PROGRESSIVE COLLAPSE AND SEISMIC ANALYSIS OF SETBACK AND STEPBACK BUILDING

FAHANA S N

Post Graduate Student, Department of Civil Engineering. Ilahiya College of Engineering and Technology, Mulavoor P O Muvatupuzha, 686673

RASIM NAVAS M S

Assistant Professor, Department of Civil Engineering. Ilahiya College of Engineering and Technology, Mulavoor P O Muvatupuzha, 686673

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Abstract— *Framed structures constructed on hill slopes show different structural behavior than that on the plain ground. In this method, one or several columns of the building are removed and the building response is investigated. A parametric study has been carried out, in which hill buildings are geometrically varied in height and length such types of failure start with a local damage which extension increases, up to the whole structure. For this study, a nine-storey steel moment-resistant frame building is considered. The prime objective of this study is to analyze the framed building by removing columns at different locations and finding out critical location of column vulnerable to progressive collapse and also prevention of progressive collapse of structure using linear static analysis and non-linear analysis. The evaluation uses current General services administration progressive collapse guidelines and as per IS 1893-2002. In this study, behavior of setback and step back building is analyzed and the worst model is then retrofitted to minimize the damage. These structural models will be analyzed for dynamic analysis on flat ground. Different parameters like lateral displacement, story drift, base shear, time period, bending moment, shear force will be analyzed and compared using SAP2000 software. Reference of GSA and IS 1893: 2002 will be considered.*

Keywords— setback; step back; progressive collapse; DCR; drift; retroffiting

I. Introduction

Progressive collapse is one of the most under-researched areas in structural engineering due to the relative scarcity of the circumstances leading to progressive collapse. Progressive collapse is a condition in which a local failure in a structural component results for complete damage to an extent disproportionate to the initial triggering event. The underlying characteristic of progressive collapse is that the final state of failure is disproportionately larger than the initial local failure. Progressive collapse are included but not limited to aircraft impact, design or construction error, fire, gas explosions, overload due to occupant misuse, transportation and storage of hazardous materials, vehicular collision and bomb explosions.

Economic development of hill areas in the last century has led to the reconsideration of building style, optimum use of construction material and method of construction. Due to scarcity of the plain land on hills, houses built on steep slopes, pose special structural and construction problems. 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.

Although, the researches carried out in past have provided a better view of structural behavior of hill buildings but the performance of the hill building in different configurations has not been studied thoroughly. Also, IS 1893 (1984) and IS 1893 (Part 1): 2002; recommend that buildings with geometrical irregularity and or having irregular distribution of mass and stiffness should be analyzed by modal analysis and torsional shear should be accounted separately, but fails to capture the true response of the structure. Thus, in order to get the realistic behavior of hill buildings subjected to seismic load, a three dimensional modelling of structure is required, considering real structural behavior of beams/columns, rigid slabs, infill masonry walls and RC shear walls, etc. Also, to incorporate the inelastic behavior of hill buildings, linear and non-linear dynamic analysis should be carried out. In the present study three dimensional modelling of two different configurations of hill buildings has been undertaken and the effect of plan aspect ratio has been parametrically studied by varying plan dimensions and height of the models. Results have been discussed in terms of static and dynamic properties of buildings such as shear forces induced in the columns at foundation level, fundamental time period, maximum top story displacements, story drifts and story shear in buildings and compared with in the considered configurations of hill buildings.

II. OBJECTIVE

The main objective in this paper is to clearly explain progressive analysis using commercially available software such as SAP2000. Studies carried out on the below objectives are linear progressive collapse analysis and obtaining the DCR value and seismic performance on dynamic time history analysis. The aim is as follows:

1. Analyze setback and step back building by column removal across and along the slope.
2. Analyze setback building with unretroffited case with different column removal scenarios.

III. BUILDING GEOMETRY

The building in our example is a nine-story steel moment frame structure, with both setback and step back detailing. The building in our example is a nine-story steel moment frame structure, with six bays in the longitudinal direction and three in the transverse direction. The longitudinal direction has a uniform column spacing of 8.25 m, while on the three-bay side columns are spaced every 9.75 m. Main girders are W21x57. Floor-to-floor height for every story is 4.3 m. W14x159 columns span from the ground to the fifth floor and W14x90 columns span from the sixth floor to the roof. The floor diaphragms are constructed of composite metal deck with slab thickness of 90 mm.

Concrete, as constituent material, is assumed to be homogenous, isotropic and elastic in nature with Poisson's ratio of concrete as 0.3. The yield stress of reinforcement steel is taken as 345 MPa. For seismic analysis, the floor system in the all the configurations is modelled as rigid frame diaphragm and beam and column members modelled as two node beam elements. The foundation in all the models is assumed to be pinned support system.

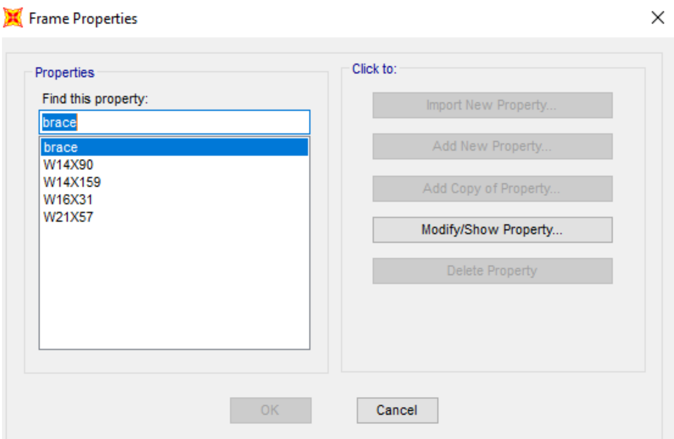


Fig 1: Frame properties

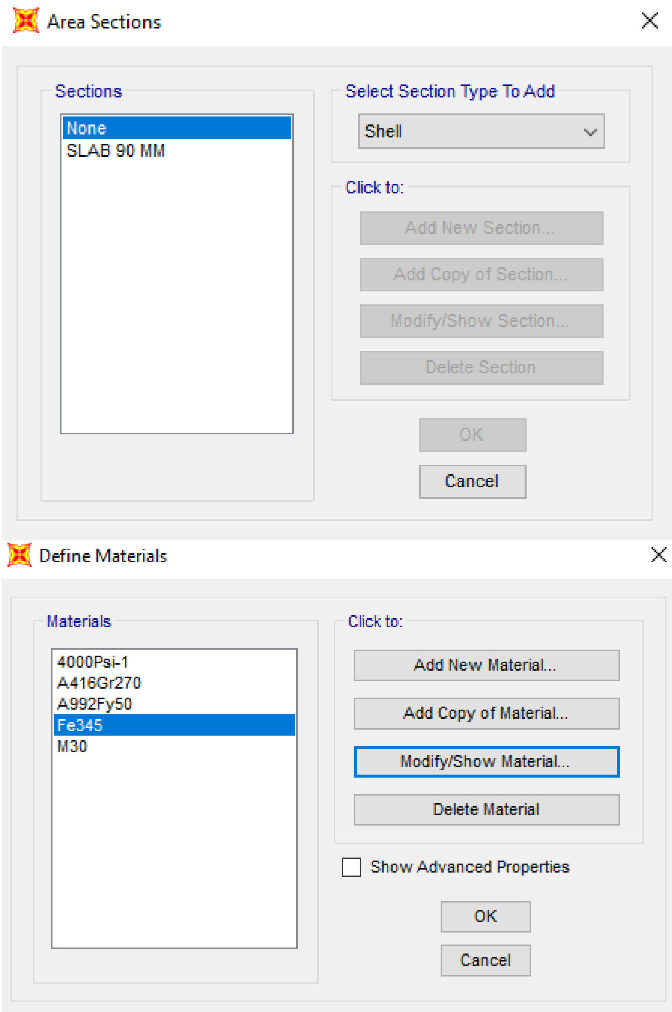
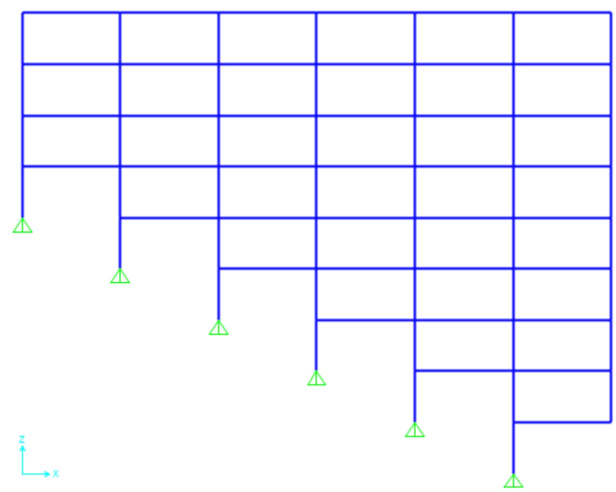


Fig. 2: Girder Section and Material Properties

IV. SAP MODELLING

A. Model



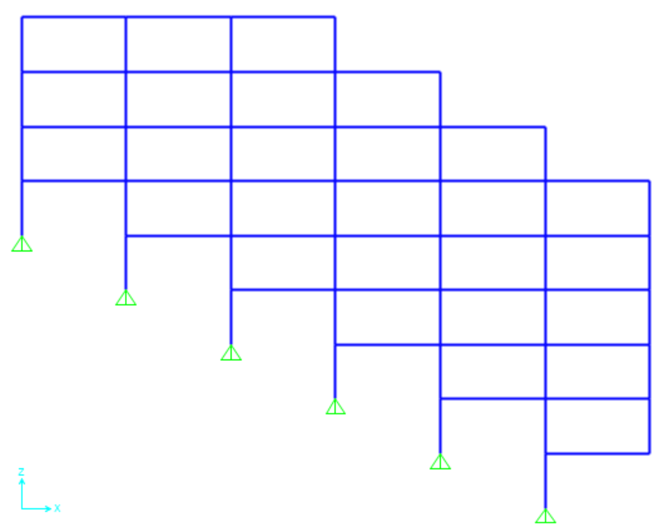


Fig 3: Model of setback and step back building

The different column removals in setback and step back building is done using SAP2000.Drift is calculated within the acceptance limit. Maximum moment and plastic moment ratio was taken to calculate DCR (Demand Capacity Ratios) value within the limit and the conclusion was made that DCR value is less than 3. Thus the building is safe from linear collapse. The demand capacity ratio calculated from linear static procedure helps to determine the potential for progressive collapse of building. The seismic parameters considered in dynamic analysis of all the models are assumed as per IS 1893 (Part 1): 2002.The model was created by removing the column along and across the slope.

Three dimensional space frame analyses of two configurations of hill buildings involving the effect of column have been carried out by parametrically varying plan and height of the models. Seismic parameters such fundamental time period, maximum top story displacement, story shear, story drift and column shear at ground level in each direction, i.e. along slope and across slope of hill, are determined using modal combination and compared within the considered configurations.

B. Load Cases And Combinations

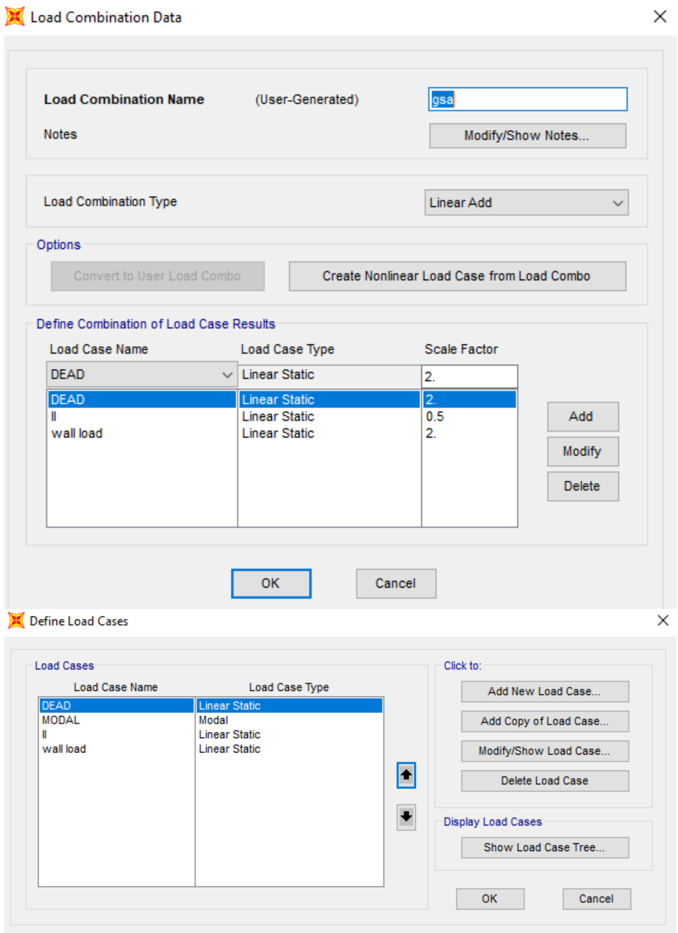


Fig 4:linear static analysis in SAP2000

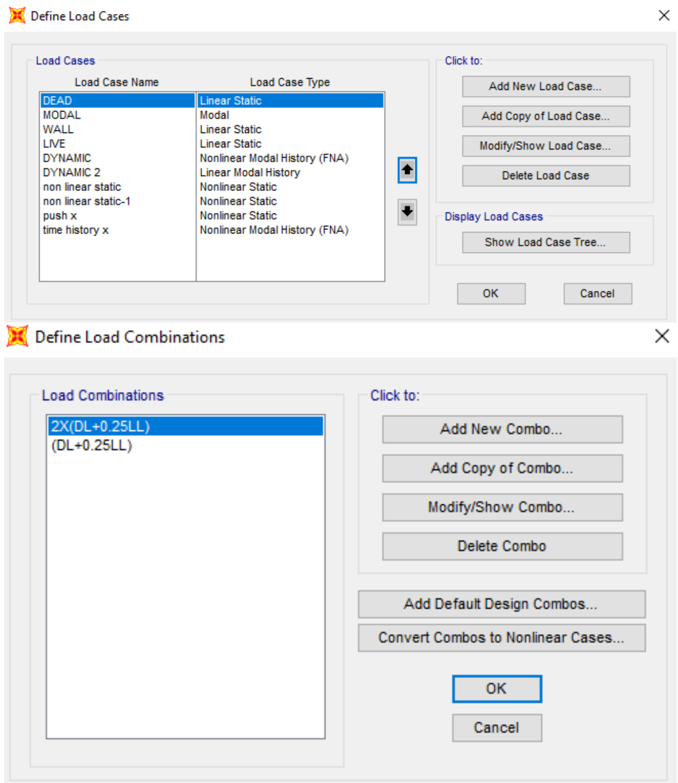


Fig 5:Dynamic analysis in SAP2000

C. Results and Discussions

In this study ,setback and stepback building was analysed using column removal.Since the structure is lying in the slope it leads to difference in stiffness value which causes the structure to fail in seismic analysis.This failure is mitigated using retroffiting technique i,e X-bracing which reduces the drift values of setback and stepback building in their acceptance limit.On keeping the retrofft in the frames configuring at corners the drift and displacement values are controlled within the limit.. In all, eighteen models of different lengths and widths have been analyzed for earthquake loads and accidental eccentricity as per codal provisions. The hill buildings are subjected to seismic loads independently in either direction viz., along and across slope of the hill. The results obtained in the analyses are discussed in terms of seismic parameters such as storey drift, fundamental time period (FTP), top storey displacement, storey shear and normalized base shear in columns at ground level and compared within the considered effects on hill buildings.

TABLE 1

TH -AL				
	DISP(m)	DRIFT(m)	SHEAR(kN)	TIME PERIOD(sec)
AL-C1	0.3144	0.068	9125.126	4.39462
AL-C2	0.3095	0.0711	9524.426	4.42007
AL-C3	0.3087	0.0721	9422.22	4.43182
AL-C4	0.3105	0.0658	8927.781	4.50883
AL-C5	0.31	0.0608	8149.472	4.51404
AL-C6	0.3078	0.0571	8279.759	4.44466
AL-C7	0.296	0.0559	7769.642	4.43752

Table 1 shows the dispalcement,drift,base shear amd fundamental time period of stepback building along the slope .In the table AL-C1,AL-C2………..AL-C7 indicates the column removal along the slope of stepback building.

TABLE 2

TH -AC				
	DISP(m)	DRIFT(m)	SHEAR(kN)	TIME PERIOD(sec)
AC-C1	0.2235	0.069	3383.804	4.39462
AC-C2	0.2225	0.072	3338.417	4.41556
AC-C3	0.2223	0.0723	3328.383	4.42033
AC-C4	0.2229	0.0722	3308.064	4.42306

Table 2 shows the dispalcement,drift,base shear amd fundamental time period of stepback building along the slope .In the table AC-C1,AC-C2………..AC-C7 indicates the column removal across the slope of stepback building.

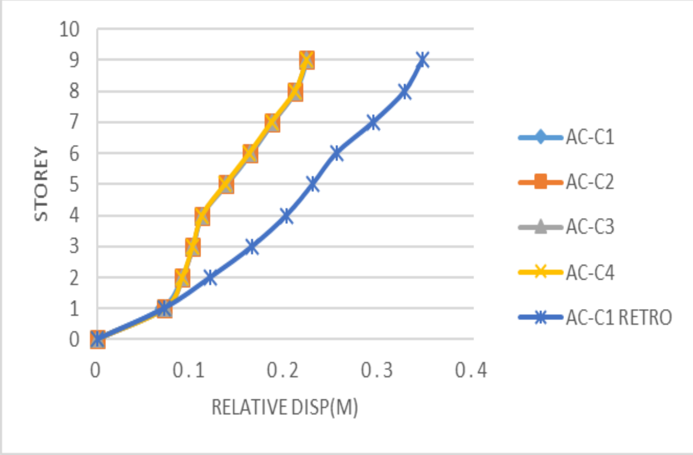


Fig 5: Graph with Storey vs displacement across the slope

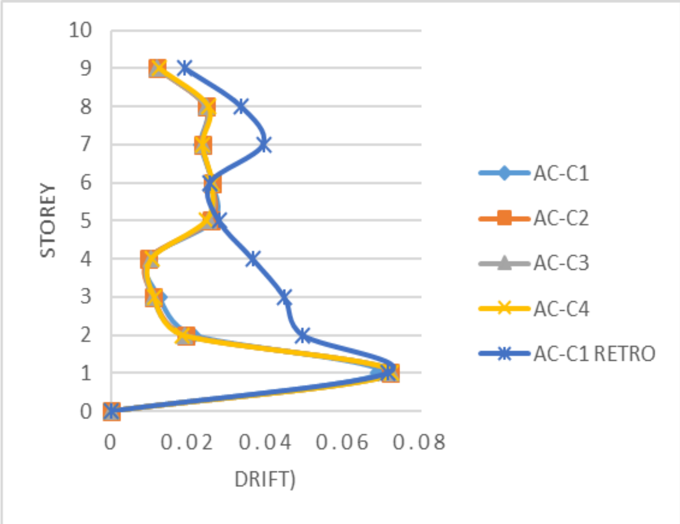


Fig 6: Graph with storey vs driftt across the slope

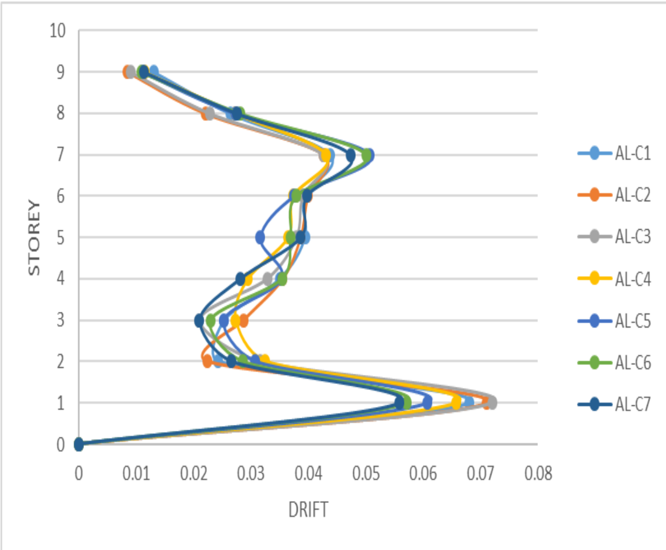


Fig 7: Graph with storey vs driftt along the slope

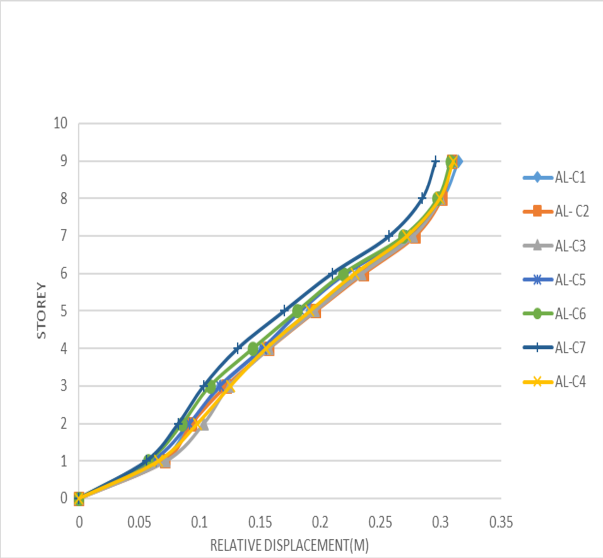


Fig 8: Graph showing the retrofit given along the slope

These graphs are the combinations of both setback and step back buildings where column removals are along and across the slope.

V. CONCLUSIONS

These are the following conclusions made after the analysis:

1. Evaluating the shear, drift, moment, time period was done in SAP2000 which provided a brief idea on safest configuration of the building.
2. Analyses gave information regarding the column removal effect in which worst condition was retrofitted using X-bracing technique.
3. To check acceptance criteria regarding drift value.
4. Seismic performance and dynamic time history were carried out.
5. Nonlinear static analysis has indicated that at least 66% of the load. As this exceeds 50%, the structure is not susceptible to progressive collapse. The performance of step-back and step-back setback configurations is significantly unlike when compared to each other and entirely different than a building resting on plain ground. The empirical relations given in IS 1893 (Part 1): 2002 (Clause 7.6) are unable to depict the correct values of time period in along and across slope direction. Since, the parameters involved in equivalent static method are entirely depend on the time period value, thus this method should not be used to design a hill building.

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