

Seismic analysis of Step-back building resting on sloping ground considering different types of Bracing system

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ABSTRACT

Buildings constructed in hilly areas pose special structural and constructional problems. Dynamic characteristics of hill buildings are different from the buildings resting on plane topography, as these are irregular and unsymmetrical in both horizontal and vertical directions. The irregular variation of stiffness and mass in vertical as well as horizontal directions, results in Centre of mass and Centre of stiffness of a storey not coinciding and not being on a vertical line for different floors. When subjected to lateral loads, these buildings result in significant torsional response. Due to site conditions, buildings on hill slope are characterized by unequal column heights which result in variation of stiffness of the columns of the same storey. The short stiff columns attract more forces and damage. The buildings resting on sloping ground mainly fails due to torsional moments which developed due to configuration of building on slope. These torsional moments may reduce by using bracing system in the buildings.

In present study, Step back building with different types of bracing systems (i.e. X, V, Inverted V, Diagonal, bare frame) are considered. These models are analyzed by response spectrum analysis using ETABS v 9.0 finite element code. The dynamic parameters obtained from analysis have been discussed in terms of fundamental time periods, maximum top storey displacements, storey drifts and base shear compared within the considered configurations of hill buildings. At last, the effective type of bracing which can be used in step back building on sloping ground is found out.

KEYWORDS: Bracing, Earthquake analysis, Hill buildings, Response Spectrum method, Step-back

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I. INTRODUCTION

Most of hill regions of India are highly seismic, normally buildings are not designed for earthquake forces except for a very few government buildings. North and northeast parts of India have large

scales of hilly terrain, which are categorized under seismic zone IV and V. Due to the economic growth and rapid urbanization in hilly regions, construction of multistorey reinforced concrete buildings on hill slopes has a popular and pressing demand. Buildings on hilly terrain are differ from those on plain ground i.e., they are very irregular

and unsymmetrical in horizontal and vertical planes, and torsionally coupled as compared to those on plain ground which are usually regular and symmetrical and thus free from torsional moment. A scarcity of plain ground in hilly area compels the construction activity on sloping ground. Hill buildings constructed in masonry with mud mortar/cement mortar without conforming to seismic code provisions have proved unsafe and, resulted in loss of life and property when subjected to earthquake ground motions. Therefore, the buildings with different architectural modifications are considered on hilly terrain (i.e. Step back building, Step back set back building). Consideration of bracings in step back building gives better results than step back set back buildings on sloping ground.

II. METHOD OF 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 finite element code ETABS 2015 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. Concrete, as a constituent material, is assumed to be homogenous, isotropic and elastic in nature with modulus of elasticity as 25000 N/mm^2 and value of Poisson's ratio is 0.2. The yield stress of reinforcement steel is taken as 500 MPa for main steel and 415 MPa for distribution steel. For bracing Fe 250 steel is used. For seismic analysis, the floor system in all the configurations is modelled as a rigid frame diaphragm and beam and column members modelled as two node beam elements. The foundation in all the models is assumed to be fixed support system. The torsional effect and accidental eccentricity are considered in the analysis as per recommendation of Indian code IS 1893 (Part 1): 2002.

Geometrical Properties

All the models have same geometrical and material properties, and rests on same inclination of ground which is 26 degrees. The geometrical properties of the structural element in the models with

designation of different model types are given in Table 1.

TABLE I. GEOMETRIC PROPERTIES OF STEP BACK BUILDING

Inter storey height	3.5 m
Foundation depth	1.75 m
Length of building along slope	7 m
Width of building across slope	5 m
Thickness of slab	150 mm
Beam size	230 × 400 mm
Column size	300 × 500 mm
Section of bracing	ISMB 300
Foundation supports	Fixed

Seismic parameters and loads

The seismic parameters considered in dynamic analysis of all the models are assumed as per IS 1893 (Part 1): 2002. The hill buildings are assumed to be in Zone V with the peak ground acceleration value of 0.36g. The importance factor I, is taken as 1.5 (for important building). Also, the response reduction factor R taken as 5 for SMRF system of the buildings. The soil strata beneath the foundation is assumed as medium soil.

The gravity and imposed loads are taken as per IS 875 (Part 1 and 2): 1987, self-weight of the structure is calculated and imposed load is assumed to be 3 kN/m^2 for a typical residential building. The frame loads are calculated and assumed to be 15 kN/m on floor slabs and 7.5 kN/m on roof slab. Since the lateral load due to earth pressure on foundation columns does not take part in the seismic weight of structure, thus its effect is neglected in the analysis to observe only the effect of lateral forces due to seismic loads.

Building Configurations

In this study, a Step back building with 8 Storey (STEPALS 8) was considered for studying the response of different types of bracings on sloping ground. The dynamic parameters obtained from analyses have been discussed in terms of base shear induced in the columns at foundation level, fundamental time periods, maximum top storey displacements and storey drifts compared within the considered configurations of hill buildings. At last, the suitability of bracing which can be effectively used in step back building on sloping ground has been suggested.

The following ETABS models are considered for the analysis.

Case 1 – STEPALS 8 without bracing (Bare Frame)

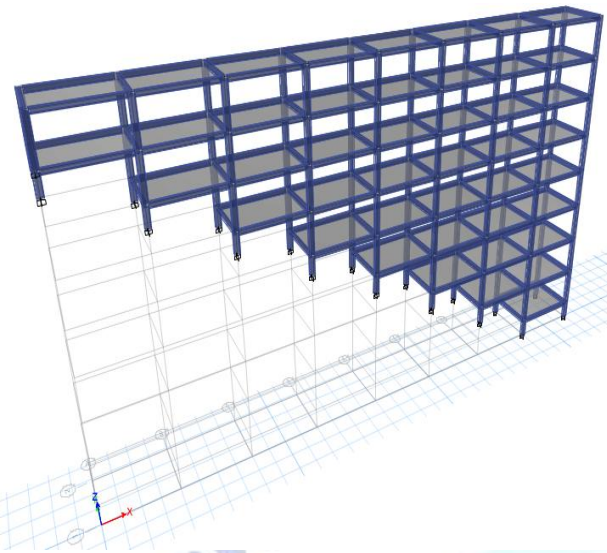


Fig. 1. Structural model for Bare Frame

Case 2 – STEPALS 8 with X bracing system

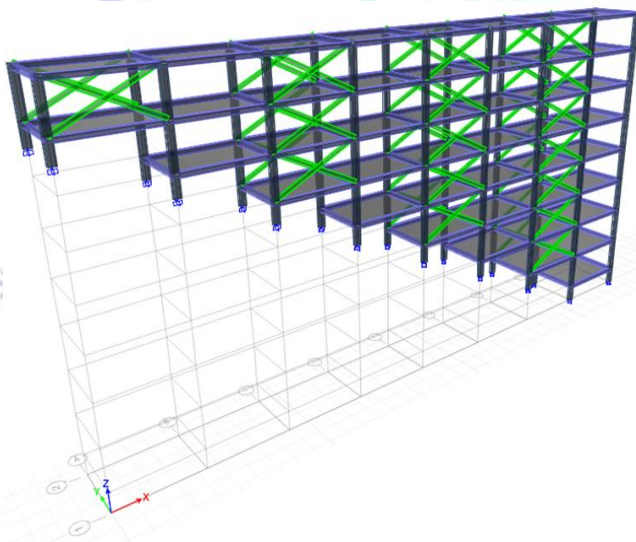


Fig. 2. Structural model for X braced Frame

Case 3 – STEPALS 8 with V bracing system

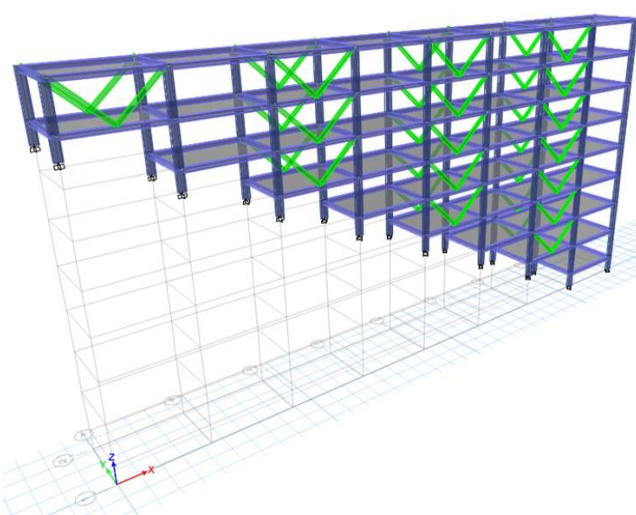


Fig. 3. Structural model for V braced Frame

Case 4 – STEPALS 8 with Inverted V bracing system

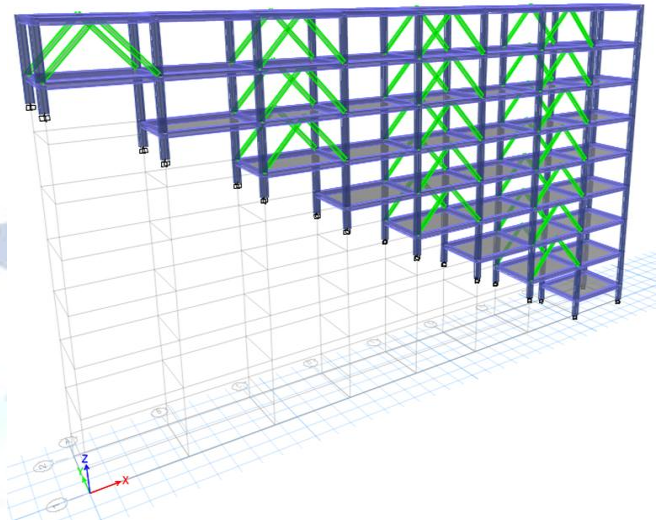


Fig. 4. Structural model for Inverted V braced Frame

Case 5 – STEPALS 8 with Diagonal bracing system

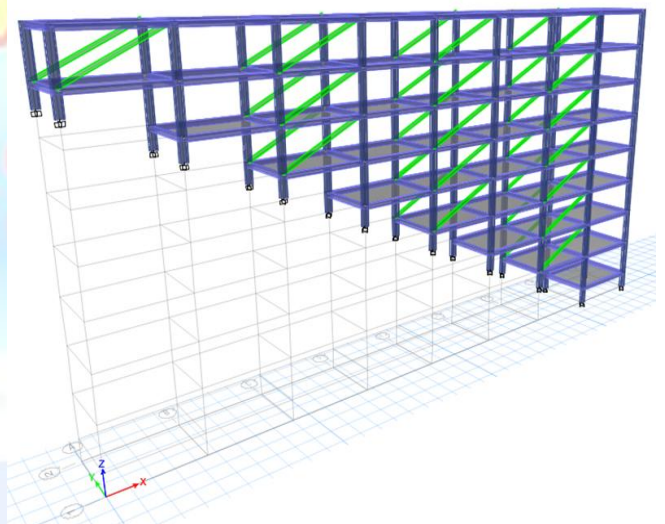


Fig. 5. Structural model for Diagonal braced Frame

III. RESULTS AND DISCUSSION

The present study is to understand the behavior of step back buildings with different types of bracing system on sloping ground under the action of earthquake forces. Results are discussed in terms of base shear induced in the columns at foundation level, fundamental time periods, maximum top storey displacements and storey drifts compared within the considered configurations of hill buildings.

A. Maximum Storey Displacements (mm)

Table 1. Maximum Storey Displacement (X Direction)

Storey	Bare frame	Diagonal	Inv V	V	X
Storey 9	33.86	18.03	16.26	16.61	16.58
Storey 8	17.50	15.22	14.30	14.40	14.52
Storey 7	10.86	12.47	12.29	12.18	12.40
Storey 6	9.96	10.42	10.62	10.39	10.66
Storey 5	8.63	8.62	8.89	8.62	8.87
Storey 4	6.95	7.25	7.50	7.23	7.46
Storey 3	5.33	5.71	5.92	5.72	5.89
Storey 2	3.25	4.08	4.48	4.3	4.45
Storey 1	0.59	0.8	0.89	0.85	0.89
Base	0	0	0	0	0

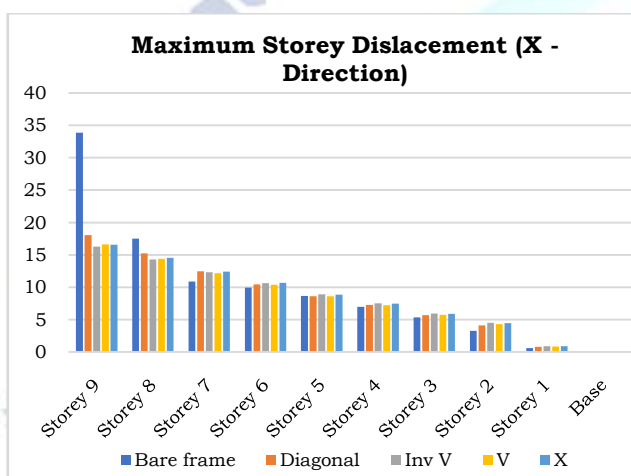


Fig. 6. Graph of Maximum storey displacement vs storey number

As we provide the bracing in X- direction so the results of displacement are considered only along X direction. The results show that the maximum storey displacement occurred in bare frame (i.e. without bracing) and the displacement is minimum in inverted V and X bracing.

B. Maximum Storey Drift

Table 2. Maximum Storey Drift

Storey	Bare frame	Diagonal	Inv V	V	X
Storey 9	6.55	5.70	5.28	5.33	5.29
Storey 8	6.71	6.57	6.55	6.65	6.60
Storey 7	7.95	7.78	7.74	7.83	7.78
Storey 6	8.72	8.61	8.56	8.61	8.59
Storey 5	8.76	8.48	8.29	8.32	8.31
Storey 4	8.15	7.90	7.72	7.71	7.73
Storey 3	6.92	6.56	6.33	6.31	6.35
Storey 2	4.93	5.52	5.81	5.67	5.80
Storey 1	1.71	2.01	2.19	2.12	2.12
Base	0	0	0	0	0

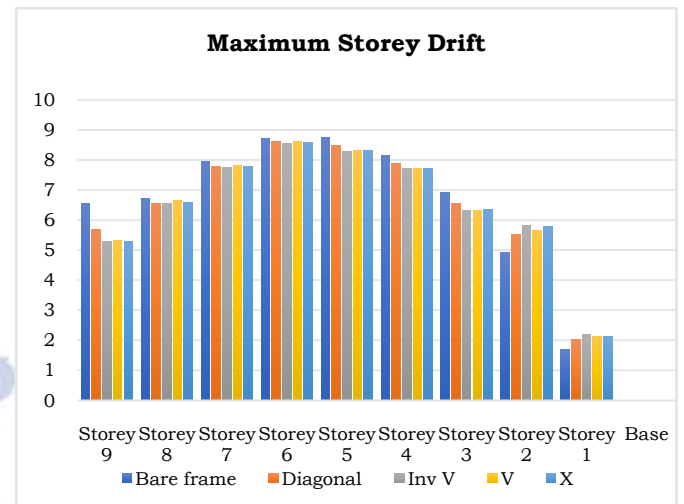


Fig. 7. Graph of Maximum storey drift vs storey number

Results shows that the maximum storey drift occurred in storey 6 and it gives maximum value for bare frame. The storey drift is minimum when we use Inverted V and X bracing as compared to other types of bracing. As the height of the building increases, the drift in stories also increase up to certain then decreases.

C. Maximum Base Shear (kN)

Table 3. Maximum Storey Drift

Types of Bracing	Maximum Base Shear (kN)
Bare frame	3996.45
X	4025.74
V	4014.97
Inv V	4014.97
Diagonal	4011.09

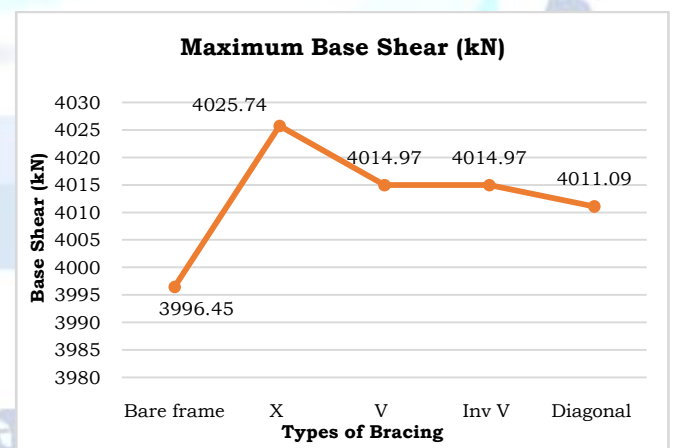


Fig. 8. Graph of Maximum base shear vs Types of bracing

Results shows that the maximum base shear was observed in X bracing and the least in bare frame due to the stiffness was higher for X bracing resulting in higher base shear. The base shear value is same for a model with V and inverted V bracing.

D. Fundamental Time Period (s)

Table 3. Maximum Storey Drift

Types of Bracing	Maximum Fundamental time Period (s)
Bare frame	2.498
X	2.472
V	2.46
Inv V	2.467
Diagonal	2.477

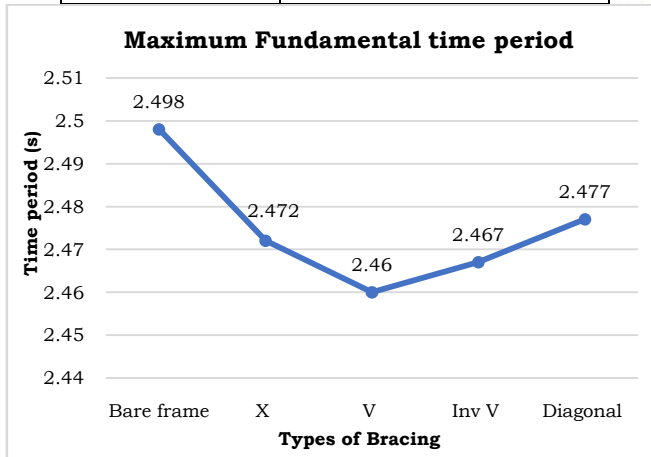


Fig. 9. Graph of Maximum fundamental time period vs Types of bracing

Results shows that the maximum fundamental time period was observed in bare frame and the least in V bracing. The time period for X and inverted V bracing is nearly same as V bracing.

IV.CONCLUSION

The selected frame models were analysed using response spectrum analysis. The first model was bare moment resisting frame and then it was braced with diagonal bracing, V bracing, inverted V bracing and cross bracing. The bracings increase the stiffness and the frequency of the frame.

Cross bracing i.e. (X Bracing) is stiffer than diagonal bracing, inverted V and V bracing. Hence, for cross bracing maximum base shear was obtained as compared to other braced models and model without bracing. Bracing decrease the lateral displacement of the moment resisting frame. The inverted V and X bracing gives better results for step back building on sloping ground. Also, at the same story, it was observed that the story drift in the building without bracing was much more compared to compared to braced systems.

The following points can be concluded from the present research study:

- The maximum storey displacement is minimum in case of X and Inverted V bracing as compared to other types of bracing for step

back building on sloping ground.

- The storey drift is minimum when we use Inverted V and X bracing as compared to other types of bracing. As the height of the building increases, drift stories also increase up to certain then decreases.
- As X bracing is stiffer than other types of bracing it gives maximum base shear value when considered in step back building.
- The maximum fundamental time period was observed in bare frame and the least in V bracing. The time period for X and inverted V bracing is nearly same as V bracing.

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