

Irregularity Mitigation in Seismic Design of Reinforced Concrete Buildings

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Abstract

The structures arranged in bumpy regions are significantly more inclined to seismic climate in contrast with the structures that are situated in level locales. To distinguish themselves from other types of buildings, sloped structures are torsionally coupled and irregular both vertically and horizontally, making them vulnerable to severe damage from earthquakes. The sections of ground story have fluctuating level of segments because of slanting ground. With an experimental setup, the behavior of a two-story sloped frame in a step-back configuration is analyzed for sinusoidal ground motion using three distinct slope angles 15°, 20°, and 25° and validated by developing a Finite Element code that is run on the MATLAB platform and utilizing the structural analysis tool STAAD Pro. By playing out a direct time history examination. From the above examination, it has been seen that as the slant point expands, firmness of the model builds because of decline in level of short segment and that outcomes in increment of seismic tremor powers on short section which is around 75% of absolute base shear and chances of harm is expanded extensively because of the arrangement of plastic pivots accordingly appropriate investigation is expected to evaluate the impacts of different ground inclines.

1. Introduction

The most destructive and unexpected natural event is an earthquake. When a structure is subjected to seismic pressures, human lives are not immediately lost; instead, the damage done to the structure causes the building to collapse, endangering the lives of its people and its possessions. Recent earthquakes that caused widespread damage to both low-rise and high-rise structures call for further research, particularly in emerging nations like India. Structures that are subject to seismic or earthquake forces are always susceptible to damage. If an earthquake occurs on a sloped building, such as a hill with an incline towards the ground, the likelihood of damage increases significantly because of the increased lateral forces on short columns on the uphill side, which can cause plastic hinges to form. Slope-side structures are not like plain-side structures because they are asymmetrical both vertically and horizontally. Large areas of hilly terrain in seismic zones IV and V may be found in the northern and northeastern regions of India. The recent earthquakes in Nepal (2015), Doda (2013), and Sikkim (2011) have inflicted enormous damage. This region's growing urbanisation, increased economic growth, and therefore rising population density have created a need for the construction of multistory RC-framed structures. Construction of houses on sloping land is required due to the shortage of plain terrain in this region. The current study involves modelling an experimental setup for a two-story building that is oriented at 15°, 20°, and 25° to the ground and is subject to sinusoidal ground motion. The results are verified through finite element coding conducted in the MATLAB platform, and the linear time history analysis performed in structural analysis and design software (STAAD Pro) confirms the obtained results.

1.1 Scope of the Study:

This research aims to investigate the dynamic response of sloping buildings to seismic excitations and sinusoidal ground motion via computational and experimental means.

The following sums up the study's scope:

- i. To investigate the dynamic response of a sloping frame to a change in slope inclination while maintaining a constant overall height, an experimental research is conducted using a two-story sloped frame model that is fixed firmly to a shaking table and capable of creating sinusoidal acceleration.
- ii. To get the natural frequency of the model, the governing differential equation for undamped free vibration is solved numerically using the finite element method.
- iii. The frame model's dynamic response is numerically evaluated using the Newmark technique.
- iv. STAAD Pro, a structural analysis tool, is used to perform linear time history analysis by introducing compatible time history in accordance with IS 1893 (Part 1):2002 spectrum for 5% damping at rocky soil.

2. Experimental Modeling

The experiments on forced and free vibration on a sloping frame model are covered in this chapter. The outcomes of the MATLAB platform's finite element coding are contrasted with the findings of the experimental investigation. The completed work is divided into the following three sections:

- Details of Laboratory Equipments
- Fabrication and Arrangement
- Free and Forced Vibration Analysis

2.1 Experimental Modeling

2.1.1 Details of Laboratory Equipments

1. Three Mild Steel plates- Three mild steel plates—two of the same size and one of a different size—are included in this model. Each floor level uses plates 1 and 2, and plate number 3 serves as the foundation plate. The plates' dimensions are displayed in table 2.1.

Table 2.1: Dimensions and Mass of mild steel plate

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

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 is 7.7 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.

2.2.2 Fabrication and Arrangement

Four 8 mm diameter holes are drilled onto the plates, through which threaded bar is able to pass. The holes are positioned 5–2 cm radially apart—from the plate's corners. In plate 3, a 2 cm slit is cut at a radial distance of 5–2 cm from each corner of the base plate that is attached to the shaking table platform. To accommodate slope angles of 15°, 20°, and 25° at a distance of 41 cm from the slot cut of the connecting leg, a 5 cm slot is formed in the base plate. These holes and slots are used to insert the threaded rods, which are then fastened to the platform using washers and nuts. The base plate is now fixed, preserving the 15°, 20°, and 25° slope angles (one at a time). At this point, Plates 1 and 2 are set at a distinct distance of 51 and 92.5 cm, respectively, from the connecting end of the base plate. To guarantee correct fixity, the screw is properly tightened. The platform and base plate are separated by the wooden logs, creating a sturdy base that resembles a sloping piece of land.



Figure 2.1: Experimental Model for 15° slope

2.2 Frequency Response Analysis

For each of the three slope angles, Figure 3.9 displays the response of frequency (Hz) on the X-axis and top storey displacement (mm) on the Y-axis. Due to the increasing frequency, slope angle, and stiffness of the short column on the hillside, the displacement is decreasing in this plot.

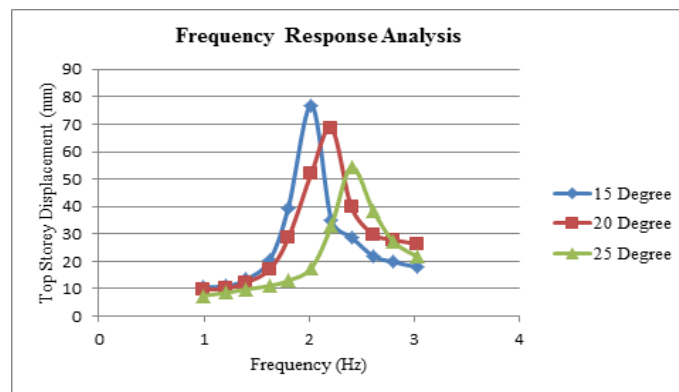


Figure 2.2: Frequency Response analysis

The dominance of the first fundamental frequency (2.05 Hz) obtained by superimposing it with the excitation frequency of value lower (1.62 Hz) and of value higher (2.80 Hz) than the fundamental frequency is shown in Figures 3.10(a) and 3.10(b) for acceleration (top storey) versus time. It can be seen in both charts that the fundamental frequency, rather than the 1.62 Hz and 2.80 Hz excitation frequencies, dominates the response.

3. Numerical & Staad Modeling

According to the literature study, a finite element model on a sloping frame must be created in order to verify the outcomes of commercial software programmes such as SAP 2000, ETABs, and STAAD Pro. Consequently, a finite element analysis is done for the forced vibration study. For the sloping frame, a finite element model is created, and free vibration analysis is used to calculate its natural frequencies. With the aid of Newmark's integration approach and forced vibration analysis, the dynamic response of the frame model is investigated. The results are verified using STAAD Pro, a structural analysis tool.

Direct integration method considers a step by step integration in time. These are of two types:

1. Explicit
2. Implicit

Data from the previous n stages is utilised explicitly in a direct integration type to safeguard future times. It is well-liked in non-linear scenarios and is simple to programme. Small steps are necessary to maintain stability because instability might arise; in other words, step size directly affects accuracy. It is conditionally stable as a result. used in the linear acceleration technique for $\Delta t \leq 0.551T_j$, in where T_j is the j th mode's natural period.

Implicit type uses the equation of motion at the current moment as well as historical data. It is more difficult to programme than the explicit technique. It is possible to make it completely stable regardless of step size. Its powerful filtering function smoothes and attenuates the predictive response, preventing the computed response from diverging or oscillating. However, using a large step size comes at the cost of losing the high frequency character that helps to smooth down the response. utilised in the technique of average acceleration.

3.1 STAAD Modeling

This study describes numerical modelling of the sloping frame in the STAAD Pro platform. The elevation and design of a two-story, sloping structure that is subject to a ground motion record are displayed in accordance with the IS 1893 (Part 1)-2002 spectrum. Three distinct slope angles—15°, 20°, and 25°—were measured. There is an explanation of every material property of the steel beam and column element. An explanation of the gravity loads is also provided. The elements' sizes are specified at the conclusion.

3.2 Frame Modeling in STAAD

STAAD Pro is used for modelling in this article. From figure 4.2 to figure 4.7, a two-story sloping frame model with a plan and elevation is displayed, with the slope angle varying. However, the building's overall height is maintained at 92.5 cm for all three models, with the first floor's height being 51 cm and the second floor's height being 41.5 cm. 30 cm in the transverse direction and 40 cm in the longitudinal direction are considered to be the bay's length.

Figure 3.1: Plan of sloped frame for 15° inclination

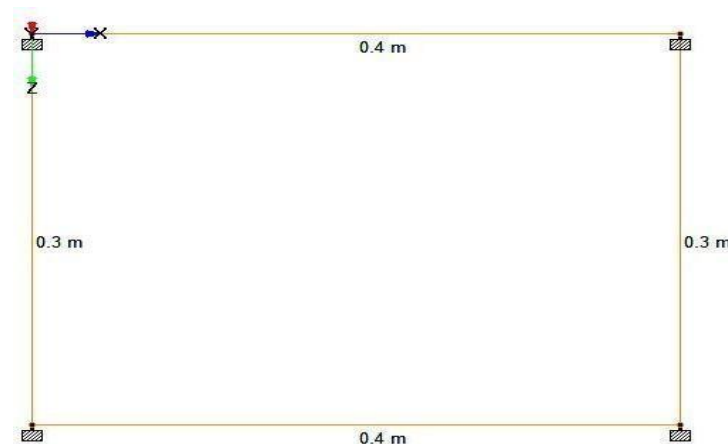


Table 3.1: Steel and Column Bar Properties

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

Within STAAD Pro. The aforementioned models are exposed to ground motion with an intermediate frequency content, and linear time history analysis is carried out using IS 1893(Part I): 2002 spectra. First and second floor story heights are assumed to be 51 cm and 41.5 cm, respectively. The short column (on the right) measures 40.65 cm in length, 37.3 cm in length, and 32 cm in length at a slope of 15°, 20°, and 25°, respectively. The

beam's length is 30 cm in the transverse (Z) direction and 40 cm in the longitudinal (X) direction. Table 4.2 displays the specifics of the beam and column sizes.

4. Results & Discussions

This chapter presents the reaction of the structure to ground motion as well as the findings for a two-story sloping building with a ground inclination of 15, 20, and 25 degrees with regard to base shear, roof acceleration, and roof displacement. For every inclination, illustrations of the tale acceleration, velocity, and displacement are also shown. The reactions resulting from ground motion are displayed according to IS 1893 (Part 1):2002 spectrums. The outcomes derived from numerical analyses are presented along with an experimental model for validation.

4.1 Two storied sloped frame with ground inclination of 15°

By using free vibration analysis, we were able to determine the natural frequencies of the model for the two distinct modes that are displayed in table 4.3, with reference to the specifics in articles 3.2.3 and 4.2.4.3:

Table 4.1: Natural Frequency of sloped frame with 15° inclination validated with Present FEM

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

Table 4.2 shows maximum storey displacement (absolute) for both experimental and finiteelement and STAAD Pro. model for 15° slope.

Table 4.2: Maximum Storey Displacement (mm) for Experimental, Finite Element and STAAD model

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

Figure 4.1 shows Maximum Storey Displacement (Absolute) vs Storey Height for experimental and numerical model.

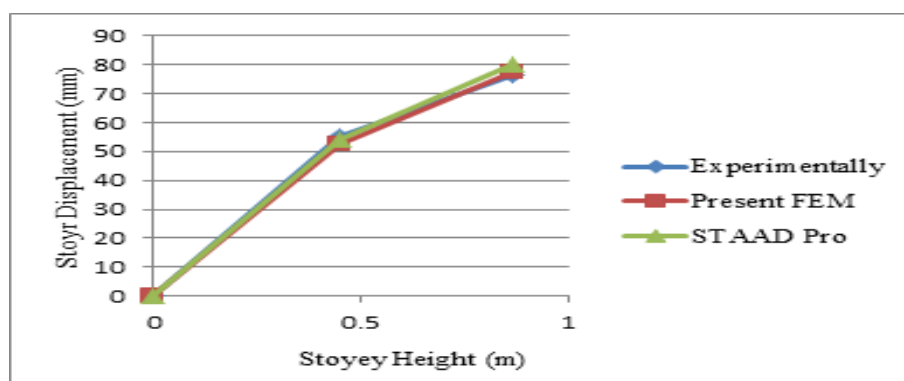


Figure 4.1: Storey Displacement vs Storey Height

4.2 Mass Participation factor of both modes for considered slope angles

According to IS 1893-2002 (Part I), when analysing structures, the number of modes taken into account should account for at least 90% of the total seismic mass. The number of modes taken into consideration here meet the requirements. The mass participation factor (%) is tabulated for modes 1 and 2, as well as for all three slope inclinations. It is shown that the mass participation factor falls as the slope inclination increases.

5. Conclusion

An earthquake is created when a structure is subjected to ground motion, which results in structural damage. In order to mitigate these impacts, it is crucial to understand seismic physics and anticipate potential reactions that may affect buildings. Base shear, maximum storey displacement, acceleration, and velocity are some examples of these characteristics. To determine the reaction of the aforementioned building, this study's analysis was carried out experimentally using finite element modelling and a structural analysis tool for validation. Every slope angle's reactions are examined and contrasted.

Based on the analytical results, the following conclusions may be made for the three sloped frame model:

- Because the short column's rigidity is low, a 15-degree slanted frame can move up to 15 storeys, whereas a 25-degree slanted frame can move up to 25 storeys.
- A 15 degree slanted frame experiences about the same storey velocity as a 20 degree and a 25 degree frame at the top story; however, the 25 degree frame experiences a minimum velocity at the first floor's storey level.
- The top floor of a 15 degree slanted frame receives the most storey acceleration, with little fluctuations when compared to 20 and 25 degree models; nevertheless, the first floor's storey level suffers the lowest and highest acceleration when using a 25 degree frame.
- The number of modes taken into consideration in the study satisfies the codal requirements; • The natural frequencies of the sloping frame rise with an increase in the slope angle.
- As the slope angle increases, the modal mass participation of the sloping frame model increases for the second mode and decreases for the first.
- In all three frame models, the top floor acceleration's time history response reaches its maximum at resonance, or when the excitation frequency coincides with the fundamental frequency.

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