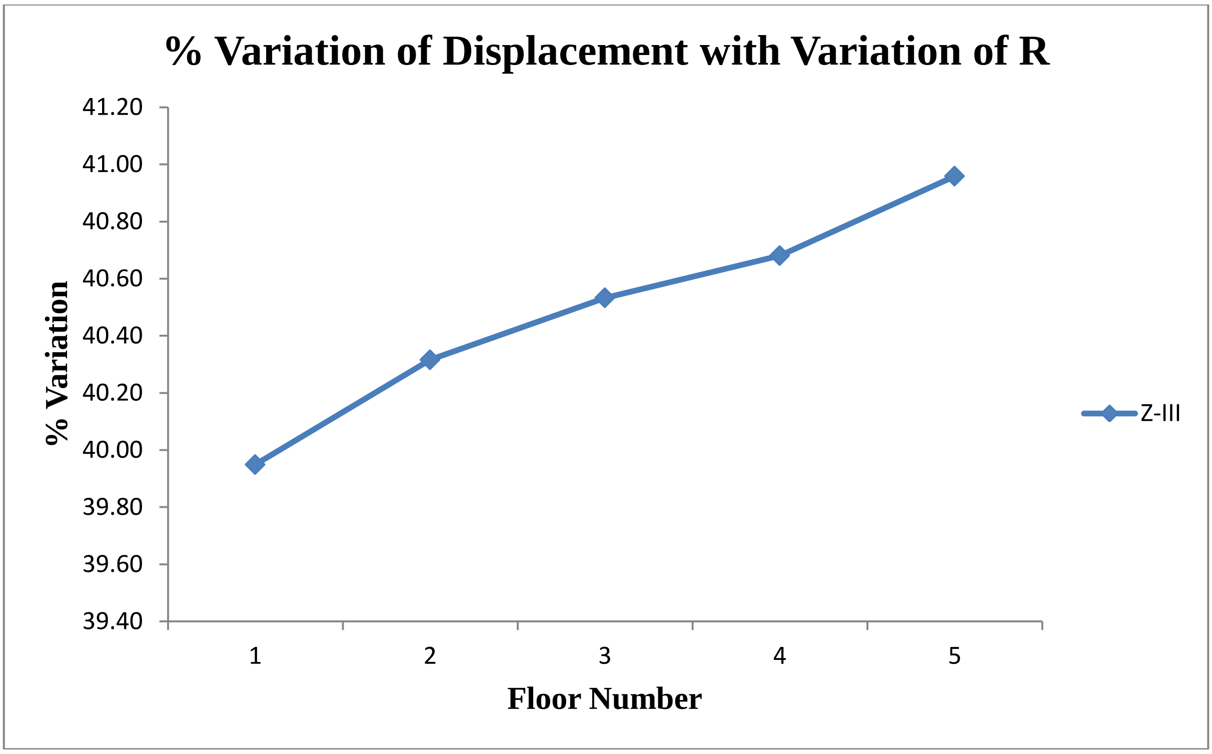

Figure 5.6 Percentage variation of Displacement for Zone III for medium soil

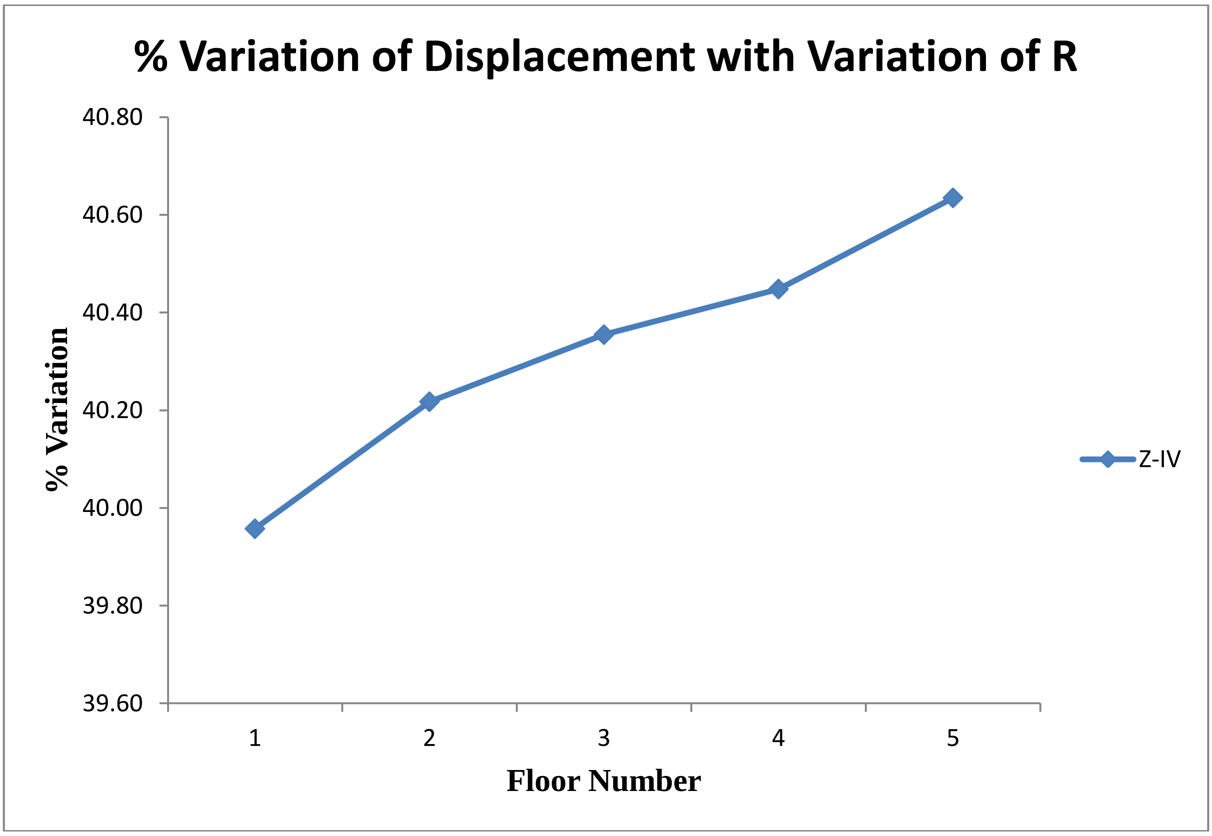

Figure 5.7 Percentage variation of Displacement for Zone IV for medium soil

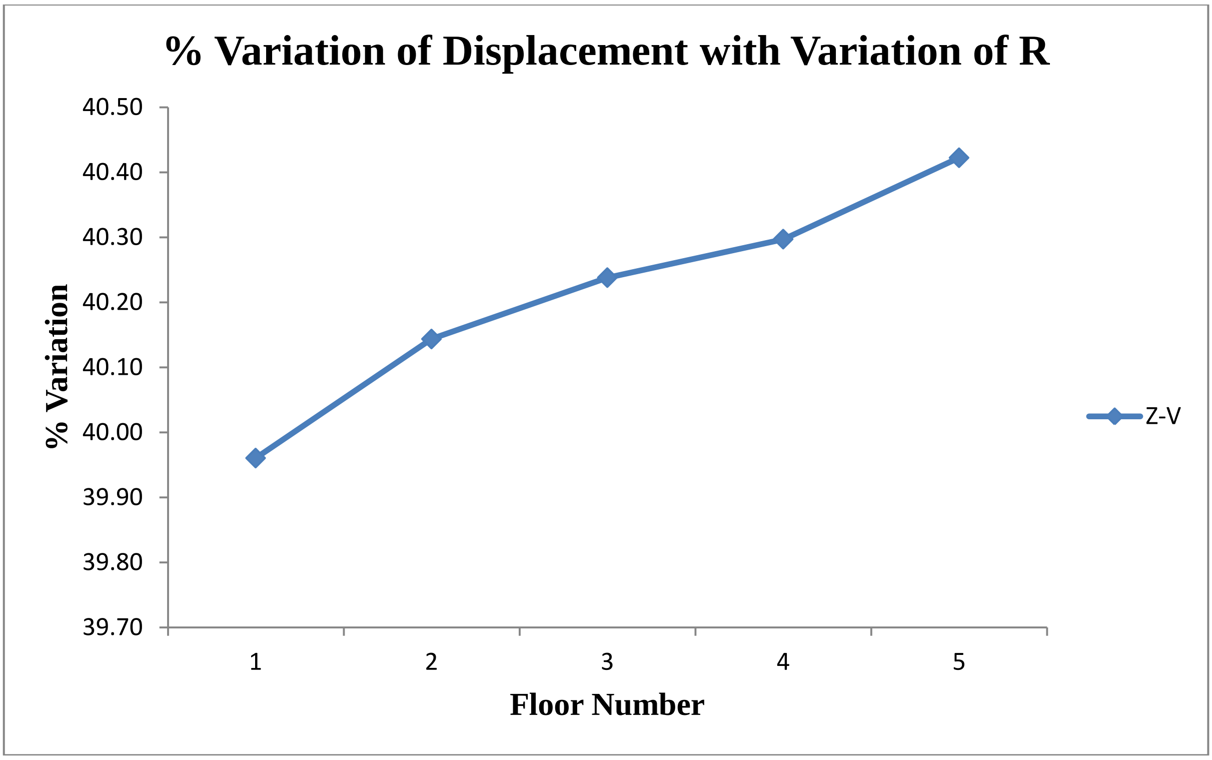

Figure 5.8 Percentage variation of Displacement for Zone V for medium soil

The displacements due to seismic forces at each floor in x direction for different response reduction factors are shown below. These displacements correspond to soft soil strata for various zone factors.

Table 5.7 Displacements corresponding to soft soil for R=3

Floor	Displacement in mm (Zone II)	Displacement in mm (Zone III)	Displacement in mm (Zone IV)	Displacement in mm (Zone V)
1	1.21	1.93	2.89	4.33
2	5.45	8.76	13.17	19.79
3	9.60	15.46	23.27	34.98
4	12.92	20.84	31.40	47.25
5	14.69	23.78	35.90	54.09

Table 5.8 Displacements corresponding to soft soil for R=5

Floor	Displacement in mm (Zone II)	Displacement in mm (Zone III)	Displacement in mm (Zone IV)	Displacement in mm (Zone V)
1	0.72	1.16	1.73	2.60
2	3.25	5.23	7.88	11.85
3	5.69	9.21	13.89	20.92
4	7.64	12.39	18.73	28.23
5	8.63	14.08	21.36	32.27

Table 5.9 Percentage variations in Displacement for soft soil

Floor	% Variation in Displacement	% Variation in Displacement	% Variation in Displacement	% Variation in Displacement
	Zone II	Zone III	Zone IV	Zone V
1	39.92	39.96	39.98	39.98
2	40.41	40.26	40.17	40.12
3	40.70	40.43	40.29	40.19
4	40.89	40.55	40.36	40.24
5	41.26	40.78	40.52	40.34

The percentage change is calculated as change in displacement corresponds to R=3 and R=5 with displacement corresponds to R=3 response reduction factor. The percentage variation of displacement in x direction with variation of R for different zones (Zone II, Zone III, Zone IV and Zone V) for soft soil has been plotted graphically as shown below

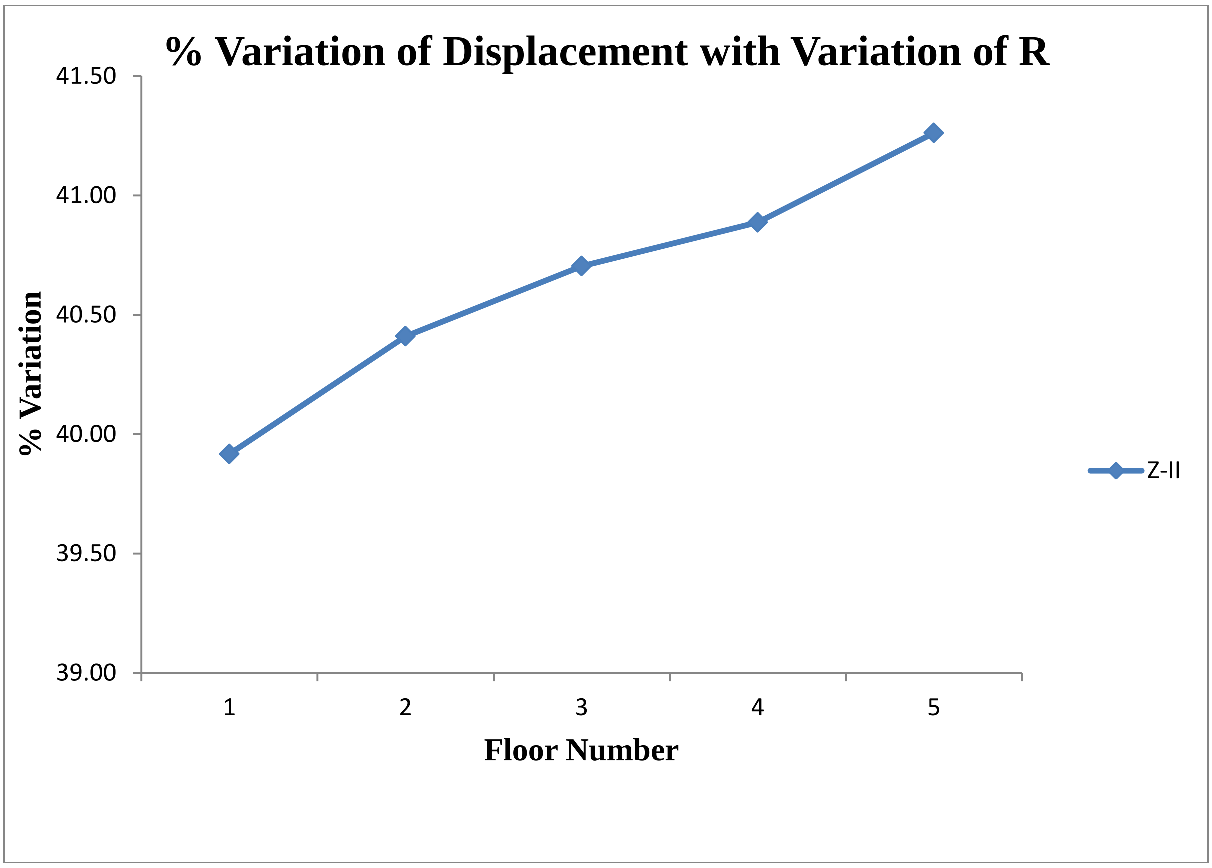

Figure 5.9 Percentage variation of Displacement for Zone II for soft soil

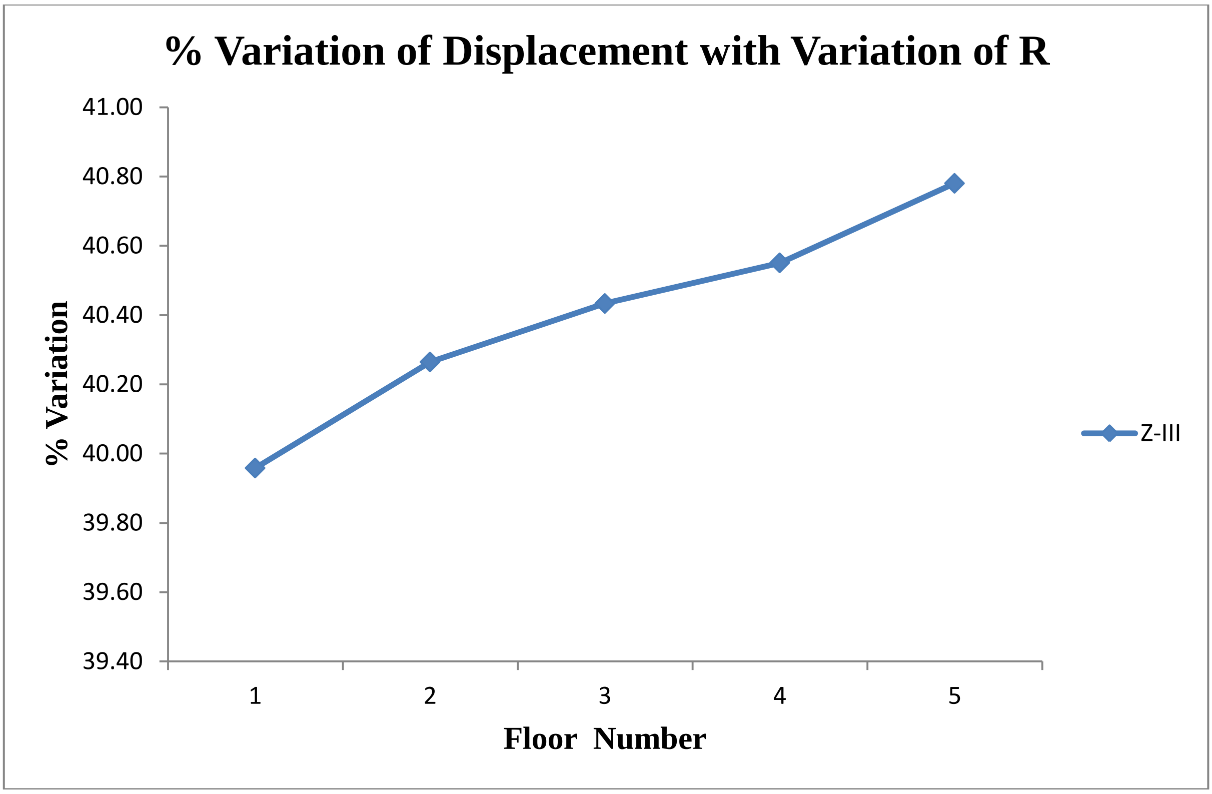

Figure 5.10 Percentage variation of Displacement for Zone III for soft soil

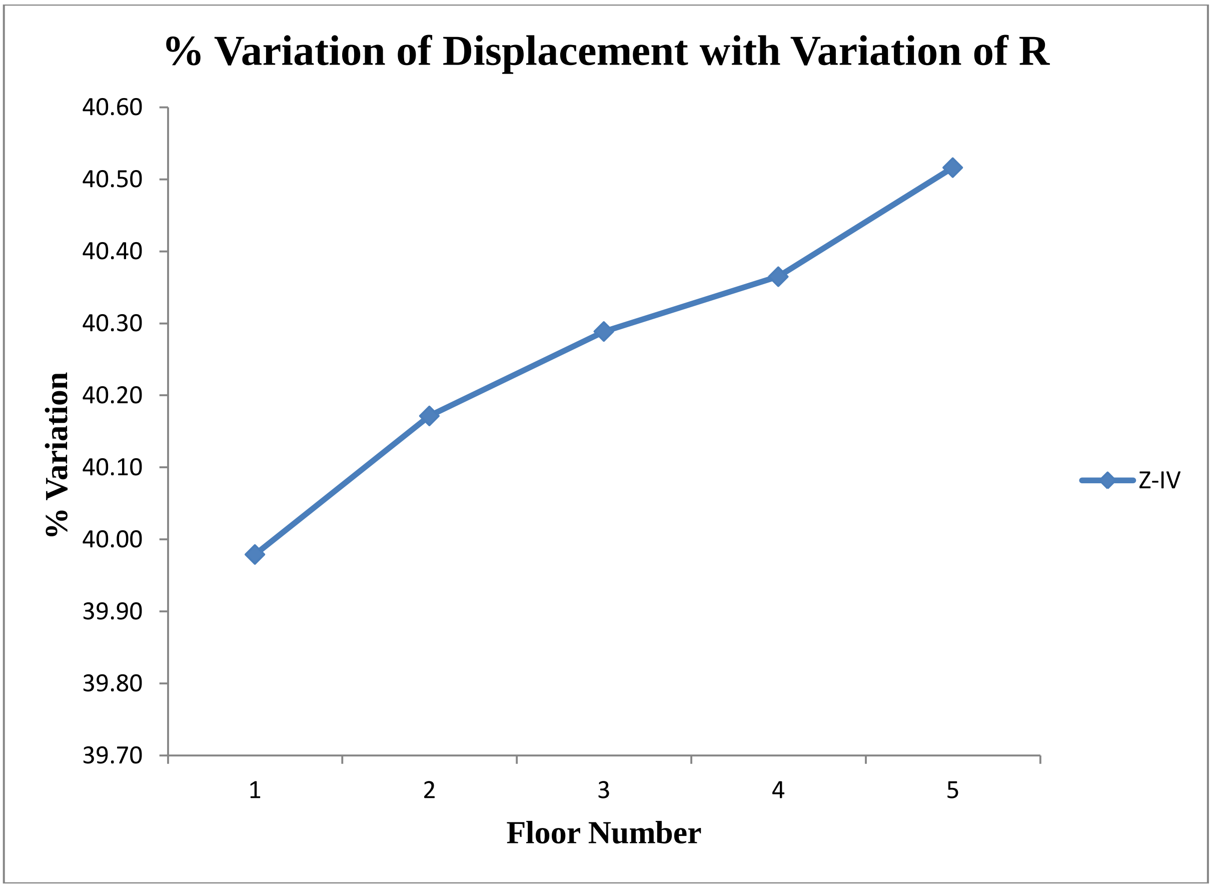

Figure 5.11 Percentage variation of Displacement for Zone IV for soft soil

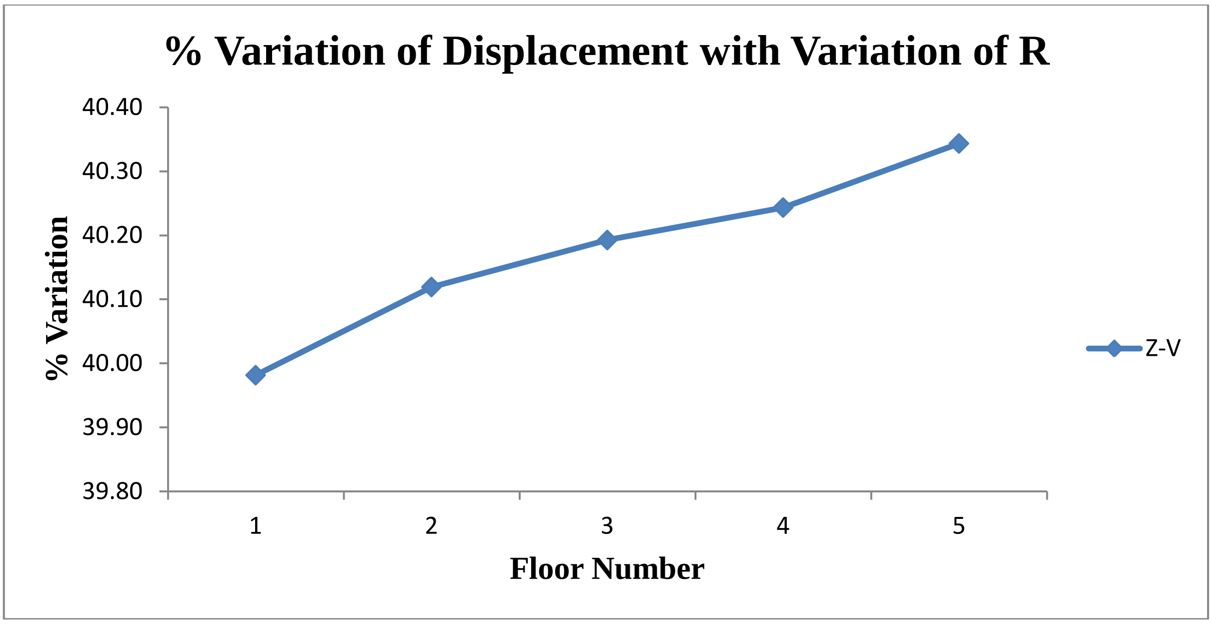

Figure 5.12 **Percentage variation of Displacement for Zone V for soft soil**

5.2 BASE SHEAR

The base shear (x direction) in each mode for different response reduction factors are shown below. These base shears correspond to hard soil strata for various zone factors.

Table 5.10 Base Shear corresponding to hard soil for R=3

Mode	Base Shear in kN (Zone II)	Base Shear in kN (Zone III)	Base Shear in kN (Zone IV)	Base Shear in kN (Zone V)
1	580.51	928.82	1393.22	2089.84
2	180.95	289.53	434.29	651.44
3	53.58	85.73	128.59	192.88
4	159.75	255.60	383.40	575.11
5	29.97	47.96	71.94	107.90

Table 5.11 Base Shear corresponding to hard soil for R=5

Mode	Base Shear in kN (Zone II)	Base Shear in kN (Zone III)	Base Shear in kN (Zone IV)	Base Shear in kN (Zone V)
1	348.31	557.29	835.93	1253.90
2	108.57	173.72	260.58	390.86
3	32.15	51.44	77.15	115.73
4	95.85	153.36	230.04	345.06
5	17.98	28.77	43.16	64.74

Table 5.12 Percentage variations in Base Shear for hard soil

Mode	% Variation in Base Shear	% Variation in Base Shear	% Variation in Base Shear	% Variation in Base Shear
	Zone II	Zone III	Zone IV	Zone V
1	39.999	40.000	40.000	40.000
2	40.000	39.999	39.999	40.001
3	39.996	39.998	40.003	39.999
4	40.000	40.000	40.000	40.001
5	40.007	40.013	40.006	40.000

The percentage change is calculated as change in base shear corresponds to R=3 and R=5 with base shear corresponds to R=3 response reduction factor. The percentage variation of base shear in x direction with variation of R for different zones (Zone II, Zone III, Zone IV and Zone V) for hard soil has been plotted graphically as shown below

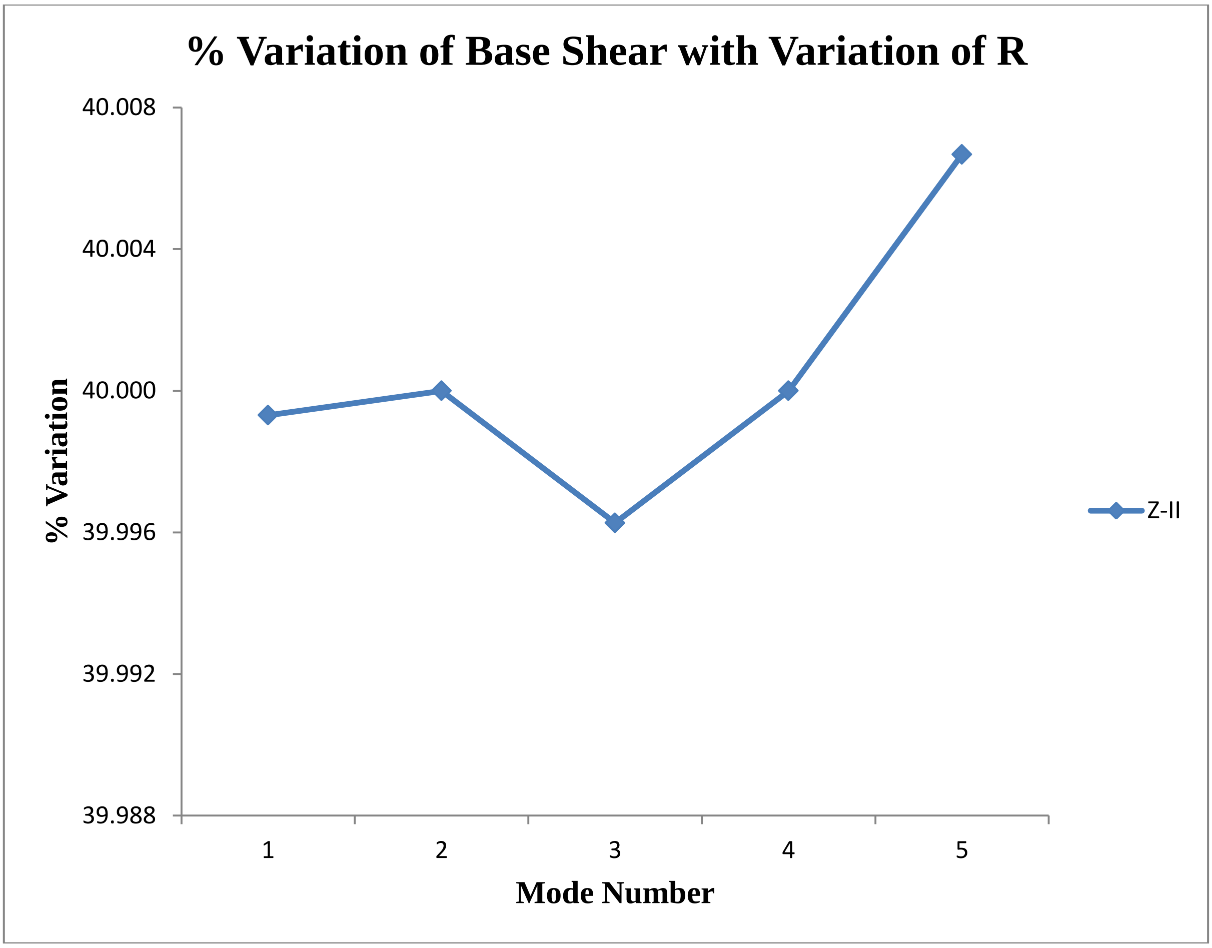

Figure 5.13 Percentage variation of Base Shear for Zone II for hard soil

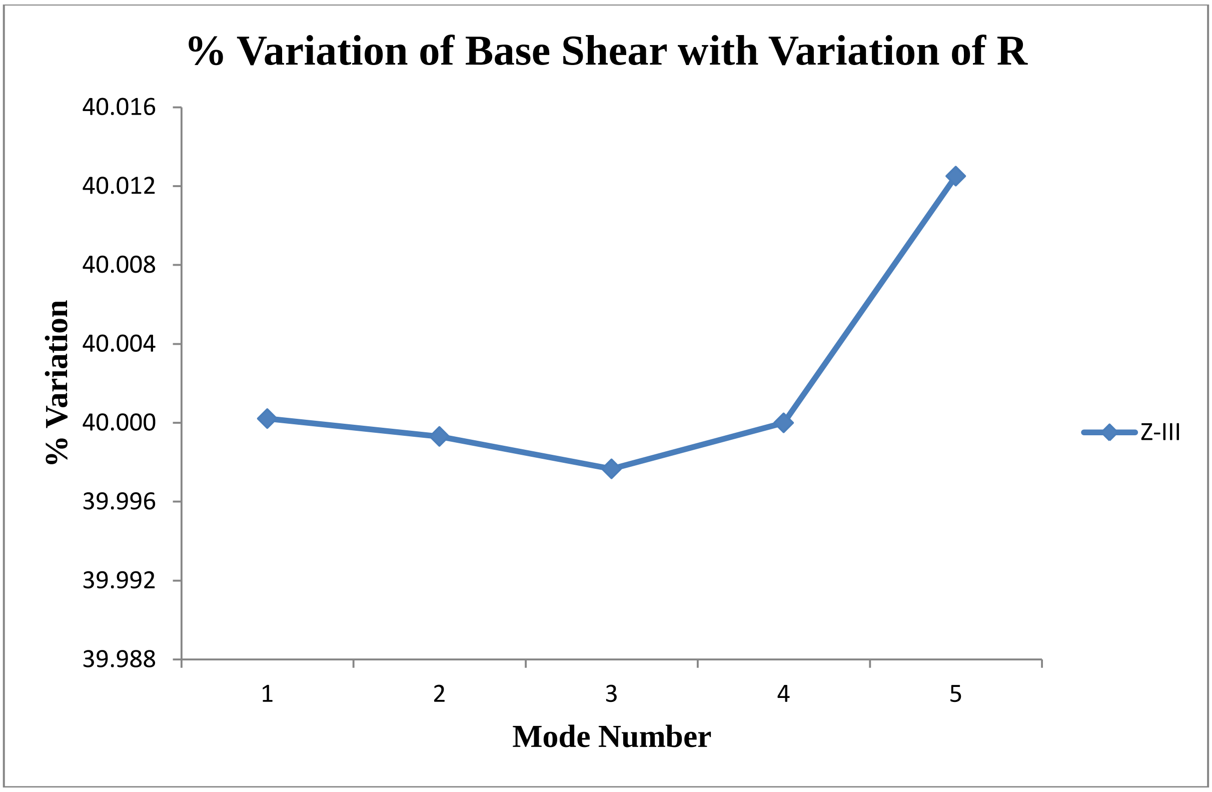

Figure 5.14 **Percentage variation of Base Shear for Zone III for hard soil**

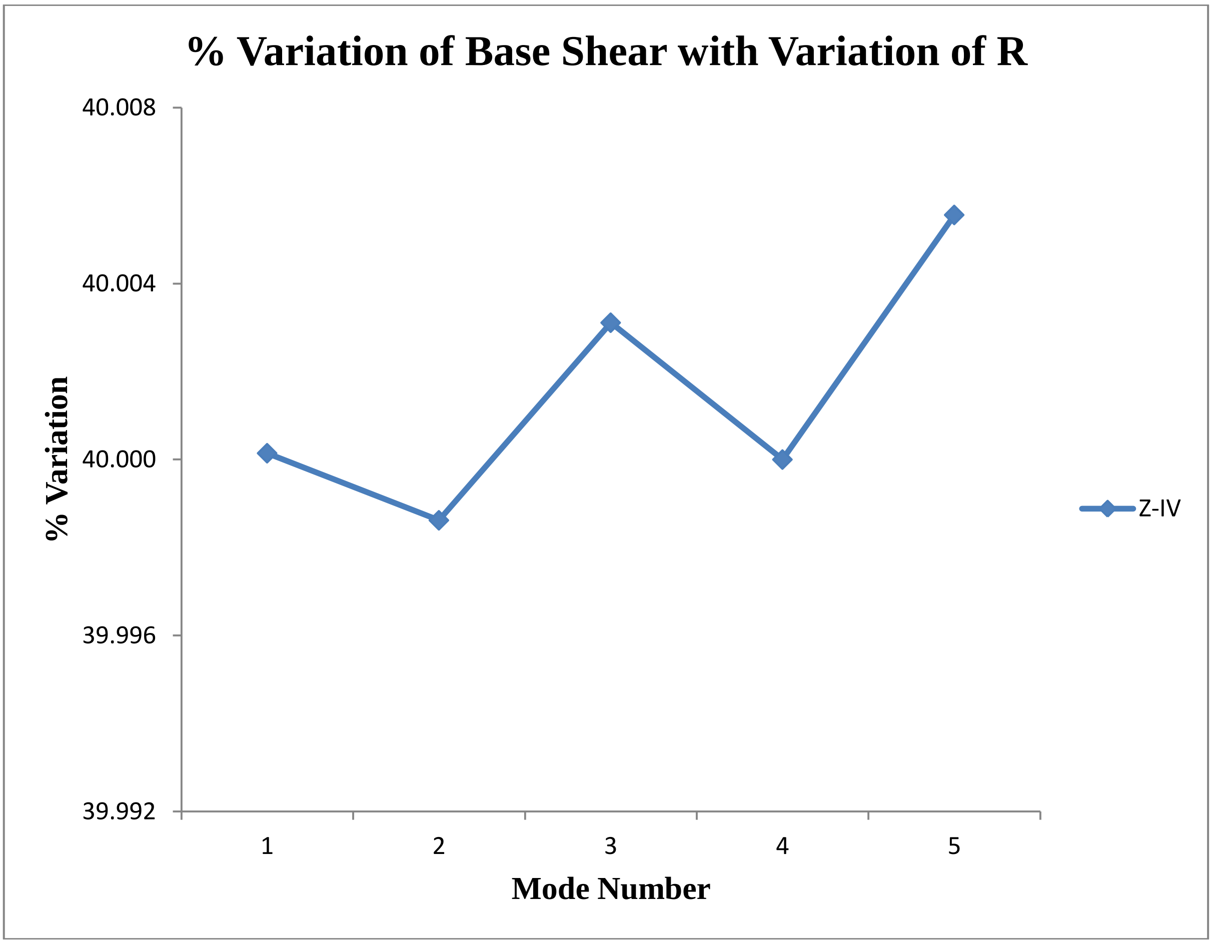

Figure 5.15 **Percentage variation of Base Shear for Zone IV for hard soil**

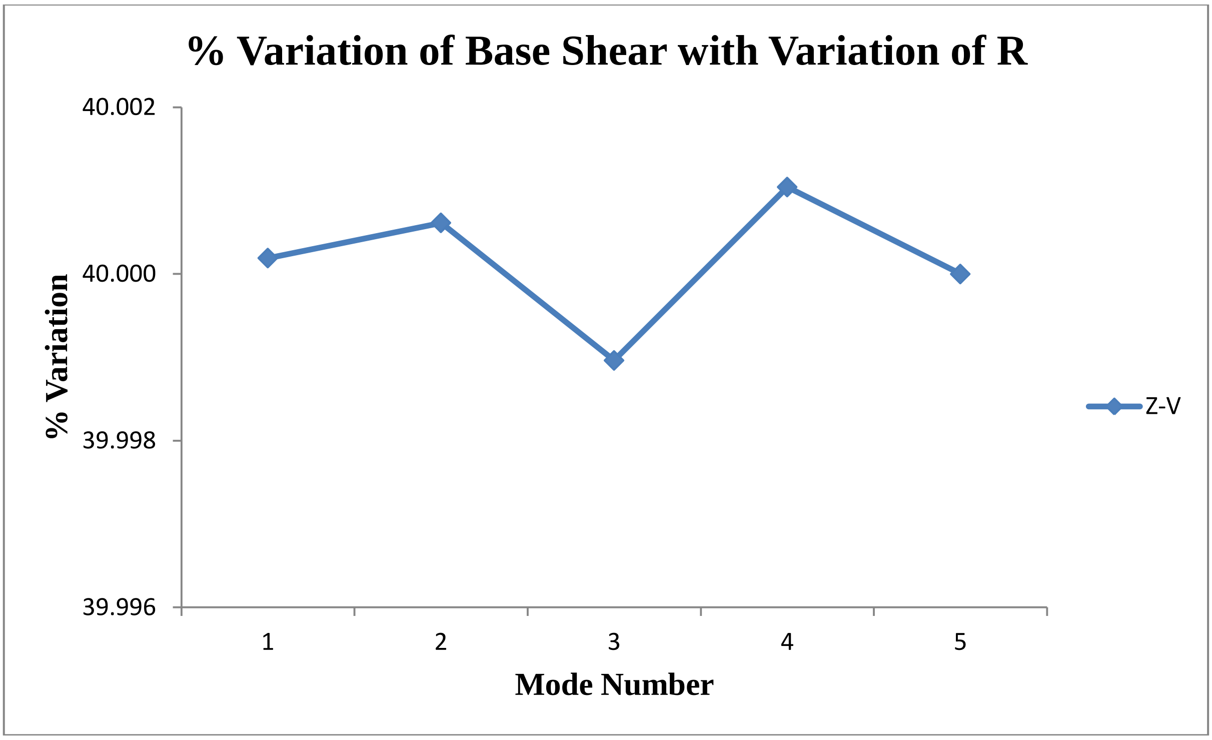

Figure 5.16 Percentage variation of Base Shear for Zone V for hard soil

The base shear (x direction) in each mode for different response reduction factors are shown below. These base shears correspond to medium soil strata for various zone factors.

Table 5.13 Base Shear corresponding to medium soil for R=3

Mode	Base Shear in kN (Zone II)	Base Shear in kN (Zone III)	Base Shear in kN (Zone IV)	Base Shear in kN (Zone V)
1	789.49	1263.19	1894.79	2842.18
2	246.10	393.76	590.64	885.96
3	72.87	116.59	174.88	262.32
4	159.75	255.60	383.40	575.11
5	29.97	47.96	71.94	107.90

Table 5.14 Base Shear corresponding to medium soil for R=5

Mode	Base Shear in kN (Zone II)	Base Shear in kN (Zone III)	Base Shear in kN (Zone IV)	Base Shear in kN (Zone V)
1	473.70	757.91	1136.87	1705.31
2	147.66	236.25	354.38	531.57
3	43.72	69.95	104.93	157.39
4	95.85	153.36	230.04	345.06
5	17.98	28.77	43.16	64.74

Table 5.15 Percentage variations in Base Shear for medium soil

Mode	% Variation in Base Shear	% Variation in Base Shear	% Variation in Base Shear	% Variation in Base Shear
	Zone II	Zone III	Zone IV	Zone V
1	39.999	40.000	40.000	40.000
2	40.000	40.002	40.001	40.001
3	40.003	40.003	39.999	40.001
4	40.000	40.000	40.000	40.001
5	40.007	40.013	40.006	40.000

The percentage change is calculated as change in base shear corresponds to R=3 and R=5 with base shear corresponds to R=3 response reduction factor. The percentage variation of base shear in x direction with variation of R for different zones (Zone II, Zone III, Zone IV and Zone V) for medium soil has been plotted graphically as shown below

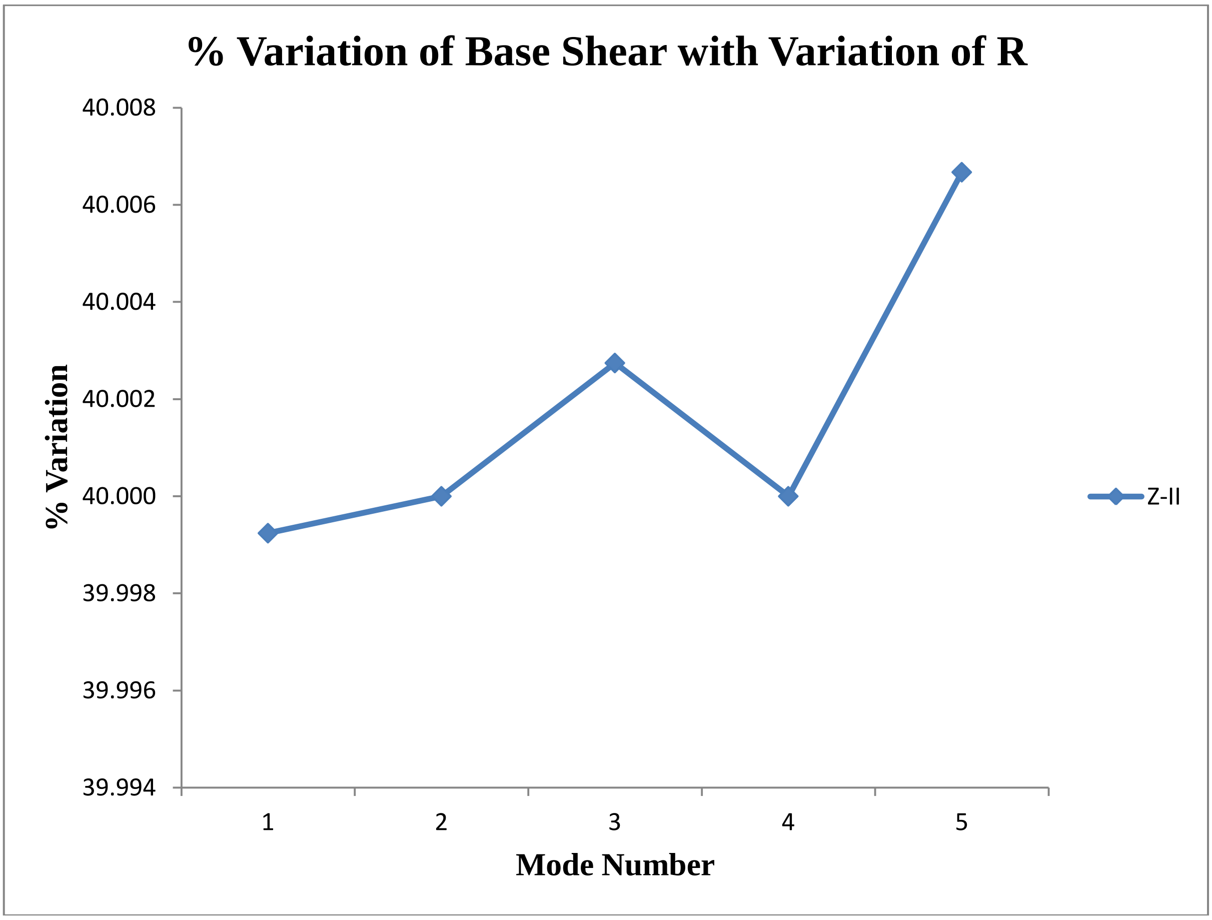

Figure 5.17 Percentage variation of Base Shear for Zone II for medium soil

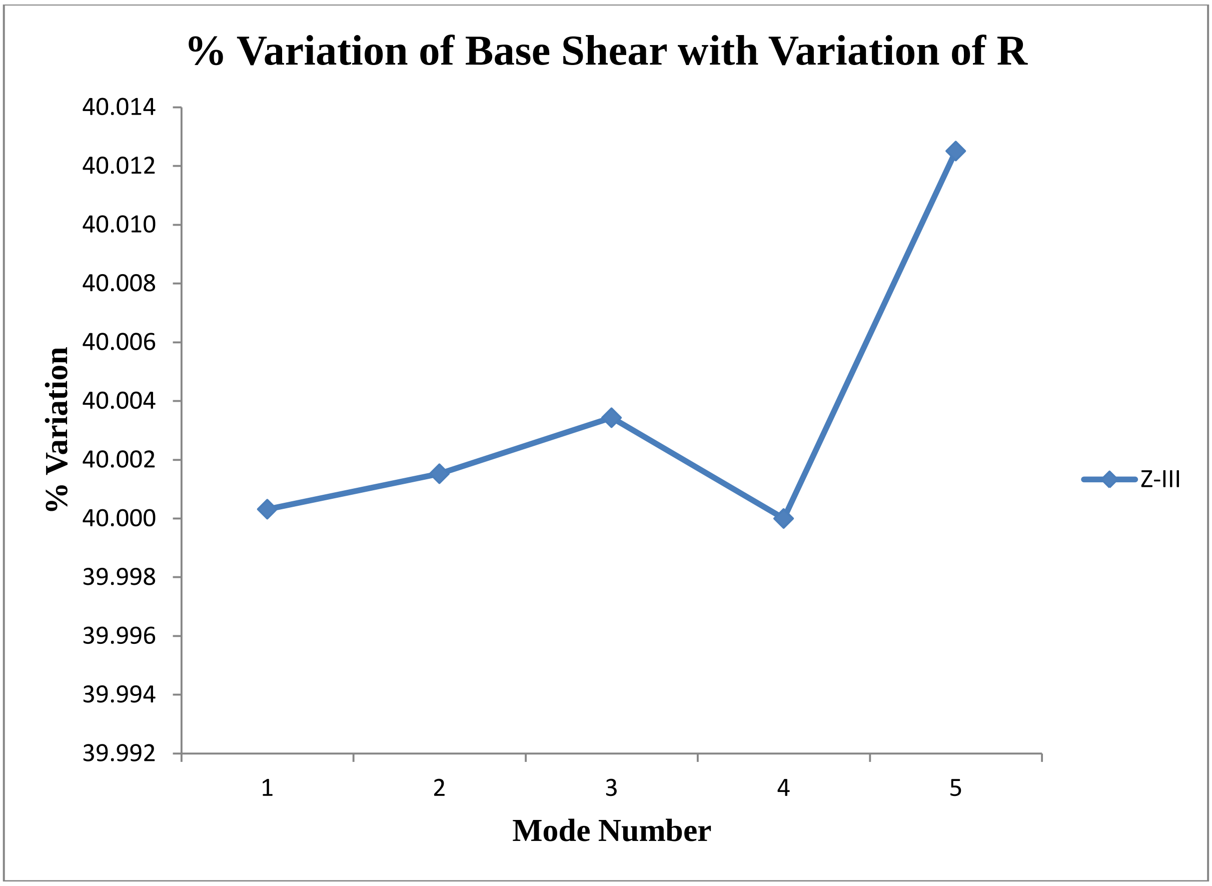

Figure 5.18 Percentage variation of Base Shear for Zone III for medium soil

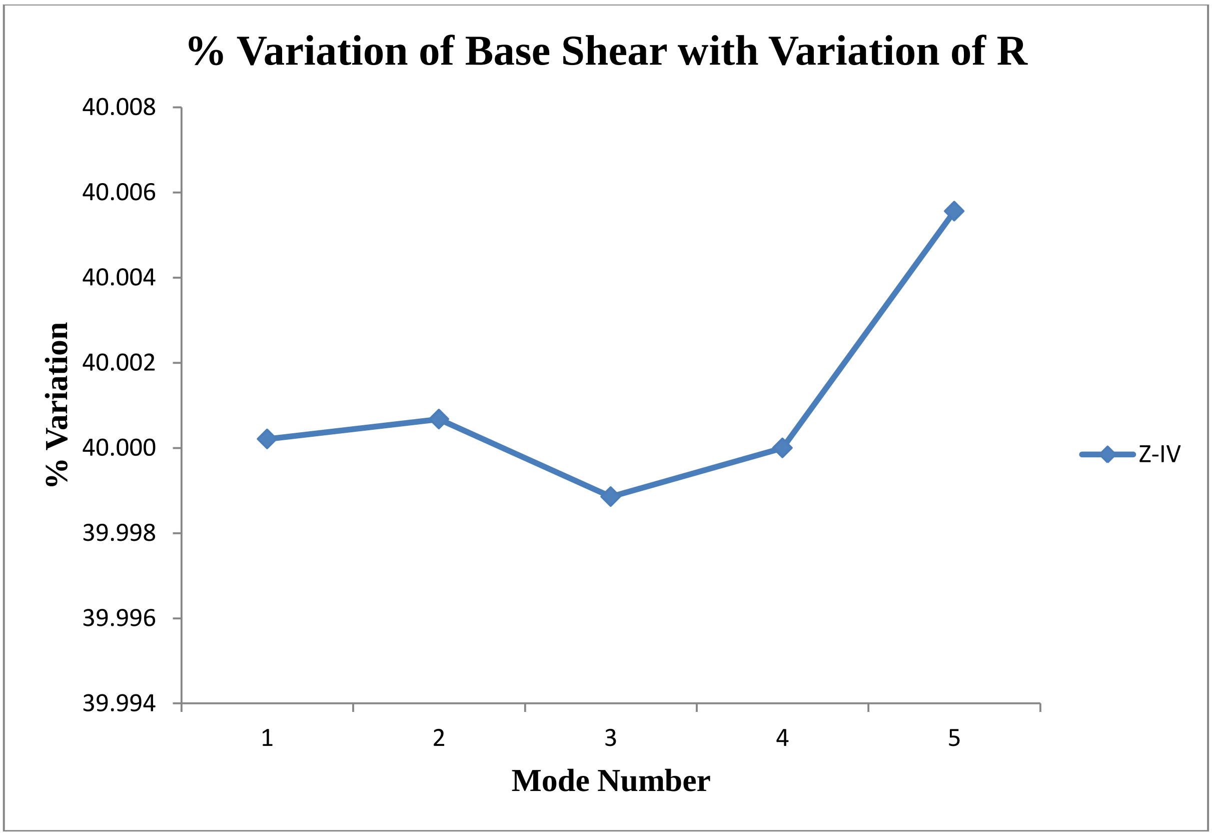

Figure 5.19 Percentage variation of Base Shear for Zone IV for medium soil

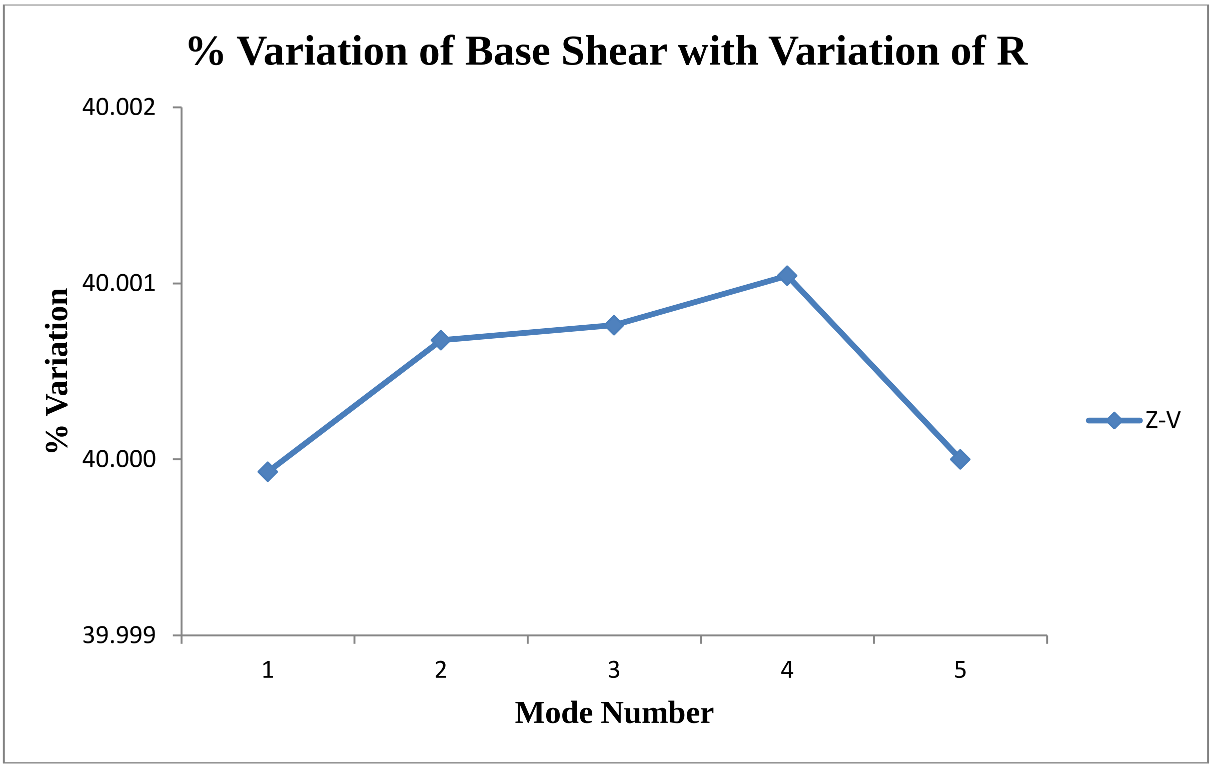

Figure 5.20 Percentage variation of Base Shear for Zone V for medium soil

The base shear (x direction) in each mode for different response reduction factors are shown below. These base shears correspond to soft soil strata for various zone factors.

Table 5.16 Base Shear corresponding to soft soil for R=3

Mode	Base Shear in kN (Zone II)	Base Shear in kN (Zone III)	Base Shear in kN (Zone IV)	Base Shear in kN (Zone V)
1	969.45	1551.12	2326.69	3490.03
2	302.19	483.51	725.27	1087.90
3	89.48	143.16	214.74	322.12
4	159.75	255.60	383.40	575.11
5	29.97	47.96	71.94	107.90

Table 5.17 Base Shear corresponding to soft soil for R=5

Mode	Base Shear in kN (Zone II)	Base Shear in kN (Zone III)	Base Shear in kN (Zone IV)	Base Shear in kN (Zone V)
1	581.67	930.67	1396.01	2094.02
2	181.32	290.11	435.16	652.74
3	53.69	85.90	128.85	193.27
4	95.85	153.36	230.04	345.06
5	17.98	28.77	43.16	64.74

Table 5.18 Percentage variations in Base Shear for soft soil

Mode	% Variation in Base Shear	% Variation in Base Shear	% Variation in Base Shear	% Variation in Base Shear
	Zone II	Zone III	Zone IV	Zone V
1	40.000	40.000	40.000	40.000
2	39.998	39.999	40.000	40.000
3	39.998	39.997	39.997	40.001
4	40.000	40.000	40.000	40.001
5	40.007	40.013	40.006	40.000

The percentage change is calculated as change in base shear corresponds to R=3 and R=5 with base shear corresponds to R=3 response reduction factor. The percentage variation of base shear in x direction with variation of R for different zones (Zone II, Zone III, Zone IV and Zone V) for soft soil has been plotted graphically as shown below

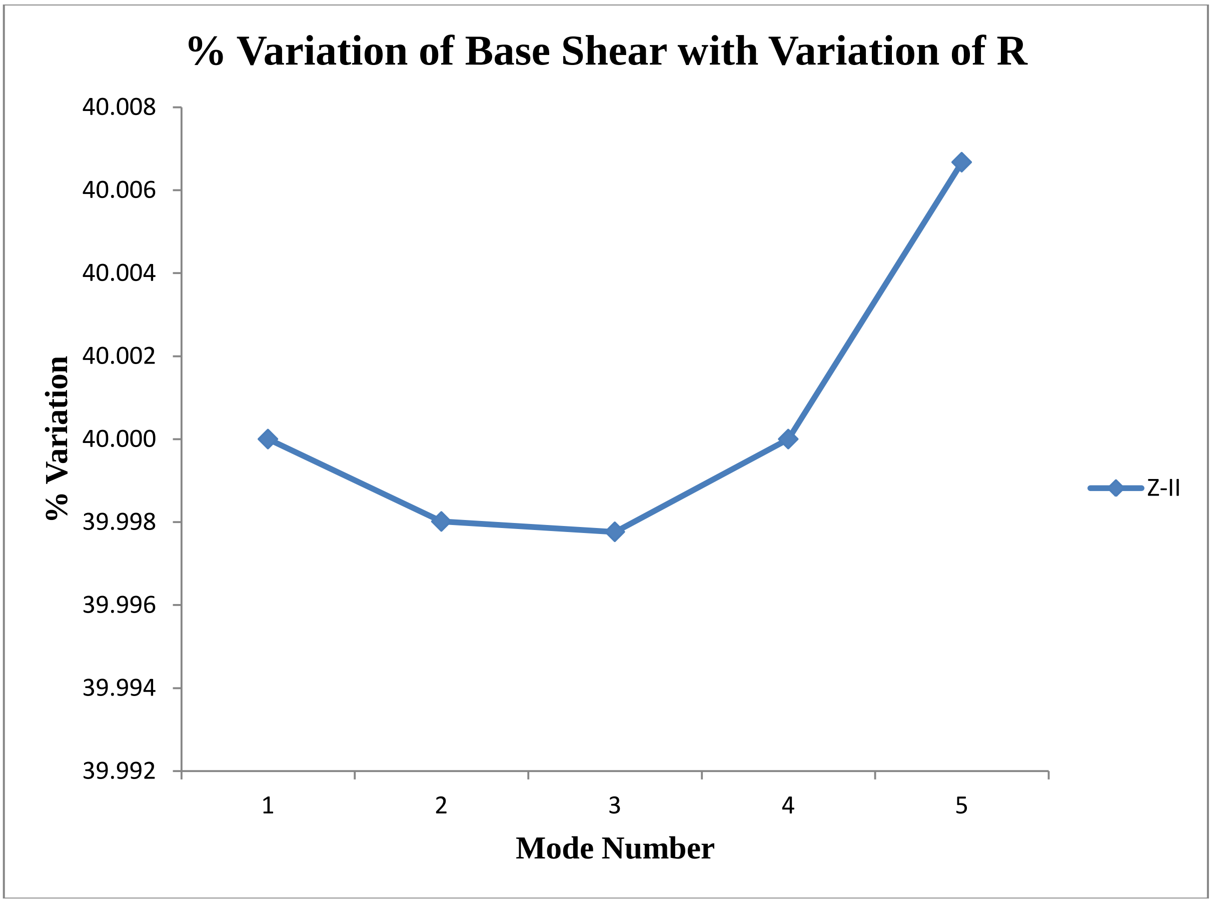

Figure 5.21 Percentage variation of Base Shear for Zone II for soft soil

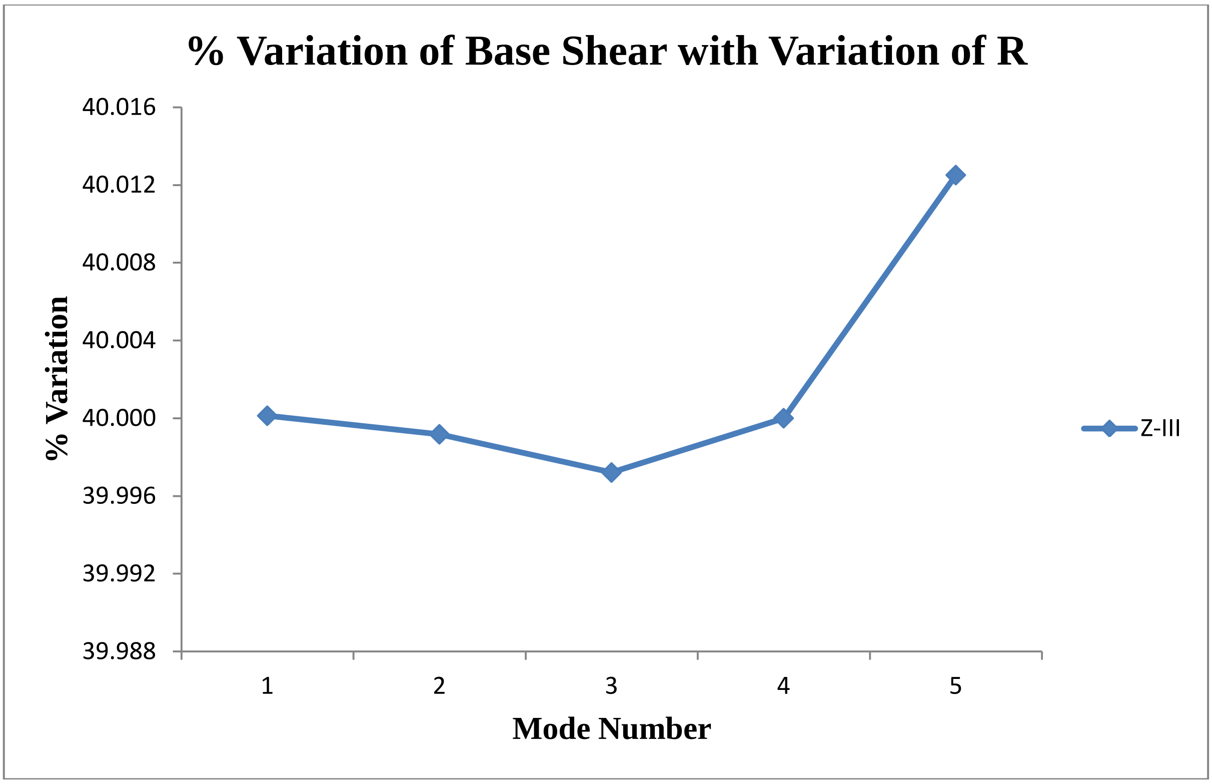

Figure 5.22 Percentage variation of Base Shear for Zone III for soft soil

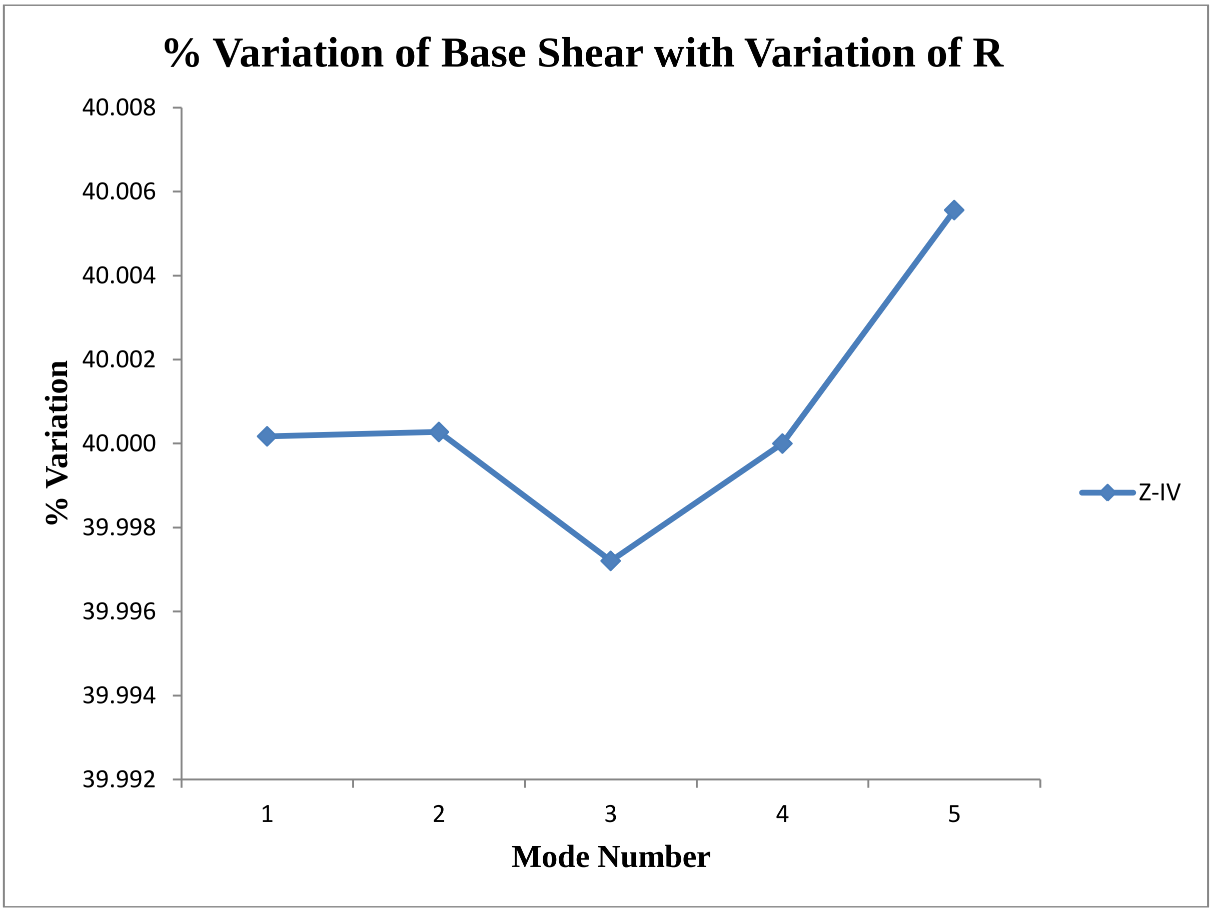

Figure 5.23 Percentage variation of Base Shear for Zone IV for soft soil

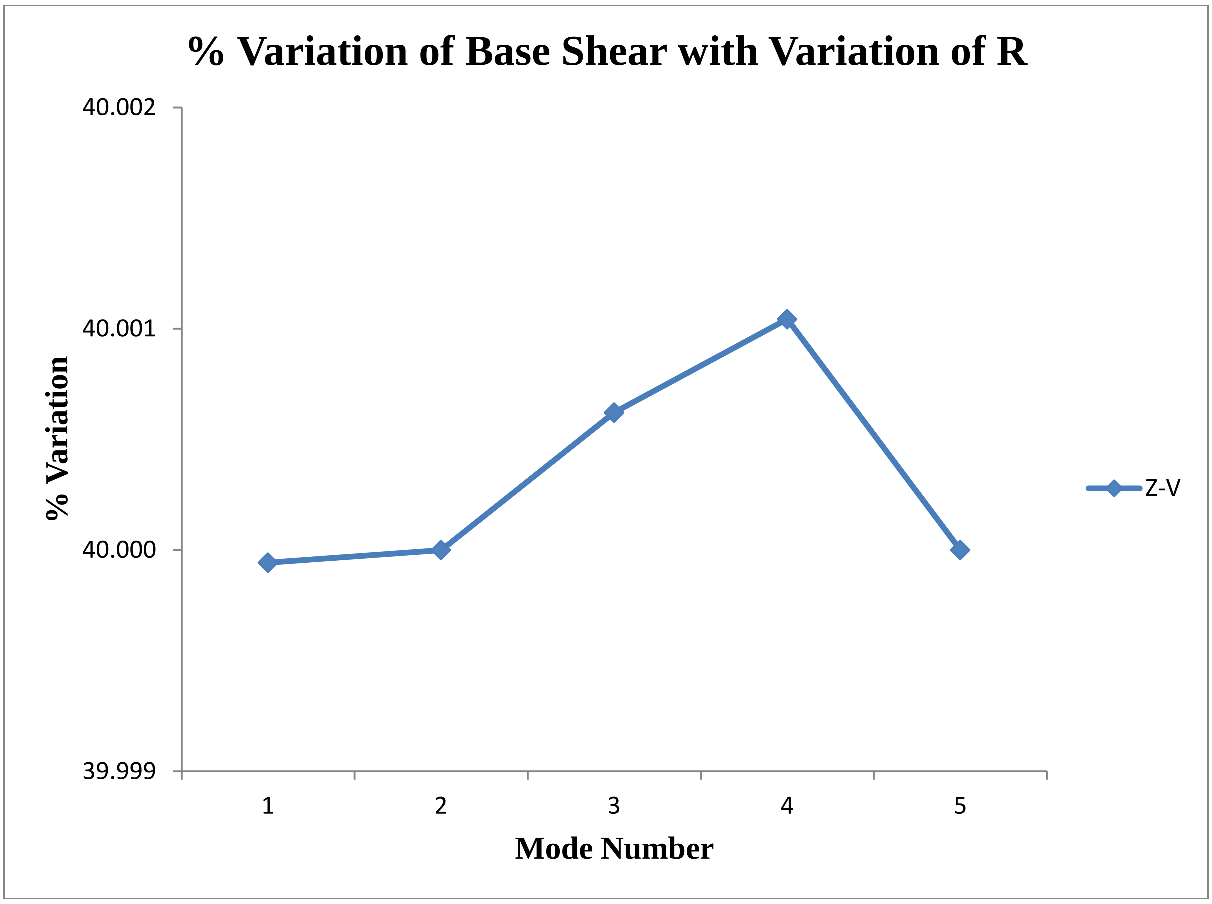

Figure 5.24 Percentage variation of Base Shear for Zone V for soft soil

5.3 PEAK STOREY SHEAR

The peak storey shear (x direction) at each floor for different response reduction factors are shown below. These base shears correspond to hard soil strata for various zone factors.

Table 5.19 Peak Storey Shear corresponding to hard soil for R=3

Floor	Peak Storey Shear in kN (Zone II)	Peak Storey Shear in kN (Zone III)	Peak Storey Shear in kN (Zone IV)	Peak Storey Shear in kN (Zone V)
6	257.20	411.52	617.28	925.93
5	455.73	729.16	1093.74	1640.61
4	591.75	946.80	1420.20	2130.30
3	697.76	1116.41	1674.61	2511.92
2	717.24	1147.58	1721.37	2582.05
1	717.24	1147.58	1721.37	2582.05

Table 5.20 Peak Storey Shear corresponding to hard soil for R=5

Floor	Peak Storey Shear in kN (Zone II)	Peak Storey Shear in kN (Zone III)	Peak Storey Shear in kN (Zone IV)	Peak Storey Shear in kN (Zone V)
6	154.32	246.91	370.37	555.56
5	273.44	437.50	656.24	984.37
4	355.05	568.08	852.12	1278.18
3	418.65	669.85	1004.77	1507.15
2	430.34	688.55	1032.82	1549.23
1	430.34	688.55	1032.82	1549.23

Table 5.21 Percentage variations in Peak Storey Shear for hard soil

Floor	% Variation in Peak Storey Shear	% Variation in Peak Storey Shear	% Variation in Peak Storey Shear	% Variation in Peak Storey Shear
	Zone II	Zone III	Zone IV	Zone V
6	40.0000	40.0005	39.9997	39.9998
5	39.9996	39.9995	40.0004	39.9998
4	40.0000	40.0000	40.0000	40.0000
3	40.0009	39.9996	39.9998	40.0001
2	40.0006	39.9998	40.0001	40.0000
1	40.0006	39.9998	40.0001	40.0000

The percentage change is calculated as change in peak storey shear corresponds to R=3 and R=5 with peak storey shear corresponds to R=3 response reduction factor. The percentage variation of peak storey shear in x direction with variation of R for different zones (Zone II, Zone III, Zone IV and Zone V) for hard soil has been plotted graphically as shown below

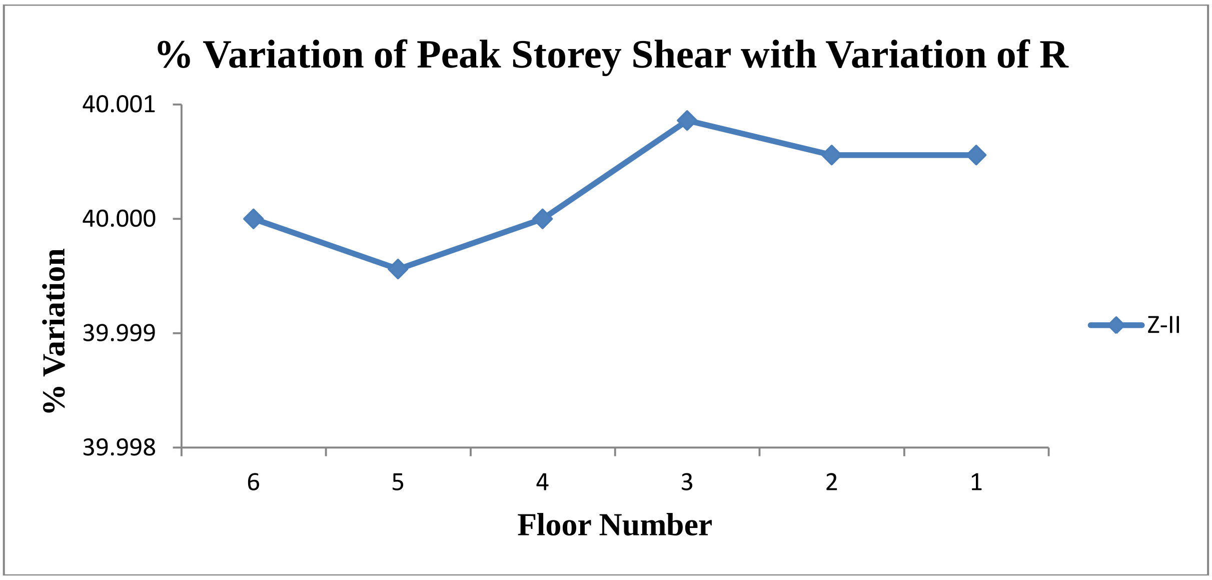

Figure 5.25 Percentage variation of Peak Storey Shear for Zone II for hard soil

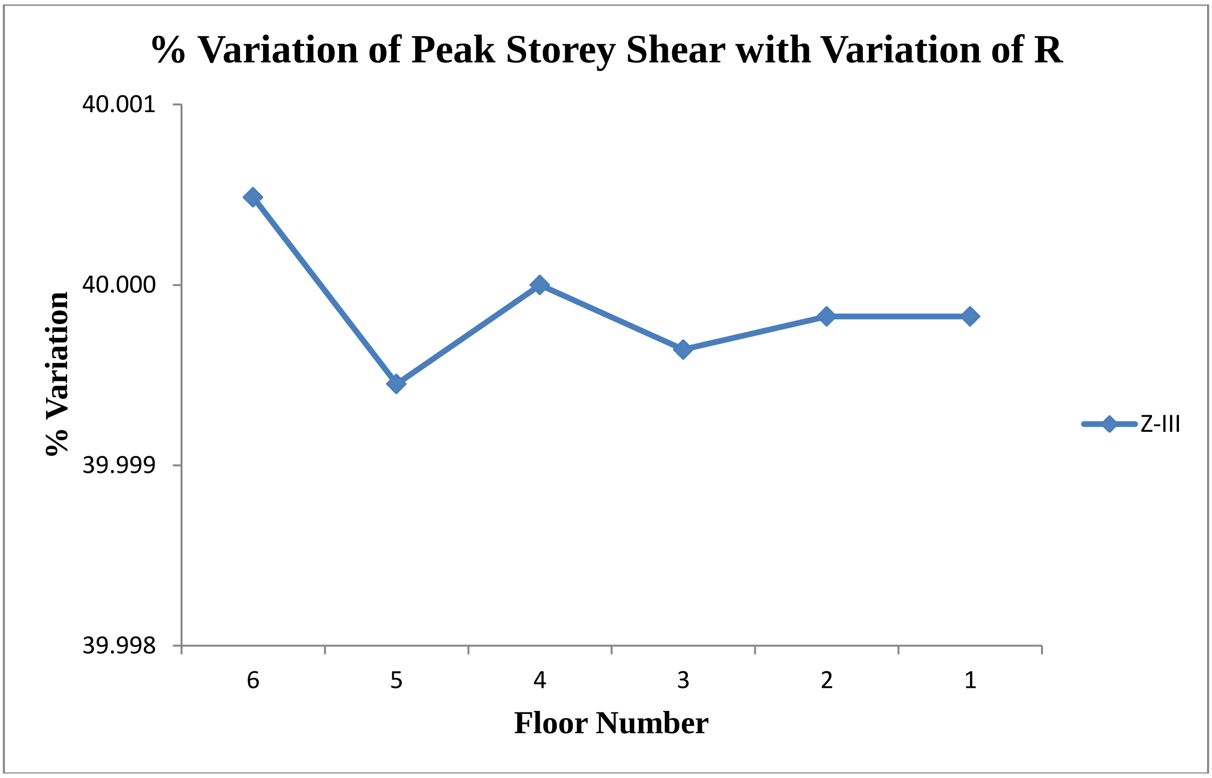

Figure 5.26 Percentage variation of Peak Storey Shear for Zone III for hard soil

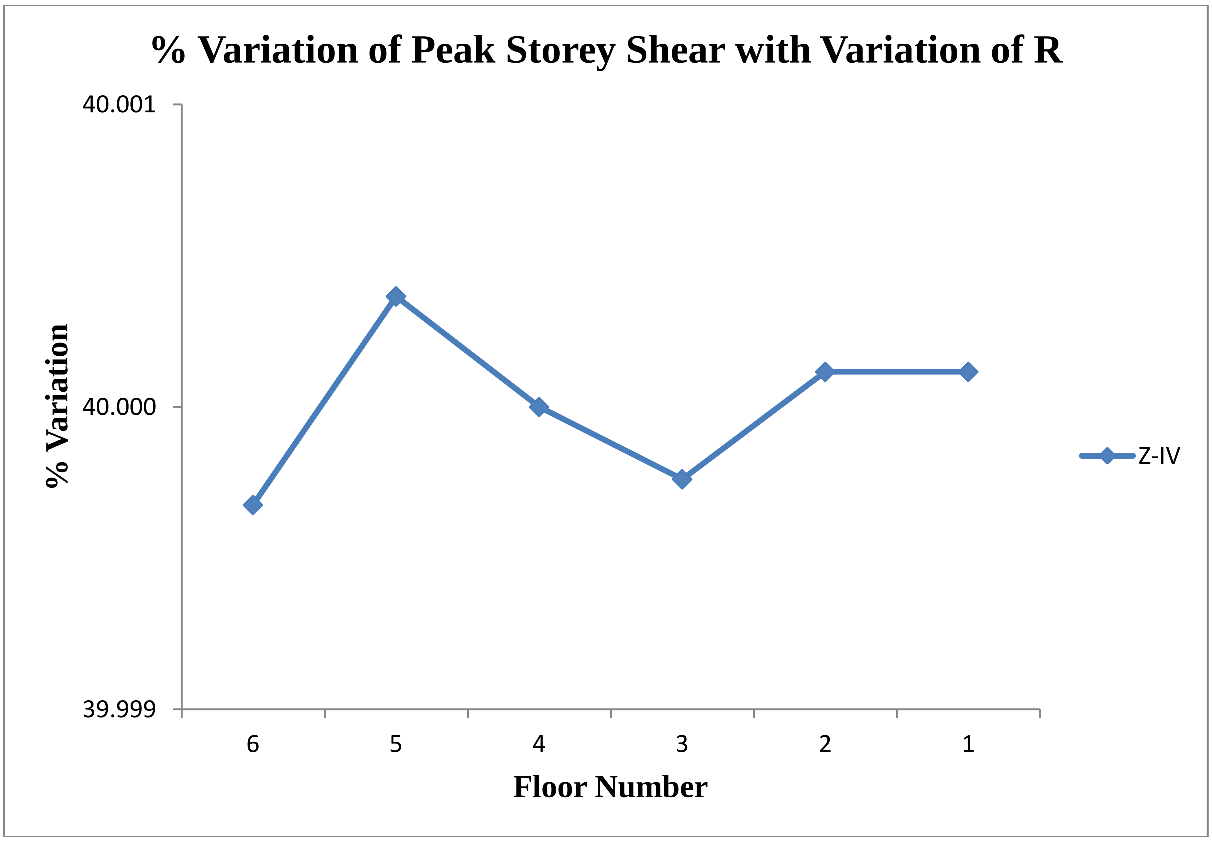

Figure 5.27 Percentage variation of Peak Storey Shear for Zone IV for hard soil

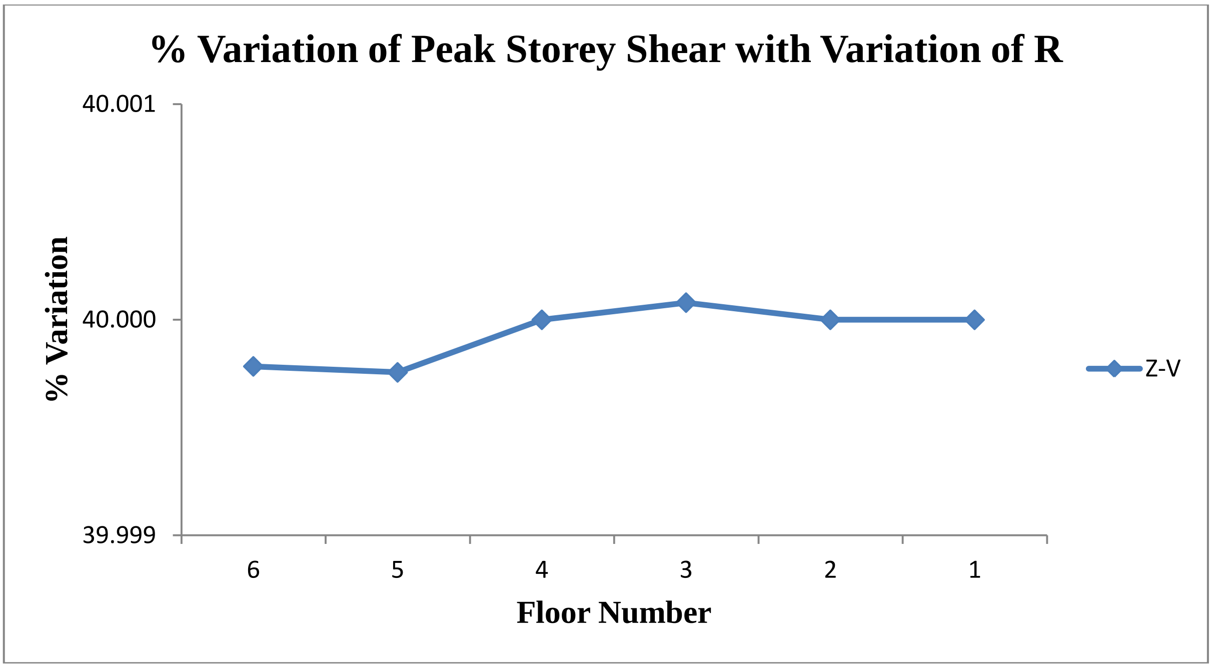

Figure 5.28 Percentage variation of Peak Storey Shear for Zone V for hard soil

The peak storey shear (x direction) at each floor for different response reduction factors are shown below. These base shears correspond to medium soil strata for various zone factors.

Table 5.22 Peak Storey Shear corresponding to medium soil for R=3

Floor	Peak Storey Shear in kN (Zone II)	Peak Storey Shear in kN (Zone III)	Peak Storey Shear in kN (Zone IV)	Peak Storey Shear in kN (Zone V)
6	319.19	510.71	766.06	1149.09
5	601.61	962.57	1443.86	2165.79
4	802.10	1283.36	1925.04	2887.56
3	937.84	1500.54	2250.81	3376.21
2	958.90	1534.23	2301.35	3452.03
1	958.90	1534.23	2301.35	3452.03

Table 5.23 Peak Storey Shear corresponding to medium soil for R=5

Floor	Peak Storey Shear in kN (Zone II)	Peak Storey Shear in kN (Zone III)	Peak Storey Shear in kN (Zone IV)	Peak Storey Shear in kN (Zone V)
6	191.52	306.42	459.64	689.45
5	360.97	577.54	866.32	1299.48
4	481.26	770.02	1155.03	1732.54
3	562.70	900.32	1350.49	2025.73
2	575.34	920.54	1380.81	2071.21
1	575.34	920.54	1380.81	2071.21

Table 5.24 Percentage variations in Peak Storey Shear for medium soil

Floor	% Variation in Peak Storey	% Variation in Peak Storey	% Variation in Peak Storey	% Variation in Peak Storey
	Zone II	Zone III	Zone IV	Zone V
6	39.9981	40.0012	39.9995	40.0003
5	39.9993	40.0002	39.9997	39.9997
4	40.0000	39.9997	39.9997	39.9999
3	40.0004	40.0003	39.9998	39.9999
2	40.0000	39.9999	40.0000	40.0002
1	40.0000	39.9999	40.0000	40.0002

The percentage change is calculated as change in peak storey shear corresponds to R=3 and R=5 with peak storey shear corresponds to R=3 response reduction factor. The percentage variation of peak storey shear in x direction with variation of R for different zones (Zone II, Zone III, Zone IV and Zone V) for medium soil has been plotted graphically as shown below

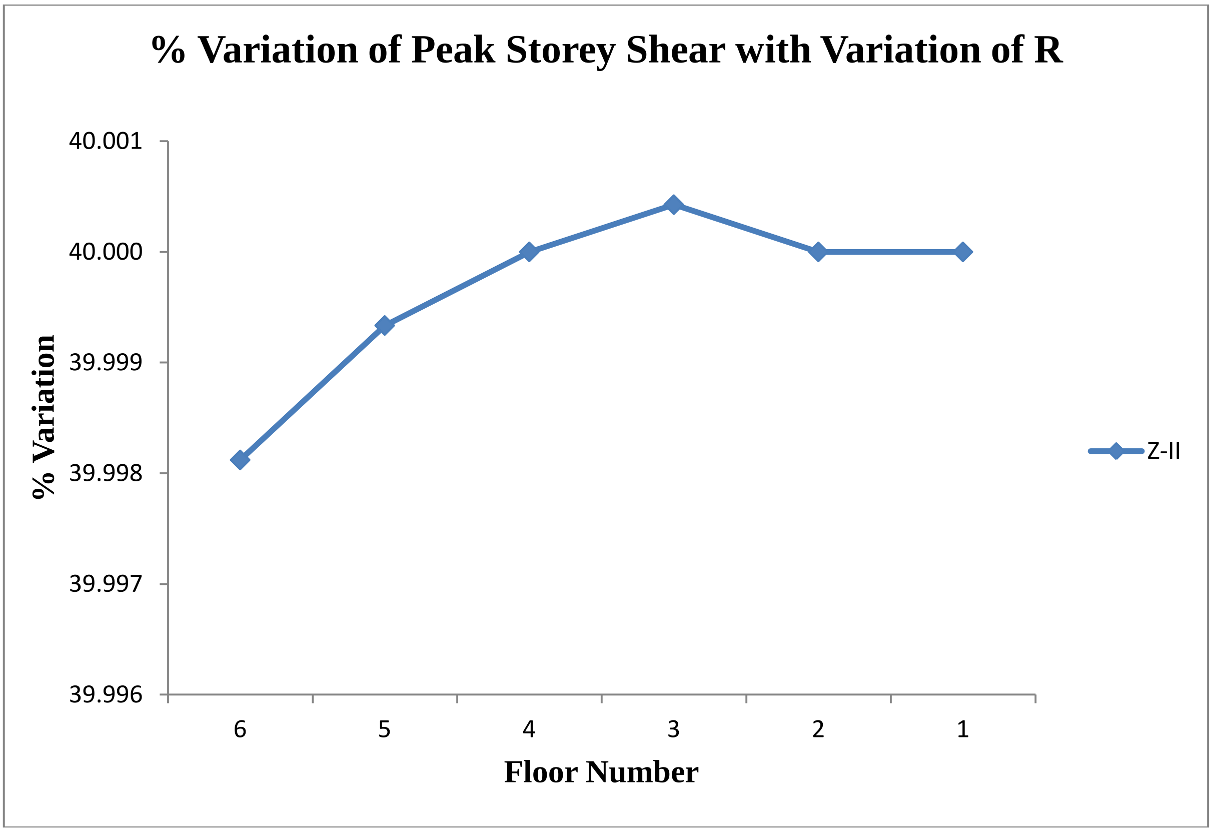

Figure 5.29 Percentage variation of Peak Storey Shear for Zone II for medium soil

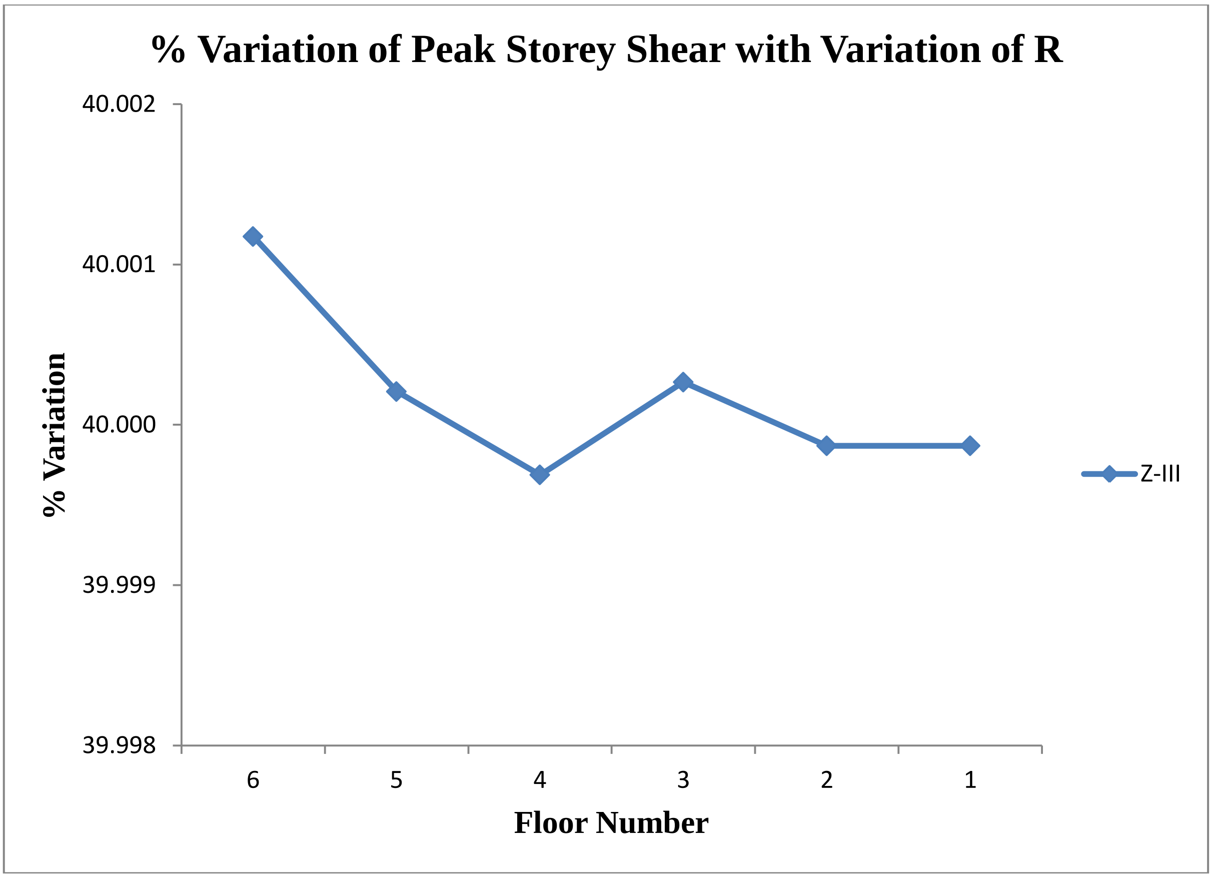

Figure 5.30 Percentage variation of Peak Storey Shear for Zone III for medium soil

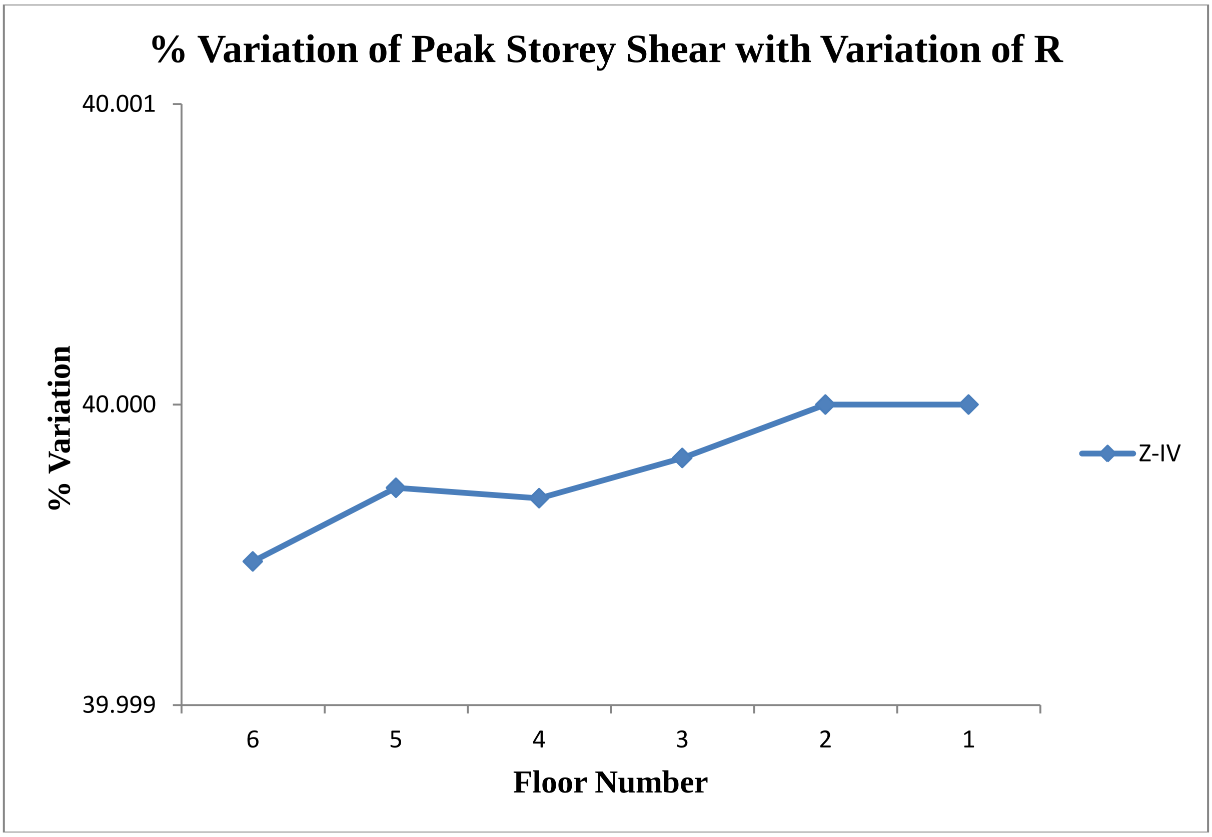

Figure 5.31 Percentage variation of Peak Storey Shear for Zone IV for medium soil

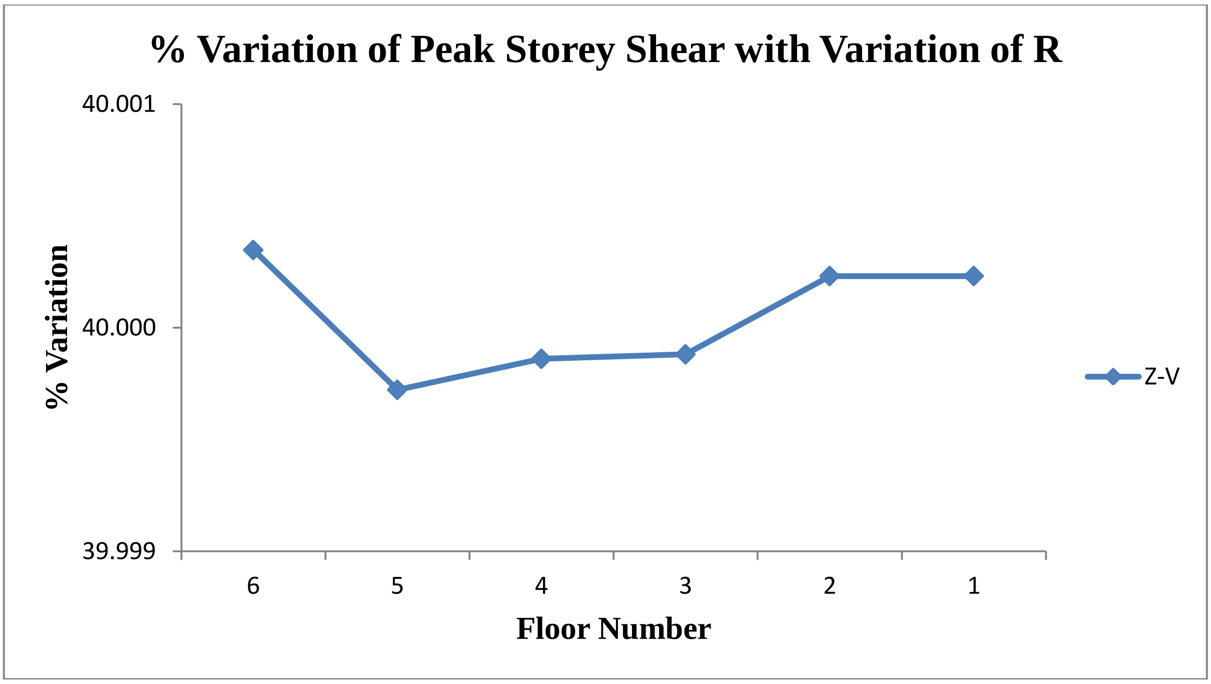

Figure 5.32 Percentage variation of Peak Storey Shear for Zone V for medium soil

The peak storey shear (x direction) at each floor for different response reduction factors are shown below. These peak storey shears correspond to soft soil strata for various zone factors.

Table 5.25 Peak Storey Shear corresponding to soft soil for R=3

Floor	Peak Storey Shear in kN (Zone II)	Peak Storey Shear in kN (Zone III)	Peak Storey Shear in kN (Zone IV)	Peak Storey Shear in kN (Zone V)
6	376.01	601.62	902.43	1353.65
5	729.70	1167.52	1751.29	2626.93
4	983.63	1573.80	2360.70	3541.05
3	1146.16	1833.85	2750.77	4126.16
2	1169.32	1870.91	2806.36	4209.54
1	1169.32	1870.91	2806.36	4209.54

Table 5.26 Peak Storey Shear corresponding to soft soil for R=5

Floor	Peak Storey Shear in kN (Zone II)	Peak Storey Shear in kN (Zone III)	Peak Storey Shear in kN (Zone IV)	Peak Storey Shear in kN (Zone V)
6	225.61	360.97	541.46	812.19
5	437.82	700.51	1050.77	1576.16
4	590.18	944.28	1416.42	2124.63
3	687.69	1100.31	1650.46	2475.70
2	701.59	1122.54	1683.82	2525.72
1	701.59	1122.54	1683.82	2525.72

Table 5.27 Percentage variations in Peak Storey Shear for soft soil

Floor	% Variation in Peak Storey Shear	% Variation in Peak Storey Shear	% Variation in Peak Storey Shear	% Variation in Peak Storey Shear
	Zone II	Zone III	Zone IV	Zone V
6	39.9989	40.0003	39.9998	40.0000
5	40.0000	40.0002	40.0002	39.9999
4	39.9998	40.0000	40.0000	40.0000
3	40.0005	40.0000	40.0001	39.9999
2	40.0002	40.0003	39.9999	40.0001
1	40.0002	40.0003	39.9999	40.0001

The percentage change is calculated as change in peak storey shear corresponds to R=3 and R=5 with peak storey shear corresponds to R=3 response reduction factor. The percentage variation of peak storey shear in x direction with variation of R for different zones (Zone II, Zone III, Zone IV and Zone V) for soft soil has been plotted graphically as shown below

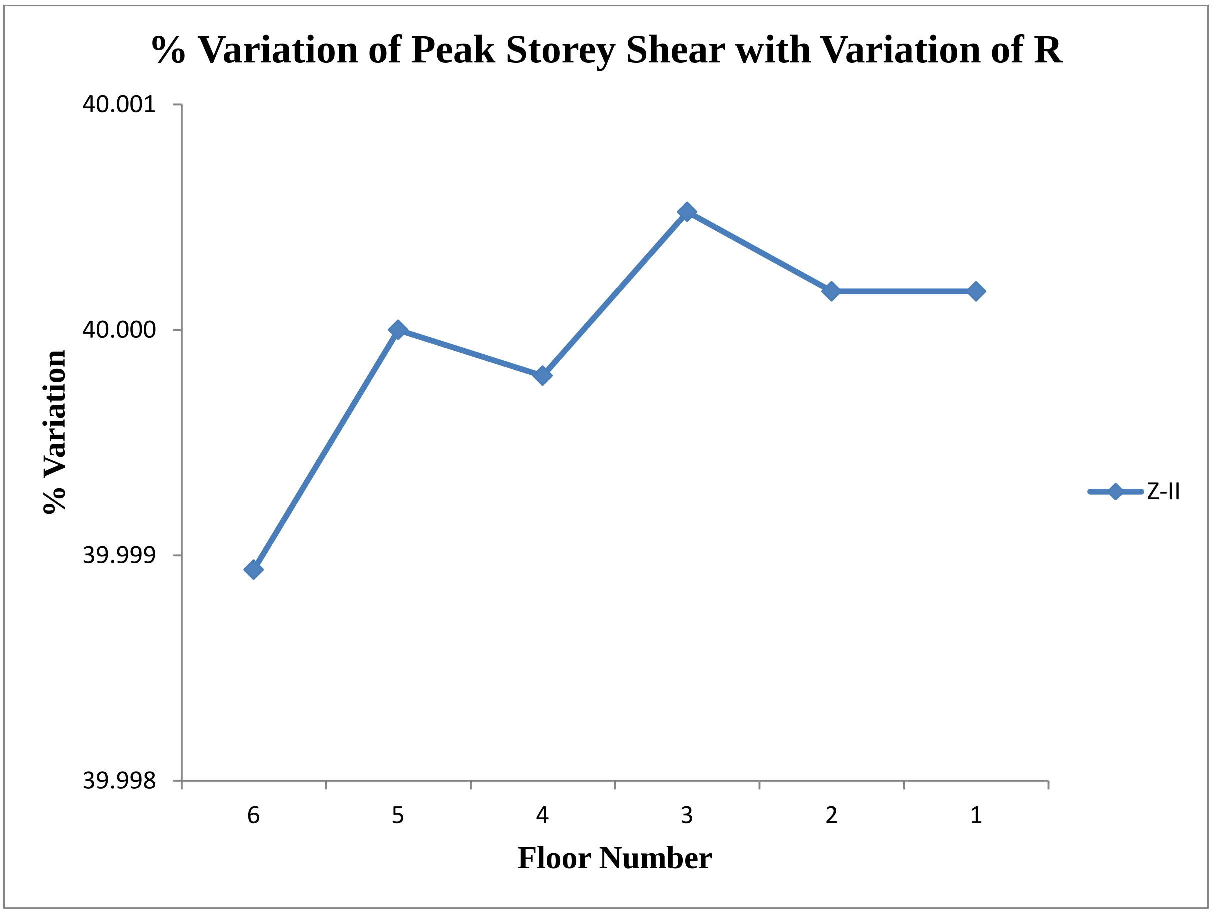

Figure 5.33 Percentage variation of Peak Storey Shear for Zone II for soft soil

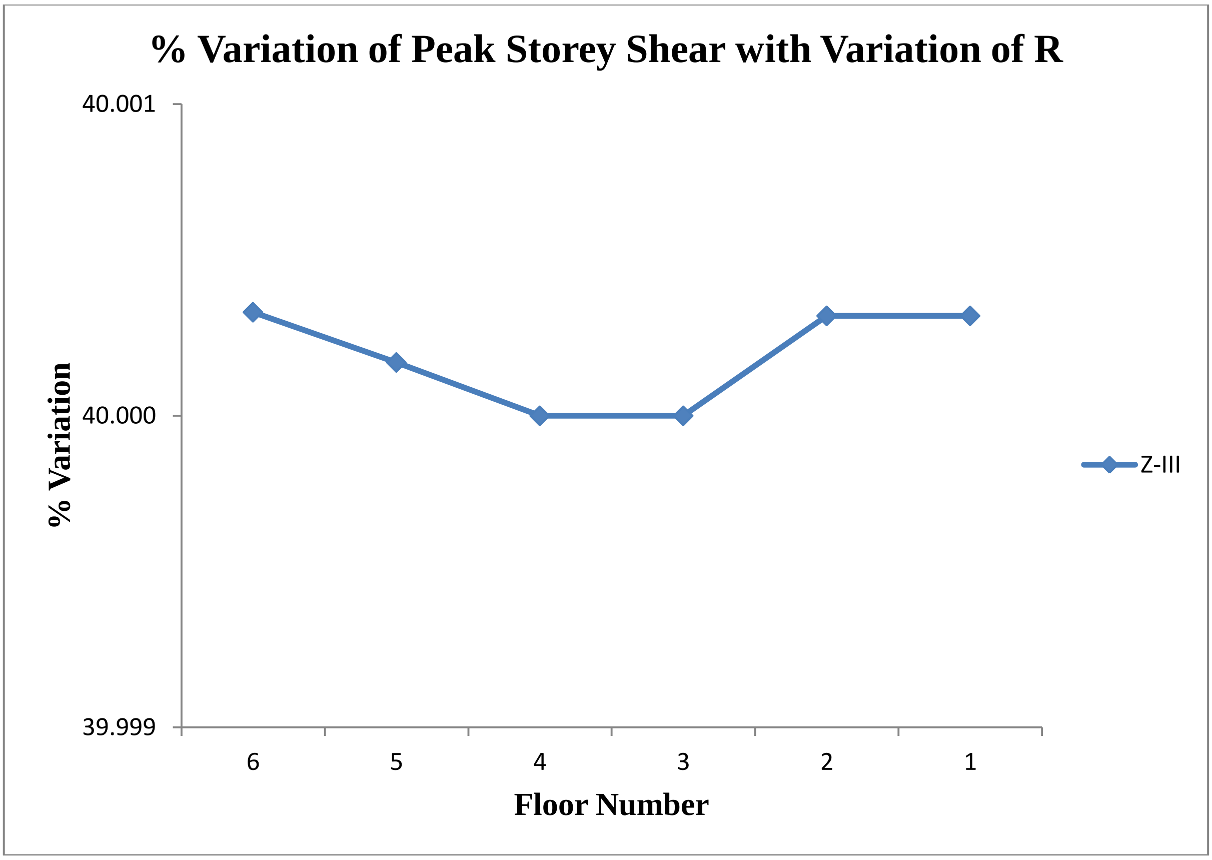

Figure 5.34 Percentage variation of Peak Storey Shear for Zone III for soft soil

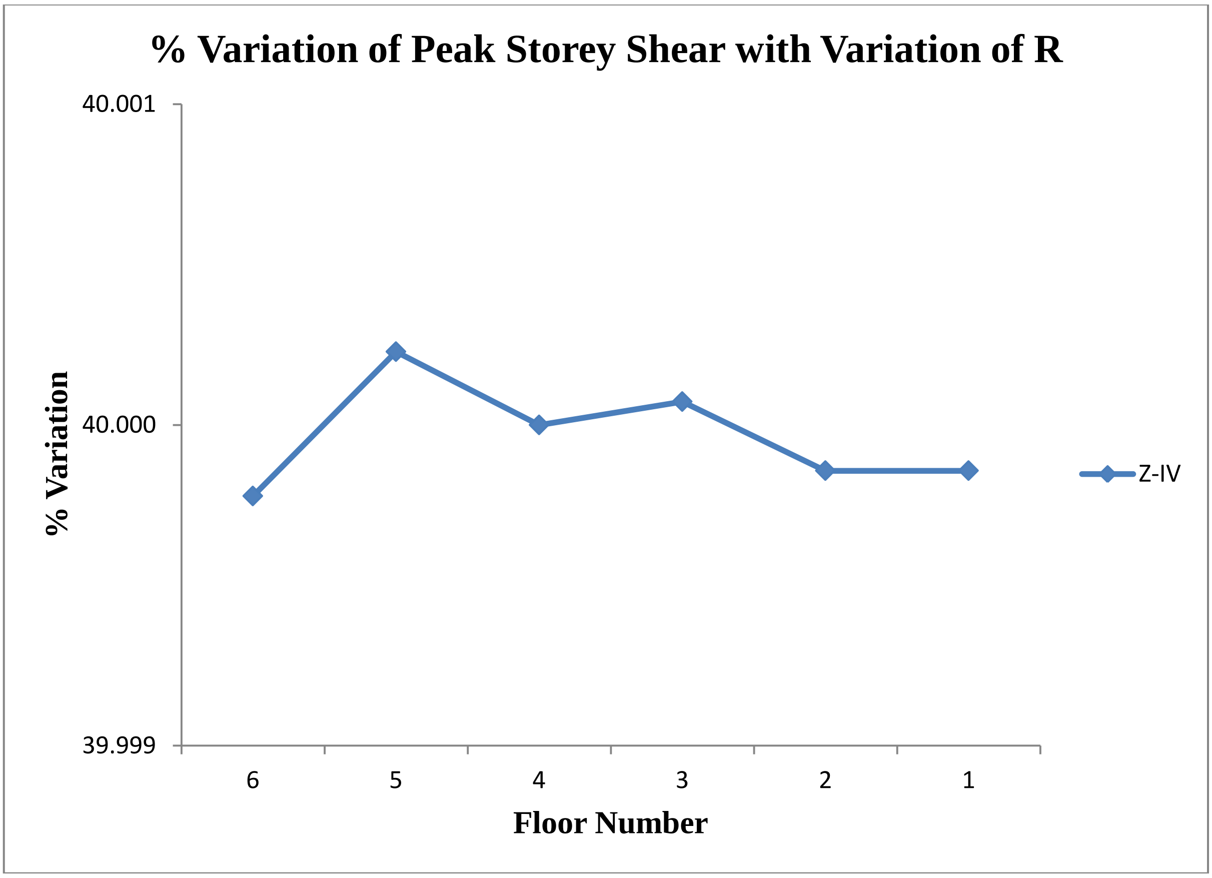

Figure 5.35 Percentage variation of Peak Storey Shear for Zone IV for soft soil

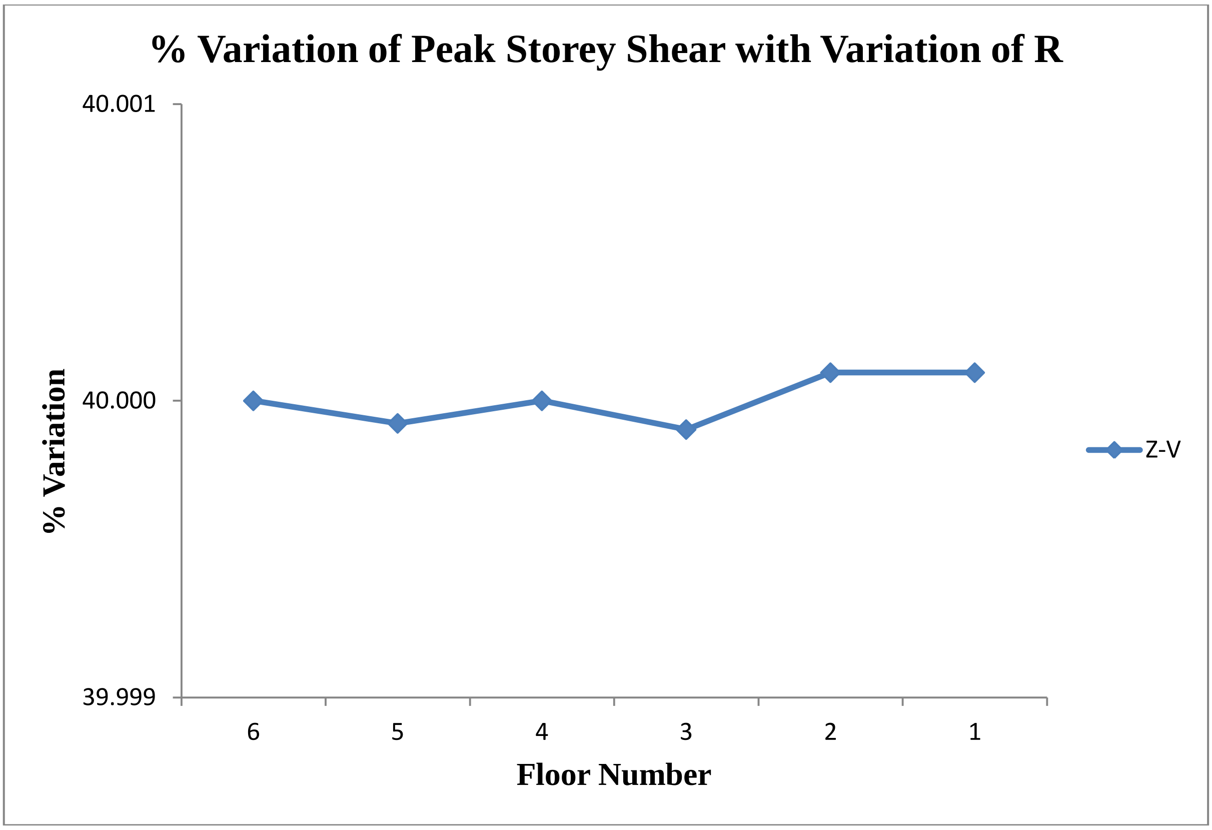

Figure 5.36 Percentage variation of Peak Storey Shear for Zone V for soft soil

5.4 FREQUENCY

The graph between frequency and mode is plotted as shown below

Table 5.28 Frequency and Time Period of vibration of building

Mode	Frequency (cycle/sec)	Period (sec)
1	1.16	0.86
2	1.32	0.76
3	1.42	0.70
4	3.66	0.27
5	4.20	0.24

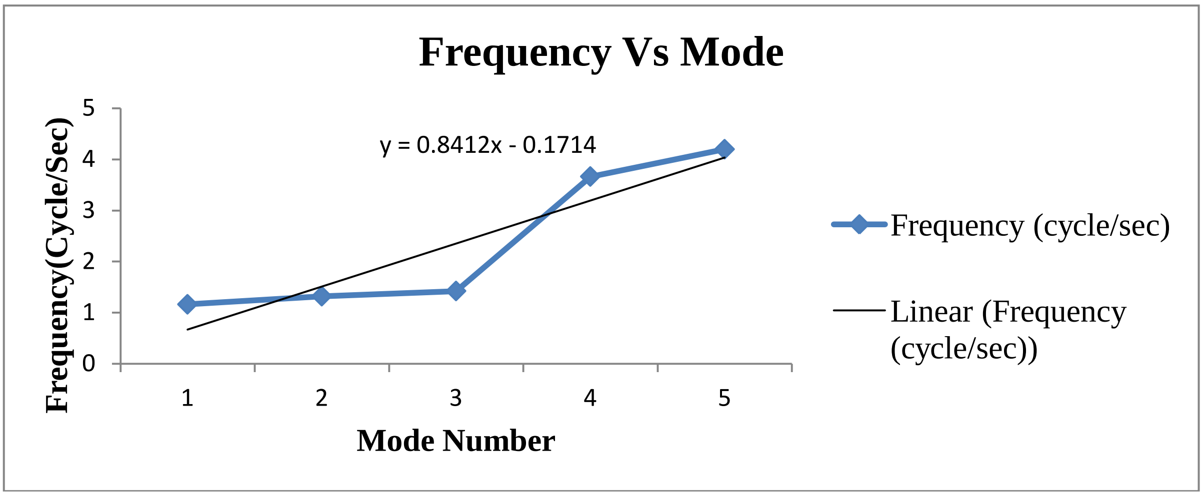

Figure 5.37 Frequency Vs Mode curve

5.5 MASS PARTICIPATION FACTOR

The graph between cumulative mass participation factor in x and z direction with mode is plotted as shown below

Table 5.29 Mass participation factor in x and z direction

Mode	Mass Participation Factor in X-Direction	Mass Participation Factor in Z-Direction	Cummulative Mass Participation Factor in X-Direction	Cummulative Mass Participation Factor in Z-Direction
1	60.67	1.67	60.68	1.67
2	16.65	35.75	77.32	37.42
3	4.57	44.82	81.89	82.24
4	7.76	0.09	89.65	82.33
5	1.46	2.87	91.11	85.20

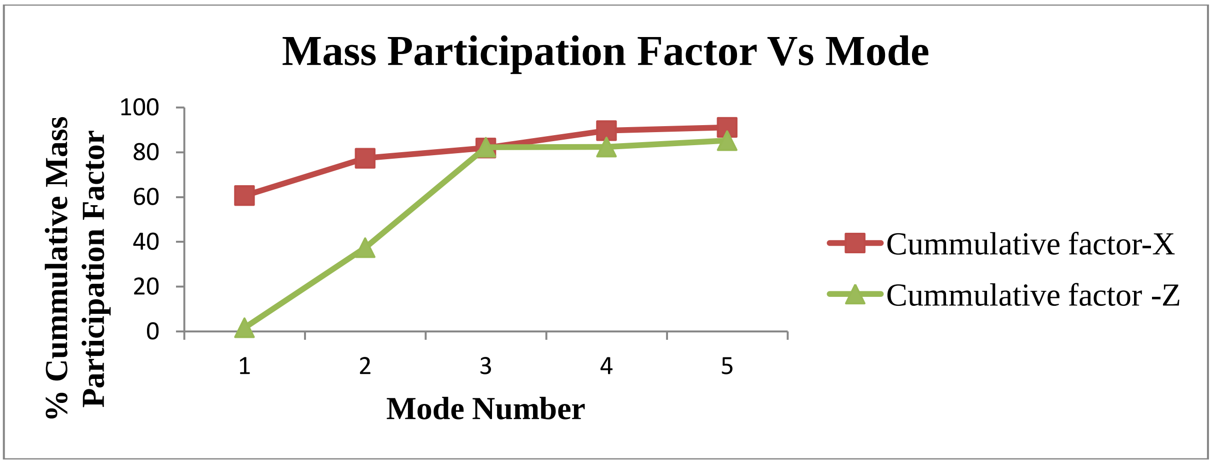

Figure 5.38 Mass participation factor Vs Mode curve

6. CONCLUSIONS

Following conclusions can be drawn from the chapter of analysis and discussion of results

1) Nearly 40% reduction in Base shear, Peak storey shear and displacements are found as a result of by providing special moment resisting frames in place of ordinary moment resisting frame in each one and in each soil strata. It may be concluded that response reduction factor (R) affects all these parameters significantly.

2) A reduction of an order of around 25-28% in displacement is achieved on constructing building on hard soil in place of medium while almost 18-19% reduction is achieved on constructing building on medium soil in place of soft soil irrespective of the building types. It shows that type of soil is an important parameter.

3) For Mode number 1, 2 & 3, almost 26-27% reduction in Base shear is achieved on constructing building on hard soil in place of medium soil while 18-19% reduction is achieved on constructing building on medium soil in place of soft soil irrespective of the building type but for mode number 4 & above, there is no change in base shear.

4) Only 19% reduction in peak storey shear is found on roof while maximum 26% reduction in peak storey shear is achieved on third floor on constructing building on hard in place of medium soil. It is noticed that reduction in peak storey shear decreases as we go up or down from third floor. On the other hand, if construction is done on medium soil in place of soft soil, 15% reduction is observed in peak storey shear on roof while maximum 18.5% reduction on third floor. This aspect may show a relation between type of soil and distribution of horizontal shear force in the structure along its height.

5) The frequency of vibration increases with higher modes.

Future scope of work

The comparison of building responses between irregular buildings with regular one could be done for various response reduction factors, zone factor and soil strata. Multi storeyed building can also be analysed by time history method or by pushover analysis. Dynamic analysis of soft storey building could also be done and comparison of building responses could be done with that of an ordinary building.

ANNEXURE

STAAD INPUT FILE

STAAD SPACE

START JOB INFORMATION

ENGINEER DATE 21-JAN-14

END JOB INFORMATION

INPUT WIDTH 79

UNIT METER KN

JOINT COORDINATES

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

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

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

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

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

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

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

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

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

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

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

51 9.05 2.25 33; 52 15.65 2.25 33; 53 0 5.55 0; 54 6.6 5.55 0; 55 9.05 5.55 0;

56 15.65 5.55 0; 57 0 5.55 6.6; 58 6.6 5.55 6.6; 59 9.05 5.55 6.6;

60 15.65 5.55 6.6; 61 9.05 5.55 9.7; 62 12.65 5.55 9.7; 63 0 5.55 13.2;

64 6.6 5.55 13.2; 65 15.65 5.55 9.7; 66 9.05 5.55 16.3; 67 12.65 5.55 16.3;

68 15.65 5.55 16.3; 69 9.05 5.55 19.8; 70 15.65 5.55 19.8; 71 0 5.55 19.8;

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76 15.65 5.55 26.4; 77 6.6 5.55 33; 78 9.05 5.55 33; 79 15.65 5.55 33;

80 0 5.55 3.3; 81 6.6 5.55 3.3; 82 0 5.55 9.7; 83 6.6 5.55 9.7; 84 0 5.55 16.3;

85 6.6 5.55 16.3; 86 0 5.55 23.1; 87 6.6 5.55 23.1; 88 9.05 5.55 23.1;

89 15.65 5.55 23.1; 90 9.05 5.55 29.7; 91 15.65 5.55 29.7; 96 0 8.85 0;

97 6.6 8.85 0; 98 9.05 8.85 0; 99 15.65 8.85 0; 100 0 8.85 6.6;

101 6.6 8.85 6.6; 102 9.05 8.85 6.6; 104 0 8.85 3.3; 105 6.6 8.85 3.3;

108 9.05 8.85 9.7; 109 12.65 8.85 9.7; 110 0 8.85 13.2; 111 6.6 8.85 13.2;

112 0 8.85 9.7; 113 6.6 8.85 9.7; 114 15.65 8.85 6.6; 115 15.65 8.85 9.7;

116 9.05 8.85 16.3; 117 12.65 8.85 16.3; 118 15.65 8.85 16.3; 119 0 8.85 19.8;

120 6.6 8.85 19.8; 121 0 8.85 16.3; 122 6.6 8.85 16.3; 123 9.05 8.85 19.8;

124 15.65 8.85 19.8; 125 0 8.85 26.4; 126 6.6 8.85 26.4; 127 9.05 8.85 26.4;

128 15.65 8.85 26.4; 129 0 8.85 23.1; 130 6.6 8.85 23.1; 131 9.05 8.85 23.1;

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136 9.05 8.85 33; 137 15.65 8.85 33; 139 0 12.15 0; 140 6.6 12.15 0;

141 9.05 12.15 0; 142 15.65 12.15 0; 143 0 12.15 6.6; 144 6.6 12.15 6.6;

145 9.05 12.15 6.6; 147 0 12.15 3.3; 148 6.6 12.15 3.3; 151 9.05 12.15 9.7;

153 0 12.15 13.2; 154 6.6 12.15 13.2; 155 0 12.15 9.7; 156 6.6 12.15 9.7;

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168 0 12.15 26.4; 169 6.6 12.15 26.4; 170 9.05 12.15 26.4;

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177 9.05 12.15 29.7; 178 15.65 12.15 29.7; 179 9.05 12.15 33;

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254 15.65 8.85 3.74; 255 12.305 12.15 0; 256 12.305 12.15 3.74;

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MEMBER INCIDENCES

1 26 27; 2 27 28; 3 28 243; 4 30 31; 5 32 245; 6 26 30; 7 27 31; 8 28 32;

9 29 246; 10 34 35; 11 36 37; 12 30 36; 13 31 229; 14 32 34; 15 33 38;

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54 16 43; 55 21 46; 56 22 47; 57 19 48; 58 20 49; 59 25 50; 60 23 51; 61 24 52;
62 53 54; 63 54 55; 64 55 247; 65 57 58; 66 59 249; 67 53 80; 68 54 81;
69 55 59; 70 56 250; 71 61 62; 72 63 64; 73 57 82; 74 58 83; 75 59 61;
76 60 65; 77 62 65; 78 66 67; 79 61 66; 80 62 67; 81 67 68; 82 71 72; 83 63 84;
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135 89 76; 136 90 78; 137 91 79; 138 82 83; 139 84 85; 140 86 87; 141 88 89;
142 90 91; 144 250 60; 147 249 60; 149 96 97; 150 97 98; 151 98 251;
152 100 101; 153 102 253; 154 96 104; 155 97 105; 156 98 102; 157 99 254;
158 108 109; 159 110 111; 160 100 112; 161 101 113; 162 102 108; 163 114 115;
164 109 115; 165 116 117; 166 108 116; 167 109 117; 168 117 118; 169 119 120;
170 110 121; 171 111 122; 172 116 123; 174 125 126; 175 127 128; 176 119 129;
177 120 130; 178 123 131; 179 124 132; 180 126 133; 181 127 134; 182 128 135;
183 133 136; 184 136 137; 185 53 96; 186 54 97; 187 55 98; 188 56 99;
189 57 100; 190 58 101; 191 59 102; 192 60 114; 193 61 108; 194 65 115;
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271 96 139; 272 97 140; 273 98 141; 274 99 142; 275 100 143; 276 101 144;
277 102 145; 278 114 157; 279 108 151; 280 115 158; 281 110 153; 282 111 154;
283 116 159; 284 118 237; 285 119 162; 286 120 163; 287 123 166; 288 124 238;
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295 137 180; 296 166 167; 297 147 143; 298 148 144; 299 147 148; 300 155 153;
301 156 154; 302 164 162; 303 165 163; 304 172 168; 305 173 169; 306 174 170;
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323 158 183; 324 182 159; 325 183 161; 326 182 183; 327 184 185; 328 185 186;
329 186 259; 330 188 189; 331 190 261; 332 184 192; 333 185 193; 334 186 190;
335 187 262; 336 196 197; 337 188 198; 338 189 199; 339 190 200; 340 201 202;
341 200 203; 342 204 205; 343 196 206; 344 197 207; 345 208 209; 346 210 211;
347 212 213; 348 214 215; 349 204 216; 350 205 217; 351 209 218; 352 211 219;
353 213 220; 354 214 221; 355 215 222; 356 220 223; 357 223 224; 358 139 184;
359 140 185; 360 141 186; 361 142 187; 362 143 188; 363 144 189; 364 145 190;
365 157 201; 366 151 200; 367 158 202; 368 153 196; 369 154 197; 370 159 208;
372 162 204; 373 163 205; 374 166 209; 376 168 212; 377 169 213; 378 170 214;
379 171 215; 380 176 220; 381 179 223; 382 180 224; 383 209 211; 384 192 188;
385 193 189; 386 192 193; 387 198 196; 388 199 197; 389 206 204; 390 207 205;
391 216 212; 392 217 213; 393 218 214; 394 219 215; 395 221 223; 396 222 224;
397 198 199; 398 206 207; 399 216 217; 400 218 219; 401 221 222; 403 262 201;
406 261 201; 408 200 202; 409 208 210; 410 202 226; 411 203 208; 412 226 210;

413 203 226; 414 227 35; 415 35 62; 416 62 109; 417 228 40; 418 40 67;

419 67 117; 420 31 32; 421 45 42; 422 47 48; 423 229 37; 424 230 45;

425 229 34; 426 230 39; 427 231 40; 428 232 43; 429 231 232; 430 58 59;

431 101 102; 432 144 145; 433 189 190; 434 83 61; 435 113 108; 436 156 151;

437 199 200; 438 72 69; 439 120 123; 440 163 166; 441 205 209; 442 74 75;

443 126 127; 444 169 170; 445 213 214; 446 85 66; 447 122 116; 448 165 159;

449 207 208; 450 233 68; 451 234 70; 452 235 124; 453 236 118; 454 237 161;

455 238 167; 458 233 234; 459 236 235; 460 237 238; 461 161 210; 462 167 211;

463 243 29; 464 246 33; 465 245 33; 466 243 244; 467 244 246; 468 244 245;

469 247 56; 470 247 248; 471 248 250; 472 248 249; 473 251 99; 474 251 252;

475 252 254; 476 252 253; 477 255 142; 478 255 256; 479 256 258; 480 256 257;

481 259 187; 482 259 260; 483 260 262; 484 260 261; 485 239 243; 486 243 247;

487 247 251; 488 251 255; 489 255 259; 490 240 244; 491 244 248; 492 248 252;

493 252 256; 494 256 260; 495 241 245; 496 245 249; 497 249 253; 498 253 257;

499 257 261; 500 242 246; 501 246 250; 502 250 254; 503 254 258; 504 258 262;

UNIT MMS NEWTON

DEFINE MATERIAL START

ISOTROPIC MATERIAL1

E 25000

POISSON 0.17

DENSITY 2.4e-005

DAMP 7.90066e+033

END DEFINE MATERIAL

UNIT METER KN

CONSTANTS

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

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

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

MEMBER PROPERTY INDIAN

*COLUMN

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

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

414 TO 419 PRIS YD 0.6 ZD 0.45

*PLINTH BEAM

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

468 PRIS YD 0.6 ZD 0.3

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

*BEAMS

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

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

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

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

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

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

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

SUPPORTS

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

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

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

MEMBER RELEASE

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

413 START FX FZ MX MY MZ

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

*LUMPED WEIGHT FOR EARTHQUAKE CONSIDERATION = 3456 tonn

*HEIGHT OF BUILDING = 15.45 m

*AS PER 1893 CODE 2002

*ZONE IV ; Z=0.24 ; I=1.5 ; R=5.0

*TIME PERIOD = (0.075)x H 0.75

* = (0.075)x 15.45 exp 0.75 =0.584 sec

* Sa /g = 2.5

* BASE SHEAR = 0.036 x 2.5 x 3456

* = 311.04 tonn

*AS PER STAAD PRO :

*CQC SHEAR (IN X DIRECTION) = 151.11 TONN

*CQC SHEAR (IN Z DIRECTION) = 158.12 TONN

*SCALING FACTOR (IN X DIRECTION) = 311.04/151.11

*Scaling factor (in z direction) = 311.04/158.12

CUT OFF MODE SHAPE 21

DEFINE 1893 LOAD

ZONE 0.24 RF 5 I 1.5 SS 2 ST 1 DM 0.05

SELFWEIGHT413 END FX FZ MX MY MZ

LOAD 3 WALL

SELFWEIGHT Y -1

MEMBER LOAD

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

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

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

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

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

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

```
126 129 131 133 134 136 140 142 150 152 155 156 159 161 162 167 169 171 172 -
175 177 178 181 184 212 215 217 219 220 222 236 238 241 242 245 247 248 252 -
255 257 258 261 263 264 267 270 298 301 303 305 306 308 324 423 -
424 UNI GY -8.1
25 UNI GY -9.8
327 TO 329 332 335 337 340 343 346 347 349 352 353 355 TO 357 384 387 389 -
391 394 396 403 410 412 UNI GY -5.8
LOAD 4 DL
FLOOR LOAD
*******************************************
*   FIRST FLOOR LVL
*******************************************
YRANGE 5.55 5.55 FLOAD -4.75 XRANGE 0 15.7 ZRANGE 0 33.1
*ADD TOILET
YRANGE 5.55 5.55 FLOAD -14.75 XRANGE 9 15.7 ZRANGE 0 6.7
*******************************************
*   SECOND FLOOR LVL
*******************************************
YRANGE 8.85 8.85 FLOAD -4.75 XRANGE 0 15.7 ZRANGE 0 33.1
*ADD TOILET
YRANGE 8.85 8.85 FLOAD -14.75 XRANGE 9 15.7 ZRANGE 0 6.7
*******************************************
*   THIRD FLOOR LVL
*******************************************
YRANGE 12.15 12.15 FLOAD -4.75 XRANGE 0 15.7 ZRANGE 0 33.1
*ADD TOILET
YRANGE 12.15 12.15 FLOAD -14.75 XRANGE 9 15.7 ZRANGE 0 6.7
```

****

*   TERRACE LVL

****

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

MEMBER LOAD

*STAIR

429 UNI GY -18.6

85 172 258 458 TO 460 UNI GY -24

LOAD 5 LL

FLOOR LOAD

****

*   FIRST FLOOR LVL

****

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

*ADD CORRIDOR

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

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

*ADD STORE

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

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

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

*DEDUCT TOILET

YRANGE 5.55 5.55 FLOAD 1 XRANGE 9 15.7 ZRANGE 0 6.7

****

*   SECOND FLOOR LVL
****

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

*ADD CORRIDOR

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

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

*ADD STORE

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

*DEDUCT TOILET

YRANGE 8.85 8.85 FLOAD 1 XRANGE 9 15.7 ZRANGE 0 6.7

****

* THIRD FLOOR LVL
****

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

*ADD CORRIDOR

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

*ADD STORE

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

*DEDUCT TOILET

YRANGE 12.15 12.15 FLOAD 1 XRANGE 9 15.7 ZRANGE 0 6.7

****

* TERRACE LVL
****

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

MEMBER LOAD

*STAIR

429 UNI GY -10

85 172 258 458 TO 460 UNI GY -13.2

LOAD COMB 6 (DL +EQ.LL)

3 1.0 4 1.0 5 0.5

PERFORM ANALYSIS

LOAD LIST 6

PRINT SUPPORT REACTION ALL

FINISH

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