ANALYSIS OF NUMERICAL AND DYNAMIC ANALYSIS OF SLOPED STRUCTURES

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Abstract

There is a higher risk of seismic damage to buildings situated on hilly terrain as opposed to flat land. Structures built on slopes become torsionally linked and more vulnerable to severe earthquake damage due to their unusual vertical and horizontal irregularities. The uneven topography causes ground-story columns in sloped places to have variable heights. Using three distinct slope angles—15°, 20°, and 25°—this research analyzes how a two-story sloping frame with a step-back arrangement reacts to sinusoidal ground motion. The results indicate that the stiffness of the model increases with the slope angle, as the short columns are shorter in length. As a result, the short column experiences an increase in earthquake forces, which constitute approximately 75% of the total base shear. With plastic hinges appearing, the likelihood of damage increases dramatically.

INTRODUCTION

There are few natural disasters as destructive and unpredictable as earthquakes. While seismic forces do not directly cause deaths, the destruction they inflict on buildings can lead to their collapse, posing a significant risk to both the people inside and their possessions. Buildings on sloping terrain, such as those in hilly areas, are much more vulnerable to the damaging effects of seismic forces, which can affect any structure exposed to them. The development of plastic hinges is a possible consequence of the increased lateral forces experienced by buildings on slopes, especially by shorter columns on the uphill side. Compared to buildings on level ground, these structures stand out due to their unique horizontal and vertical irregularities.

Seismic zones IV and V encompass a large portion of hilly northeastern and northern

India. Recent earthquakes in Nepal (2015), Sikkim (2011), and Doda (2013) all produced massive devastation in these regions. A multi-story reinforced concrete (RC)-framed building is in high demand because of the increasing population density, fast urbanization, and economic expansion. However, the scarcity of flat land often necessitates the construction of structures on sloped ground. This study modeled a two-story framed building under sinusoidal ground motion, considering ground inclinations of 15°, 20°, and 25°.

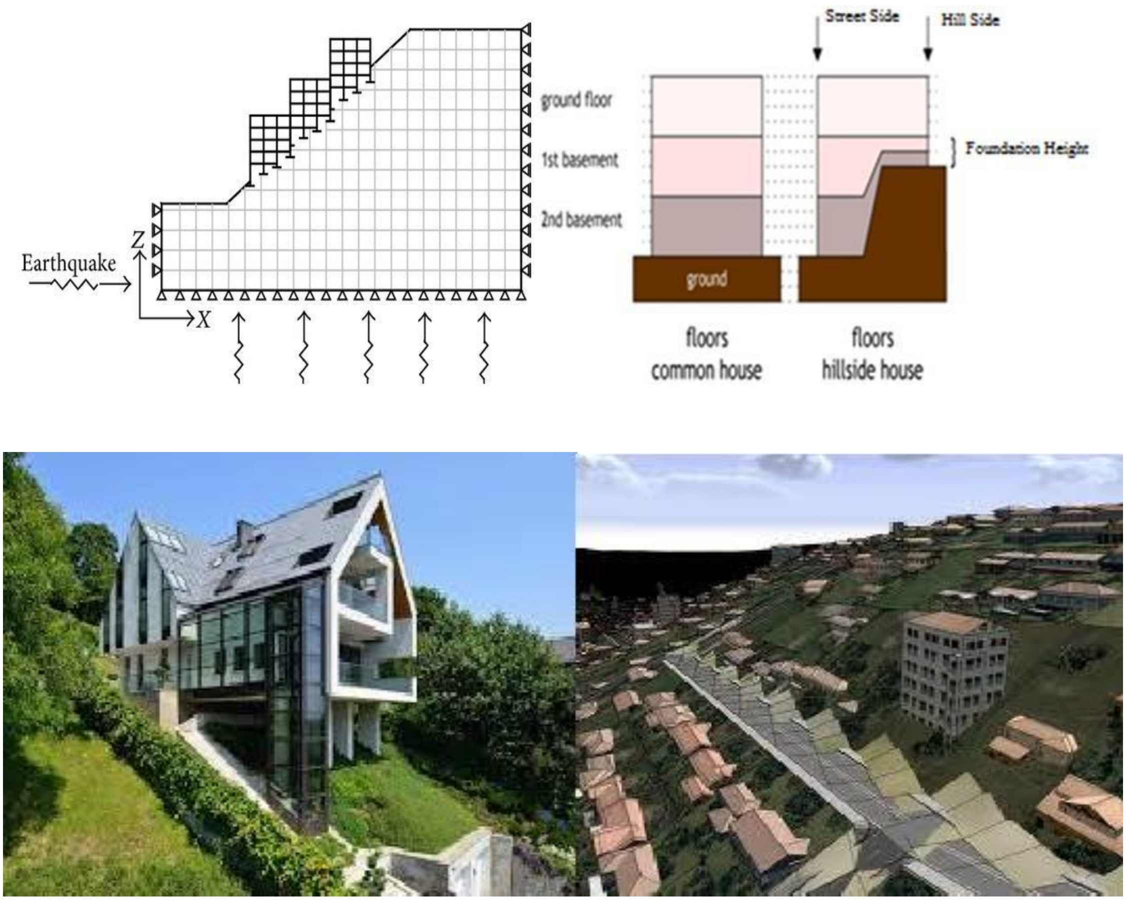

Figure1: Buildings on sloping ground

Origin of the Project

Using numerical analysis, Sreerama and Ramancharla (2013) evaluated seismic behavior on flat ground and slopes of varied angles. So far, there has been no experimental investigation into the seismic behavior of buildings situated on slopes.

Objective and Scope

This project's objective is to investigate, through numerical and experimental means, the dynamic response of sloped buildings to earthquake excitations and sinusoidal ground motion.

Here is a brief overview of the study's scope:

- Researchers conduct the experimental investigation using a two-story sloping frame model, securely fastened to a shake table.

LITERATUREREVIEW

Overview

This review explains the features of the structures caused by the change in the slope angle. Following that, we will go into how the uneven layouts affect susceptibility to seismic forces. Researchers have provided a few explanations for changing the slant angle.

Experimental analysis of structures on sloping land does not form the basis of any research.

How Irregular Structures on Slopes in India Respond to Earthquakes

Two types of geometric and topological anomalies in building models were investigated by Ravikumar et al. (2012): plan irregularity (geometry and diaphragm discontinuity) and vertical irregularity (setback and sloping ground). Ravikumar et al. (2012) employed a pushover study that took into account various lateral load scenarios in all three directions to determine these seismic demands. The three-story tall constructions under assessment exhibit a distinct pattern of flaws in their blueprints and façades.

In contrast to the amazing sensitivity of the slope model, plan irregular models exhibit greater deformation for lower force levels. Life safety and collapse avoidance are the two main goals of the models, with the exception of slope variants. Sreerama and Ramancharla (2013) noted that disasters such as the Kangra earthquake, the Shillong Plateau earthquake, and the Bihar-Nepal earthquake in 1980 each claimed the lives of over 375,000 people and caused the destruction of over 100,000 buildings. Because of the geometrical configuration of the hill, the dynamic properties of buildings on flat ground are different from those of buildings on sloped land.

Structures vary not just vertically but also laterally. The variation in mass and stiffness inside the storeys causes increased lateral forces, making the column more susceptible to damage on the uphill side. Using IS-456 and SAP2000, they constructed and analyzed five G+3 buildings with different slope angles (0, 15, 30, 45, 60°). In one column, the base reaction grows as the slope angle does, but in another column, it falls and then rises. The building's natural life expectancy diminishes with increasing slope angle, and while short columns may withstand weights on nearly every story, lengthy columns are too pliable to do so.

Seismic Response of Structures with varying Layouts

We analyzed the response spectrum with the torsional effect in mind. Examining dynamic features including top-story displacement, base-shear and basic time periods has helped researchers determine the suitability of constructions on sloped land.

We take a slope angle of 27 degrees. In all, 24 RC buildings ranging in height from 4 to 11 floors were considered for the study. The top story's displacement and the amount of time it takes for an earthquake to travel along a building's longitudinal axis both grow linearly with the building's story count. In contrast to step-back construction, the results of static and dynamic analyses of step-back buildings are very similar. Compared to the same values in the longitudinal direction, the transverse displacement of the top story is approximately 3.8 to 4 times larger. When compared to the other two structures, the shear forces caused by the setback structure are significantly lower. Most impact hits the ground-level column, making it vulnerable.

Using both linear and nonlinear time series analysis, Singh et al. (2012) conducted an analytical investigation. They thought about constructing a nine-story RC frame building on a steep slope at a 45-degree angle to the horizontal. Along the slope, there were three stories; across the slope, there were nine stories and seven bays.

Babu et al. (2012) tested a variety of symmetric and asymmetrical structures built on flat and sloping ground using pushover analysis.One of the options they evaluated for the four-story skyscraper was to build it one story above ground and at a 30 degree angle. The researchers discovered that the short column in the pushover analysis faced the most severe conditions and was not located within the collapse prevention (CP) zone. They then compared the several cases they examined. A symmetrical building causes 24% more displacement than a structure on level ground, while a symmetrical construction causes 70% more displacement up to the failure limit.

Their focus has been on unfinished frames and buildings with inside walls. The researchers conducted pushover analysis in a ten-story building.

Both the infill-walled and unfilled frames are comprised. The structures featured five bays positioned along the slope, each inclined at a 27-degree angle to the horizontal. We took into consideration the SMRF frame system. A building with a bare frame has a time period of 1.975 seconds, which is approximately 96–135% longer than a building with infill walls. This disparity is attributed to the increased stiffness of the former, leading to a higher frequency.

Additionally, they observed that in the case of a bare frame, the lack of an infill wall and the resulting reduced rigidity cause the building to shift more. Infilled frames had a base shear that was approximately 250% higher than bare frames, according to their findings.

Experimental Modeling

Introduction

Experimental Modeling

Details of Laboratory Equipments

The experimental investigations concerning free and forced vibration on a sloped-frame-model are covered in this chapter. Hier we compare the experimental data with the MATLAB-based Finite-Element-Programm. There are three sections to the work:

- Laboratory Equipment Specifications
- Construction and scheduling
- Analyzing vibrations forcibly and freely

1. Each floor uses plates 1 and 2, and plate 3 functions as the base. Table 3.1 lists the dimensions of the plates:

Table3.1: DimensionsandMassofmild steelplate

Plate No.	Dimension (cm)	Mass (kg)
Plate 1 & 2	50 x 40 x 1	15.44
Plate 3	70 x 40 x 1	21.76

2. We utilize a threaded rod with a diameter of 7.7 mm.

3. The specified quantity of nuts and washers is 32 pieces per set. There are a total of twenty-four pieces needed to construct a two-story assembly: twenty-four for the baseplate and eighteen for the threaded rods that attach to the shake table's plates.

4. To create solid ground, use wooden logs and boards.

We also utilize small wedge-shaped logs of wood to aid in the upright fitting of the column with the plates.

Figure3.1: WoodenWedgeandlogs

1. **Shake Table**- One tool for simulating a seismic event on a construction site is the shake table. A horizontal, one-way movable platform measuring 1000 mm x 1000 mm makes up the shake table. The shake table arranges its 81 tie-down points in a grid of 100 mm by 100 mm. There is a 100 kg maximum payload. The maximum movement of the table is one hundred millimetres, or approximately 50 millimetres. We can confirm the seismic performance of structures by testing their responses on the rectangular platform. We place the test specimen on the platform, then shake it on this table. A 440-volt input powers a control panel that regulates the table's frequency.

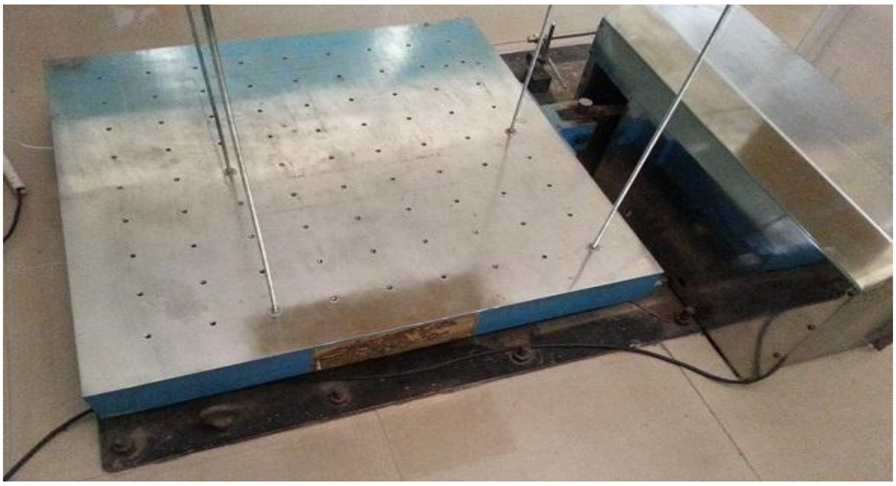

Figure3.2: Shake Table

2.Vibration Analyser-An integral part of any condition monitoring program is the vibration analyzer (VA). Another name for it is predictive maintenance. For time waveform (TWF) measurements of acceleration, velocity, and displacement, it is a useful tool. However, the most commonly used spectrum comes from a fast Fourier transform. If you need crucial data on the model's frequency, Vibration Analyzer is the tool for you.

Figure3.3: Vibration Analyser

2. **Control Panel**- The user can observe and adjust the model's forcing frequency with this tool.

3. **Figure3.4:** Control Panel

4. **Personal Computer** – An Intel(R) Core (TM) i5 processor, 4 GB of RAM, a 32-bit OS, and Windows 7 Professional were the components of the testing PC. We utilized NVGate as the data acquisition software. The monitor shows all the data collected while the model is vibrating at the same time.

5. **Accelerometer**- This instrument can help measure the correct acceleration. "Proper acceleration" refers to the acceleration an item experiences during free fall, not the coordinate acceleration, which is the rate of velocity change over time. When an accelerometer detects vibration, it sends a signal to a vibration analyzer, which in turn sends that signal to a computer.

Figure 3.5: Accelero meter

Fabrication and Arrangement

Here, we are fixing the base plate sequentially, preserving the 15°, 20°, and 25° slope angles. The first plate is now 51 cm from the linked end of the base plate, and the second plate is 92.5 cm away. Tightening the screw ensures correct fixity. To create a stable base that mimics slopinWe wedge wooden logs between the base plate and the platform to create a stable base that mimics sloping terrain. and one to plate 2, resulting in a total of three plates. The computer links the vibration analyzer and the accelerometers to it. The accelerometer captures the values resulting from vibration. The linear variable displacement transducer, also known as "one LVDT," records the movement of the device. While applying the vibration, shake the table. We maintain the ground motion's maximum amplitude at 5 mm. The "Structural Engineering" lab at NIT Rourkela was the site of all the experiments.

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Free Vibration Analysis

We refer to a mechanical system as vibrating freely when we use an initial input to set it off. Before providing one or more natural frequencies, the vibrating mechanism will dampen to zero. To find the model's inherent frequencies, this experimental setup employs free vibration analysis. The FFT analysis yielded two dominant frequencies, both naturally occurring. We will base additional analysis on these two dominant frequencies. We can determine the inherent frequency of the system by applying a light push on Plate 1 (the top floor), taking readings, and

Models for Experimentation

Figures displaying the experimental model with varying slope angles are as follows:

Model for Experimental 15° Slope

Figure3.6: Experimental Model for 15° slope

ExperimentalModelfor20°slope

Figure3.7: Experimental Model for 20° slope

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Experimental Results and Discussions

We conducted free vibration analysis for each frame model throughout the trial, as detailed in article 3.2.3. We obtained the first two natural frequencies for two modes, as shown in Table 3.2.

Table3.2: Natural frequencies of model with different slope inclinations

Type of Model	Mode 1 (Hz)	Mode 2 (Hz)
15°	2.05	5.80
20°	2.20	5.945
25°	2.60	6.55

$$x = x_o \sin(\omega t)$$

where $\omega = 2\pi f$, x_o is the amplitude of excitation in millimeters (mm), and f is the frequency of excitation in Hertz (Hz).

The range of the excitation frequency in this expression encompasses the model's natural frequency and beyond. We maintained a constant displacement amplitude of excitation at xo=5x_o = 5xo=5 mm.

Table3.3:Upper Limits on Absolute Floor Displacements for a 15-degree Frame Model

Storey No.	Maximum Storey Displacement (mm)
1	55.2
2	76.6

Table3.4:Absolute Maximum Storey Displacements for a 20-degree-inclination Frame Model

Storey No.	Maximum Storey Displacement (mm)
1	44.0
2	68.3

Frequency Response Analysis

For each of the three slope angles, Figure 3.9 displays the relationship between the X-axis frequency (Hz) and the Y-axis top storey displacement (mm). By plotting the effects of increasing frequency, slope angle, and short column stiffness on a hillside, we see that displacement decreases.

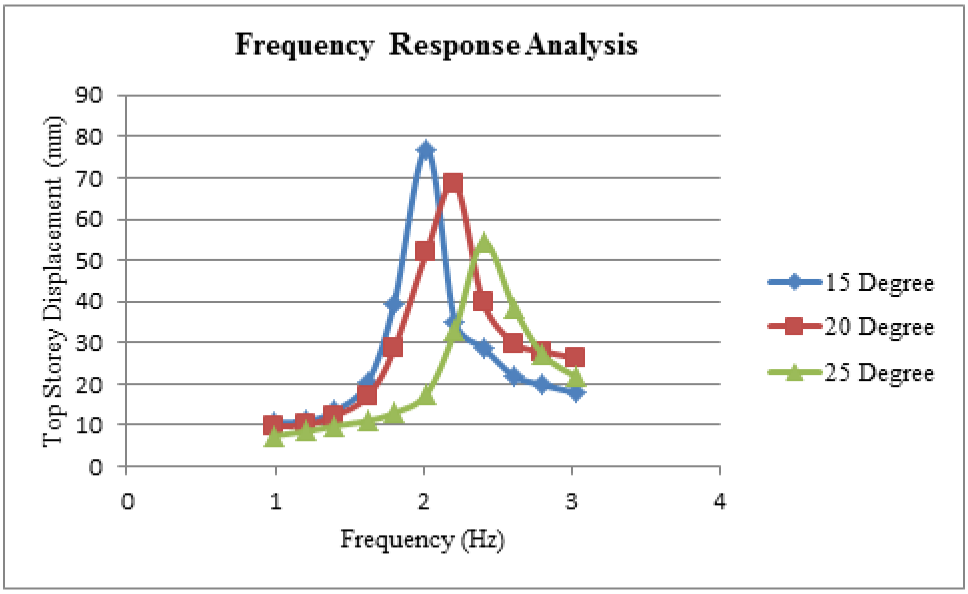

Figure3.9: Frequency Response analysis

The most dominating frequency, the first fundamental frequency, is 2.05 Hz.

Structural Elements

If you believe STAAD Pro. The spectra of IS 1893 (Part I): 2002 demonstrate that ground motion with intermediate frequency content affects the aforementioned models. After that, we put these models through a linear time series analysis. There are 51 cm of story height on the ground floor and 41.5 cm on the second.

Table4.2: DetailsofBeamand Columnwith lengthand crosssectiondimensions

Element	Cross Section Dimension (mm)	Length (cm)
Beam (X)	100 x 100	40
Beam (Y)	80 x 80	30
Column 1st floor	7.7	51
Column 2nd floor	7.7	41.5

Ground Motion and Time History Analysis

Ground Motion

Due to plate tectonics, the majority of earthquakes occur. On the surface of the Earth, there are enormous, thin, and hard plates, called tectonic plates, that move relative to one another.

These plates are located in the lithosphere, the uppermost region of the mantle.

Seismographs record seismic waves, while accelerographs detect ground acceleration for engineers. There are primarily two varieties of seismic waves: body waves and surface waves. There are two subtypes of body waves: primary waves (P-waves) and secondary waves (S-waves). Rayleigh waves and Love waves are the two varieties of surface waves.

Significant ground motion is defined as earthquakes with a magnitude of 50 kilovolts or higher. There are three translational and three rotational displacements that make up the motion. The ground acceleration at its peak, known as PGA, represents the highest absolute value. There are three main features of an earthquake: the frequency content, the time length, and the PGA. We can express the frequency content of an earthquake as PGA/PGV, as a function of both peak ground velocity (m/s) and acceleration due to gravity (g). There are three levels of frequency content: high, middle, and low.

High-frequency content: PGA/PGV > 1.2.

The relative value of PGA and PGV is 0.8. The ratio of PGA to PGV is approximately 0.8, indicating an intermediate level of low frequency content.

We classify earthquakes based on factors like focal depth, location, epicentral distance, magnitude, and causation. Two distinct characteristics of an earthquake are its intensity and its magnitude. The magnitude of an earthquake is proportional to the degree to which the ground at a certain spot shakes. We use the Modified Mercalli (MM) scale to measure this qualitative tremor. An earthquake's magnitude refers to the amount of seismic energy it releases at its site. Richter magnitude scale is a quantitative way to measure an earthquake. Although the strength of an earthquake can change depending on its location, its magnitude remains constant everywhere.

The graph in Figure 4.9 displays the time-dependent change in ground acceleration. The ground motion lasts for 40 seconds and reaches its maximum of -1.0 g at t = 11.90 seconds.

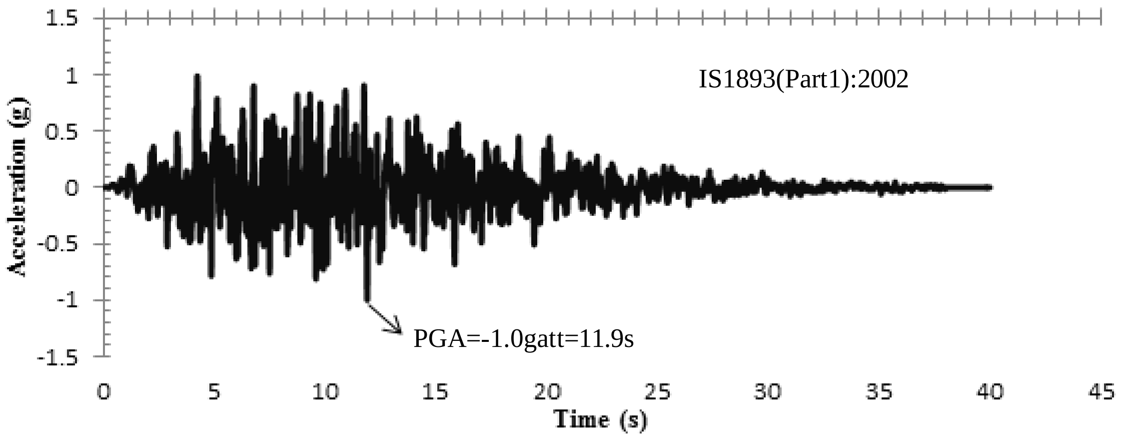

Figure4.9: Compatible Time Historyasper spectraofIS1893(Part1):2002for 5%damping at rocky soil

Analysis Time History

Determining how a structure physically reacts to a given force is the main focus of structural analysis. Structural dynamics is the study of how structures respond to dynamic loads. One kind of dynamic loading is ground motion. As an additional

When the structure experiences sudden loads like wind blasts, explosions, or earthquakes, inertial forces apply.

When applied to a structure in increments of time, time history analysis reveals the structure's dynamic reaction in relation to acceleration, force, moment, or displacement. The time function provides a description of the response under loading. The higher the accuracy, the tighter the intervals are. Many think this approach is more grounded in reality than the response spectrum method. Tall or high-rise buildings, often known as flexible structures, can benefit from this approach.

We conduct the analysis using the STAAD Pro platform. For structural design in India, the structure is tested using ground motion recorders that are consistent with the time history of acceleration according to the spectrum of IS 1893 (Part 1):2002 (Artificial

Ground Motion)

Numerical Results and Discussions

Overview

We also graphically display the displacement, acceleration, and velocity for each angle. This section displays the response to ground motion based on the IS 1893 (Part 1):2002 spectrum. We validate the experimental model and also give results from numerical investigations.

Twostoriedslopedframewithgroundinclinationof15°

Based on the information in articles 3.2.3 and 4.2.4.3, we were able to determine the model's natural frequencies for two distinct modes using free vibration analysis, as shown in table 4.3:

Table 4.3: Natural Frequency of sloped frame with 15°

Type of Model	Mode 1 (Hz)	Mode 2 (Hz)
Experimental	2.05	5.80
Present FEM	2.2283	6.1679

Table4.4: Maximum Storey Displacement (mm) for Experimental, Finite Element and STAAD model

Storey No.	Experimental (mm)	Present FEM (mm)	STAAD Pro (mm)
1	55.2	52.43	54.4
2	76.6	77.3	80.2

Figure4.10 shows Maximum Storey Displacement (Absolute)vsStoreyHeightfor experimental and numerical model.

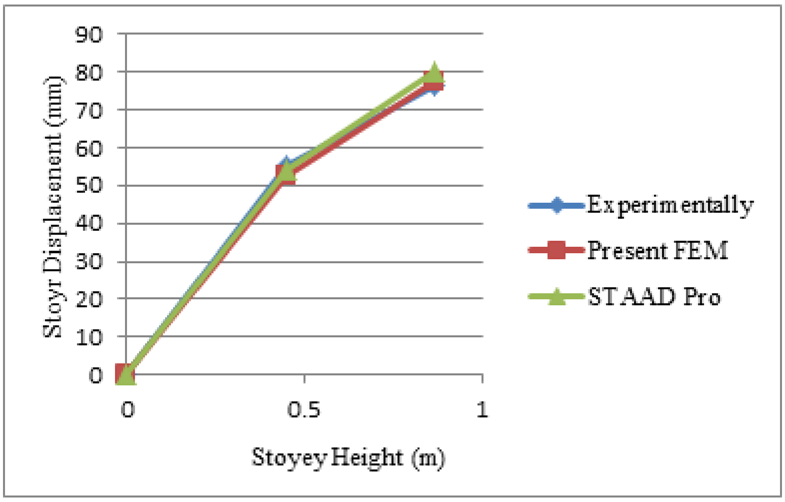

Figure4.10: Storey Displacement vs Storey Height

SUMMARY AND CONCLUSIONS

Summary

Exposure of a building to ground motion can trigger an earthquake. In order to mitigate these consequences, it is vital to understand the characteristics of earthquakes and anticipate how they can affect buildings. Base shear, maximum storey displacement, velocity, acceleration, and so on are some of these characteristics.

CONCLUSIONS

Based on the analysis of the three-sloped frame model, we find that: • A 15-degree slanted frame has the least storey displacement due to the short column's low rigidity, but a 25-degree slanted frame has the least storey displacement overall.

When it comes to the top storey, a 15-degree sloping frame is nearly as fast as a 20- or 25-degree sloping frame, but a 25-degree sloping frame hits its lowest and highest points on the 1st floor.

- The first level of a 25-degree frame, on the other hand, is subject to the maximum and minimum acceleration, respectively.
- This study's number of modes analyzed is sufficient to meet the requirements of the statute.
- The top floor acceleration's time-history response is best for all three frame models when the excitation frequency is in phase with the fundamental frequency. This is called resonance.
- The base shear is nearly the same across all structures. But because the ground-story columns absorb most of the shear force—roughly 75%—the short column is more likely to sustain damage. It is critical to follow correct design specifications to avoid making plastic hinges. Looking ahead to my career.

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