Experimental And Numerical Studies on Dynamic Analysis of Sloped Buildings

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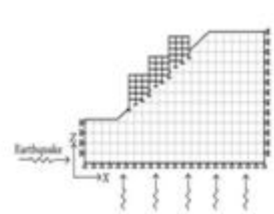
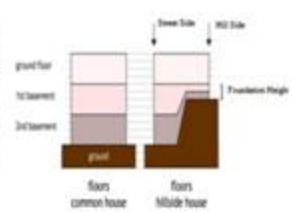
Abstract- *The buildings situated in hilly areas are much more prone to seismic environment in comparison to the buildings that are located in flat regions. Structures on slopes differ from other buildings since they are irregular both vertically and horizontally hence torsionally coupled and are susceptible to severe damage when subjected to seismic action. The columns of ground storey have varying height of columns due to sloping ground. In this study, behaviour of two storied sloped frame having step back configuration is analyzed for sinusoidal ground motion with different slope angles i.e., 15°, 20° and 25° with an experimental set up and are validated by developing a Finite Element code executed in MATLAB platform and using structural analysis tool STAAD Pro. by performing a linear time history analysis. From the above analysis, it has been observed that as the slope angle increases, stiffness of the model increases due to decrease in height of short column and that results in increase of earthquake forces on short column which is about 75% of total base shear and chances of damage is increased considerably due to the formation of plastic hinges therefore proper analysis is required to quantify the effects of various ground slopes.*

Keywords- Ground Motion, linear time history analysis, frequency content, finite element code

I. INTRODUCTION

Earthquake is the most disastrous and unpredictable phenomenon of nature. When a structure is subjected to seismic forces it does not cause loss to human lives directly but due to the damage cause to the structures that leads to the collapse of the building and hence to the occupants and the property. Mass destruction of the low and high rise buildings in the recent earthquakes leads to the need of investigation especially in a developing country like India. Structure subjected to seismic/earthquake forces are always vulnerable to damage and if it occurs on a sloped building as on hills which is at some inclination to the ground the chances of damage increases much more due to increased lateral forces on short columns on uphill side and thus leads to the formation of plastic hinges. Structures on slopes differ from those on plains because they are irregular horizontally as well as vertically. In north and north-eastern parts of India have large scale of hilly terrain which fall in the category of seismic zone IV and V. Recently Sikkim (2011), Doda (2013) and Nepal earthquake (2015) caused huge destruction. In this region there is a demand of construction of multistory RC framed buildings due to the rapid urbanization and increase in economic growth and therefore increase in population density. Due to the scarcity of the plain terrain in this region there is an obligation of the construction of the buildings on the sloping ground. In present work, a two storeyed framed building with an inclination of 15°, 20° and 25° to the ground subjected to sinusoidal ground motion is modelled with an experimental setup and validated with a finite element coding executed in the MATLAB platform and results obtained are validated by performing linear time history analysis in structural analysis and design software (STAAD Pro.).

II. EXPERIMENTAL MODELLING

2.1 Details of Laboratory Equipments

1. Three Mild Steel plates- In this model, there are three mild steel plates, two of same sizes and the other of different size. Plate no. 1 and 2 are used in each storey level and plate no. 3 used as base plate. The dimension of plates is shown in table:

Dimensions and Mass of mild steel plate

2. Four Threaded rods- The threaded rods are used as columns which are connected with mild steel plates in each storey level. The diameter of threaded rod used is7.7 mm.

3. Nuts and washers- The number of set of Nuts and washers used is 32. Each 8 sets for two storey levels to connect threaded rods with steel plates and 8 nos. for base plate and 8 nos. for connecting threaded rod to the plate of shake table.

4. Wooden logs and planks- The wooden logs and planks are used to obtain firm ground. The logs of wood are inserted in between base plate and shake table to fill the space between inclined base plate and platform of shake table. Wedge shaped small logs of wood are also used which facilitates in erect fitting of column with plates.

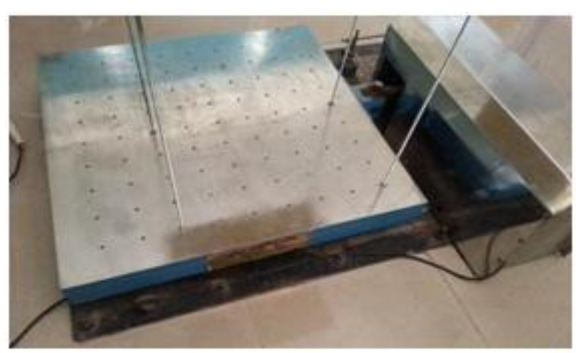
5. Shake Table- Shake table is used to simulate the seismic event happening on the site. The shake table consists of horizontal, unidirectional sliding platform of size 1000 mm x 1000 mm. It consists 81 tie down points at a grid of 100 mmx 100mm. The maximum payload is 100 kg. The maximum displacement of the table is 100 mm (±50 mm). The rectangular platform is used to test the response of structures to verify their seismic performance. In this table the test specimen is fixed to the platform and shaken. The frequency of the table is controlled by a control panel which is run by input voltage of 440 volts.

Plate No.	Dimension (cm)	Mass (kg)
Plate 1 & 2	50x40x1	15.44
Plate 3	70x40x1	21.76

6. Vibration Analyser- Vibration analyser (VA) is an important component to condition monitoring program. It is also referred as predictive maintenance. It is used to measure the acceleration, velocity and displacement displayed in time waveform (TWF). But the commonly used spectrum is that derived from a Fast Fourier Transform (FFT). Vibration Analyser provides key information about the frequency information of the model.

7. Control Panel- This device is used to allow the user to view and manipulate the forcing frequency of the model. The range of frequency available for the operation of shake table is from 0 to 20 Hz.

8. Personal Computer – The computer system used to perform the test consists of Intel(R) Core (TM) i5 processor with 4 GB RAM, 32-bit operating system and running Windows 7 professional. The software used for data acquisition is NV Gate. This software facilitates user to conduct the FFT analysis of the received signal and record various graphs i.e., time versus acceleration, time versus velocity and time versus displacement. All the records obtained during the vibration of the model is simultaneously displayed in the monitor.



9. Accelerometer- It is a device which is used to measure the proper acceleration. Proper acceleration does not meant to be the co-ordinate acceleration (rate of change of velocity with tim) but it is the acceleration which it experiences due to the free fall of an object. Accelerometer transfers its record to the vibration analyser which is received by computer and transforms it to a signal.

2.2.Experimental Model for 15°,20°,25° slope

Type of model	Natural frequency	
	Mode 1	Mode 2
15°	2.05	5.80
20°	2.2	5.945
25°	2.6	6.55

2.3 Experimental Results

During the experiment, free vibration analysis was performed for each frame model . The first two natural frequencies obtained for two modes are shown in table.

Each of the above frame model were excited with sinusoidal harmonic loading which is defined by following expression

$$x = x_o \sin\omega t ; \qquad [\omega = 2\pi f]$$

where xo is the amplitude of excitation (mm) f is the

frequency of excitation (Hz)

In the above expression, the frequency of excitation is applied over a range which included the natural frequency of the model. The displacement amplitude of excitation was kept constant i.e., x_o = 5 mm. Themaximum storey displacements obtained at resonance condition

Table : Maximum Storey Displacements (Absolute) for frame model of 15° inclination

Storey No.	Max.storey displacement (mm)
1	32.9
2	58.3

Table : Maximum Storey Displacements (Absolute) for frame model of 15° inclination

Storey No.	Max.storey displacement (mm)
1	44
2	68.3

Table : Maximum Storey Displacements (Absolute) for frame model of 15° inclination

Storey No.	Max.storey displacement (mm)
1	55.2
2	76.6

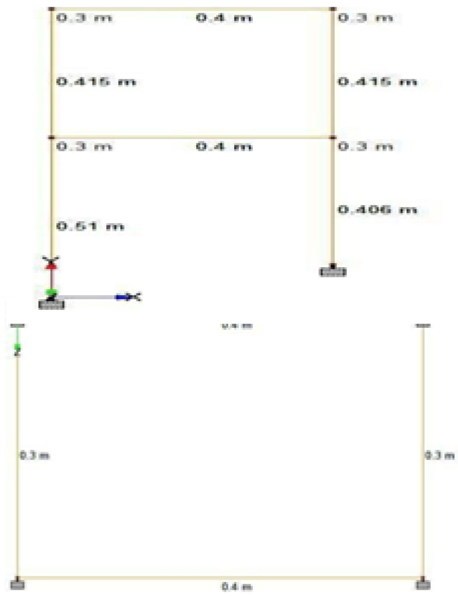
III. STAAD MODELING

Introduction

In this study, numerical modeling in STAAD Pro platform of the sloped frame is described. The plan and elevation of two storied sloped building subjected to ground motion record as per spectra of IS 1893 (Part 1)-2002 is shown. There are three different slope angle taken which are 15°, 20° and 25°. All the material properties of steel beam and column element are explained. Gravity loads considered are also explained. At the end the size of the elements are described.

Frame Modeling in STAAD

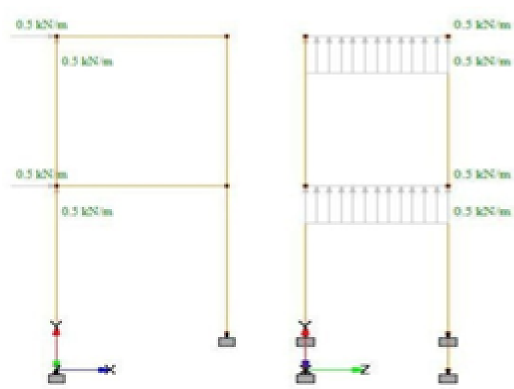
In this article, modelling is done in STAAD Pro. A two storied sloped frame model with plan and elevation is shown from figure 4.2 to figure 4.7 with different slope angle. But the total height of the building in all the three model is kept same i.e., 92.5cm of which height of first floor is 51 cm and 41.5 cm for the second floor. The length of bay is taken as 40 cm in longitudinal direction and 30 cm in transverse direction.



Loads

Uniformly distributed load of 0.5044 kN/m is applied in both longitudinal (X) direction and Y-direction at each storey level. The figure 4.8 shows front and side elevation of applied loads in X and Y directions.

The load applied is the mass of plate which is experimental model multiplied by the acceleration due to gravity i.e., 15.44*9.81=151.466 N or .151466 kN. This value of load is uniformly distributed throughout the length of beam 0.151466/0.3=.50488 kN/m.



Material Properties

The table 4.1 shows the properties of materials that are used in the modelling of structure in Staad Pro.

Title	Steel Properties	Column Bar Properties
Modulus ofElasticity	20000 GPa	77.3 GPa
Poisons ratio (ν)	0.3	0.3
Mass Density (Kg/m^3)	7720	7300
Shear modulus	7692.307 GPa	29.615 GPa

IV. CONCLUSION

Following conclusions can be drawn for the three sloped frame model from the results obtained in analysis:

- 15 degree sloped frame experiences maximum storey displacement due to low value of stiffness of short column while the 25 degree frame experiences minimum storey displacement.
- 15 degree sloped frame experiences nearly the same storey velocity as of 20 degree and 25 degree in the top storey but the velocity is maximum for the storey level of first floor while for 25 degree frame velocity is minimum for level of first floor.
- 15 degree sloped frame experiences maximum storey acceleration for the top floor with little variations with the 20 degrees and 25 degrees model but for the storey level of the first floor, acceleration is maximum and is minimum for the storey level of the first floor for 25 degrees frame.
- The natural frequencies of the sloped frame increases with the increase in the slope angle.
- The number of modes considered in the analysis is satisfying the codal provisions. The modal mass participation of the sloped frame model are decreasing for the first mode and increasing for the second mode with the increase in slope angle.
- For all the three frame models, time history response of the top floor acceleration is maximum at resonance condition i.e., when excitation frequency matches with fundamental frequency.
- The base shear of all the buildings are nearly the same with little variations but their distribution on columns of ground storey is such that the short column attracts the majority (75% approx.) of the shear force which leads to plastic hinge formation on the short column and are vulnerable to damage. Proper design criteria should be applied to avoid formation of plastic hinge.

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