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Seismic Analysis of Building Resting on Sloping Ground

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Abstract: In India, for example, the north-east states. The scarcity of plain ground in hilly areas compels construction activity on sloping ground resulting in various important buildings such as reinforced concrete framed hospitals, colleges, hotels and offices resting on hilly slopes. The behavior of buildings during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings. Various models were analyzed using staad pro. after all result and comparison it is found that buildings with set back and step back patterns give more stable pattern during earthquake.
Keywords: set back, step back, axial forces, displacement, slope

I. INTRODUCTION

Hill buildings are different from those in plains. They are very irregular and unsymmetrical in horizontal and vertical planes. Hence, they are susceptible to severe damage when affected by earthquake ground motion. The approach and the accuracy of analytical results depend upon the idealization of geometry of the structure and the loading on the structure.

The present work aims at providing an analytical approach for finding out the displacements, storey drifts, natural frequency, time period, base shear for a multistory building resting on a sloping ground subjected to seismic load. Response spectrum analysis based on the IS (1893:2002) codal provisions is to be performed on the model using STAAD PRO. Using the displacement characteristics various structural outputs such as natural frequency, time period, axial forces and bending moments are to be computed.

II. OBJECTIVES OF PRESENT WORK

The objectives of this work are as follows:

A. To study the effectiveness of configuration of building frames such as step back and step back-set back frames.
B. To study the variation of base shear with respect to variation in number of bays, hill slope angle, storey height for different configurations of building frames.
C. To study the variation of time period with respect to variation in number of bays, hill slope angle, storey height for different configurations of building frames.
D. To study the variation of top storey displacement with respect to variation in number of bays, hill slope angle, storey height for different configurations of building frames.
E. To carry out modeling and response spectrum analysis of seismic behaviour of multi-Storied R.C.C. buildings resting on sloping ground
F. Three dimensional space frame analysis is carried out for different configurations of buildings ranging from Six, eight and ten storey resting on sloping ground under the action of seismic load by using STAAD PRO. software.
G. Dynamic response of these buildings, in terms of base shear, fundamental time period and displacement are find out and compared within the considered configuration as well as with other configurations.
H. To calculate the design lateral forces on sloping ground buildings using response spectrum analysis and to compare the results of different configurations of structures.

III. DETAILED METHODOLOGY

A. Introduction

India has track record of catastrophic earthquakes, at various regions, which left behind loss of many lives and heavy destruction to property and economy. Analysis of buildings in hill region is somewhat different than the buildings on leveled ground, since the column of the hill building rests at different levels on the slope. Such buildings have mass and stiffness varying along the vertical and horizontal planes resulting the center of mass and center of rigidity do not coincide on various floors, hence they demand torsional analysis, in addition to lateral forces under the action of earthquakes.

The unsymmetrical buildings require great attention in the analysis and design under the action of seismic excitation. Past earthquakes in which, buildings located near the edge of a stretch of hills or on sloping ground suffered serious damages. The shorter column attracts more forces and undergoes damage, when subjected to earthquakes. The other problems associated with hill buildings are, additional lateral earth pressure at various levels, slope instability, different soil profile yielding unequal settlement of foundation.

B. *Literature Review*

RC framed structures constructed on hill slopes show different structural behavior than on the plain ground. Because of steep slopes, buildings are constructed generally in step-back configuration, though a combination of step-back and setback building configuration is also common. There is a development of torsional moments due to the unsymmetrical nature of these buildings and eccentricity caused by the difference in the alignments of the center of mass and stiffness at each floor. Additionally, at the location of setbacks, an increase in the stress concentration has also been reported, when the building is subjected to seismic forces. Recent earthquakes, struck in hill regions viz., Nepal (2015), Sikkim (2011), Kashmir (2005), Uttarkashi (1990) and Bihar-Nepal (1988) have shown major casualties caused by design flaws and failures in RC as well as masonry structures. A significant amount of research work has been done involving hill buildings. Previous studies have described various problems and suggested different techniques regarding mathematical modelling formulation and lateral load analysis of step-back and setback buildings.

C. *Loading And Load Combinations*

1) *Dead Load:* Dead loads can be defined as "It is self weight of structure present as permanent or stationary loads which are transferred to the structure or structural members throughout their life Span." Dead load is mainly due to self weight of structural members, permanent partition walls, fixed permanent equipment and fittings. The magnitude of dead load is calculated from the unit weight of different materials. It does depend upon unit weight of material. The IS Code 875 (part-I)-1987, Page No.08 and Table 1 used for unit weight of building materials . From the table 1, the unit weight of concrete is taken as 25kN/m3, assuming 5% steel in the reinforced concrete.

Self-weight of the structural elements

a) Wall load on each floor beam = 15.41 kN/m
b) Wall load on roof beam = 6.70 kN/m and
c) Floor finish = 1.5 kN/m2

2) *Live/Imposed Load:* Live load defined as "It is movable and temporary load on floors and roofs on the structure without any acceleration or impact." These loads are assumed to be produced by the intended use or occupancy of the building including weight of movable partition or furniture etc. The imposed loads to be assumed in design of building are contained in IS: 875 (Part-2) 1987, Table 1. The floor slabs have to be designed to carry either uniformly distributed loads or concentrated loads, whichever produce greater stresses in the part under consideration. Since it is unlikely that at any one particular time all floors will be simultaneously carrying maximum loading, the code permits some reduction in loads in designing columns, load bearing walls, pier and their support and foundations. The imposed loads depend upon the use of building.

a) Live load on each floor = 4 kN/m2
b) Live load on roof floor =2 kN/m2

3) *Seismic/Earthquake Load:* Earthquake loads depend upon the place where the building is located. As per IS 1893-2002 (Part-I) (General Provisions for Buildings), India is divided into four seismic zones. The code gives recommendations for earthquake resistant design of structures. Now, it is mandatory to follow these recommendations for design of structures.

As per IS 1893(Part I) -2002 following parameters considered for earthquake Load analysis.

a) Importance factor 1.5
b) Response Reduction factor 5.0
c) Presuming special RC moment resisting frame for all configurations and height of building.
d) Average response acceleration coefficient for rock or soil sites.

Sa/g = 1+15 T when $0.00 \leq T \leq 0.10$ seconds
2.50 $0.10 \leq T \leq 0.40$ seconds
1/T $0.40 \leq T \leq 4.00$ seconds

4) Load Combination

Four different load combinations considered as per the code (IS 1893PartI: 2002) which are as following

a) Combination 1 1.5(DL+LL)
b) Combination 2 1.2(DL+LL±EL)
c) Combination 3 1.5(DL ±EL)
d) Combination 4 0.9DL±1.5EL

D. Methods of analysis

Since earthquake forces are random in nature and unpredictable, the static and dynamic analysis of the structures have become the primary concern of civil engineers.

The main parameters of the seismic analysis of structures are load carrying capacity, ductility, stiffness, damping and mass. IS 1893-2002 is used to carry out the seismic analysis of multi-storey building.

It is used to understand the response of buildings due to seismic excitations in a simpler manner. There are different types of seismic analysis methods. Some of them used in the project are

1) Equivalent Static or linear static Method.
2) Response Spectrum Method/ linear dynamic analysis.
3) Time History Method/Nonlinear Dynamic analysis.
4) Non-linear static method/Pushover method.

a) *Response Spectrum Method/ Linear Dynamic Analysis:* Dynamic analysis is carried by using response spectrum method. In this method peak response of a structure during an earthquake is obtained directly from earthquake response spectrum. Response spectrum method of analysis shall be performed using the design spectrum specified in Clause 6.4.2 or by a site specific design, spectrum mentioned in Clause 6.4.6 of IS 1893(Part 1):2002

E. Material and Model parameters

Concrete, as a constituent material, is assumed to be homogenous, isotropic and elastic in nature with modulus of elasticity as 25000 N/mm2 and value of Poisson's ratio is 0.2. The yield stress of reinforcement steel is taken as 500 MPa for main steel and 500 MPa for distribution steel. In the present study, three groups of building (i.e. configurations) are considered, out of which two are resting on sloping ground and third one is on plain ground. The first one is set back buildings and next two are step back and step back-set back buildings.

The slope of ground is 10 degree with horizontal, which is neither too steep nor too flat. The height and length of building in a particular pattern are in multiple of blocks (in vertical and horizontal direction), the size of block is being maintained at 5m x 5 m x 4m. The depth of footing below ground level is taken as 2 m where, the hard stratum is available. The buildings of different configurations are shown in chapter-4.The building with equal number of storey's/bays have same floor area in all three configurations.

The properties of frame members of buildings that are considered for analysis are given in table 4.1.The results such as Lateral loads, Base shear, Storey displacement, Storey drift and Torsion of the building are studied for buildings with different ground slopes and compared.

F. Analysis

Three-dimensional space frame analyses of Step back buildings have been carried out by considering different types of bracing systems. The seismic analysis is carried out by using equivalent static approach and response spectrum method using Staad Pro. and seismic parameters such as maximum storey displacement, maximum storey drift, maximum base shear and fundamental time period are compared. The parameters are determined using SRSS modal combination and compared within the considered configurations.

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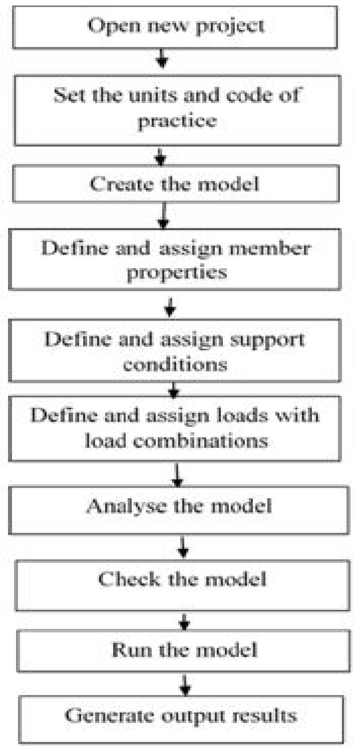
The diagrammatic view of overall project steps is as follows :-



G. Results and Conclusions

After analyzing various models with varying slope angle and building height comparative results will be plotted to study the behavior of RCC models on sloping ground.

IV. MODELLING AND ANALYSIS

A. Material Parameter

Table below shows the various values of material to be used in the present work.

Table 1 Material Constants

Sr No	Material	Constant
01	Grade of steel:	Fe 500
02	Density of concrete:	25 kN/m3
03	Density of masonry wall	20 kN/m3
04	Modulus of elasticity for concrete	27386.13 Mpa
05	Poisson’s Ratio	0.2

B. Seismic Parameter

Table below shows the various values of Seismic parameters to be used in the present work

Table 2 Seismic Parameters

Sr No	Seismic Parameter	Value
01	Zone factor	0.36 (Zone V)
02	Importance factor	1.5 (Residential Building)
03	Response reduction factor	5
04	Type of Frame	Special moment resting frame (SMRF)
05	Type of soil	Hard rock

C. Load Values

Table below shows the various values of loads to be considered and their values. Dead loads are considered from IS 875 Part 1 Live Loads are considered from IS 875 Part 2 and Seismic loads are considered as per IS 1893: 2002 Part 1

Table 3 Loading Values

Sr No	Seismic Parameter	Value
01	Self weight	Auto calculated by staad pro
02	Brick wall	16.1 Kn/m
03	Floor Finishes	1.5 Kn/m^2
04	Floor Load	3Kn/m^2

D. Model Parameters

The various structural parameters which are to be considered for analysis in the present work are as follows

Table 4 Building Parameters

Sr No	Parameter	Value
01	Size of Building	12m X 20m
02	Number of bays in Z direction	3 (4m each)
03	Number of bays in X direction	5 (4m each)
04	. Floor to floor height:	3.5 m
05	Depth of Foundation	1.75 m
06	Slab thickness	125 mm
07	Wall thickness	230 mm
08	Grade of concrete (Beam)	M30
09	Grade of concrete (Column):	. M30
10	Number of Storey's	06, 08, 10
11	Slope angle	10^0, 20^0
12	Size of Column	300 x 600 mm
13	Size of Beam	300 x 600 mm

E. Model Details

Various geometric and sloping ground combinations were considered for analysis which consist of Step Back and Set back Buildings with 06, 08 and 10 storey on with labels are listed in the table 5 below.

Table 5 Model Details

Sr no	Model Details	Label
01	RCC Step Back 6 storey model with 10^0 ground slope	SB610
02	RCC Step Back 8 storey model with 10^0 ground slope	SB810
03	RCC Step Back 10 storey model with 10^0 ground slope	SB1010
04	RCC Step Back and Set Back 6 storey model with 10^0 ground slope	SS610
05	RCC Step Back and Set Back 8 storey model with 10^0 ground slope	SS810
06	RCC Step Back and Set Back 10 storey model with 10^0 ground slope	SS1010

Table 6 Model Description

Description for 10^0 Ground Slope
SB610, SB = Set Back 6 = Number of Storey's 10 = Ground Slope
SS610, SS = Set Back and Set Back 6 = Number of Storey's 10 = Ground Slope

F. Plan of Model

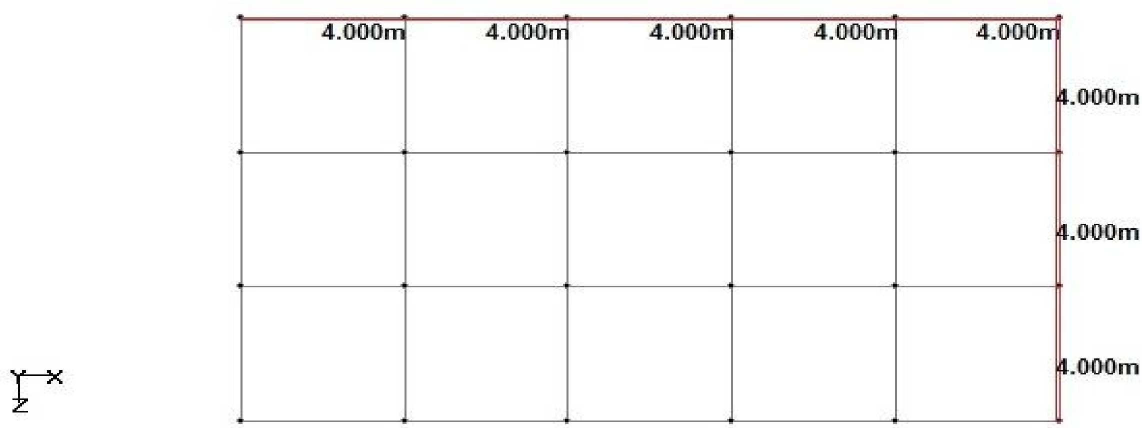


Fig. 1 Plan of model

G. Section for Models with 10^0 Ground Slope

1) Section of 6 storey Set Back and Set back Step back building

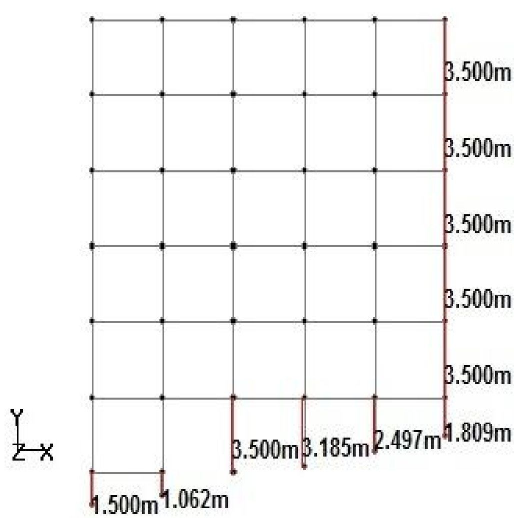


Fig. 2 Six storey set back model

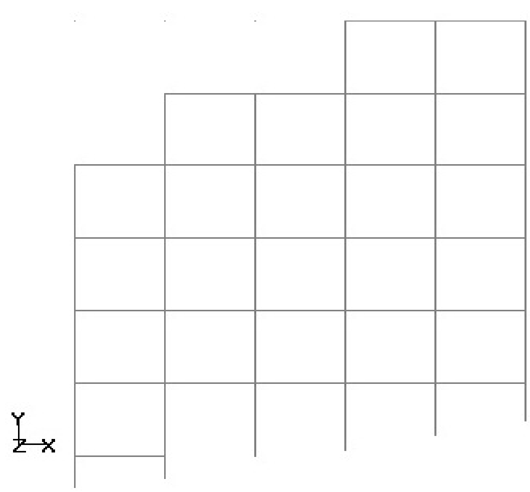


Fig. 3 Six storey set back step back model

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2) Section of 8 storey Set Back and Set back Step back building

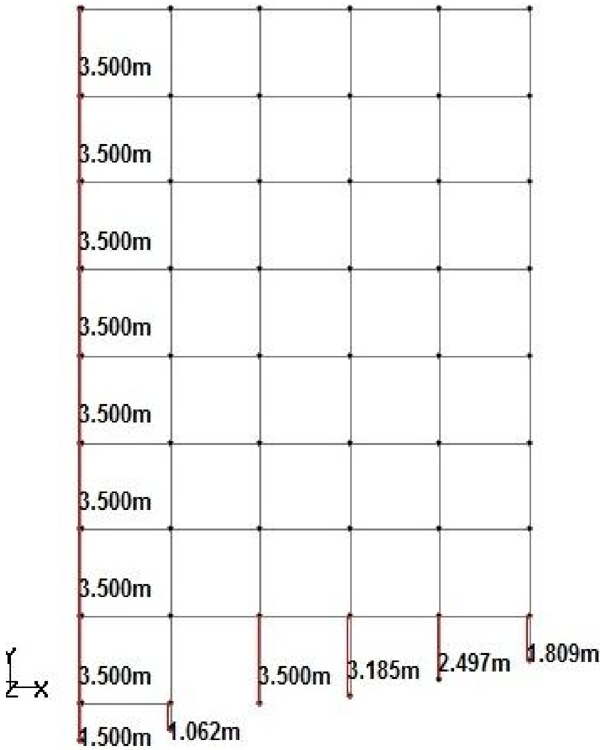

Fig. 4 Eight storey set back model

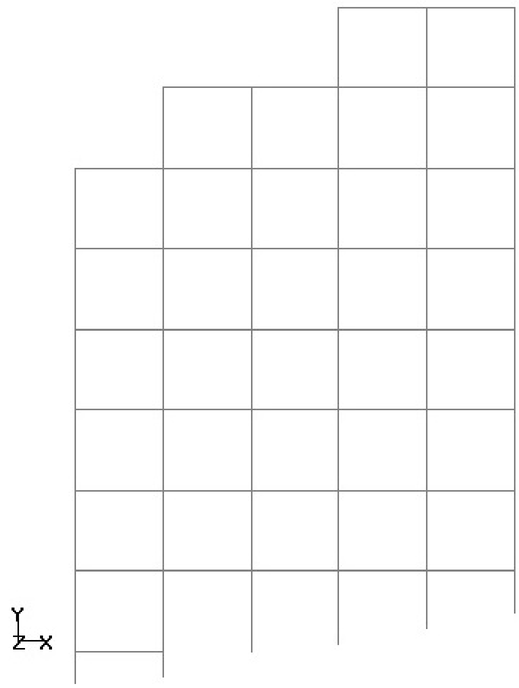

Fig. 5 Eight storey set back step back model

3) Section of 10 storey Set Back and Set back Step back building

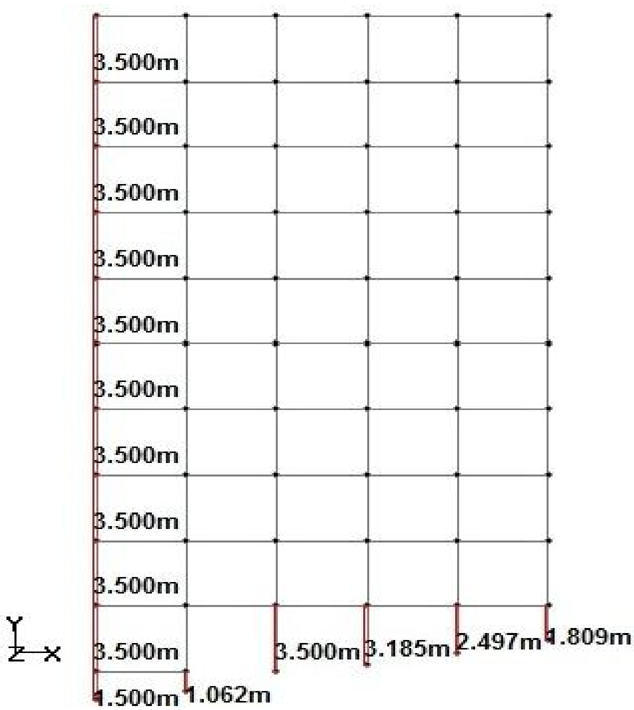

Fig. 6 Ten storey set back model

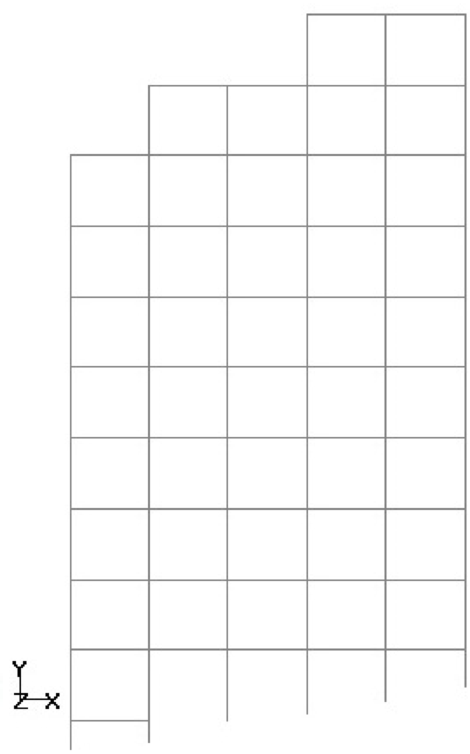

Fig. 7 Ten storey set back step back model

9 3d View of Models on 10^0 Sloping Ground

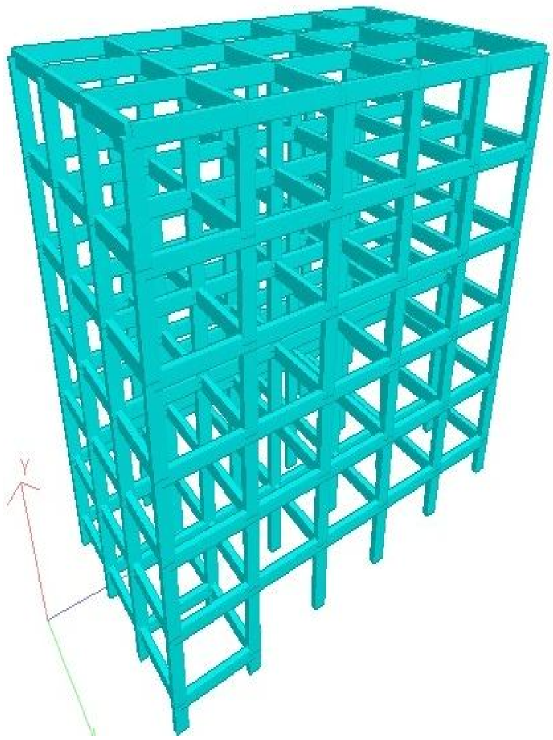

Fig. 8 3D view of SB610

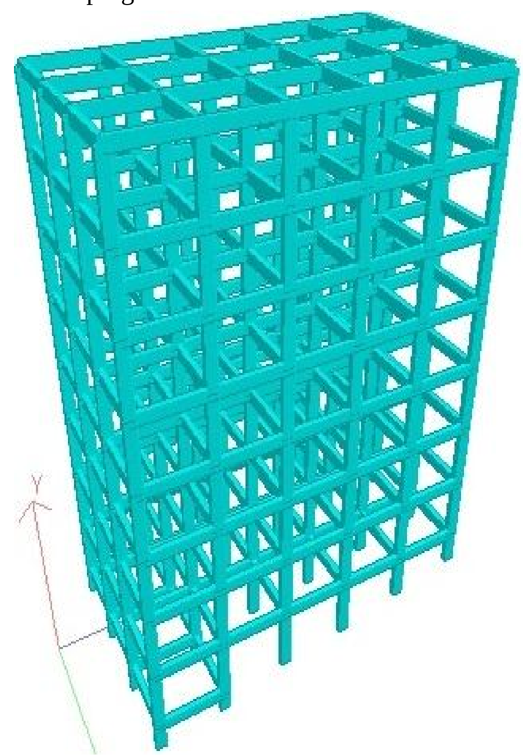

Fig. 9 3D view of SB810

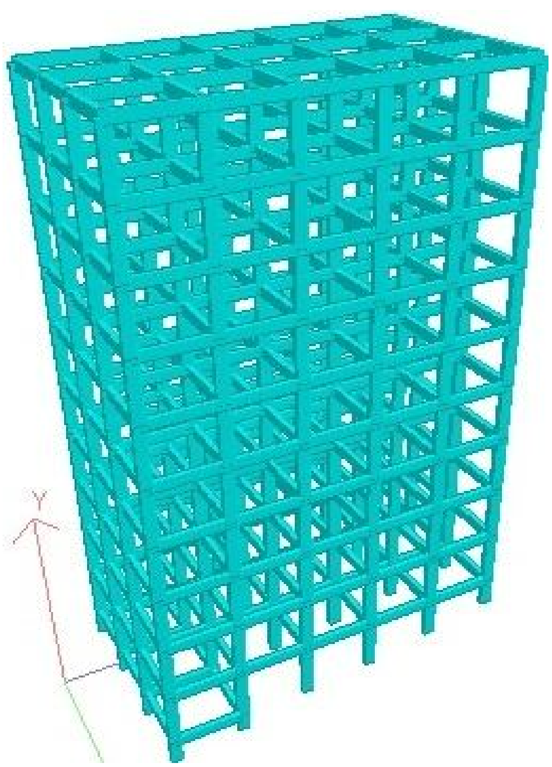

Fig. 10 3D view of SB1010

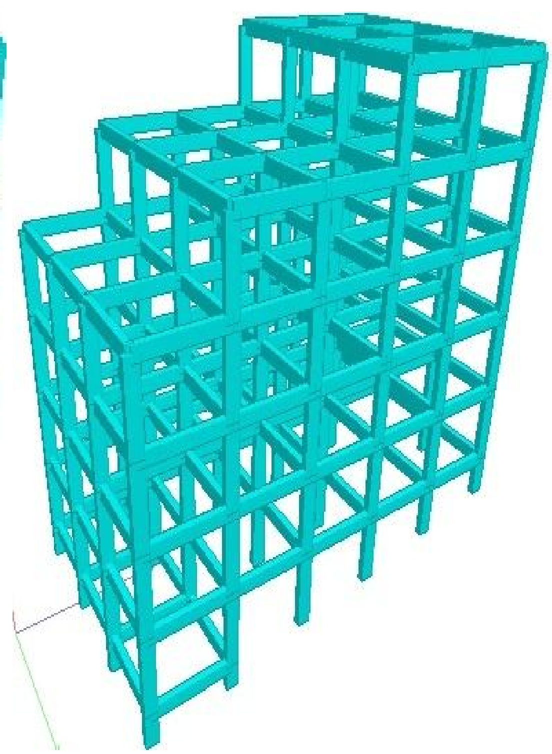

Fig. 11 3D view of SS610

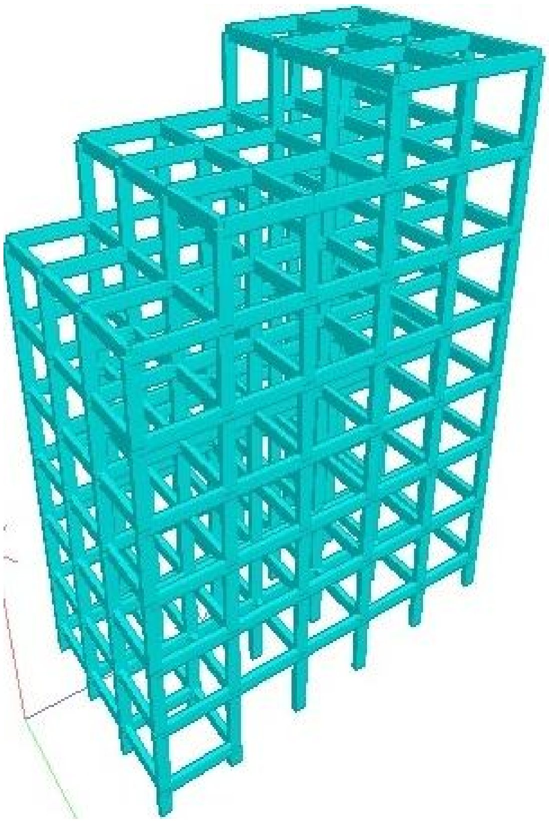

Fig. 12 3D view of SS810

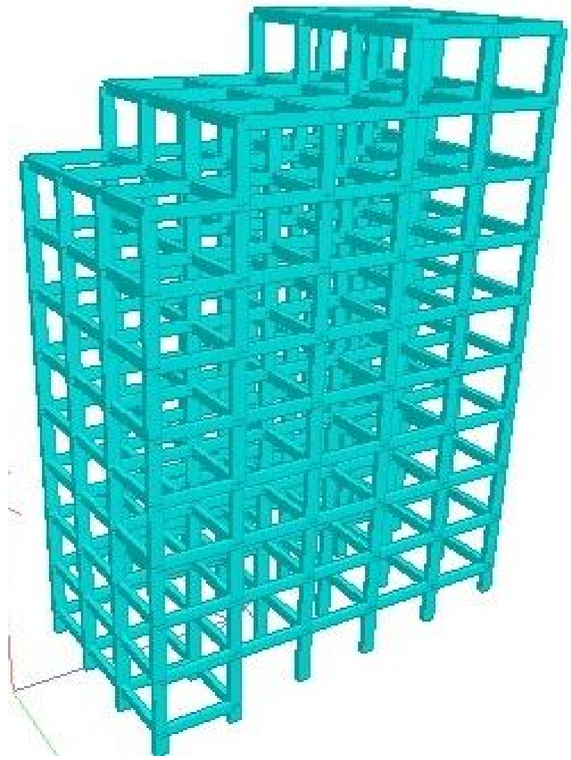

Fig. 13 3D view of SS1010

V. RESULTS AND COMPARISONS

A. Comparison of all models on 10^0 sloping ground

1) Comparison for Maximum Axial Forces and Bending Moment

Table 7 Axial force and Bending moment comparison

Sr. No	Model	Max. Axial Force (KN)			Max. Bending Moment (KN.M)		
		FX	FY	FZ	MX	MY	MZ
1	SB610	1751.19	225.29	122.57	8.38	192.13	299.45
2	SB810	2512.11	258.22	141.92	9.66	224.09	348.43
3	SB1010	3278.27	283.65	156.65	10.45	248.12	386.48
4	SS610	1718.14	212.55	136.52	7.01	208.96	311.24
5	SS810	2478.17	250.49	154.03	7.89	239.67	259.47
6	SS1010	3240.52	278.66	166.87	8.58	261.39	391.00

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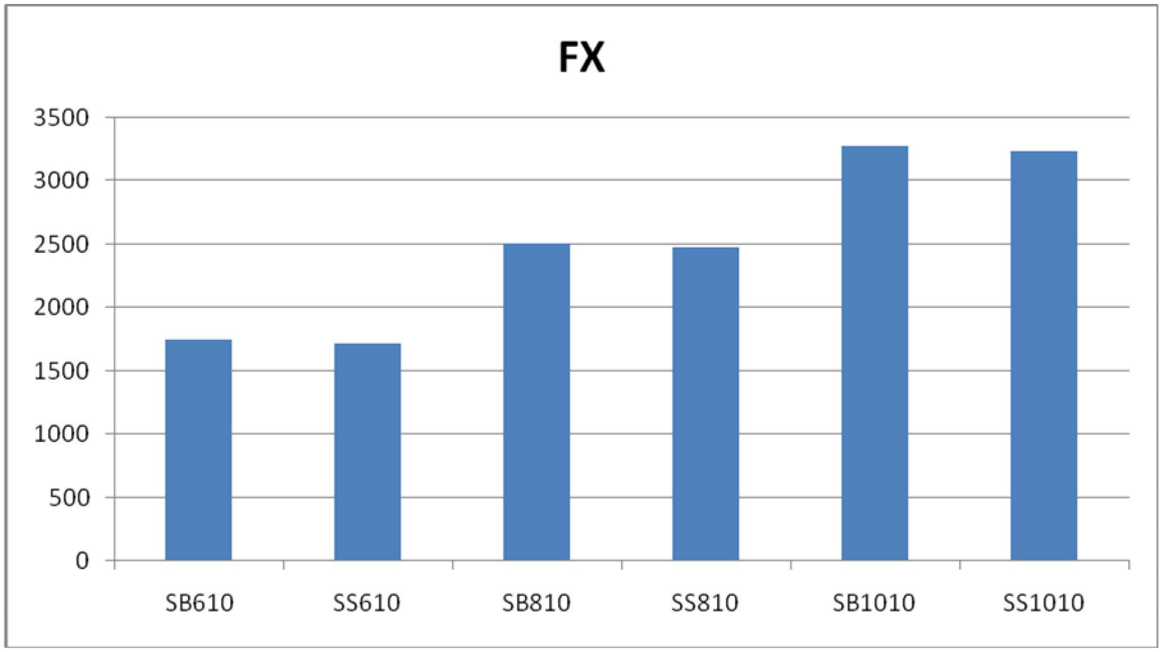

Fig 14 Comparison of Axial forces in X – Direction

2) Comparison for Maximum Reaction and Bending Moment

Table 8 Max. Reaction and bending moment comparison

Sr. No	Model	Max. Reaction (KN)			Max. Bending Moment (KN.M)		
		FX	FY	FZ	MX	MY	MZ
1	SB610	221.17	1751.19	122.59	173.73	8.38	293.76
2	SB810	256.17	2512.11	141.93	194.30	9.66	339.10
3	SB1010	283.13	3278.27	156.66	211.86	10.45	373.51
4	SS610	195.55	1718.14	136.54	143.38	7.01	266.49
5	SS810	234.55	2478.17	154.04	169.41	7.88	317.72
6	SS1010	264.76	3240.52	166.84	188.35	8.58	356.25

Fig 15 Comparison of Base reaction in Y – Direction

3) Comparison for Maximum Displacement

Table 9 Displacement Comparison

Sr. No	Model	Direction (MM)			Resultant
		X	Y	Z	
1	SB610	26.95	0.71	70.15	70.31
2	SB810	43.99	1.36	111.14	111.49
3	SB1010	63.95	2.25	158.71	159.37
4	SS610	23.77	0.62	66.13	66.28
5	SS810	38.57	1.17	106.11	106.43
6	SS1010	58.54	1.94	151.78	152.35

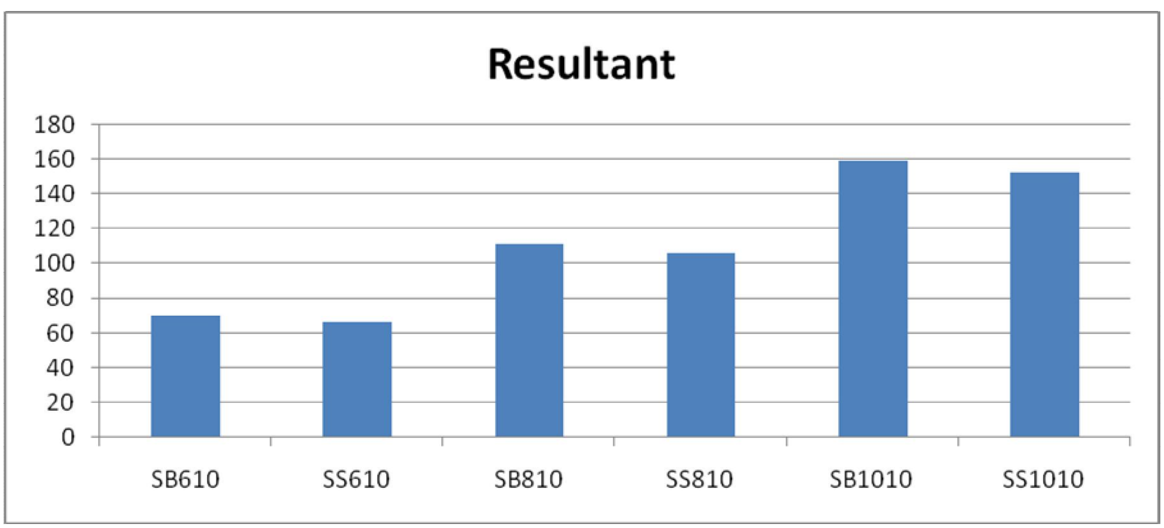

Fig. 16 Comparison of Resultant Displacement

4) Modal Frequency comparison for all models

Table 10 modal frequency comparison

Sr No	Mode	Frequency					
		SB610	SB810	SB1010	SS610	SS810	SS1010
01	01	0.75	0.54	0.42	0.87	0.61	0.46
02	02	1.01	0.76	0.61	1.20	0.87	0.67
03	03	2.17	1.65	1.28	2.23	1.76	1.37
04	04	2.28	1.93	1.55	2.49	1.97	1.65
05	05	2.61	2.04	1.96	2.88	2.20	2.00
06	06	3.14	2.66	2.19	3.11	2.71	2.31

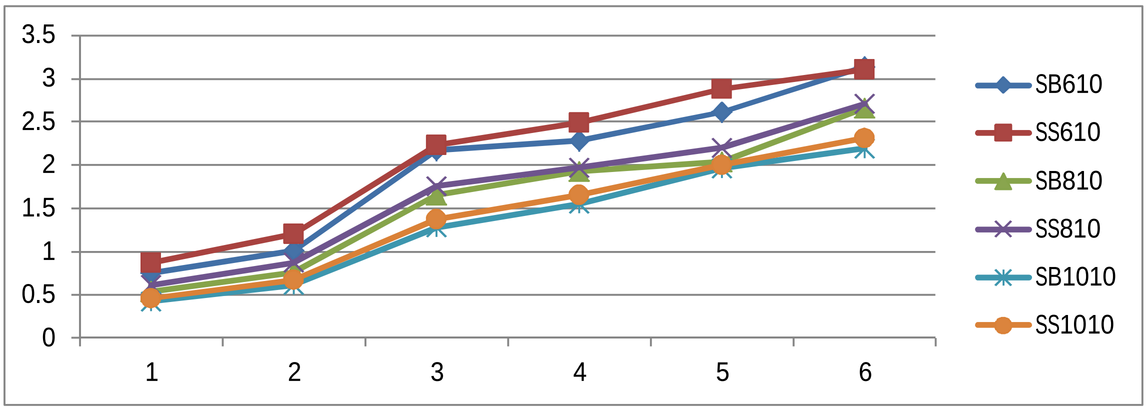

Fig. 17 Comparison of Frequency

5) Time period comparison for all models

Table 11 Time period comparison for all models

Sr No	Mode	Time Period					
		SB610	SB810	SB1010	SS610	SS810	SS1010
01	01	1.35	1.84	2.36	1.15	1.64	2.14
02	02	0.98	1.32	1.65	0.83	1.15	1.48
03	03	0.46	0.61	0.78	0.45	0.56	0.72
04	04	0.44	0.52	0.65	0.40	0.50	0.60
05	05	0.38	0.49	0.51	0.35	0.45	0.49
06	06	0.32	0.38	0.46	0.32	0.37	0.43

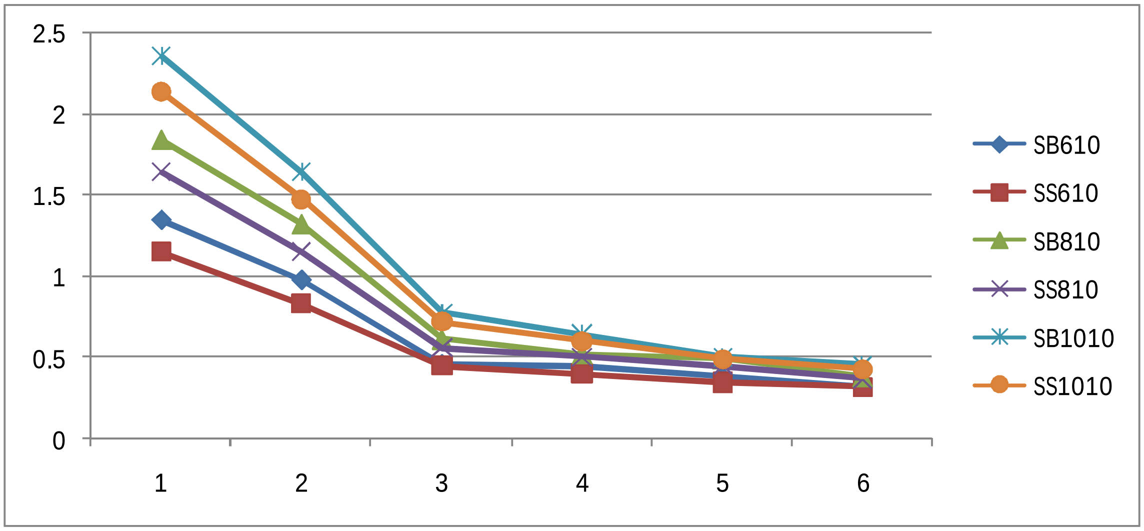

Fig. 18 Comparison of Time period

VI. CONCLUSIONS

From all above results and comparative tables following conclusions were drawn

A. Buildings resting on sloping ground and having set back step back configuration gives lower values of axial forces and bending moments
B. Buildings resting on 10^0 ground slope with set-back step back pattern reduces base reaction values and moments intensity
C. Compared to only set back building, buildings with set back and step back configuration gives lowest values of displacement.
D. As storey height increases modal frequency and time period requirement of building reduces on grounds with 10^0 slope.

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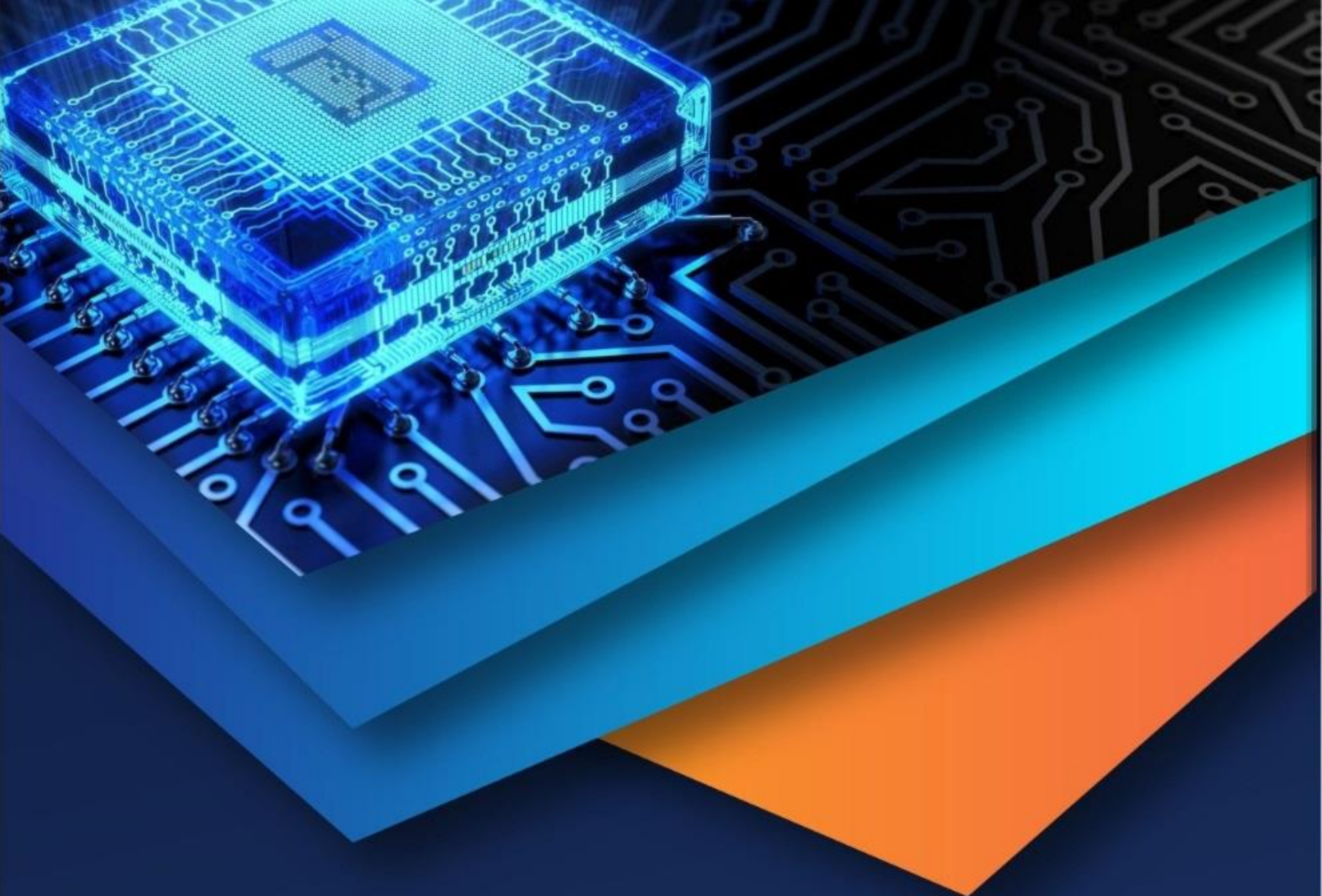

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