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Seismic Analysis Of Reinforced Concrete Buildings In Hilly Topography

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Abstract
The behaviour of a building during earthquakes depends critically on its overall shape, size, geometry and Building site, in addition to how the earthquake forces are carried to the ground. Hence, at the planning stage itself, architects and structural engineers must work together to ensure that the unfavorable features are avoided and a good building configuration & site condition is chosen. In some parts of world, hilly area is more prone to seismic activity; e.g. northeast region of India. Most of the northern hilly region of India lies in the seismically active belt of the Himalayan range. Three major earthquakes (M>8) Kangra (1905), Bihar-Nepal (1934) and Assam (1950) have occurred in this hilly track during the last century and it may repeat. Analysis and comparative study of buildings on sloping ground considering seismic forces with different seismic zones III & zone IV is carried in this paper. The software used for the analysis in present study is SAP 2000v14.0 Advanced. In the present study, 56 RC buildings with different no. of storey ranging from 4 to 10 storey (13.5m to 31.5m height) resting on sloping ground and plane ground are considered for linear static & dynamic analysis. The work has been divided into two phase and each phase consists of four groups of buildings and in each group, 7 numbers of buildings are considered. In 1st group, buildings are resting on plane ground & in 2nd, 3rd, and 4th group, buildings are resting on sloping ground with angle of slope 23 degree, 27 degree & 31 degrees respectively. In first phase, all 28 numbers of buildings have been analyzed under seismic zone III & in second phase, same 28 numbers of buildings have been analyzed under seismic zone IV. The buildings with equal number of storey have same geometric properties and floor area in both phases. The height and length of buildings in a particular pattern are in multiple of blocks (in vertical & horizontal direction), the size of block is being maintained at 5m x 4m x 3m. The depth of footing below ground level is taken as 1.5m where the hard stratum is available. It is concluded that the performance of buildings on sloping ground during seismic excitation could prove more vulnerable than the building on plane ground. There is increase in the value of shear force as the height of building (No. of Storey) increases by Equivalent Static Analysis (ESA) and Response Spectrum Analysis (RSA) along the slope & across the slope direction.

Key Word: Seismic analysis, Sloping ground, Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA).

1. INTRODUCTION

The hilly seismic regions of our country ranges from Jammu & Kashmir, Himachal Pradesh, North Uttar Pradesh, North Bihar, Sikkim, North Bengal, Assam, Meghalaya, Nagaland, Arunachal Pradesh, Manipur, Tripura and Mizoram. All these vast regions are undergoing rapid changes due to economic development and being the frontier states. It has vast populated area in the hilly regions and all kind of construction practices (i.e. Engineered and non-engineered, traditional & modern) are followed. All short of building materials i.e. adobe, brunt brick, stone masonry and dressed stone masonry, timber reinforced concrete, bamboo, etc., which is locally available, is used for the construction of houses. The adobe, brunt brick, stone masonry and dressed stone masonry buildings are generally made over level ground in hilly regions. Since the level land on hilly regions is very limited, there is a pressing demand to construct buildings on hill slopes in a hilly terrain as shown in Fig.1

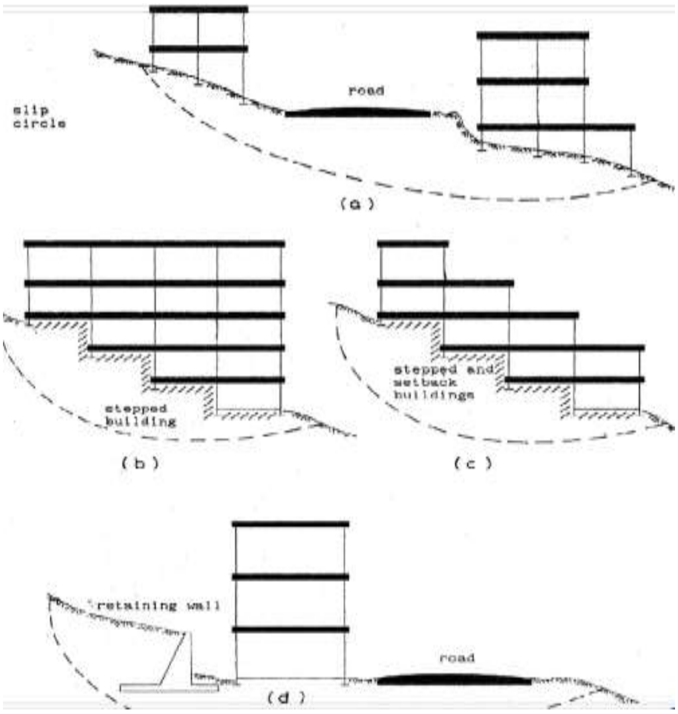


Fig. 1 Buildings on hill slopes

A scarcity of plain ground in hilly area compels the construction activity on sloping ground. Traditionally the Hill buildings are constructed in masonry with mud mortar/cement mortar without conforming to seismic codal provisions have proved unsafe and, resulted in loss of life and property when subjected to earthquake ground motions. Landslides and slope failures are responsible for millions of dollars of damage to public and private property every year. Today, the analysis and solution of landslide problems as well as the prevention of landslide problems requires an understanding of geology, hydrology, seismology, geotechnical exploration and engineering, computerized analytical methods, and practical and constructible engineering solutions. Every property is different, and slopes present special challenges to Engineer. But sloped properties can be particularly attractive because they often offer beautiful views. Building on slopes and know the challenges to be mastered by the structural design and floor plan. But we also know the many interesting options created by clever use of such a property. For example, a house on a slope can have two ground floors, if desired. And an intelligently placed terrace or garage can turn a house on a slope into something very special. So there is no need to be afraid of sloped properties.

1.1. Mechanics of Earth Slope

If the equilibrium of the sliding wedge is to be maintained, the disturbing moment (W x d) must be opposed by the shearing resistance of the soil along the arc of failure. The failure surface is assumed as a part of a circle.

$$W \times d = S \times La \times r \quad (1)$$

Where, W = weight of soil of wedge BDCB of unit thickness BC = failure arc with r as the radius and O as the center of rotation La = length of failure arc BC S = shear resistance, d = distance of line of action of W from the vertical line passing through the center of rotation.

2. LITERATURE REVIEW

Critical literature review is carried to identify the research gaps and scope to carry out this research. [1] presented the various design problems and precautions to be taken for framed buildings on hill slopes. A one dimensional (1D) simplified method of analysis of framed buildings on hill slopes is presented and the results of natural time periods are compared with those obtained by using three dimensional (3D) frame analysis. [2] carried seismic analysis, behaviour and analytical modeling of components of hill buildings. Due to varied configurations of buildings in hill areas, these buildings become highly irregular and asymmetric. Buildings constructed in hill areas are much more vulnerable to seismic environment. [3] simplified 3D dynamic analysis of hill buildings based on transformation of stiffness and mass of various components about a common arbitrarily-chosen reference axis. Few actual hill building problems have been analyzed with the simplified method and the rigorous method of analysis. [4] various types of differently configured RC framed building are studied from structural/seismic safety point of view under the action of dead, live, and earthquake loads. Two building frames having step-back and a combination of step-back and setback configurations respectively are considered for studying the seismic response. [5] three dimensional space frame seismic analysis performed on 24 RC buildings with three different configurations like, Step back building, step back set back building and set back buildings ranging from 4 to 11 storey (15.75 m to 40.25 m height). Two buildings are resting on sloping ground and third building is on plane ground under the action of seismic load. 3-D analysis including torsional effect has been carried out by using response spectrum method. [6] highlighted the inherent difference in behavior of the adopted building configuration from conventional framed structure under the action of static and dynamic loads. Further the soil-structure interaction indicates an increase in displacement & shear over the fixed base parameter. On the basis of the study the step back-set back configuration has employed to advantage in hilly regions. [7] recommends that where a regular building or framing system has one setback in which the plan dimension of the tower in each direction is at least 0.75 times the corresponding plan dimension of the lower part, such a building may be considered as being without a setback for the purposes of determining and distributing earthquake forces. Buildings with other conditions of setback in either zone A or 1, the tower shall be designed as a separate building using the larger of values of the seismic response factor C at the base of the tower determined by considering the tower as a separate building for its own height or as part of the overall structure, the resulting shear from the tower shall be applied at the top of the lower part of the building which shall be otherwise considered separately for its own height. For buildings with other conditions of setback shall be analyzed by considering the dynamic characteristics of such buildings. [8] specifies that where the centroids of mass and the centers of stiffness of the different floors do not lie approximately on vertical lines, a dynamic analysis shall be carried out to determine the torsional effects, a setback is a sudden change in plan dimension or a sudden change in stiffness along the height of a building. The effects of major changes in stiffness and geometry are best investigated by dynamic methods. The design eccentricity for regular asymmetric structures has been specified as 1.5e+0.lDn or 0.5e-0.1Dn where Dn is the plan dimension of the building in the direction of computed eccentricity, e is the distance between the location of the resultant of all the forces at and above the level being considered and the center of rigidity at the level being considered. [9] suggested to consider effect of structural torsion to be taken into account by assigning 3 DOF per floor; i.e. mutually orthogonal two components of translation and one component of rotation. Seismic loads and actions are correspondingly evaluated by means of the spectral and modal methods. [10] specifies that a coupled system consisting of appendage and the main structure must be analyzed according to modal analysis procedure which includes evaluation of natural periods and associated oscillating modes for a structural model. [11] specified for buildings having irregular shape and/or irregular distribution of mass and stiffness in horizontal and vertical planes, [11] recommends modal analysis using response spectrum method. It also states that provision shall be made in all buildings for increase in shear force on the lateral force resisting elements resulting from the horizontal torsional moment arising due to an eccentricity between the center of mass and the center of rigidity at various floors. The design eccentricity shall be taken 1.5 times the computed eccentricity between the center of mass and center of rigidity. Negative torsional shears shall be neglected. The significant point in the IS: Code is that 50% increase in the value of eccentricity for the calculation of torsional moments to be used in calculation of shears due to torsion. [11] does not give ample guidance in the analysis of buildings on hill slopes.

3. MODELLING AND ANALYSIS

Earthquake response analysis is an art to simulate the behavior of a structure subjected to an earthquake ground motion based on dynamics and a mathematical model of the structure. The correct analysis depends upon the proper modeling of the behavior of materials, elements, connection and structure. Therefore, it is important to select an appropriate and simple model to match the purpose of the analysis.

In the present study, 56 RC buildings with different no. of storey ranging from 4 to 10 storey (13.5m to 31.5m height) resting on sloping ground and plane ground are considered for linear static & dynamic analysis. The work has been divided into two phase. Each phase consists of four groups of buildings and in each group, 7 numbers of buildings are considered. In first group, buildings are resting on plane ground & in 2nd, 3rd, and 4th group, buildings are resting on sloping ground with angle of slope 23 degree, 27 degree & 31 degrees respectively. In first phase, all 28 numbers of buildings have been analyzed for seismic zone III & in second phase, same 28 numbers of buildings have been analyzed for seismic zone IV. The buildings with equal number of storey have same geometric properties and floor area in both phases. The height and length of buildings in a particular pattern are in multiple of blocks (in vertical & horizontal direction), the size of block is being maintained at 5m x 4m x 3m. The depth of footing below ground level is taken as 1.5 m where the hard stratum is available. Other properties are, height of building: 3m, slab thickness: 0.15m, wall thickness: 0.23m, parapet wall thickness (1m): 0.23m, grade of concrete: M25, modulus of elasticity: 25000N/mm², Poisson's Ratio: 0.20, seismic zone: III & IV, zone factor: 0.16 & 0.24, soil type: I, Importance factor: 1.0 damping: 5%, response reduction factor: 3.0, live load: 3 kN/m^2 for all typical floors 1.5 KN/m^2 for roof. The properties of frame members of buildings that are considered for analysis are given in Table 1.

Table 1. Geometrical properties of building members

Angle of Slope (Deg.)	No. of Storey (m)	Beam (m)	Base Column (m)	Column (m) 1-2	Column (m) 3-4	Column (m) 5-6	Column (m)
21, 27, & 31	4 (13.5)	0.45x0.25	0.50x0.35	0.50x0.35	0.45x0.25	-	-
	5 (16.5)	0.45x0.25	0.50x0.35	0.50x0.35	0.50x0.30	-	0.45x0.25
	6 (19.5)	0.50x0.25	0.55-0.40	0.55x0.40	0.50x0.35	0.50x0.28	-
	7 (22.5)	0.50x0.25	0.55x0.40	0.55x0.40	0.50x0.35	0.50x0.28	0.50x0.28
	8 (25.5)	0.50x0.30	0.60x0.50	0.60x0.50	0.60x0.40	0.50x0.40	0.50x0.30
	9 (28.5)	0.50x0.30	0.60x0.50	0.60x0.50	0.60x0.40	0.50x0.40	0.50x0.30
	10 (31.5)	0.55x0.30	0.65x0.50	0.65x0.50	0.60x0.50	0.50x0.40	0.50x0.30

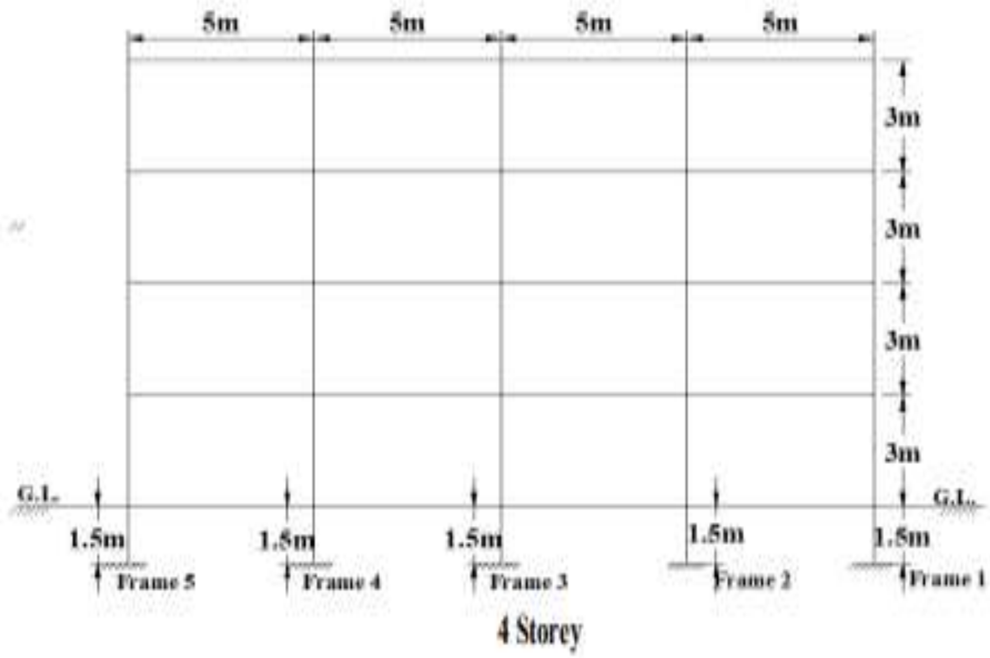
Once the structural model has been Prepared, it is possible to perform analysis to determine the seismically induced forces in the structures. There are different methods of analysis which provide different degree of accuracy. For the present study linear static and dynamic analysis are used to determine the response of the structure to various types of loading as per IS: 1893(I)-2002 using

SAP2000. The analysis is based on following assumptions: i) material is homogenous, isotropic and elastic, ii) the values of modulus of elasticity and Poisson’s ratio are 25000 N/mm² and 0.20 respectively, iii) the floor diaphragms are rigid in their plane, iv) axial deformation in column is considered, v) torsional effect is considered as per [11].

The average response acceleration coefficient (Sa/g) obtained from response spectra is then multiplied by the design seismic coefficient factors to get the design horizontal seismic coefficient as:

$$Ah = Z/2 * I/R * Sa/g \quad (2)$$

For the purpose of determining seismic forces Where, Z is a zone factor, is for the Maximum considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Maximum Considered earthquake (MCE) zone factor to the factor for Design Basis Earthquake (DBE). ‘I’ is importance factor, depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance. R is the response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However, the ratio (I/R) shall not be greater than 1.0.



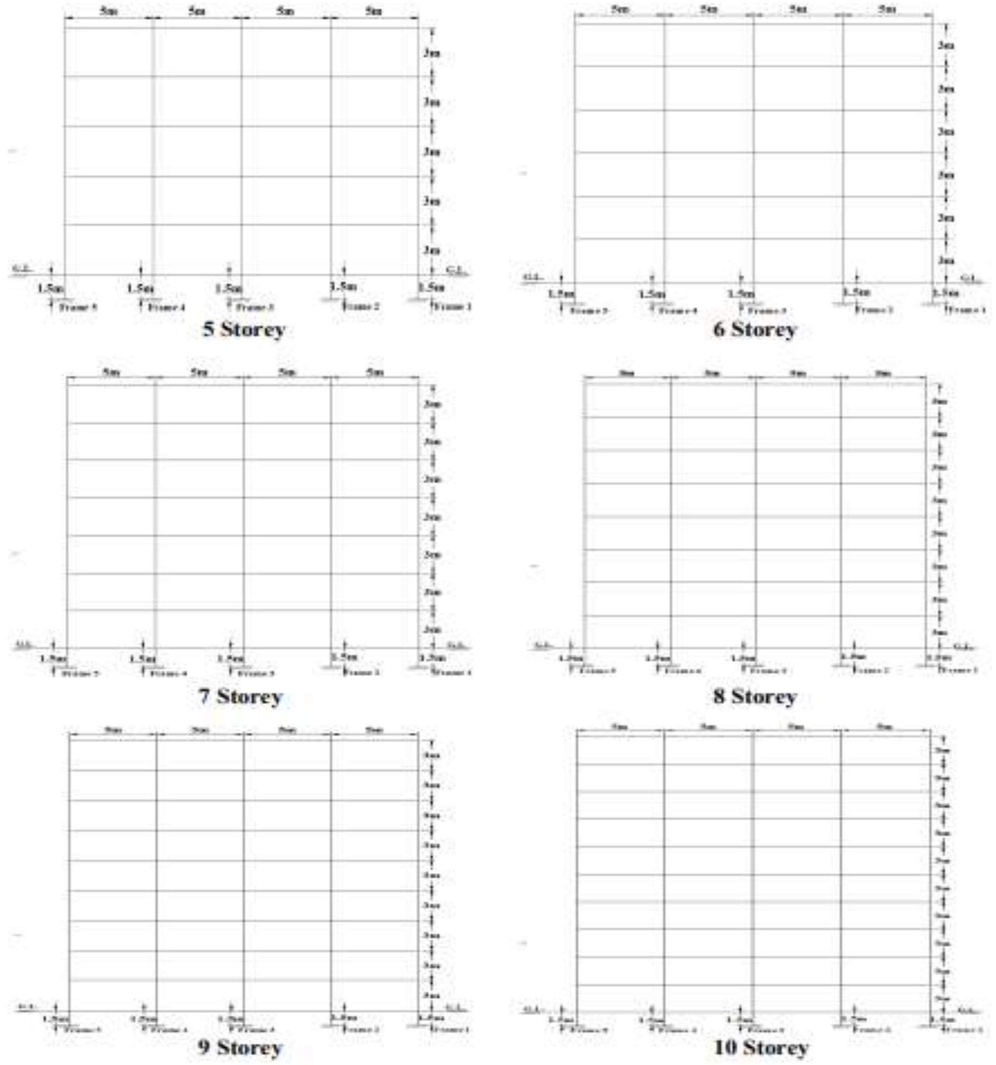
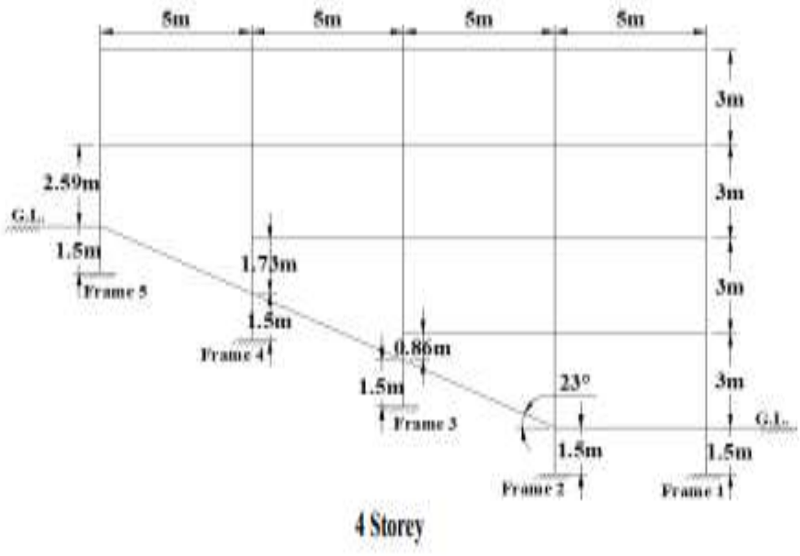


Fig. 2 Buildings on plane ground (4 to 10 storey)



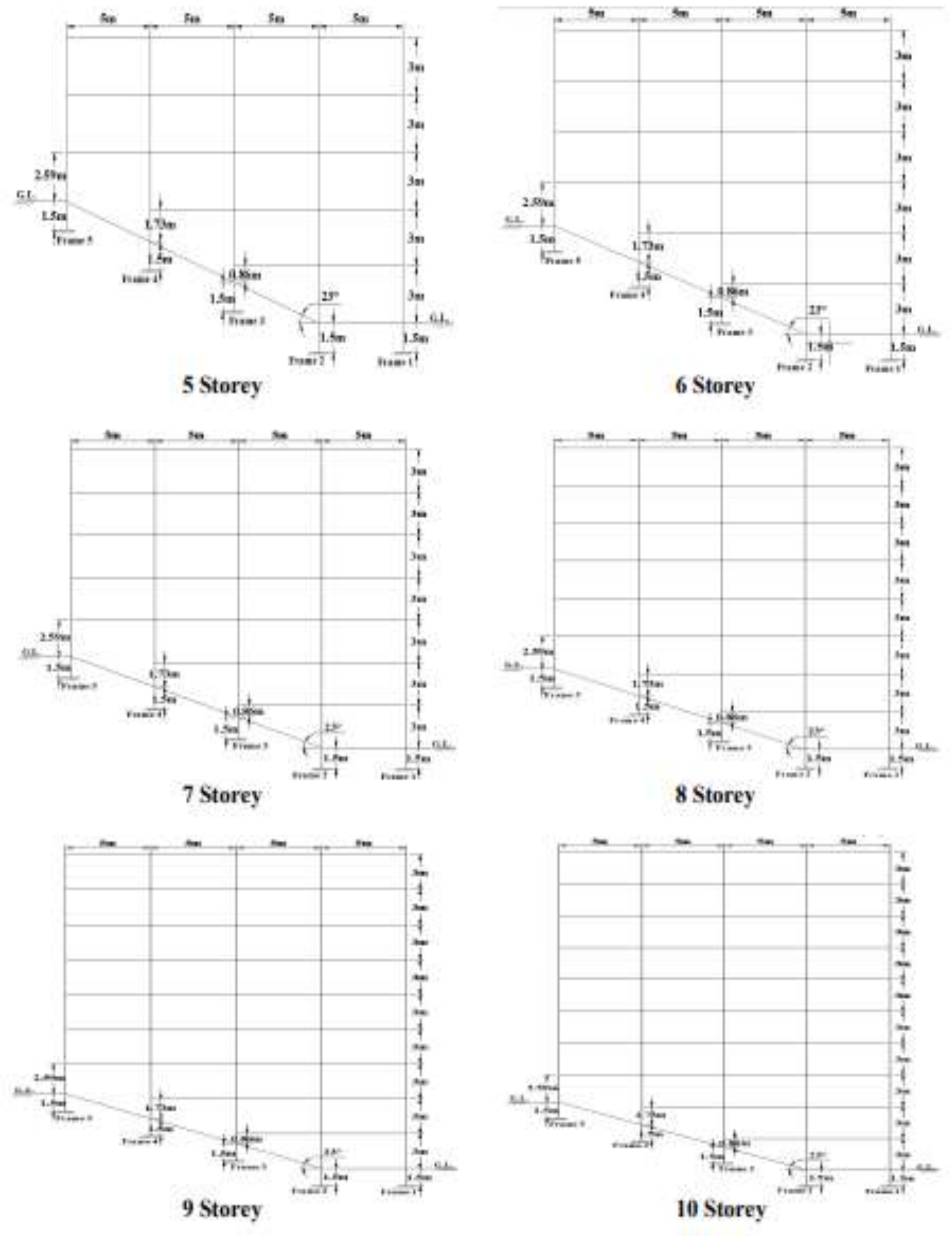


Fig. 3 Buildings on hilly ground (Angle 23° 4 to 10 storey)

4. RESULT AND DISCUSSION

Total 56 RC buildings with different no. of storey ranging from 4 to 10 storey (13.5m to 31.5m height) resting on sloping ground and plane ground have been analyzed by Static & Dynamic (Response Spectrum) Analysis. The seismic force was applied in X- direction and Y-direction independently. Results have been obtained from Static and Dynamic (Response Spectrum) Analysis for different angle of slopes (23, 27, 31 degree) and plane ground in different seismic Zones (Zone III and Zone IV) using SAP2000 software.

4.1. Three Fundamental Modes of Building

First three fundamental modes and time period of buildings on sloping ground is shown in Fig.4

First Mode- 0.71 Sec. Sec. Second Mode- 0.47 Sec. Third Mode- 0.45 Sec.

Fig.4 Fundamental mode shapes and time period

4.2. Time Period

Comparison of time period between different Angle of Slope (23, 27 and 31 degree) and plane ground has by Equivalent Static Analysis and Response Spectrum Analysis in X direction for all buildings situated in Zone III is presented Fig. 5(a) and Fig. 5(b).

From the graph, it is observed that there is linear increase in the value of time period as the height of building (No. of Storey) increases by Equivalent Static Analysis and Response Spectrum Analysis. It is found that, the value of time period is same between different angle of slope & plane ground for all buildings by Equivalent Static Analysis, but in case of Response Spectrum Analysis it is decreases as we increase the sloping angle. It is maximum in case of plane ground by Response Spectrum Analysis.

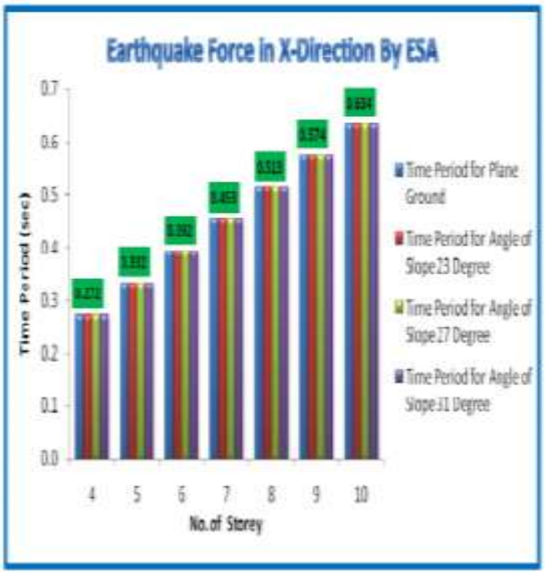


Fig. 5 (a) Time period for different angle of slope and plane ground by ESA–X direction

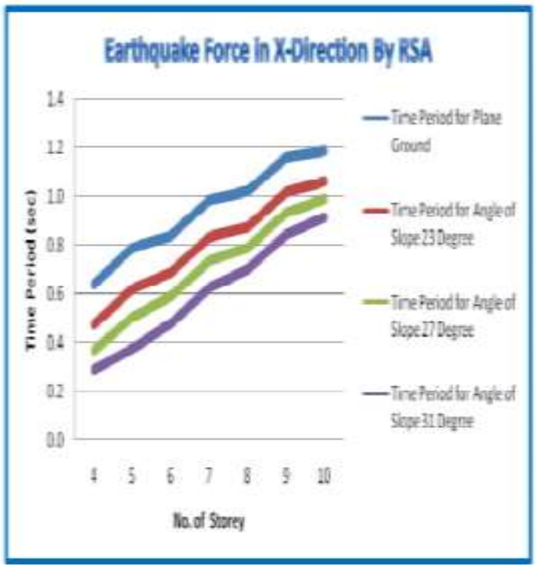


Fig. 5 (b) Time period for different angle of slope and plane ground by RSA–X direction

4.3. Maximum Top Storey Displacement

Comparison of maximum top storey displacement between different angle of slope (23, 27 and 31 degree) and plane ground has by Equivalent Static Analysis and Response Spectrum Analysis in X direction for all buildings situated in Zone III is presented in Fig.6 (a) and Fig.6 (b).

From the graph, it is observed that there is increase in the value of maximum top storey displacement as the height of building (No. of storey) increases by Equivalent Static Analysis and Response Spectrum Analysis in X direction. It is found that, the value of maximum top storey displacement is decreases as the angle of slope increase. It is also found that maximum top storey displacement for different angle of slope is less as compared to plane ground for all buildings by Equivalent Static Analysis and Response Spectrum Analysis in X direction.

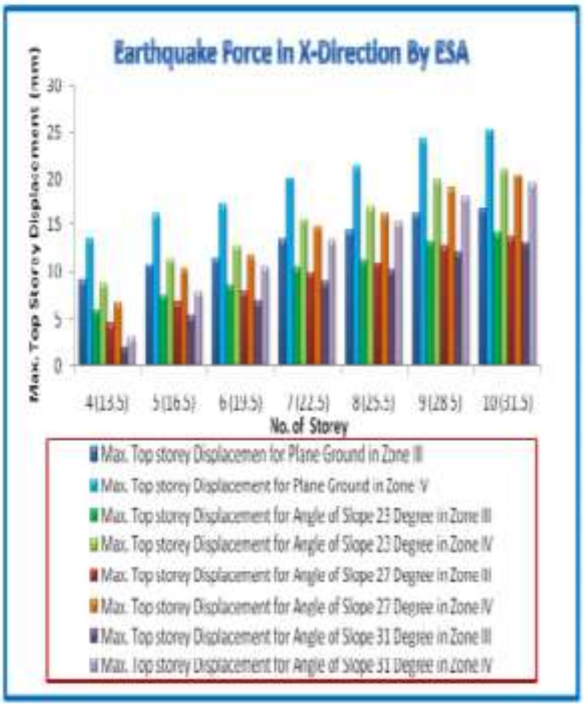


Fig 6 (a) Max. top storey displacement for zone III and IV by ESA-X direction

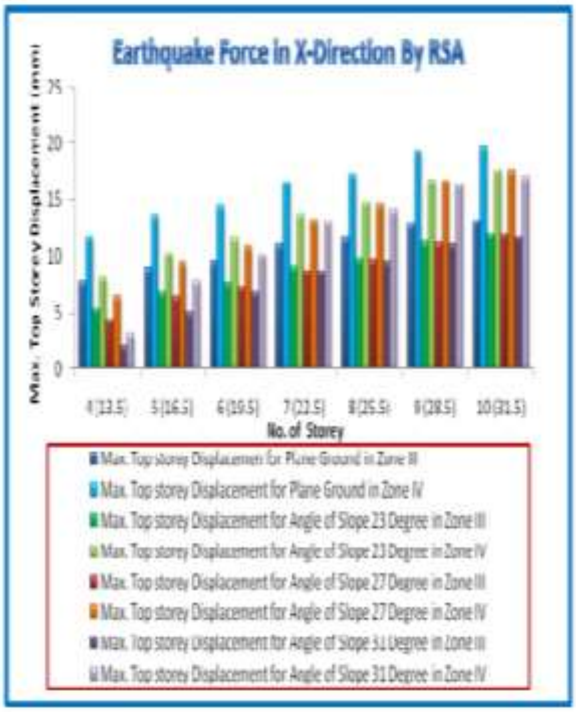


Fig 6 (b) Max. top storey displacement for zone III and IV by RSA-X direction

4.4. Shear Force

Comparison of shear force between frame 1 to frame 5 for different angle of slope (23, 27 and 31 degree) and plane ground by equivalent static analysis in x direction for all buildings situated in seismic zone III and IV is presented in Fig.7(a to d) for X - direction.

From the graph, it is observed that, the value of shear force is same for frame 1 & 5 and frame 2 & 4 in case of plane ground. it is also observed that the value of shear force is higher in frame 2 & 4 as compared to frame 1 & 5. shear force in frame 3 is nearly same. It found that the value of shear force in frame 5 is much higher than other frames in case of sloping ground (angle of slope 23, 27 & 31 degree) in X direction. It is observed that there is increase in the value of shear force as the height of building (no. of storey) increases by equivalent static analysis and response spectrum analysis in X direction. The value of shear force is increases as the angle of slope increase.

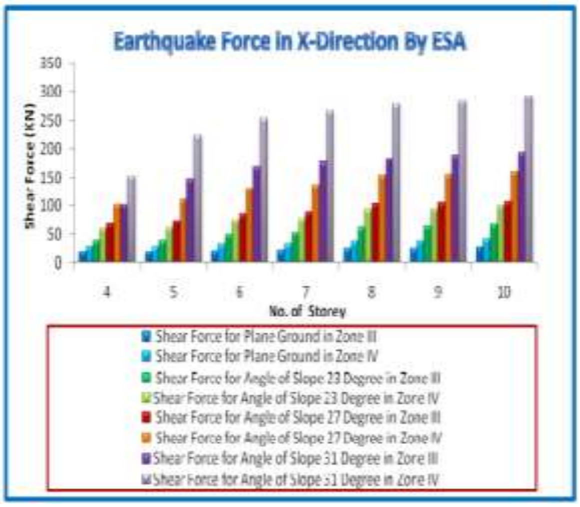


Fig. 7(a) Shear force between frame 1 to frame 5 for different angle of slope by ESA–X direction

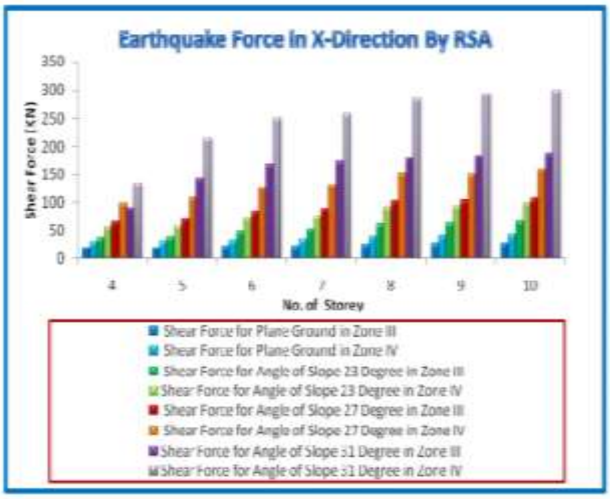


Fig. 7(b) Shear force between frame 1 to frame 5 for different angle of slope by RSA–X direction

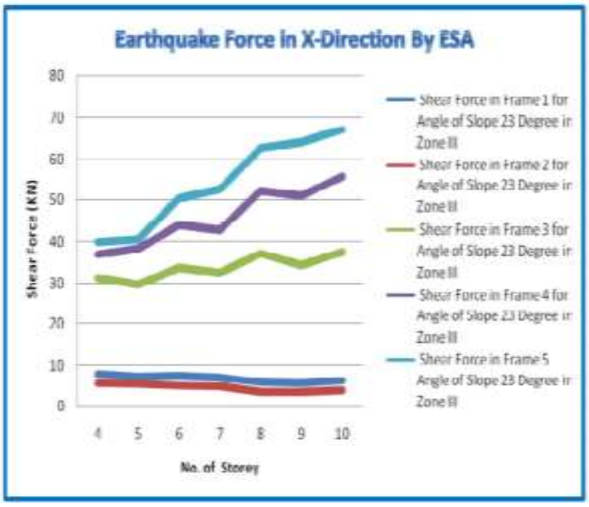


Fig. 7(c) Shear force between zone III & zone IV for different angle of slope by ESA–X direction

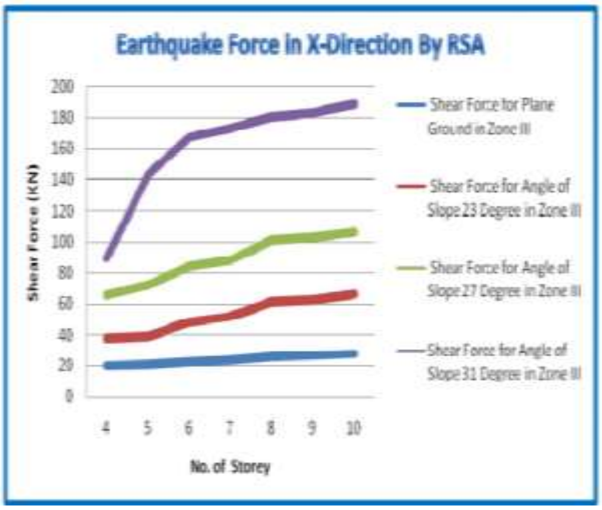


Fig. 7(d) Shear force between zone III & zone IV for different angle of slope by RSA–X direction

CONCLUSIONS

Based on Static Analysis and Dynamic Analysis (Response Spectrum Analysis) of buildings resting on plane ground & sloping ground, the following conclusions are drawn:

- The performance of buildings on sloping ground during seismic excitation could prove more vulnerable than the building on plane ground. The extreme left columns at ground level are the worst affected in case of buildings on sloping ground. Special attention should be given to these columns in design and detailing as per IS:13920-1993.
- There is no change in the value of time period between different angle of slope & plane ground for all buildings analyzed by Equivalent Static Analysis along the slope & across the slope direction but in case of Response Spectrum Analysis it is decreases as we increase the sloping angle.
- Maximum top storey displacement and shear force obtained are higher in seismic Zone IV as compared to Zone III by Equivalent Static Analysis & Response Spectrum Analysis along the slope & across the slope directions. There is increase in the value of maximum top storey displacement

as the height of building (No. of Storey) increases by Equivalent Static Analysis & Response Spectrum Analysis along the slope & across the slope direction.

- Shear force for different angle of slope is higher as compared to plane ground for all buildings by Equivalent Static Analysis and Response Spectrum Analysis along the slope & across the slope direction.

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