M. Tech Structural Engineering Aditya Vishwakarma 2023

ANALYSIS OF SEISMIC SUSCEPTIBILITY OF AN IRREGULARLY PLANNED SETBACK STRUCTURE WITH A SOFT STOREY ON SLOPING TERRAIN AND PLAIN TERRAIN

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

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CANDIDATE'S DECLARATION

I, ADITYA VISHWAKARMA, 2K21/STE/03, of M.Tech (Structural Engineering), hereby declare that the project Dissertation titled "Analysis Of Seismic Susceptibility Of An Irregularly Planned Setback Structure With A Soft Storey On Sloping Terrain And Plain Terrain" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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<u>CERTIFICATE</u>

I hereby certify that the Project Dissertation titled "Analysis Of Seismic Susceptibility Of An Irregularly Planned Setback Structure With A Soft Storey On Sloping Terrain And Plain Terrain" which is submitted by ADITYA VISHWAKARMA, 2K21/STE/03, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **PROF. NIRENDRA DEV**

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ABSTRACT

The construction of multi-story setback buildings with soft storey, or open ground floor, is in high demand and becoming more and more popular. This effort decreases the setback configuration's vertical stability and the lateral load resisting system's rigidity. When a building is supported on sloping land, there are several possibilities for short and long columns inside the same structure. During earthquake shaking, all columns and floor slabs at every level move horizontally by the same amount, which may result in structural damage. In this study, an attempt is made to examine the seismic performance of setback buildings standing on flat ground as well as on a slope, with soft storey layout. ETABS, a widely used software programme, was used to analyse simple 3-D frames of SETBACK structures. Using the study findings several graphs were drawn for like base shear, storey drift, storey stiffness, displacement, rotation about z axis are developed for both terrains i.e. plain and sloping. To create a technical expertise two identical structure were examined on both terrains. All the modelled structures with open ground storey have been analysed using two distinct methods: equivalent static force technique, response spectrum method. To counteract this soft storey impact and the severe reactions, mitigation approaches have been implemented, and the most effective of these mitigation techniques is provided.

ACKNOWLEDGEMENT

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ADITYA VISHWAKARMA

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

The effects of unplanned growth are being felt by the average person in a booming country like India. Many amateur performers Those who work in the real estate development industry supply subpar civil engineering products and profit from the general public's ignorance of numerous specialised civil engineering topics. Given the large private sector of real estate developers' dishonest behaviour and the fact that 78% of India's population, and 60% of India's land area are at risk of moderate to severe seismic shaking, it is essential for the Indian common man to be aware of some unvarnished truths regarding ideal earthquake safety procedures.

The study of earth vibrations, primarily brought on by earthquakes, is known as seismology. The main focus of seismology is the study of these vibrations using diverse methodologies in order to better understand their nature and the numerous physical processes that cause them.

One such hypothesis that was able to explain the occurrence of earthquakes occurring along fault lines is the elastic rebound theory. As a whole, the science of earthquakes is still largely unexplored, and much remains to be learned.

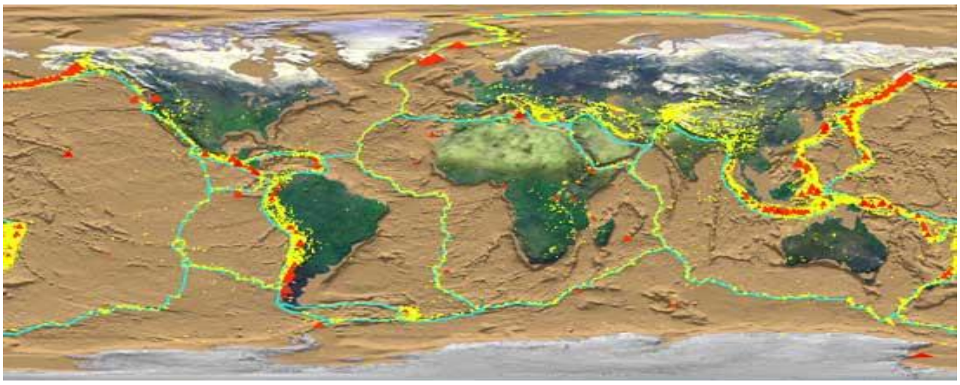

Fig 2.1 Edges Of The Tectonic Plates

Epicentres are clustered along the fault lines, as is seen. There is still a lot of uncertainty around the cause of seismic activity that occurs away from fault boundaries, One of the such example is bhuj, Gujarat earthquake in 2001. Additionally, earthquake forecasting has not yet been done but would be significant if done so. The Bhuj earthquake of 2001, in particular, raised the most concerns about the fragility of reinforced concrete buildings in India. This sad incident has vividly shown shortcomings in the whole system in charge of Indian buildings, not just the common engineering design practise. Since 2001, a detailed investigation has been conducted on the various parties' roles in the creation of these structures. There is a common belief ***"that human deaths are not caused by earthquakes but rather by poor engineering"***. In current contemporary culture, functional efficiency and aesthetic appeal are the most sought-after qualities in architectural design. The creation of multi-story setback buildings with a soft storey also known as an open ground storey is therefore becoming more necessary. As a result of this effort, the system's ability to withstand lateral stresses becomes less stiff, and the setback arrangement causes vertical anomalies in the structure.

1.2 OPEN GROUND STOREY RC BUILDING

Such structures are frequently referred to as open ground storey buildings because the entire ground floor is left exposed and no infill masonry walls are constructed in the bays between the beams and columns. Even though there are no walls constructed between the bays between the frame elements, there are often full height glass windows just around the building's perimeter. Even these structures receive treatment as open ground-storey structures.

The building is much stronger in the higher floors than in the open ground story due to the existence of walls in the upper stories. As a result, the building's upper levels almost move as a single unit, with the open ground floor experiencing the majority of the building's horizontal displacement. As a result, during earthquake shaking, these structures oscillate back and forth like inverted pendulums. it is understandable that columns in the open ground level are badly strained. If the columns are weak, they may suffer serious damage or possibly cause the structure to collapse because they lack the necessary strength to withstand these high loads. Buildings with open ground floors are sometimes known as buildings on stilts.

In order to accommodate parking in the building's ground floor, architects mandate that there be no masonry infill walls there and the masonry infill walls in the upper storey be the same width as the columns, obliterating all traces of the columns once construction is complete.

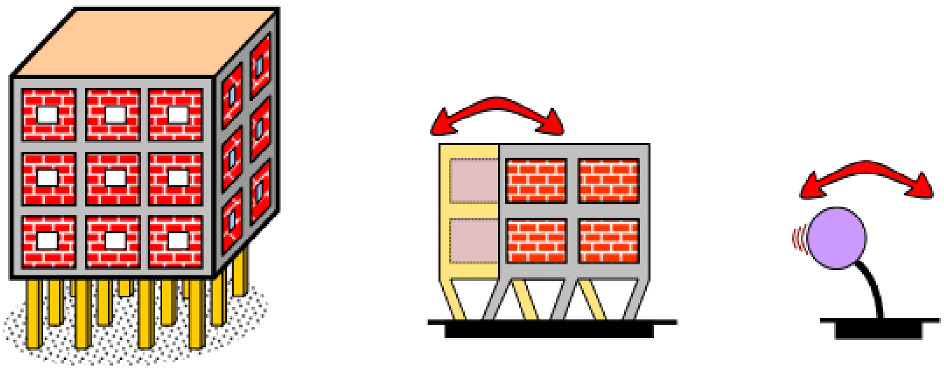

Fig 1.2 Open ground-storey structures have both structural and design flaws

A structure with an open ground floor walls and columns in the upper floors have two distinct features, compared to just columns in the first floor, specifically:

(a) It is quite flexible in the ground story, as shown by the fact that Its total horizontal displacement in the base level alone is substantially more than its total horizontal displacement in any of the floors above. Soft story is a different title for this flexible ground floor.

(b) Its ground storey is relatively weak; that is, Its base floor alone can sustain far less of the overall horizontal earthquake power than any of the storeys above it.. As a result, the open ground floor might potentially be weak.

1.3 WEAK COLUMN-STRONG BEAM SYSTEM

In structures, the horizontal members are supported by the vertical elements. Therefore, horizontal members must be weaker than vertical members. Beams often have the same width as columns and are deeper than columns. But beams contain more steel. They are thus more durable than the columns.

1.4 EFFECT OF SMALL COLUMN SIZE ON BEAM-COLUMN JOINTS:

If the column width is narrow, it is impossible to grab the beam bars securely inside it. Joints experience pull-push pressures as a result of earthquake shaking, which has two effects:

(a) loss of grip on the beam bars at the joint Strong concrete and wide columns help keep the beam bars in place.

(b) causes concrete to fracture diagonally and to compress, which causes joints to be irreparably damaged by intense seismic shaking.

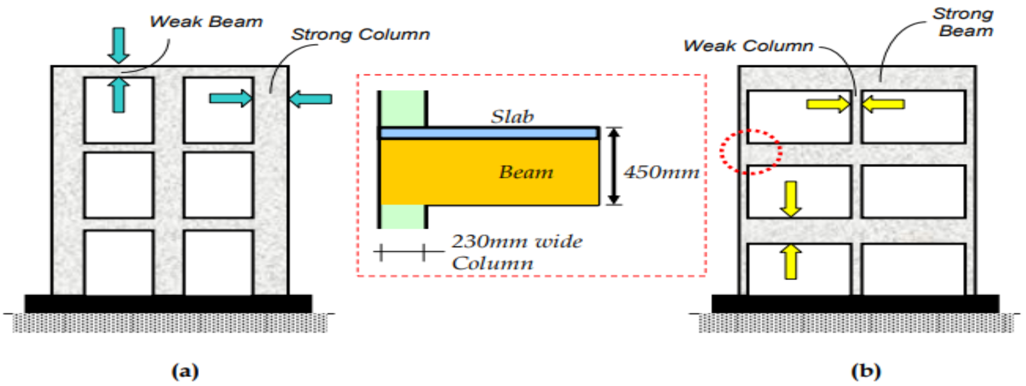

Fig 1.3 : (a) Strong-Column Weak-Beam Design (b) WeakColumn Strong-Beam Design

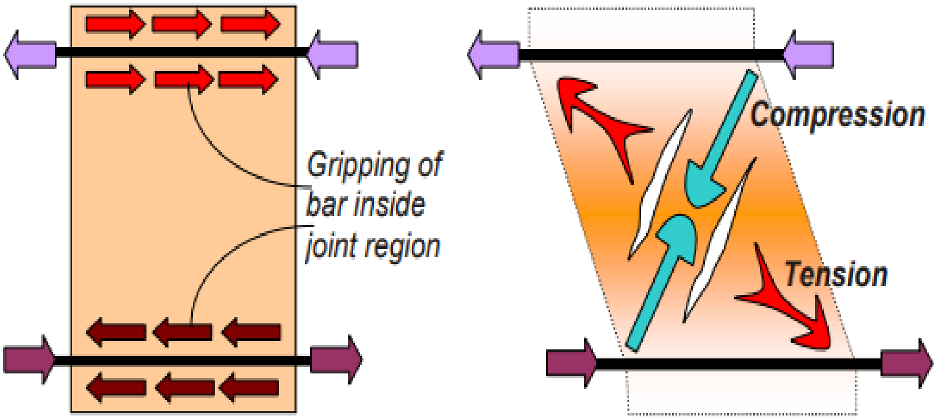

Fig 1.4 : Effect of Small Column Size on Beam-Column Joints

1.5 STEPBACK AND SETBACK BUILDING ON HILLY SLOPES

Buildings on hill slopes are unique from other buildings in certain ways. Such structures may feature setbacks in addition to their different storeys stepping back towards the hillside. A setback is a rapid shift in a building's plan size or stiffness along its height. Uneven column heights at the same level may occur from a building's stepping back towards a hillside. Two different kinds of columns, one resting on the floor below and the other on sloping ground, may support the floors. Some of the building's columns may be in the cutting (i.e., on solid ground) while others may be in the filling (i.e., on soft ground). In hilly locations, buildings are often arranged differently, which results in very uneven and asymmetrical structures. These structures exhibit strong torsional reaction in addition to translational response when exposed to lateral stresses.

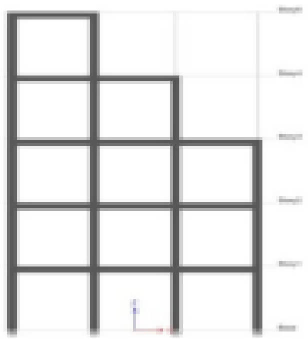

Fig 1.5(a)

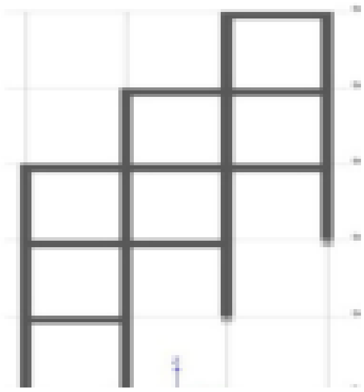

Fig 1.5(b)

Fig 1.5

(a) Setback building on plain ground (b) Setback Stepback building on sloping ground

1.6 PROBLEMS ASSOCIATED WITH HILL BUILDINGS

There are additional problems in buildings located on hilly terrains than plain terrain:-

a) Buildings in hilly terrain are uneven and asymmetrical, and as a result, they are prone to strong torsion pressures as well as lateral stresses from earthquakes.
b) On the slope of a hill, several structures are supported by columns of various lengths. Due to their greater rigidity and susceptibility to damage from earthquakes, shorter columns receive larger forces.
c) In addition to typical regular loads as described for structures in plain regions, buildings in hill locations are exposed to lateral earth pressure at different levels.
d) On the hillside, the soil profile is not uniform, which causes variable soil qualities at various elevations. The amount of internal friction, cohesiveness, bearing capacity, and other characteristics may vary. It might lead to uneven foundation settlement and localised slope collapse.

The shorter columns in reinforced concrete (RC) frame structures with columns of varying heights within one level sustained greater damage during previous earthquakes than the higher columns within the same floor.

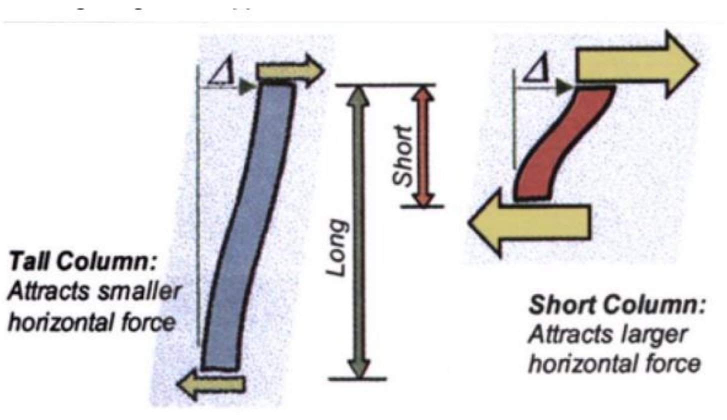

Fig 1.6 Effect Of Long And Short Column

Since tall columns and short columns having a similar sectional area both move horizontally during an earthquake by the same amount, small columns perform badly. However, the long column is less stiffer than the short column and short column draws greater seismic force. A column's stiffness determines its resistance to deformation; the more stiff the column, the more effort is needed to distort it. A short column might sustain substantial damage during an earthquake if it is not properly built to withstand such a powerful impact. The Short Column Effect is the name given to this phenomenon.

This sort of damage to columns is caused by shear failure and often takes the appearance of X-shaped cracking.

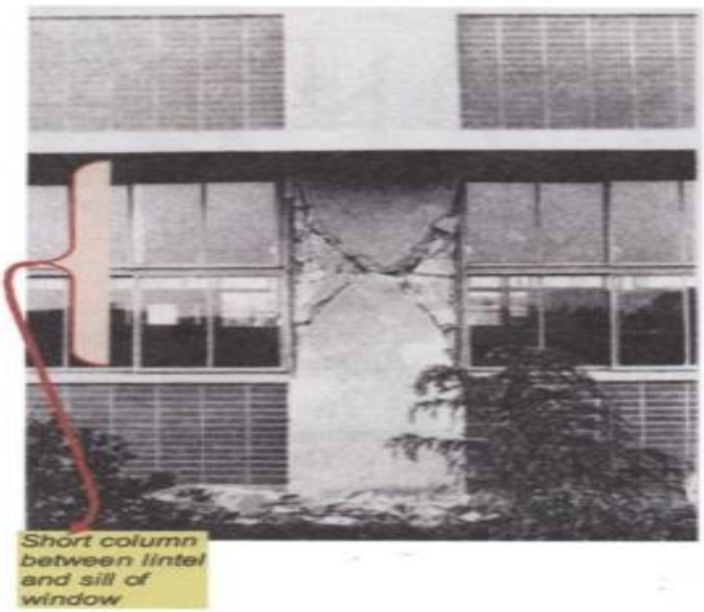

Fig 1.7 Shear Failure(X-Shaped Cracking)

Buildings often experience the short column effect. when a structure is supported on sloping ground, In the event of an earthquake, the floor slab and each column will shift horizontally by the same amount. (Known as Rigid Floor Diaphragm Action). When Tall And Short Columns are present on the same floor, the shorter columns are more vulnerable to damage from earthquakes and are subject to much greater forces.

1.7 OBJECTIVE OF THESIS

The main objective of thesis are:

- To study the seismic behaviour of the structure with irregular plan in sloping ground.
- To compare the performance of the set back building resting on sloping ground and in the plain ground with open storey.
- Implementation of Modification technique to overcome the stiffness deficiency and improve structural response.

1.8 ORGANIZATION OF THESIS

Chapter 1: discuss the introduction and account of the topic use and importance.

Chapter 2: outlines of some of the literature and earlier research on seismic analysis on vertical irregular structure.

Chapter 3: explains the methodology and provides information about the structural details and analysis that were done.

Chapter 4: results and discussion on the various parameters that were analysed

Chapter 5: conclusions and future scope of the work

CHAPTER 2

LITERATURE REVIEW

The literature evaluation is done in the fields of open ground storey vulnerability under powerful earthquake, influence of vertical irregularity under varied terrains, and response of setback structures under seismic loading. Review of published research on the behaviour of irregular open ground story (OGS) structures under seismic stress is the focus of this chapter. The response parameters comprise torsion, lateral displacement, inter-storey drift, and ductility demand

Murthy et al (2012) The stiffness and strength irregularity in the ground storey should be reduced, if not eliminated, for certain existing structures or for all new buildings that have or need to have open ground floors. Select bays in the ground storey may have RC walls constructed around them, while bays that extend the whole height of the structure may have masonry walls erected within them or may be left open. Of course, masonry walls will be used to fill the remaining bays in the top levels.

Birajdar and Nalawade(2004) examined the seismic response of three distinct layouts of buildings placed on sloping ground and plain ground i.e. stepback building, setback building, stepback setback building and concluded that out of these three configuration stepback buildings are more susceptible for earthquake and setback and stepback buildings the short columns are more effected by the seismic loadings.

Ghosh and Debbarma (2015) examined the inadequacy of structures with open ground storey using both the linear static and linear dynamic methods. They recommended adding shear barriers to the open ground floor to increase stiffness, control displacement and drift, and decrease failure.

Mohammed Umar Farooque et al.(2018) In this work, structural analysis tool "Etabs" was used to analyse 3D analytical models of eight-story structures that were both symmetric and asymmetric. Buildings lying on sloped ground experience more lateral displacement than those on plain ground, while the existence of shear walls may lessen this displacement. Because of the influence of asymmetry along the longitudinal direction, there are more instances of plastic hinge creation in structures on sloping ground in the longitudinal direction than the transverse direction.

G Suresh et al. (2014) Two sets of buildings configurations are taken into consideration in the research, both of which are perched on slopes. 27 degrees is the slope with respect to the horizontal. This study demonstrates that step back and set back building frames perform better than step back building frames. However, when bracings are taken into account, step back building frames perform better than set back and step back building frames.

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Y. Singh et al.(2012) The seismic behaviour of hill structures during the devastating Sikkim earthquake of the 18th of September 2011, is discussed in this research.. Under cross-slope excitation, the hill buildings are prone to strong torsional effects. The different heights of the columns lead to stiffness irregularity during along-slope excitation, and the short columns nearly entirely withstand storey shear. In the case of downhill structures, the storey at road level is more vulnerable to damage, according to the results of the linear and non-linear dynamic analysis.

Momen Mohamed. M. Ahmed et al. (2021) Attempts have been made in this study to compare the actual seismic performance of structures with two typical forms of vertical irregularities, such as soft stories and setbacks, to that of a normal (reference) building. For irregular models, soft story irregularity causes an increase in lateral distortion of around 10%; for irregular T and irregular L models, vertical soft story and setback irregularity causes an increase in lateral deformation of about 20%.

Sujit Kumar et al.(2014) study of, and comparison with, a G+4 storey RCC building built on flat ground using seismic analysis are done at slope angles of 7.50 and 150 degrees. According to IS: 1893–2002, seismic forces are taken into account. By applying the structural analysis system, the effect of sloping ground on the performance of buildings during earthquakes is explored. STAAD Pro v8i. Compared to flat ground, the crucial moment of bending in the column increases significantly at a 15° slope. The crucial value of the column's axial force, however, essentially stays the same for all terrain slopes. hence, in order to give additional resistance, the column of these sections needed extra steel.

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R. B. Khadiranaikar et al. (2015) In this study, it is shown that structures sitting on sloped ground experience more displacement and base shear than structures resting on flat ground, and that shorter columns are more susceptible to damage from earthquakes due to the increased pressures they draw. that more bays are shown to be better in seismic situations and that time and top storey displacement in hill slope constructions decrease as the number of bays increases.

Rahul Ghosh et al.(2017)used the equivalent static force technique, the response spectrum approach, and time history analysis to analyse setback structures on plain and sloping ground, and extreme responses were observed for setback buildings with open ground floor**..** The model with reinforced concrete filled steel tubes (RCFSTC) does not block any OGS access, stiffness is evenly distributed throughout the entire base of the structure, moreover, at the junction's RC column segment remains unchanged., so there will not form any hinges.

Pratiksha et al. (2016) In this study, the Response Spectrum Method is used to compare sloping land with various slopes to plain ground while doing analysis. Different sloping ground configurations are used to study the dynamic response and maximum displacement in columns. The displacement of a building exhibits the same behaviour as a typical construction on sloping terrain. The restriction of the column causes the displacement value to decrease as the slopes rise.

Sripriya Arjun et al. (2016) This research examines the behaviour of a G+3 story sloping frame building with a step back set back arrangement for sinusoidal ground motion at various slope angles using the structural analysis programme STAAD Pro. This analysis was done in accordance with IS:1893 (part 1): 2002. More so than in a transverse direction, the base shear operates in the longitudinal direction. This analysis shows that because of the lower displacement values, increasing the height of the structure is safe for 21.8 and 26.57 degrees..

CHAPTER 3

METHODOLOGY

3.1 OVERVIEW

All of the models are examined using the linear static approach, also known as the equivalent static force method (ESFM), and the linear dynamic approach, also known as the response spectrum method (RSM). The results of ESFM and RSM studies are compared in order to examine the seismic response of the structures. When conducting modal studies, mode shapes are often gathered in normalised form; as a result, the outputs of the response spectrum approach must be correctly scaled. The base shear obtained from ESFM and RSM were equaled in order to scale the results of the present experiment. In the ESFM investigation, numerous load combinations advised by various codes were employed, and the combination 1.5 (DL ± EL) had the most effect.

There are two ways to think about how design earthquake loads on structures affect those structures:

a) Dynamic analysis method, and

b) Equivalent static method

Dynamic analysis itself can be carried out in three different ways, including:

1) Response spectrum method,

2) Time history method, and

3) Modal time history method

3.2 EQUIVALENT STATIC METHOD OR EQUIVALENT STATIC FORCE METHOD

This linear static analysis. This method explains how to utilise a seismic design response spectrum to explain how an earthquake's ground motion affects a building when a variety of elements are at play. This strategy assumes that the structure will respond in its predetermined way. By applying parameters to take into account taller buildings with specific higher modes and low degrees of twisting, the utility of this technique is increased in different construction codes. Many codes have adjustment variables that lessen the design demands to account for the effects of the structure's "yielding" The corresponding static technique applies the lateral force equivalent of the design foundation earthquake statically. The "centre of mass" of the design is where the corresponding lateral pressures are exerted at each floor level. It is located at the eccentricity of the estimated "centre of rigidity (or stiffness)"..

For the study of conventional structures with a roughly natural period Ta of less than 0.4 s, equivalent static technique may be utilised..

The base measurement of a structure at plinth level in the axis of lateral strains is marked by d (in metres), while the building height from the support is denoted by h (in metres). The following formula may be used to get the design acceleration coefficient:

For areas with Type I soil (rock or hard soil):

$$\frac{Sa}{g} = \begin{cases} 2.5 & 0 < T < 0.40S \\ \frac{1}{T} & 0.40s < T < 4s \\ 0.25 & T > 4.00s \end{cases} \tag{3.1}$$

For Type II soil (medium soil):

$$\frac{Sa}{g} = \begin{cases} 2.5 & 0 < T < 0.55s \\ \frac{1.36}{T} & 0.55s < T < 4s \\ 0.34 & T > 4.00s \end{cases} \tag{3.2}$$

For Type III soil (soft soil):

$$\frac{Sa}{g} = \begin{cases} 2.5 & 0 < T < 0.67s \\ \frac{1.67}{T} & 0.67s < T < 4s \\ 0.42 & T > 4.00s \end{cases} \tag{3.3}$$

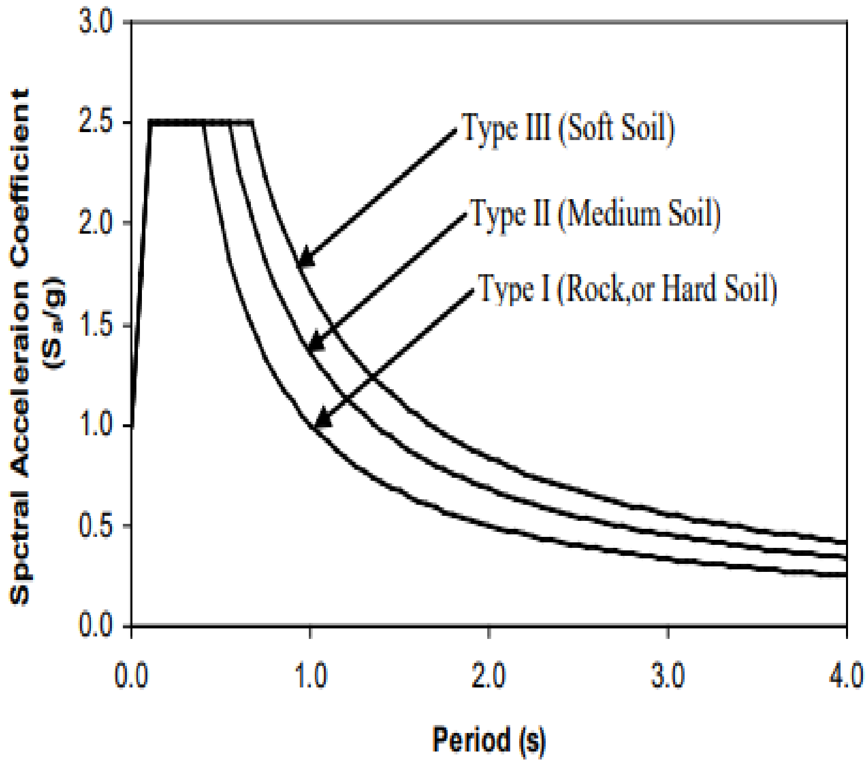


Fig 3.1 Spectra For Equivalent Static Method

The design base shear is to be distributed along the principal direction of building determined by:

$$V_B = A_h W \tag{3.4}$$

Where,

A_h = design horizontal acceleration coffecient value using approximate fundamental time period T_a

W = seismic weight of the building

The design horizontal seismic coefficient A_h for a structure shall be determined by;

$$A_h = \frac{(\frac{Z}{2})(\frac{S_a}{g})}{(R/I)} \qquad (3.5)$$

Where,

z = seismic zone factor

I = importance factor for corresponding structures

a) 1.5 for critical and lifeline structure
b) 1.2 for business continuity structures
c) 1.0 for the rest

The design lateral force at floor i is given as follows,

$$Q_i = A_h \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_j^2} \qquad (3.6)$$

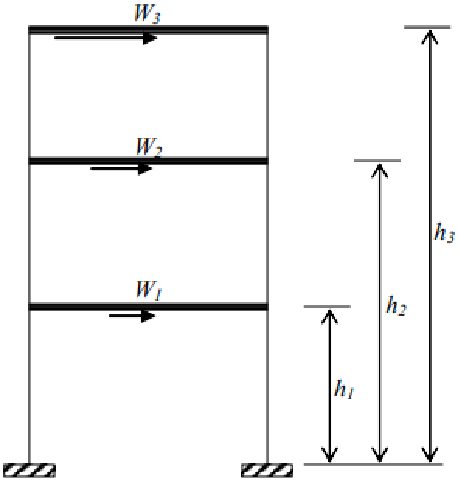


Fig 3.2 Building Model Under Seismic Load

3.3 RESPONSE SPECTRUM ANALYSIS

The maximum responses to a certain seismic ground motion are shown graphically as response spectra on a range of idealised single-degree freedom systems with various natural periods but the same damping. The response being considered here may have a maximum absolute acceleration, maximum relative velocity, or maximum relative displacement.

RSA is used for dynamic structure analysis. It is referred regarded as a dynamic analysis since it accounts for the structure's modal mass participation and mode shapes for different construction frequencies. Every structure vibrates at several distinct frequencies as well as not just one, and in the event of an earthquake, the structure's response is a synthesis of its many natural frequencies. No structure, whether natural or man-made, would ever respond to earthquakes outside of their typical frequency, you must understand. The shapes that each mode produces are known as eigen-vectors, and the corresponding frequencies of the structure will be referred to as eigenvalues. The only natural frequencies that are currently essential for recording the structure's overall response are the initial few. Typically, 90% of the modal mass must participate for codes to reflect the system's overall reaction..

RSA better reflects the "natural" reaction of the structure to seismic shaking since it is based on the mode shapes and natural periods of the building. It gives the building a more realistic "dynamic" reaction since the narrative forces are produced using the tale accelerations, mass, and eigenvectors.

RSA should always be used, no matter what sort of structure is used. It will always provide you a better grasp of the structure's efficiency and requirements, such as the base shear, story shear, and crucial times in the construction.

A building must have RSA if it has re-entrant corners asymmetry in the floor plan, horizontal and vertical lateral system discontinuities, an off-centered core where the centre of stiffness is far from the centre of mass, and where the building's torsional mode may be under control, is significantly tall (5–6 stories or more), or has a variety of lateral systems. These several elements combine to impede the structure's "ideal" and natural behaviour. Since it's essential to identify this "unusual" conduct, RSA should be utilised. The demand for the moments is relatively large since, as in the case of Esfm, it is based on a cantilever type loading distribution that ignores the important influence of higher mode of construction. However, with RSA, it is not the case.

3.4 STRUCTURE MODELLING

The fundamental architecture of these buildings is investigated in order to compare the varied responses of setback created structures and conventional constructed structures. The completely infilled setback model and the OGS setback model are then put into practise to account for the impact of soft storeys on setback structure. The OGS setback model is then modified in a number of ways to make up for the lack of rigidity and improve structural responsiveness brought on by the setback effect and soft storey design. The responses of different setback models are also investigated on sloping ground.

Integrated building design software ETABS 2020 version 20.0.0 is utilised to generate and analyse the models.

Steps involved in Modelling the Building:

- choose File > New Model
- Select use Built in settings
- Choose Metric SI units Display
- Values for the Simple Story Data and Uniform Grids Spacing should be entered in the New Model Quick Template box.
- The number of grids is 4 in both the x and y axes, and the grid spacing is 4m.
- Take storey height as 3m.
- Structural properties and slab properties are defined.
- The primary window will display the model..
- Select define-material attributes to define the concrete material property. concrete as a new material and then clicking "ok" Defining column section properties

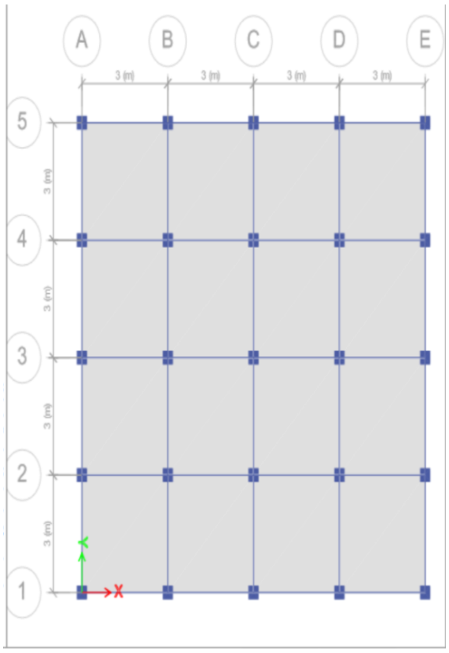
- Define the frame section property next.. .

For shear wall definition,

- Click Define and choose Section Properties > Wall Sections.
- Choose 'Add New Property' then 'Wall Properties'.
- Define the shear wall's breadth. Enter wall material after going to wall property and writing wall for the property name..
- Modelling type should be –Shell thin for shear walls. Click ok
- To define a slab, pick slab 1, specify section attributes, and slab sections.
- In the window for slab properties, choose edit property. Click "OK"
- Sections of the beam and column have been defined.
- to apply wall load on roof click on Edit alike stories.
- Distribute the loads. To assign a beam, column, or slab, choose Assign -Frame -Section Properties. After assigning, click OK.
- To assign support, choose assign-joints-restraints from the menu.
- Establishing load patterns. To assign all the loads, click on define-load patterns-assign. Next, choose define-mass source and then OK.
- Choose assign-shell loads-uniform-live loads/dead loads to allocate the loads. Snap the window shut.
- Wall loads are calculated by choosing every beam and then modifying similarity since the terrace will not have the same load.
- Assign frame loads that are evenly distributed.
- In order to choose the load combination, click define-load combination-add new combo.
- The design's last checks for any warnings. If there aren't any alerts, the model is sound.
- Select "Analyse -- Run Analysis"
- A thorough summary report that contains all of the parameters' findings will be produced.

3.5 ELEVATION AND PLAN AND STRUCTURAL DETAILS OF MODELS

A T-shape residential setback building resting on plain and sloping terrain with five storey (G+4) has been analysed having plan area of 4mX4m.



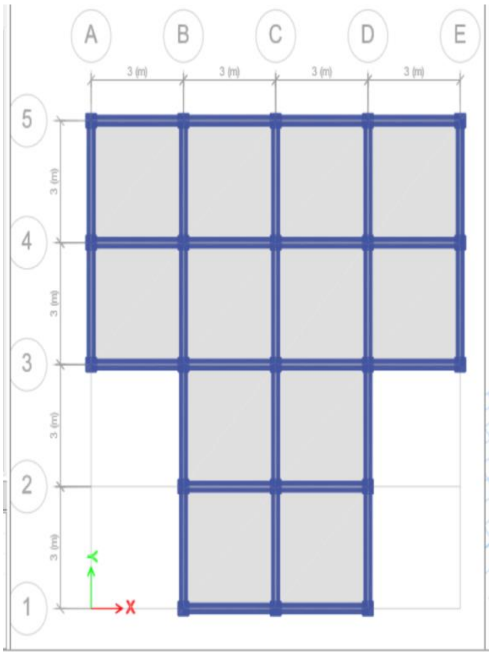


Fig 3.3(a) Regular Plan **Fig3.3(b) Irregular Plan**

Fig 3.3 Regular And Irregular Plan Of Buildings

3.5.1 Columns And Beam

The model for columns is a two-noded rectangular continuous vertical line element, whereas the model for beams is the same but with a horizontal element. To avoid deviating from the topic at hand and keep the discussion centred on the soft story effect alone, the columns are assumed to be square. To support the strong column weak beam hypothesis, the cross sectional areas of the beams are maintained lower than those of the columns.

3.5.2 Slab

Slabs are designed as four rectangular shell area parts with nodding corners. By restricting all of the degrees of freedom at each base joint, base conditions are rendered fixed. All of the structure's joints have joint diaphragms that are fixed, allowing the nodes of the beam, column, and slabs to be contained on each joint as a single unit.

3.5.3 Masonary Walls

Macro modelling, which is simple to model, allows for speedier analysis and yields excellent findings, has been used in this research to model the walls. The strut lengths match the diagonal length of the wall exactly. The strut's width has been set at one-fourth of the wall's diagonal length, and its thickness is the same as the wall's thickness. All other characteristics of the strut are identical to those of a brick wall. Two nodded pinned line components are used to depict the struts.

3.5.4 Shear Walls

Shear walls are very useful in many instances of structural engineering due to their high in plane stiffness and strength, that may be employed to withstand gravity loads while resisting strong horizontal forces. In this analysis, M25 grade concrete shear walls are represented by four nodded shell area components.

3.5.5 CFSTC (Concrete Filled Steel Tube Column)

CFSTC is made of hollow square steel tubes with a 100mm thickness and a size of 550mm x 550mm. The hollow tube is filled with the same 350mm x 350mm RC column that has the same concrete grade (M30) and reinforcing placement as the other 350mm x 350mm columns.

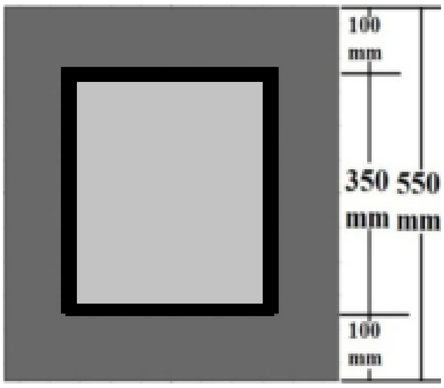


Fig3.4 Cross Section Of CFSTC

Here are provided all structure-related details in table given below:

Table 3.1 Properties Of Materials Used In Structural Elements

Materials Properties	
Unit weight of concrete	25 kN/m3
characteristic strength of concrete	30 MPa
Unit weight of Infill walls	21.2068 kN/m3
compressive strength of masonry walls	4.1 MPa
modulus of elasticity of masonry walls	2300 MPa,
characteristic strength of steel	500 MPa

Table 3.2 Data For Seismic Design

Seismic Design Data	
Soil type	Medium soil
Zone factor(Z)	0.36
Damping ratio	5%
Reduction factor	5
Frame type	Special moment resisting frame
Importance factor(I)	1

Table 3.3 Dimensions Of Structural Elements

Structural Elements	
Column	350mmx350mm
Beam	250mmx300mm
Wall thickness	250mm
Slab thickness	150mm
Steel tube	550mmx550mmx100mm
Shear wall thickness	200mm
Single strut width	1060mm
Single strut thickness	250mm

3.6 FIGURES AND DESCRIPTION OF THE MODELS

The analysis is based on a three-dimensional RC construction with a level foundation and vertical irregularity. For investigation, several building geometries were selected. These architectural forms exhibit a certain level of irregularity. Thirteen different buildings with storey height 3m were considered for the study with different position of shear wall in the ogs and modification of the base storey column with cfstc, there is one regular building model and remaining are irregular.

Irregular frames having foundation at same level are named as I_0,I_1,I_2,I_3,I_4,I_5,I_6 depending on the position of shear wall and modification of column, and irregular frames having foundations at different level (Stepback-Setback building) are named as T_0,T_1,T_2,T_3 depending on the postion of cfstc column and exterior infill walls. The regular frame is configured as $R_{0.}$

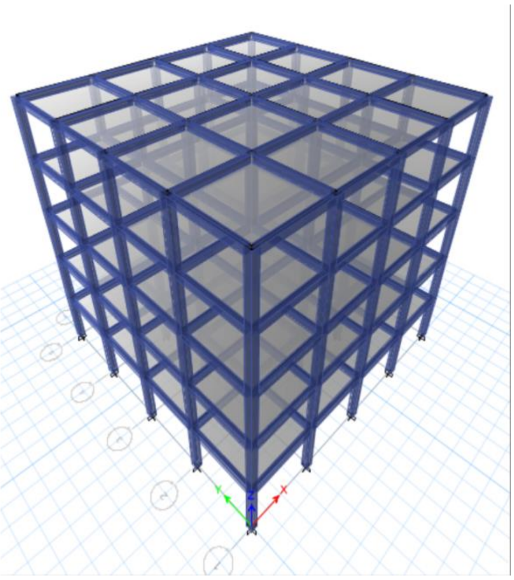


Fig 3.5(a) model R_0

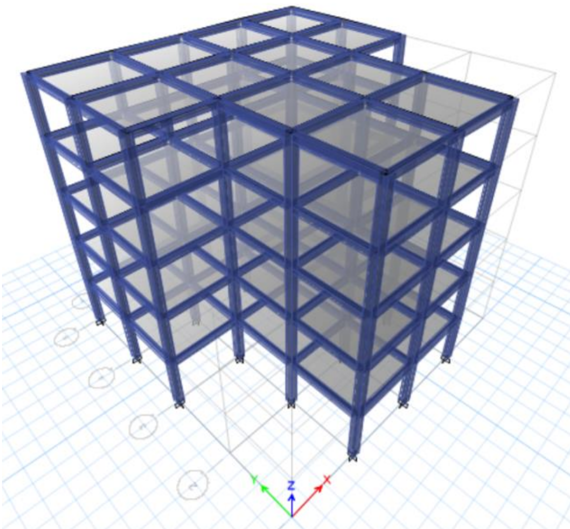


Fig 3.5(b) model R_1

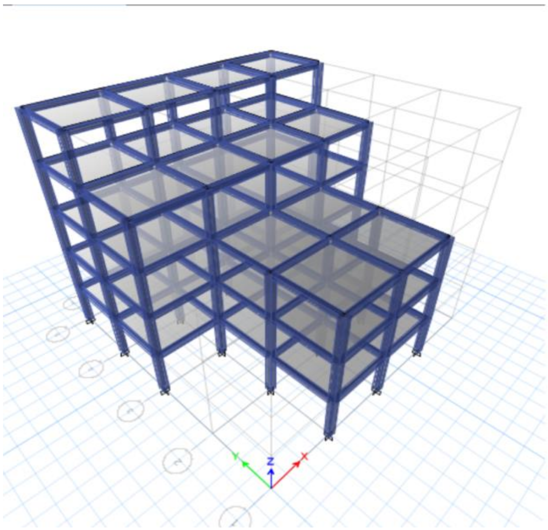


Fig 3.5(c) model I0

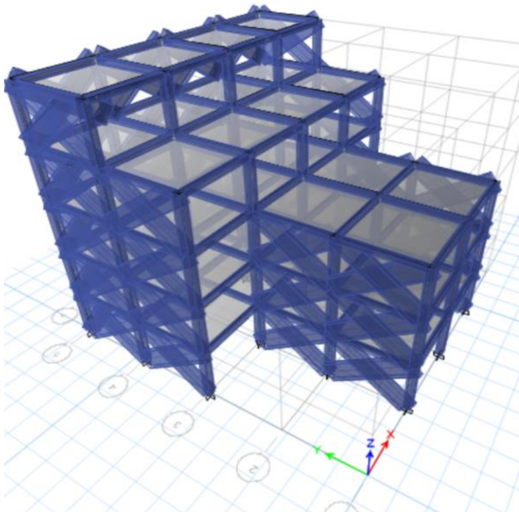


Fig 3.5(d) model I1

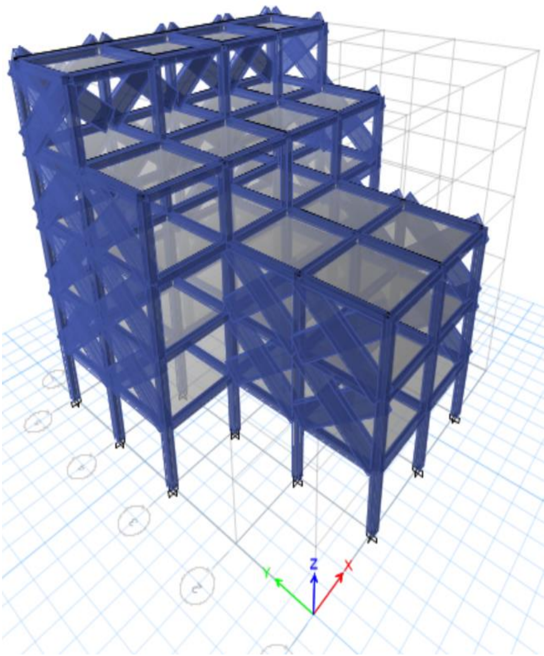


Fig 3.5(e) model I_2

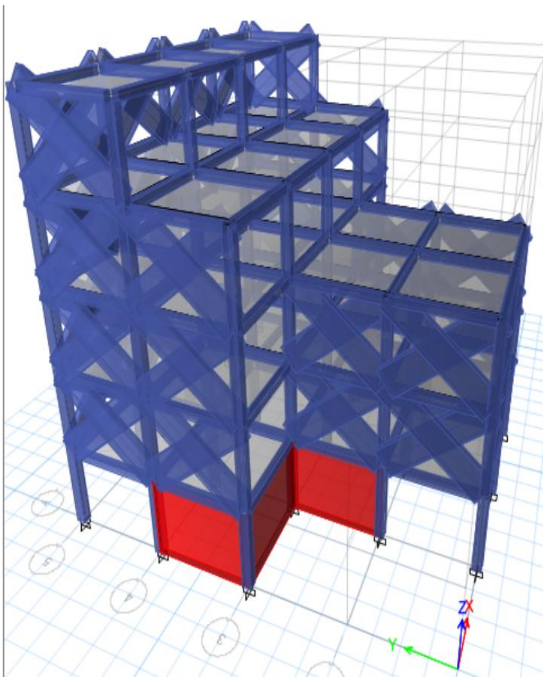


Fig 3.5(f) model I_3

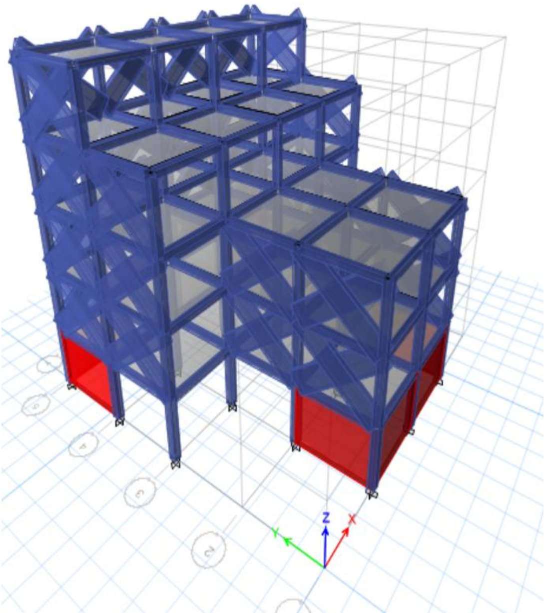


Fig 3.5(g) model I_4

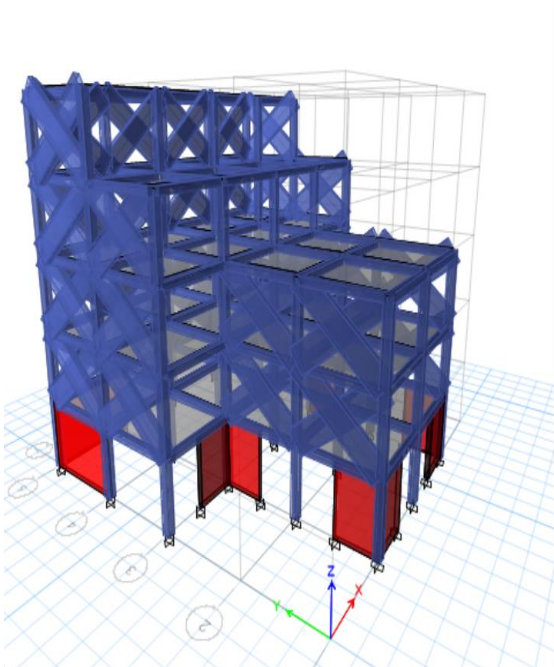


Fig 3.5(h) model I_5

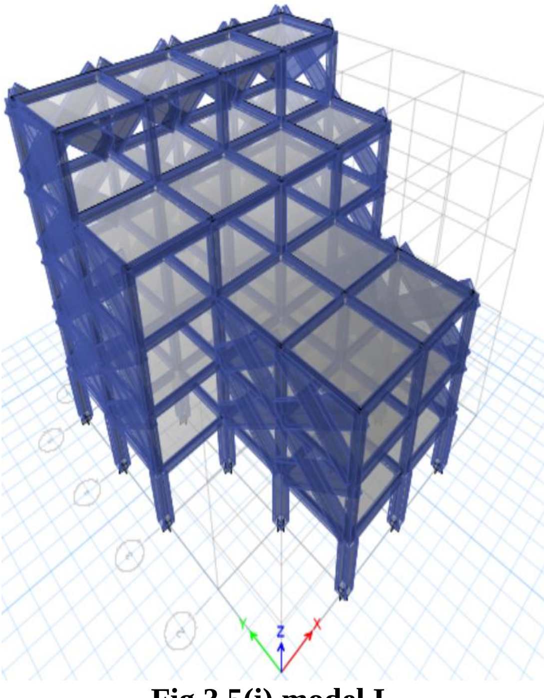


Fig 3.5(i) model I_6

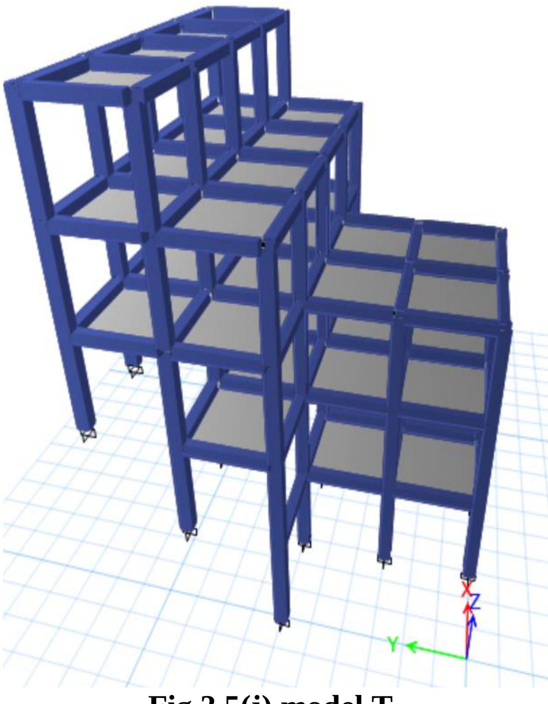


Fig 3.5(j) model T_0

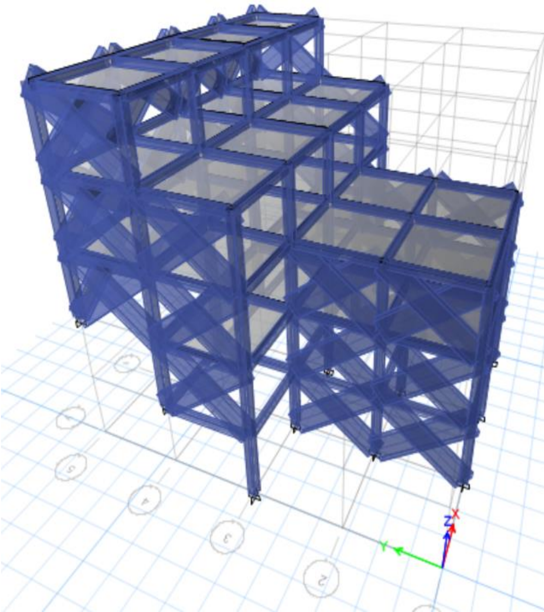


Fig 3.5(k) model T_1

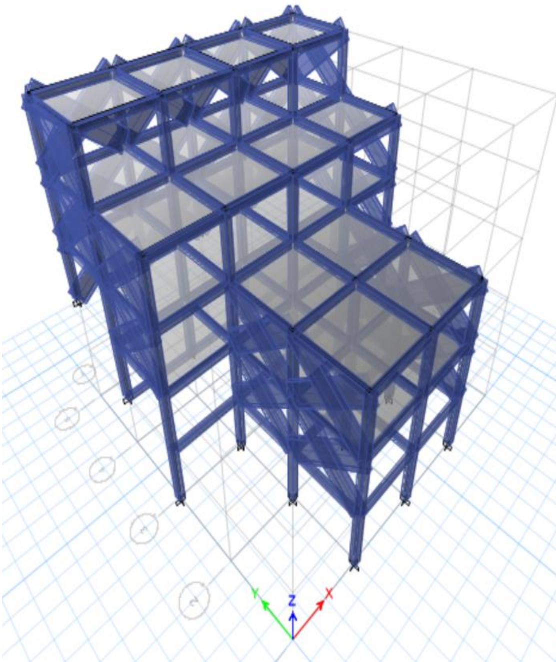


Fig 3.5(l) model T_2

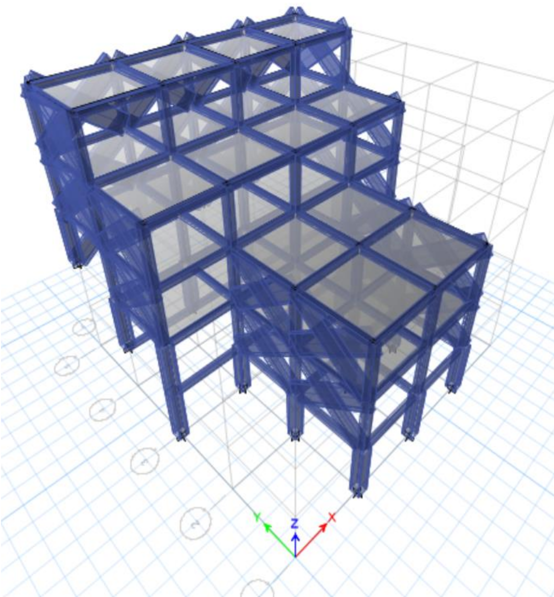


Fig 3.5(m) model T_3

Fig 3.5 Images of models resting on plain and sloping ground

Table 3.4 Notations Of Analysed Models

Model Description	Notations
Regular rectangular bare frame on plain terrain	R_0
Irregular T planned bare frame on plain ground	R_1
Irregular T planned setback bare frame on plain ground	I_0
Same as I0 ,Fully infilled with strut as wall	I_1
Irregular plan setback building with OGS, but other storey infilled with strut as wall	I_2
Same as I2 with ogs having shear wall at central peripheral sid]es	I_3
Same as I2 with ogs having shear wall at outer corner panels	I_4
Same as I2 with ogs having shear wall at inner and outer sides	I_5
Same as I2 but OGS are replaced by CFSTC	I_6
Irregular plan setback bare frame on sloping terrain	T_0
Irregular T planned fully infilled setback bare frame on sloping terrain	T_1
Irregular plan setback building with OGS, but other storey infilled on sloping ground	T_2
Same as model T2 but OGS are replaced by CFSTC	T_3

CHAPTER 4

RESULTS AND DISCUSSION

4.1 AXIAL FORCE

Figure 4.1 illustrates the variation of the axial force along the increasing storey height of conventional and setback building on plain ground terrain .

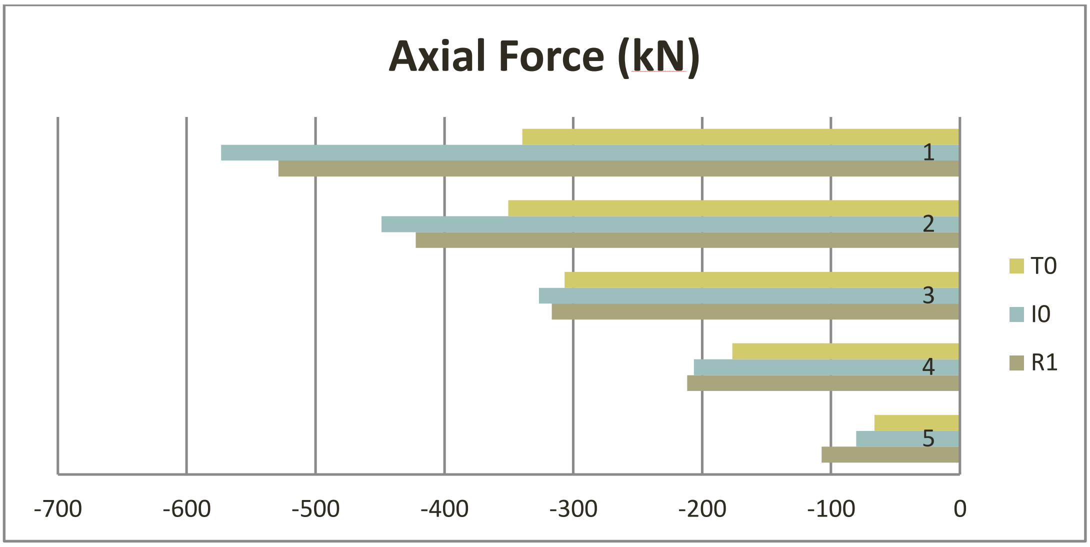


Fig4.1: Axial Force Distribution

The setback is absent till 2nd floor and the axial force of I0 is greater than that of R1. The axial force in the third floor is roughly equivalent. After the third storey, the axial force is observed to decrease Comparing model I0 to model R1. This drop in axial force at the fourth and fifth floors is the result of the Setback effect.

4.2 STOREY STIFFNESS

Lateral load resisting system and structural components like columns, walls are both responsible for the stiffness of a particular storey. Stiffness of each storey is thematically represented as shown in Figure 3. Figures 3a and 3b,illustrate that for both methods it is shown that the type of stiffness change throughout the rising heights of storey is similar. Model I2 and T2 with an Open Ground Storey at the bottom storey demonstrates that the Open ground Storey has much less stiffness than the uppermost storey in both cases. Consequently, this modellings demonstrates the soft storey effect, Which is the most susceptible to seismic damage.

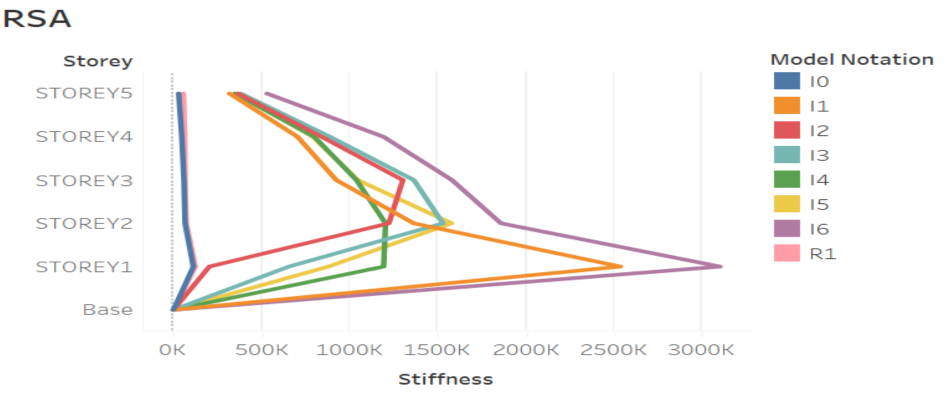


Fig4.2 (a) ***Stiffness Of Structure Resting On Plain(RSA)***

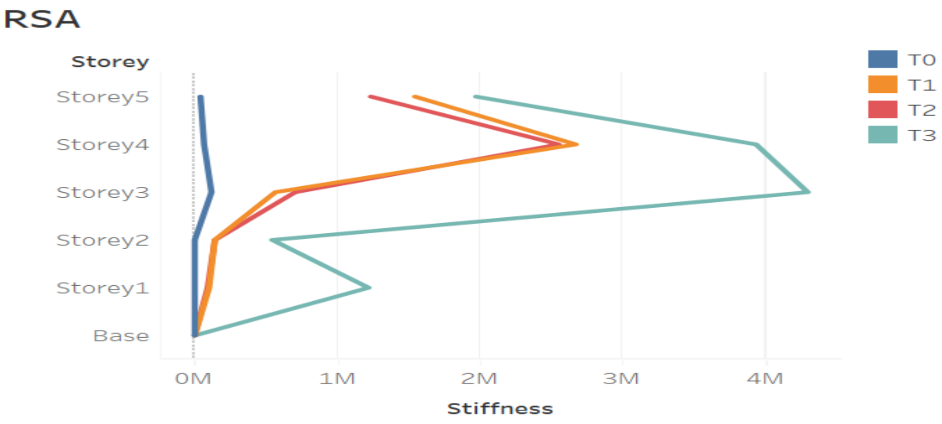


Fig 4.3(b) ***Stiffness Of Structure Resting On Slope(RSA)***

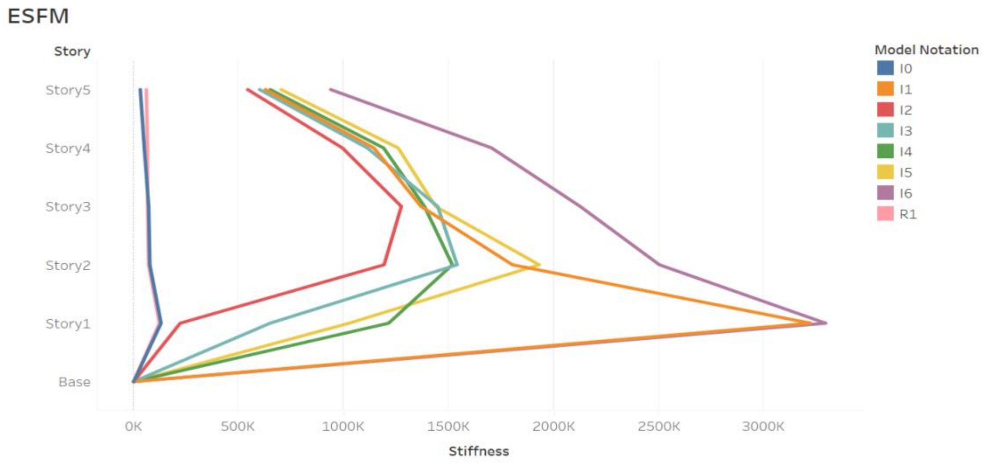


Fig 4.2(c) ***Stiffness Of Structure Resting On Plain(ESFM)***

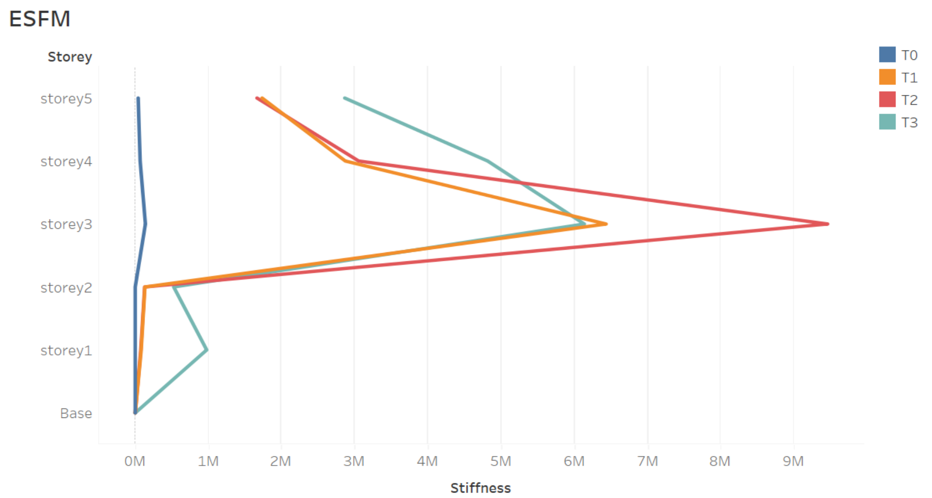


Fig 4.2(d) ***Stiffness Of Structure Resting On Slope(ESFM)***

To solve this issue, shear walls are added to the following models I3, I4, and I5, and CFSTC columns replace the standard RC columns of OGS in model I6 and T3. Table 3 displays the percentage of stiffness of the ground storey (GS) relative to the immediate above level. Consequently, the results indicate that the insertion of shear walls and the CFSTC mitigated the abnormality of soft storey stiffness in lieu of conventional RC column.

Table 4.1: Stiffness Percentage Of OGS

Model	R_1	I_0	I_1	I_2	I_3	I_4	I_5	I_6
ESFM	171.5	169.5	178.6	18.5	142.1	180.6	153.1	131.6
RSA	172.4	171.5	186.0	16.6	142.8	199.1	155.6	166.8

4.3 STOREY DRIFT

The relative movement between neighbouring floors is known as storey drift. The outcomes of both RSM and ESFM are depicted in Figure7. The findings of the both methods have similarity in their behaviour , however their values differ based on their respective modelling and analytic techniques. According to (IS1893,2016), severe drift criterion is 0.004 mm and none of the storey drifts surpass the recommended value. On evaluating the setback irregular planned structures I0 demonstrates maximum storey drift for each storey using both ways. Model I1, which is completely infilled with strut as a wall, is not recommended, The remaining models have even greater inter-storey drift control than model I1 in both techniques, with model I6 having the best drift control.

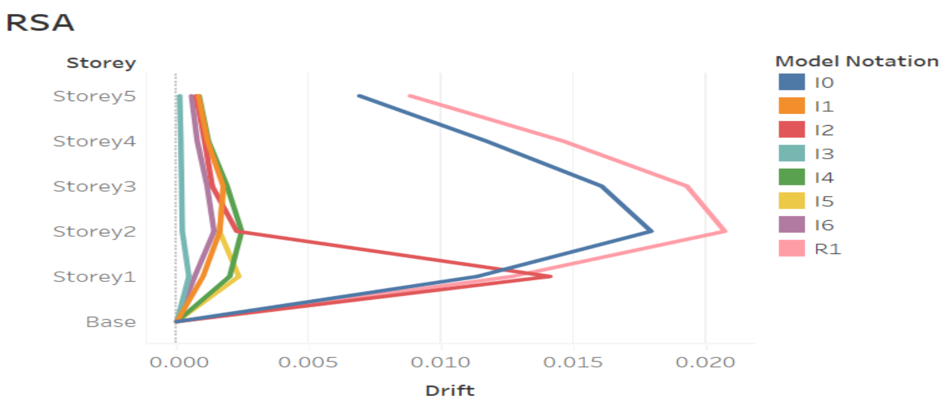


Figure 4.3(a) Drift Of Structure Resting On Plain(RSA)

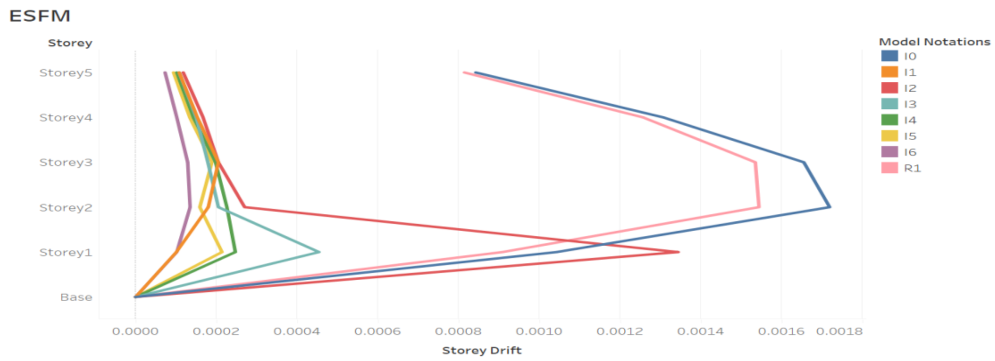


Figure 4.3(b) ***Drift Of Structure Resting On Plain(ESFM)***

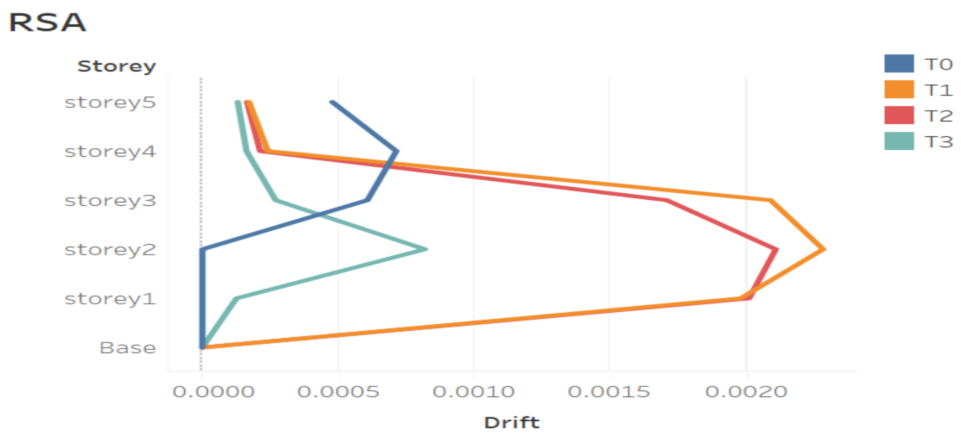


Figure 4.3(c) ***Drift Of Structure Resting On Slope(RSA)***

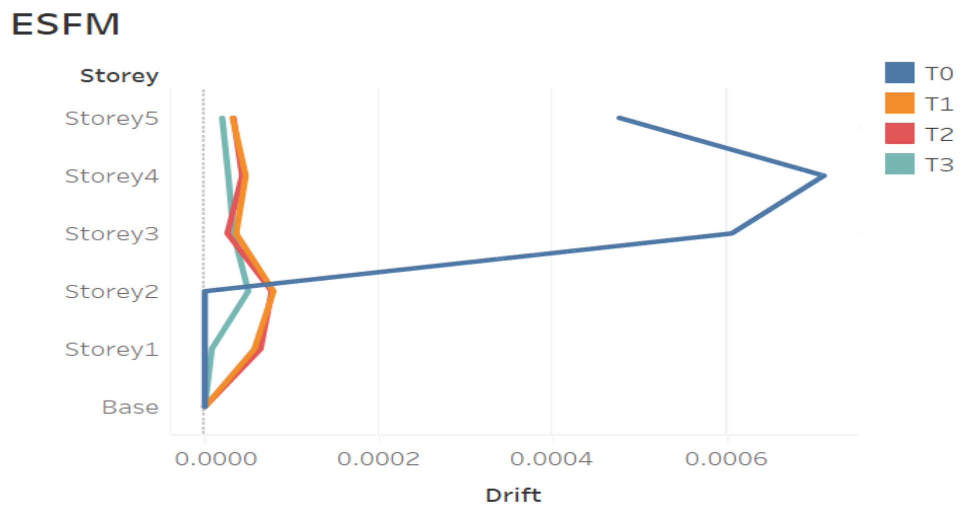


Figure 4.3(d) ***Drift Of Structure Resting On Slope(ESFM)***

4.4 DISPLACEMENT

The results of calculating storey displacement using both approaches for all models are displayed in Fig.6. Maximum base storey displacement in the direction of force, i.e. in the X direction, has been observed for model I0 because of the lower stiffness resulting from soft storey effect for both approaches. The remaining models where OGS is changed by three ways have significantly smaller storey displacements than models I0 and R1. Model I1, which is completely infilled with strut as a wall, is not recommended, but the remaining models have excellent displacement control. Out of setback Models I4, I6, have demonstrated the most effective displacement control using both approaches and in both directions and among setback stepback models T3 has effective displacement control in both X and Y directions.

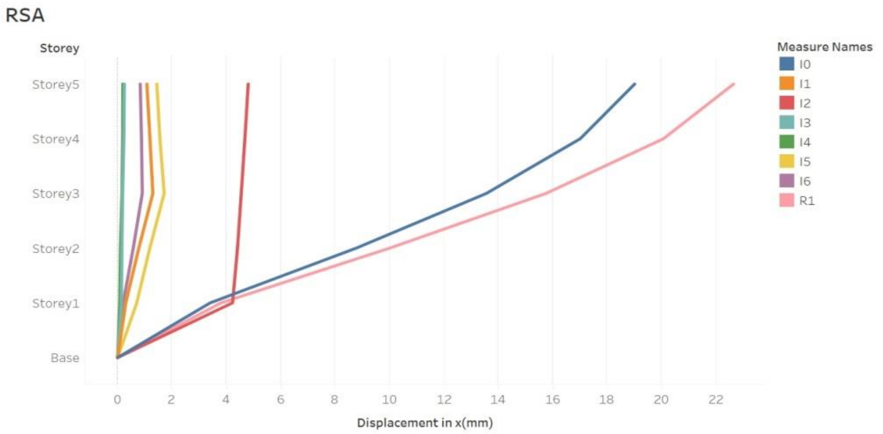


Fig 4.4(a) ***Displacement Of Structure in X direction Resting On plain(RSA)***

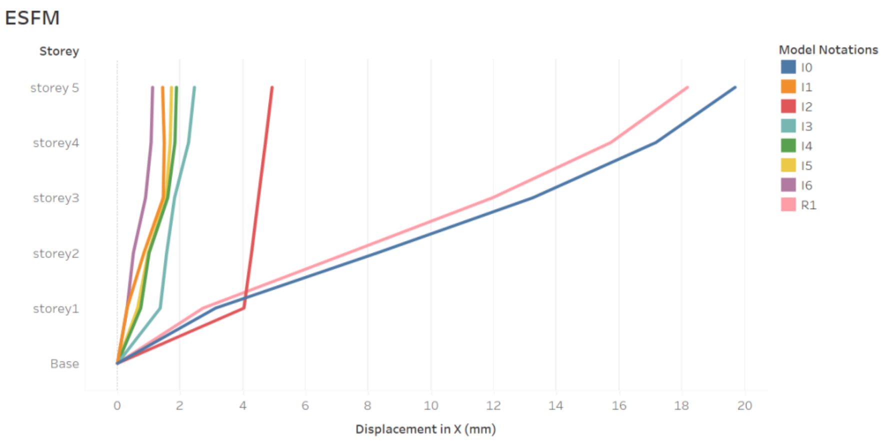


Fig 4.4(b) ***Displacement Of Structure in X direction Resting On plain(ESFM)***

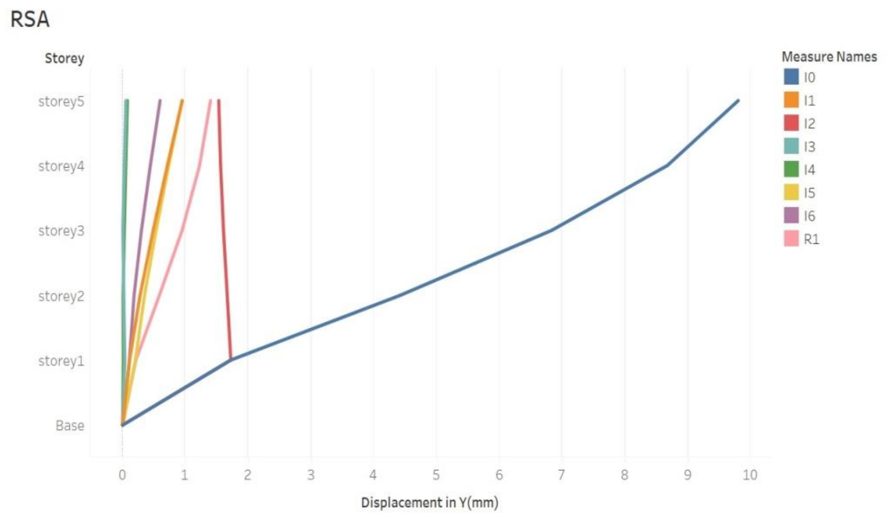


Fig 4.4(c) ***Displacement Of Structure in Y direction Resting On plain(RSA)***

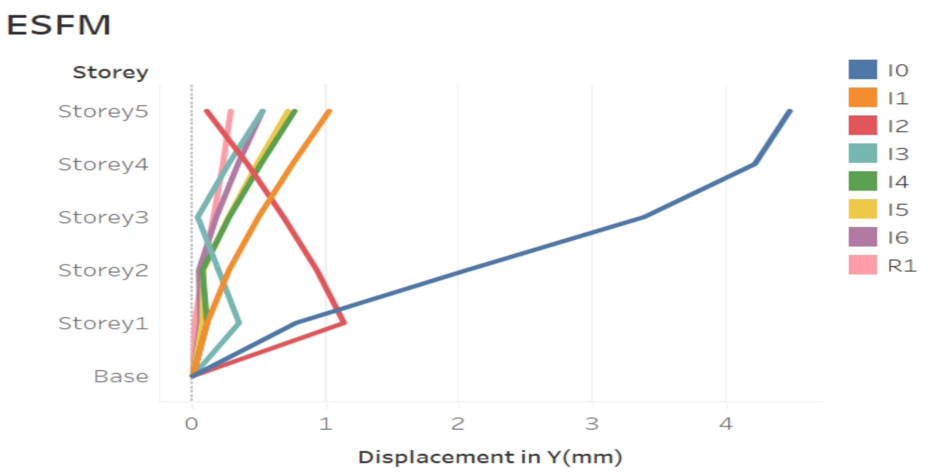


Fig 4.4(d) ***Displacement Of Structure in Y direction Resting On plain(ESFM)***

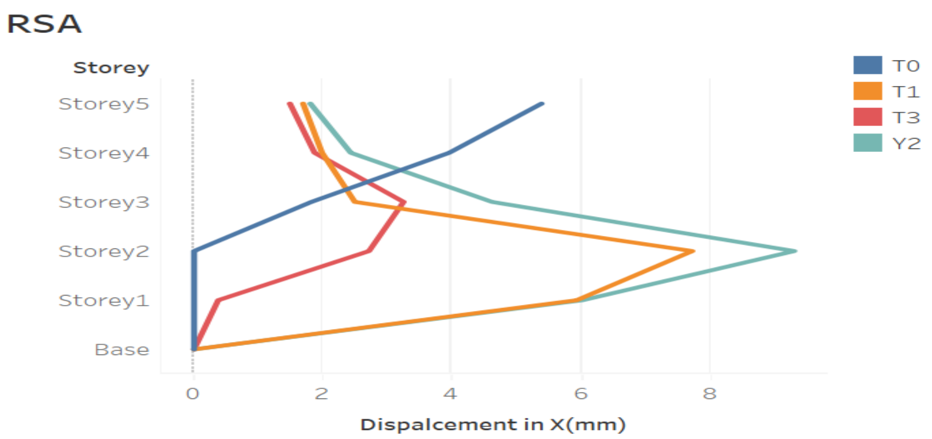


Fig 4.4(e) ***Displacement Of Structure in X direction Resting On slope(RSA)***

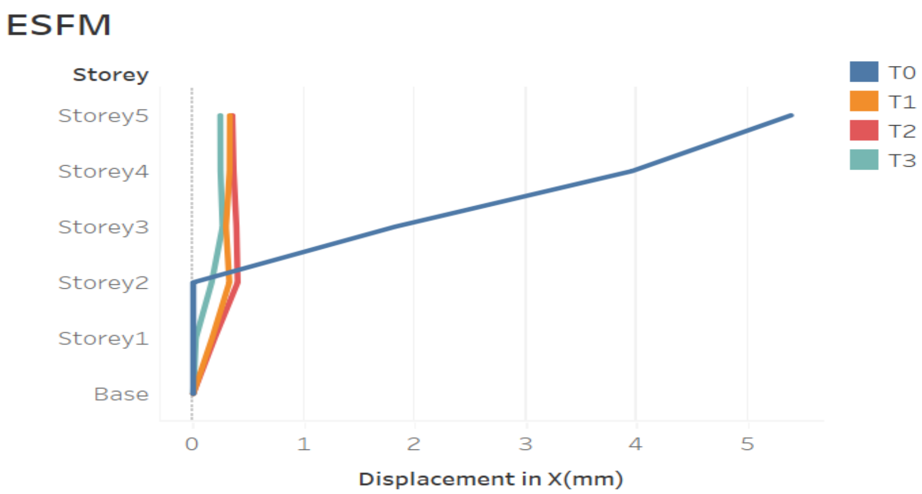


Fig 4.4(f) ***Displacement Of Structure in X direction Resting On slope(ESFM)***

4.5 TORSION

Torsion results from a building's eccentricity when the building's centre of mass does not coincide with its centre of rigidity. Because of the moment of torsion at the centre of structural resistance, torsion creates spin in building about axis of rigidity. Due to the fact that the structure is a setback building and rests on sloping ground, its mass, stiffness, and layout are uneven in vertical and horizontal planes. Consequently, the reaction of torsion is taken, and its rotation about the axis Z is depicted in Figure. The results indicate that as the storey height rises, so do the torsional responses. The maximum torsional response of the bare frame models I0 and T0 has been measured. Out of three models I3, I4, and I5, in which the OGS is rectified by shear walls, model I5, in which the shear wall is located in the outer and inner end panels, demonstrates the most effective rotation control in GS .

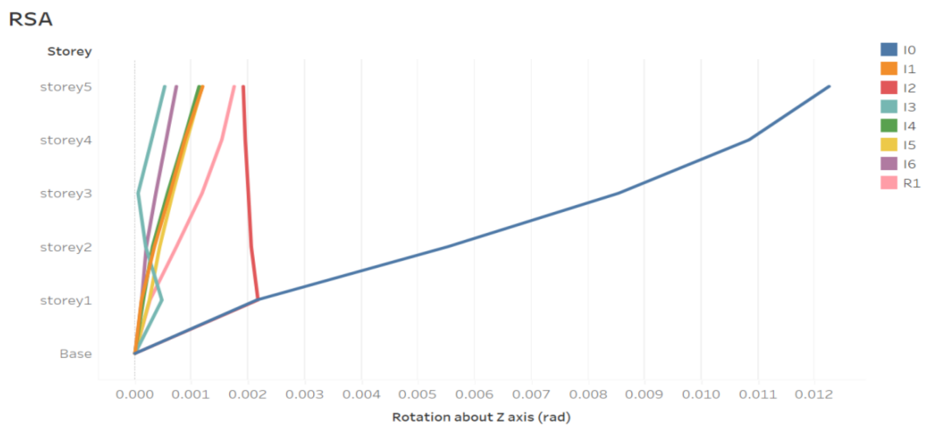


Fig 4.5 (a) Rotation About Zaxis(Rad) Of Structure Resting On Plain(RSA)

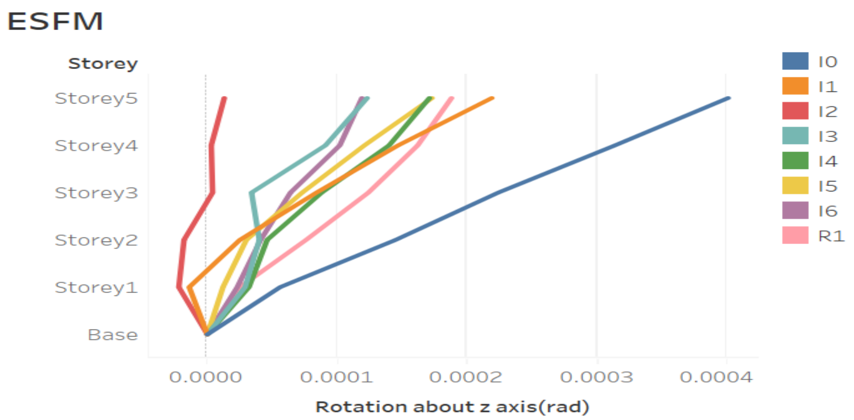


Fig 4.5(b) Rotation About Zaxis(Rad) Of Structure Resting On Plain(ESFM)

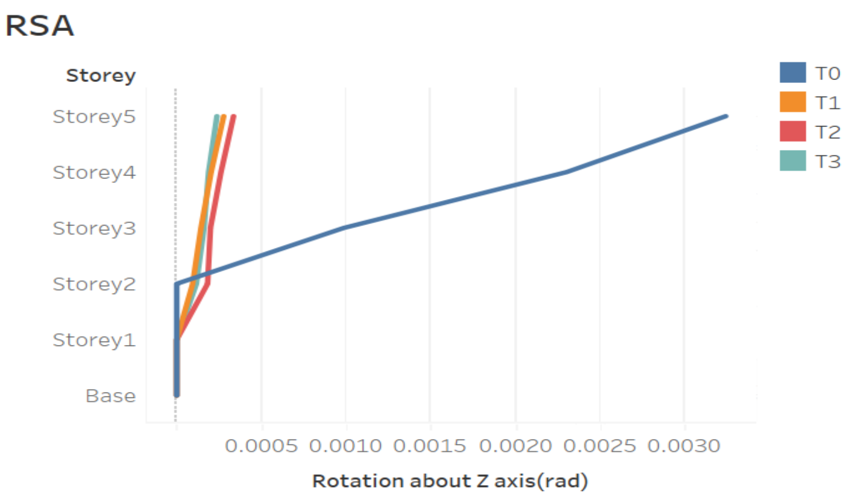


Fig 4.5(c) Rotation About Zaxis(Rad) Of Structure Resting On Slope(RSA)

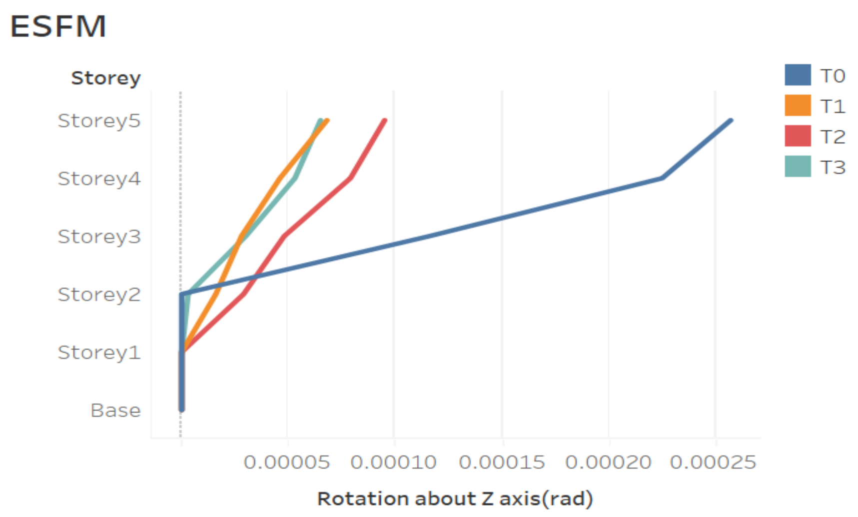


Fig 4.5(d) Rotation About Zaxis(Rad) Of Structure Resting On Slope(ESFM)

4.6 BASE SHEAR

Mass and Stiffness is a function of the base shear, therefore, with the exception of the bare frame model, the base shear has been increased in all other models owing to the increased mass and stiffness given by the infilled walls, as well as addition of concrete filled steel tubes. Figure 6 depicts the base shears of the models on two different terrains i.e. plain and sloping.

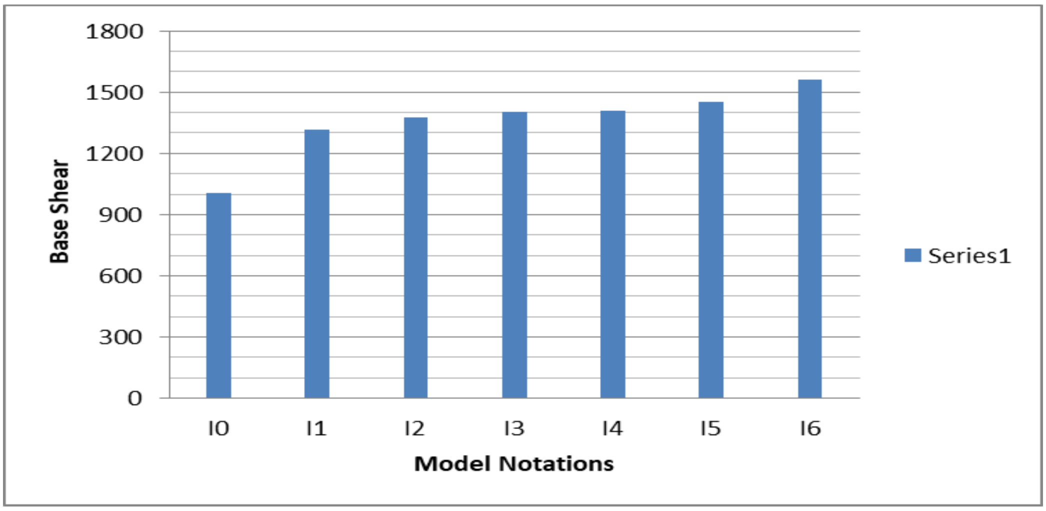


Fig 4.6 (a) Base Shear of structure resting on plain

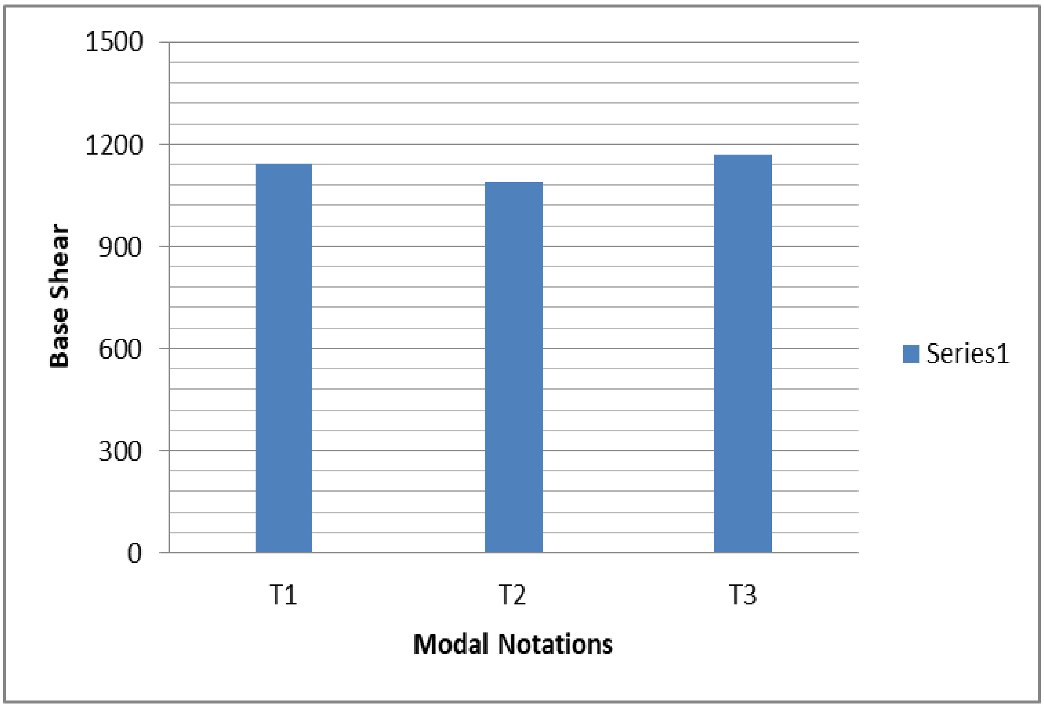


Fig 4.6(b) **Base Shear of structure resting on slope**

CHAPTER 5

CONCLUSIONS

In this study, the response of the seismic loads of setback structures has been analysed using two distinct techniques: ESFM and RSM. In addition, the high vulnerability of these buildings has been evaluated when OGS is included. The twisting of structure is seen because of the differences in mass, rigidity, and geometry of the setback structure. The columns of the vertical irregular structures which are at the upper level of the slopes are susceptible to greater bending moments; thus, additional design and construction considerations must be addressed. Due to the absence of infill walls, the OGS model's stiffness on setback buildings fell suddenly and is severely affected by earthquake loading, since its reactions are significantly greater than those of the other models. The OGS function cannot fulfilled by the fully infilled model , the OGS models are changed utilising shear walls, with CFSTC columns substituting the OGS columns. With these tactics, OGS structures respond to earthquake loads extraordinarily effectively, even better than the fully infilled frame with single strut as wall. Using these strategies, the stiffness of the base storey these models is more than that necessary to overcome the soft storey effect of the open ground storey model, and it also improves the upper storey stiffness. The control of storey displacement, drift, and torsion is found to be good with all of these systems, and their regulating powers are almost identical. Uniformly distribution of shear wall exhibits superior control of torsion, however the difficulty with shear wall is that it obstruct accesses in open ground storey, hence stiffness is concentrated at certain points of the structure limiting the functional efficiency of the structure. CFSTC does not obstruct accessibility in OGS, and the stiffness is spread equally throughout base storey. It has been determined that CFSTC in OGS is the most efficient method for preventing the collapse of vertical irregular buildings with ground storey open arrangement during earthquakes. This article suggests in setback structure with soft storey(OGS) on plain and hillly terrain there will be usage of CFSTC in lieu of conventional RC columns.

APPENDICES

Appendix 1

Tablea.1.1 Displacement In X Direction (RSA)

STOREY	R1	I0	I1	I2	I3	I4	I5	I6
Storey5	22.6409	19.0041	1.0736	4.7991	0.2453	0.188	1.4405	0.8288
Storey4	20.064	17.0032	1.1857	4.676	0.2265	0.1831	1.5517	0.8744
Storey3	15.7461	13.5527	1.2923	4.5424	0.1819	0.1601	1.7098	0.9035
Storey2	9.996	8.7664	0.7771	4.405	0.1567	0.1007	1.1798	0.5715
Storey1	3.7987	3.4018	0.2966	4.2229	0.1362	0.0741	0.7016	0.2023
Base	0	0	0	0	0	0	0	0

TableA.1.2 Displacement In X Direction (ESFM)

storey	R1	I0	I1	I2	I3	I4	I5	I6
storey 5	18.165	19.685	1.438	4.928	2.453	1.88	1.721	1.119
storey4	15.724	17.16	1.489	4.716	2.265	1.831	1.679	1.072
storey3	11.956	13.242	1.458	4.492	1.819	1.601	1.544	0.894
storey2	7.354	8.279	0.842	4.273	1.567	1.007	0.978	0.506
storey1	2.725	3.125	0.304	4.03	1.362	0.741	0.642	0.307
Base	0	0	0	0	0	0	0	0

Table A.1.3 Drift Of Structure Resting On Plain (RSA)

STOREY	R1	I0	I1	I2	I3	I4	I5	I6
Storey5	0.009	0.007	0.001	0.001	0.0001	0.001	0.001	0.001
Storey4	0.015	0.012	0.001	0.001	0.0002	0.001	0.001	0.001
Storey3	0.019	0.016	0.002	0.001	0.0002	0.002	0.002	0.001
Storey2	0.021	0.018	0.002	0.002	0.0002	0.002	0.002	0.001
Storey1	0.013	0.011	0.001	0.014	0.0005	0.002	0.002	0.001
Base	0.000	0.000	0.000	0.000	0.0000	0.000	0.000	0.000

Table A.1.4 Drift Of Structure Resting On Plain(ESFM)

Storey	R1	I0	I1	I2	I3	I4	I5	I6
Storey5	0.0008	0.0008	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Storey4	0.0013	0.0013	0.0002	0.0002	0.0002	0.0001	0.0001	0.0001
Storey3	0.0015	0.0017	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001
Storey2	0.0015	0.0017	0.0002	0.0003	0.0002	0.0002	0.0002	0.0001
Storey1	0.0009	0.0010	0.0001	0.0013	0.0005	0.0002	0.0002	0.0001
Base	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table A.1.5 Rotation About Z Axis Of Structure Resting On Plain(RSA)

Storey	R1	I0	I1	I2	I3	I4	I5	I6
storey5	0.002	0.012	0.001	0.0019	0.0005	0.0011	0.0012	0.0007
storey4	0.002	0.011	0.001	0.0019	0.0003	0.0009	0.0009	0.0006
storey3	0.001	0.009	0.001	0.002	0.0001	0.0006	0.0007	0.0004
storey2	0.001	0.006	0	0.002	0.0002	0.0003	0.0004	0.0002
storey1	0	0.002	0	0.002	0.0005	0.0001	0.0003	0.0001
Base	0	0	0	0	0	0	0	0

Table A.1.6 Roation About Z Axis Of Structure Resting On Plain(ESFM)

Storey	R1	I0	I1	I2	I3	I4	I5	I6
Storey5	0.00019	0.00040	0.00022	0.00001	0.00012	0.00017	0.00017	0.00012
Storey4	0.00016	0.00031	0.00015	0.00000	0.00009	0.00014	0.00012	0.00010
Storey3	0.00012	0.00022	0.00008	0.00000	0.00003	0.00009	0.00007	0.00006
Storey2	0.00008	0.00015	0.00003	-0.00002	0.00004	0.00005	0.00003	0.00004
Storey1	0.00003	0.00006	-0.00001	-0.00002	0.00003	0.00003	0.00001	0.00002
Base	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Table A.1.7 Stiffness Of Structure Resting On Plain(RSA)

STOREY	R1	I0	I1	I2	I3	I4	I5	I6
STOREY5	56857	29874	318408	366831	382414	349150	359720	530964
STOREY4	64266	47406	704027	841231	887772	799254	791315	1191694
STOREY3	66205	59664	923524	1300854	1363502	1037962	1045537	1579718
STOREY2	72345	65873	1362414	1221806	1528316	1202844	1577303	1857521
STOREY1	124748	112990	2534854	203597	654598	1192328	878503	3099842
Base	0	0	0	0	0	0	0	0

Table A.1.8 Stiffness Of Structure Resting On Plain(ESFM)

Story	R1	I0	I1	I2	I3	I4	I5	I6
Story5	60311	31678	626625	542632	599216	650000	701863	937826
Story4	66033	50560	1143547	993576	1112120	1189419	1258713	1703713
Story3	66483	71447	1367081	1273717	1446470	1383632	1436513	2124705
Story2	71386	76890	1802602	1191567	1539172	1516424	1929706	2501741
Story1	122442	130379	3220942	221540	649233	1213516	1025144	3292711
Base	0	0	0	0	0	0	0	0

Appendix 2

Table A.2.1 Displacement In X Direction Of Structure Resting On Slope(ESFM)

Storey	T0	T1	T2	T3
Storey5	5.384	0.33	0.352	0.244
Storey4	3.954	0.327	0.364	0.246
Storey3	1.818	0.295	0.389	0.264
Storey2	0	0.325	0.4	0.166
Storey1	0	0.17	0.193	0.024
Base	0	0	0	0

Table A.2.2 Displacement In X Direction Of Structure Resting On Slope(RSA)

Storey	T0	T1	T3	T3
Storey5	1.29	2.216	2.778	1.985
Storey4	0.979	1.623	2.208	1.524
Storey3	0.479	1.144	1.871	1.287
Storey2	0	0.754	1.775	1.207
Storey1	0	0.394	1.059	0.565
Base	0	0	0	0

Table A.2.3 Drift Of Structure Resting On Slope(ESFM)

Storey	T0	T1	T2	T3
Storey5	0.000477	0.000032	0.000033	0.00002
Storey4	0.000712	0.000047	0.000043	0.000027
Storey3	0.000606	0.000036	0.000026	0.000033
Storey2	0	0.000079	0.000077	0.00005
Storey1	0	0.000057	0.000064	0.000008
Base	0	0	0	0

Table A.2.4 Drift Of Structure Resting On Slope(RSA)

Storey	T0	T1	T2	T3
storey5	0.000477	0.000171	0.000164	0.00013
storey4	0.000712	0.00024	0.000212	0.000162
storey3	0.000606	0.002086	0.001705	0.000269
storey2	0	0.002279	0.002105	0.000817
storey1	0	0.001976	0.002007	0.000125
Base	0	0	0	0

Table A.2.5 Roation About Z Axis Structure Resting On Slope(ESFM)

Storey	T0	T1	T2	T3
Storey5	0.000257	0.000068	0.000095	0.000065
Storey4	0.000225	0.000046	0.000079	0.000053
Storey3	0.000116	0.000028	0.000048	0.00003
Storey2	0	0.000016	0.000029	0.000003
Storey1	0	0	0	0
Base	0	0	0	0

Table A.2.6 Roation About Z Axis Structure Resting On Slope(Rsa)

Storey	T0	T1	T2	T3
Storey5	0.003236	0.000277	0.000335	0.000237
Storey4	0.002299	0.000203	0.000261	0.000188
Storey3	0.000985	0.000143	0.000199	0.000161
Storey2	0	0.000094	0.000182	0.000116
Storey1	0	0	0	0
Base	0	0	0	0

Table A.2.7 Stiffness Of Structure Resting On Slope(ESFM)

Storey	T0	T1	T2	T3
storey5	40107.55	1732336	1663058	2861263
storey4	66990.88	2868652	3051123	4812110
storey3	138936.9	6429057	9453279	6131635
storey2	0	132076.3	128956.5	525587.7
storey1	0	81268	75816.2	975641.8
Base	0	0	0	0

Table A.2.8 Stiffness Of Structure Resting On Slope(Rsa)

Storey	T0	T1	T2	T3
Storey5	40022.99	1542666	1233874	1969511
Storey4	65228.63	2667207	2548082	3929354
Storey3	116930.6	564055.6	702542.8	4290709
Storey2	0	140145.9	140375.5	542429.8
Storey1	0	100473.7	90564.34	1216620
Base	0	0	0	0

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