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PROGRESSIVE COLLAPSE ANALYSIS OF RC BUILDINGS ON HILL STATION BY USING NON-LINEAR DYNAMIC ANALYSIS

[1]SHAIK MOHAMMED ABID, [2]SHAIK SANA SULTANA
[1] Student, M.Tech (Structural Engineering), Vignan's university, skmdabid051@gmail.com
[2] Assistant professor, Department of Civil Engineering, Vignan's university, ssanasultana15@ gmail.com

Abstract— ***The loss of catenary action in reinforced concrete structures caused due to the progressive collapse which is the collapse of all, or a large part of a structure precipitated by damage or failure of a relatively small part of it. In this project, it is proposed to carry out progressive collapse analysis of G+3 storey RC frame building with Non-Linear Dynamic Analysis on normal and varying ground slopes of hill stations, mainly 10^0,15^0 and 20^0 with the help of methodology mentioned in GSA 2003 guidelines. Reinforced Concrete Building consisting of 5 X 5 bay of 5 m each in both directions have been taken and designed by Indian Standard codes as a special moment resistant frame. Different Structural models of buildings on varying ground slopes have been created in finite element method based software ETABS and loads are applied as per GSA 2003 guidelines, for evaluation of progressive collapse nonlinear dynamic method of analysis has been used. To perform non-linear dynamic analysis time history data of Bhuj Earthquake has been applied to the building models. By following the guidelines of general services administration GSA 2003, such as column removal case one at a time has been carried out, namely removal of Corner column both small and long in case of varying ground slopes and Exterior column at ground floor. For all three cases, nonlinear dynamic analysis has done and DCR values are evaluated. Depending upon DCR ratios it is observed that buildings designed as per Indian standard codes are vulnerable to progressive collapse or not. Also comparison of results obtained due to non linear dynamic analysis like story displacement, base shear and story shear for both along the slope and across the slope of buildings due to effect of column removal conditions as mentioned above has been plotted.***

***Keywords* — Progressive Collapse Analysis, Hill Stations, Non Linear Dynamic Analysis, Varying Ground Slopes, ETABS.**

I. INTRODUCTION

The loss of catenary action in reinforced concrete structures caused due to the progressive collapse which is the collapse of all, or a large part of a structure precipitated by damage or failure of a relatively small part of it. Catenary action is the mechanism of reinforced concrete buildings to resist the progressive collapse of the building. The General Services Administration (GSA, 2003) explains a somewhat more specific definition of the phenomenon: "Progressive collapse is a situation where the local failure of a primary structural component leads to the collapse of adjoining members which, in turn, leads to additional collapse." The phenomenon is of particular concern since progressive collapse is often (though not always) disproportionate, i.e., the collapse is out of proportion to the event that triggers it. Hence, in structures susceptible to progressive collapse, small events can have catastrophic consequences. Some of the main reasons for the occurrence of progressive collapse are gas and bomb explosions, aircraft and vehicular impact, design and construction errors, heavy earthquakes, storage and transportation of hazardous material and overload due to occupant misuse.

Previous researches on the progressive collapse mainly focus on analysis of concrete and steel frame structures on the normal ground surface. The latest news report published on 20 November 2017, American scientists are of opinion that the world could see an increase in the number of strong earthquakes in 2018 and the next few years due to periodic slowing of the Earth's rotation. In India, Some seismologists have also alerted on 23 November 2017 predicting that some hill area in the north region of our country could be visited by a heavy earthquake of Magnitude 8 in near future, says Chief of Seismology Center. Some of the hill stations in the North-East India mainly fall under seismic zones IV. Progressive collapse analysis is essential to avoid the disproportionate collapse of buildings on hill stations.

Existing researches on analysis of buildings on the sloped ground shows that there is a lot of necessity for the non linear dynamic analysis of structures constructed in those locations. Because buildings constructed on varying ground slopes are considered as irregular structures both in plan and height of buildings. Since, non-linear dynamic analysis considers both geometric non-linearity and material non-linearity.

As per General Services Administration 2003 the RC structures analyzed in this research are considered as "typical" structural systems which are defined as having relatively simple layout with unusual structural configurations such as vertical discontinuities, plan irregularities, closely spaced columns,etc. To know the potential for progressive collapse for atypical structure, the instantaneous loss of one of following first floor columns one at a time is considered:

i) A short column located at the corner of the building.

ii) A long column located at the corner of the building.

iii) A short exterior column near the middle of the short side of the building.

For non-linear dynamic analysis purposes the following vertical load shall be applied downward to the structure under investigation:

Load = (DL + 0.25LL)

The General Services Administration utilizes the alternate path method to ensure that progressive collapse does not occur. Acceptance criteria for the primary and secondary structural components shall be determined as:

$$\mathbf{DCR = (Q_{UD}/Q_{CE})}$$

Where,

Q_{UD} = Acting force determined in component (moment, axial force, shear, and combined forces).

Q_{CE} = capacity of the component (moment, axial force, shear and combined forces)

The Acceptance Criteria for demand capacity ratio DCR is $\leq$ 2.0.If it exceeds the value then it means the structure has high potential for progressive collapse.

II. OBJECTIVE

In the present research, the progressive collapse analysis of a G+3 storied RC framed building on varying ground slopes of hill stations is investigated by following the GSA 2003 guidelines. Modelling and analysis is performed using ETABS. The main objectives of the research are as follows:

1. To understand the potential for progressive collapse of G+3 story RC building on 0^0 sloped ground (i.e.; on flat ground) of hill station in sudden column loss scenario with Non-linear dynamic analysis.

2. To understand the potential for progressive collapse of G+3 story RC building on 10^0 sloped ground of hill station in sudden column loss scenario with Non-linear dynamic analysis.

3. To understand the potential for progressive collapse of G+3 story RC building on 15^0 sloped ground of hill station in sudden column loss scenario with Non-linear dynamic analysis.

4. To understand the potential for progressive collapse of G+3 story RC building on 20^0 sloped ground of hill station in sudden column loss scenario with Non-linear dynamic analysis

5. To check whether a RC building designed and detailed by Indian codes for seismic loads and wind loads provides any resistance to Progressive collapse or not.

III. MODELLING

The location of building models is considered as shimla. The buildings on different ground slopes selected for this study are atypical with varying ground storey height based on angle of slope. The plan of is same in both X and Y directions with 5 bays of 5m each is considered.

The following Loads are considered for the analysis:

1. Dead Load as per IS 875 (Part I).
2. Live Load IS 875 (Part II)
3. Wind Load as per IS 875 (Part III).
4. Seismic loading as per IS: 1893 (Part I): 2002

The following Properties are considered for the models:

DESCRIPTION	SPECIFICATION
Seismic Zone	IV
Wind Speed	49m/s
Response Reduction Factor	5
Importance Factor	1.5
Grade of Concrete	M25
Live Load	1.5kN/m ^{2}
Grade of Steel	Fe415
Floor Height	3m
Beam Sizes	300mm x 500mm
Column Sizes	300mm x 600mm
Slab Thickness	125mm

Table 1: Details and dimension of the building models

The plan below shows the column and beam details of the building models. Since the corner columns are mentioned as short corner and long corner because of the different height of the columns along the slope of the building models on 10^0,15^0 and 20^0 respectively.

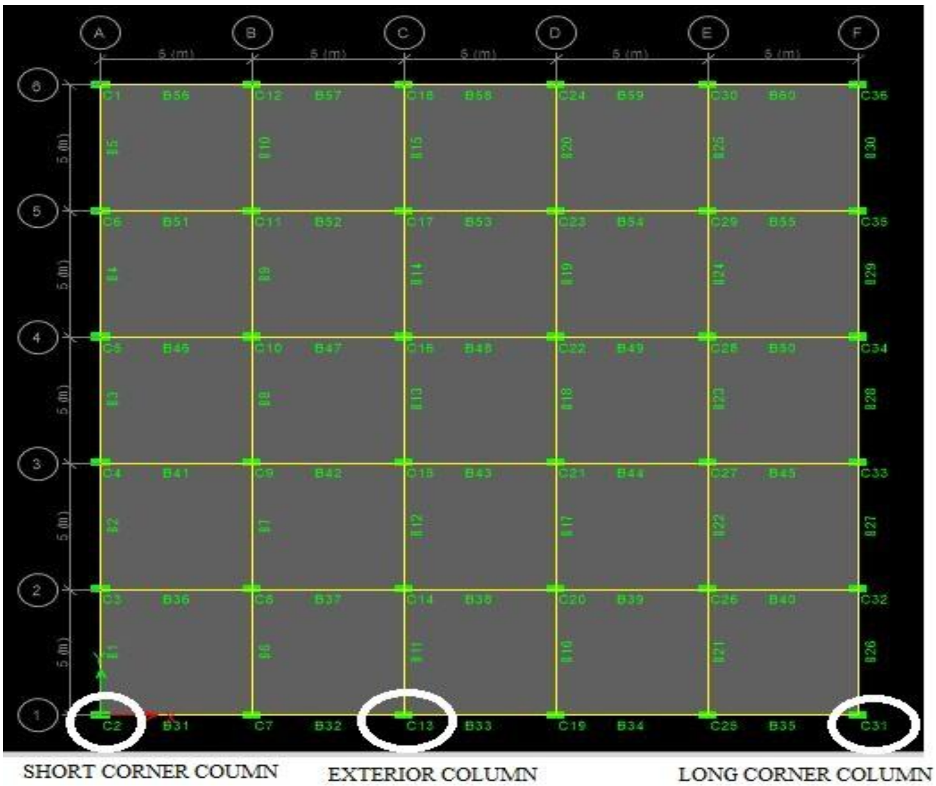

Fig 1: Beam and Column details of buildings

IV. METHODOLOGY

After creating the building models in ETABS software, the ground acceleration data i.e., time history data of the Bhuj earthquake has been selected and applied to the building models in both X and Y directions in order to carry out non-linear dynamic analysis. Later the dead loads and live loads are applied on the buildings as per Indian standards.

Similarly, by following the IS1893:2002, seismic loads are applied to the building models and at the same time with the help of IS875 (Part III) wind loads are given to the building models.

Before performing the progressive collapse modeling of the buildings is carried out in ETABS and loads are applied as per Indian standards. Then, the non-linear dynamic analysis of the buildings is carried out and the required results are obtained.

In GSA2003, Section 4 explains the complete design guidance and analysis methodology for both new and existing constructions of RC structures.

Progressive collapse potential can be determined by the following procedure:

1. Load the model with (DL + 0.25LL). Remove a vertical support from the location being considered and conduct a non-linear dynamic analysis of the structure.
2. Determine which members have DCR values that exceed the acceptance criteria and redesign those sections.
3. Re-run the analysis and Continue this process until no DCR values are exceeded.
4. If the DCR values are still exceeded then the structure will be considered to have a high potential for progressive collapse.

V. RESULTS AND DISCUSSION

A. Progressive Collapse Analysis Results:

The following bar charts show the demand capacity ratio (DCR) values of beams and columns and also those values which are greater than the acceptance criteria (i.e., DCR ≤ 2.0) are shown in the bar charts below.

Note that, in 0 degree sloped building corner columns are symmetrical and hence long corner does not exist in those buildings.

1) **Short Corner Column Removal:** When short corner C2 column removed B31 and B1 are the adjacent beams in all stories. DCR values have been calculated from the obtained Bending moment values of beams before and after removal of column from the non-linear dynamic analysis.

   Similarly, when short corner C2 column removed C7 and C3 are the adjacent Columns in all stories. Hence their DCR values are calculated from the obtained Axial Force values before and after removal of column from non-linear dynamic analysis.

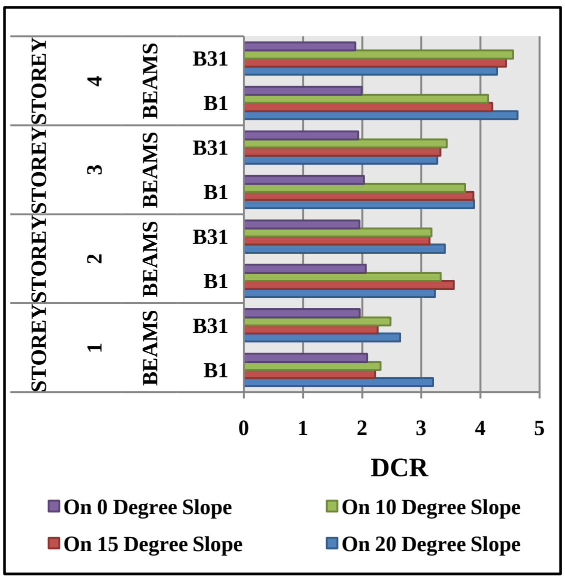

Fig 2: DCR of Beams when Short Corner Column Removed

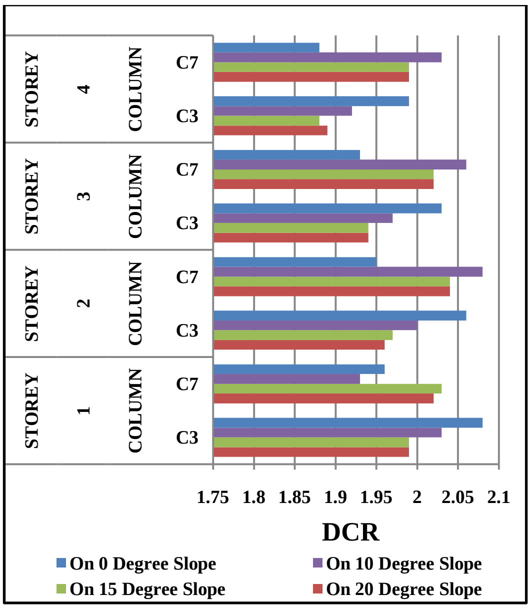

Fig 3: DCR of Columns when Short Corner Column Removed

2) **Long Corner Column Removal:** When long corner C31 column removed B35 and B26 are the adjacent beams connected to the removed long column in all stories. DCR values have been calculated from the obtained Bending moment values of beams before and after removal of column from the non-linear dynamic analysis.

When Long corner C31 column removed, C25 and C32 are the adjacent Columns in all stories. Hence their DCR values are calculated from the obtained Axial Force values before and after removal of column from non-linear dynamic analysis.

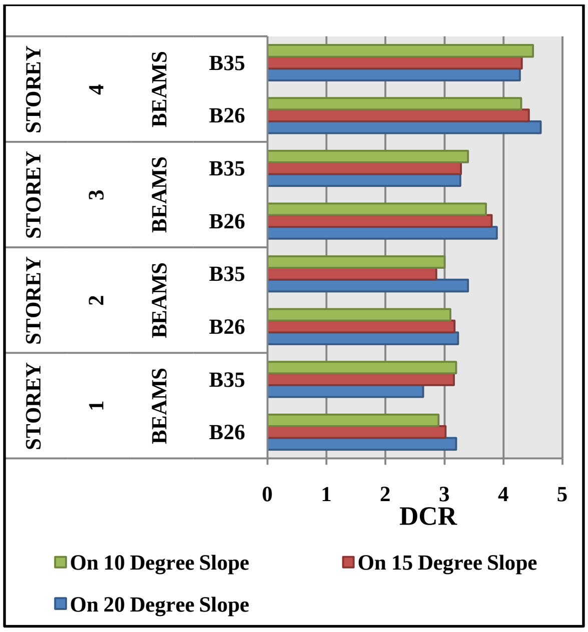

Fig 4: DCR of Beams when Long Corner Column Removed

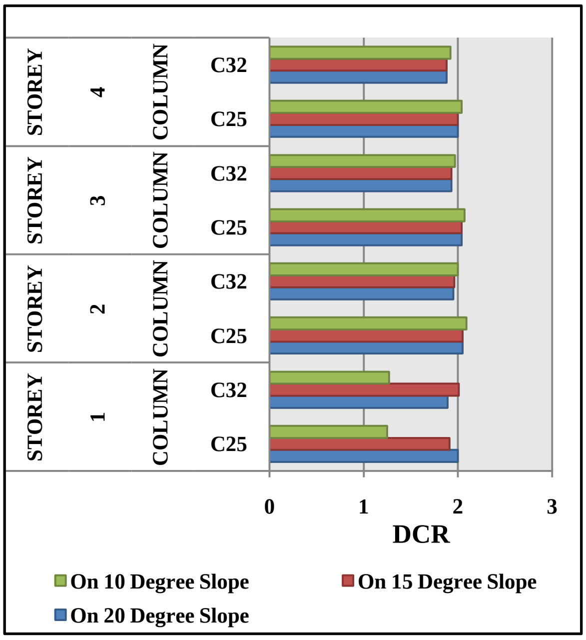

Fig 5: DCR of Columns when Long Corner Column Removed

3) **Exterior Column Removal:** When exterior column C13 removed B32, B33 and B11 are the adjacent beams connected to the removed short column in all stories.DCR values have been calculated from the obtained Bending moment values of beams before and after removal of column from the non-linear dynamic analysis.

Similarly, when exterior column C13 removed, C7,C14 and C19 are the adjacent Columns in all stories. Hence their DCR values are calculated from the obtained Axial Force values before and after removal of column from non-linear dynamic analysis.

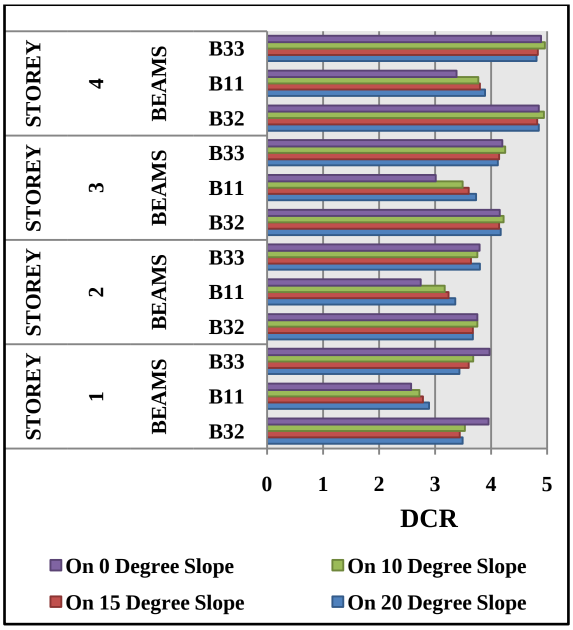

Fig 6: DCR of Beams when Exterior Column Removed

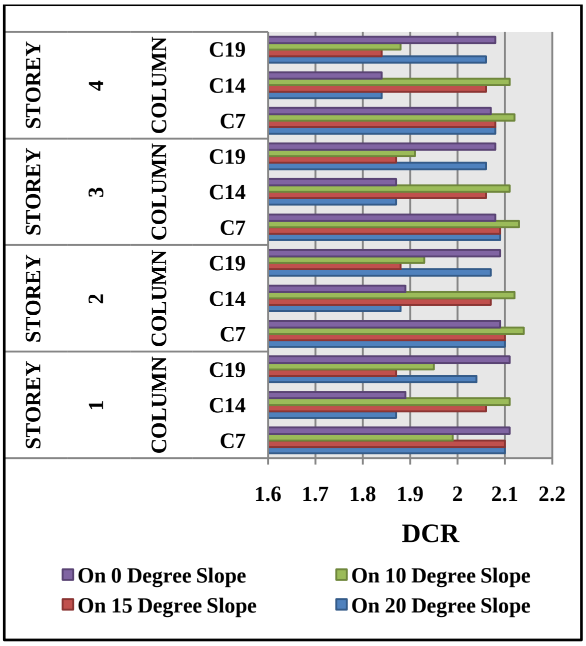

Fig 7: DCR of Columns when Exterior Column Removed

B. Non-linear Dynamic analysis Results of 0 Degree slope:

The maximum storey displacements and the Base Shear values FX and FY of 0 Degree sloped Building before and after removal of columns obtained when the time history data of Bhuj earthquake along X and Y directions applied to perform before and after removal of column have been obtained from the non-linear dynamic analysis are shown in the figures below:

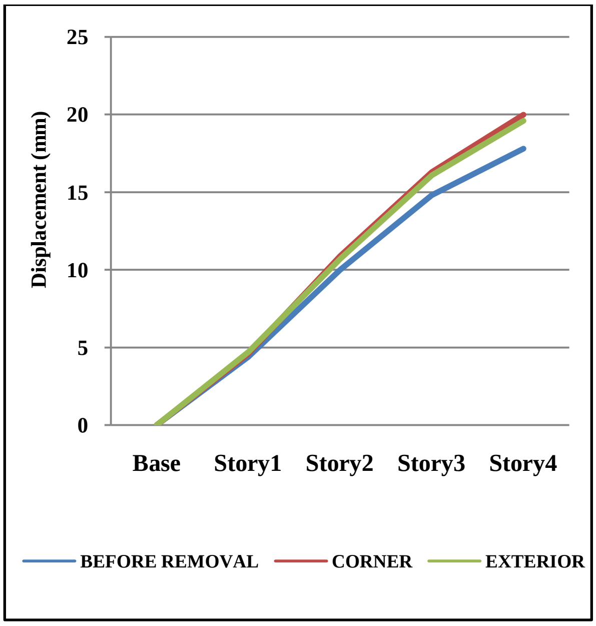

Fig 8: Comparision of Max.Story Displacements

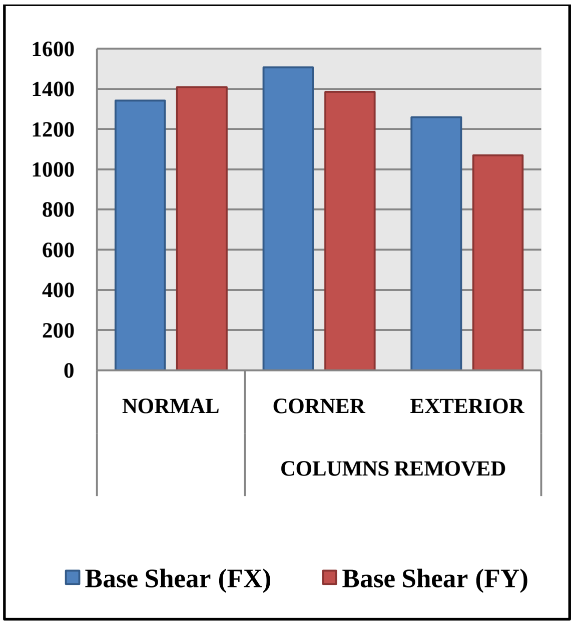

Fig 9: Comparision of Base Shear

C. Non-linear Dynamic analysis Results of 10 Degree slope:

The maximum storey displacements and the Base Shear values FX and FY of 10 Degree sloped Building before and after removal of columns obtained when the time history data of Bhuj earthquake along X and Y directions applied to perform before and after removal of column have been obtained from the non-linear dynamic analysis are shown in the figures below:

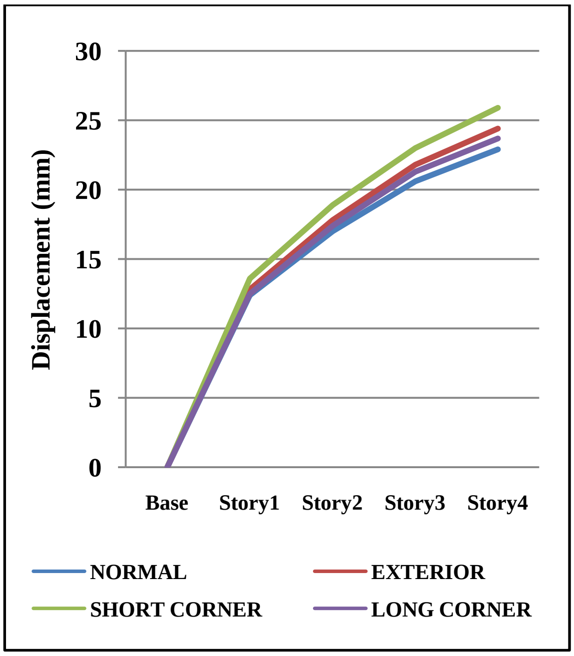

Fig 10: Comparision of Max.Story Displacements

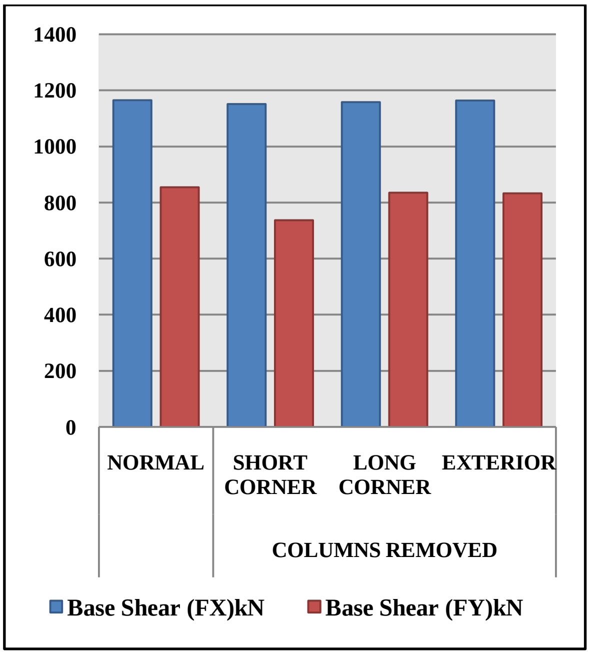

Fig 11: Comparision of Base Shear

D. Non-linear Dynamic analysis Results of 15 Degree sloped Building:

The maximum storey displacements and the Base Shear values FX and FY of 15 Degree sloped Building before and after removal of columns obtained when the time history data of Bhuj earthquake along X and Y directions applied to perform before and after removal of column have been obtained from the non-linear dynamic analysis are shown in the figures below:

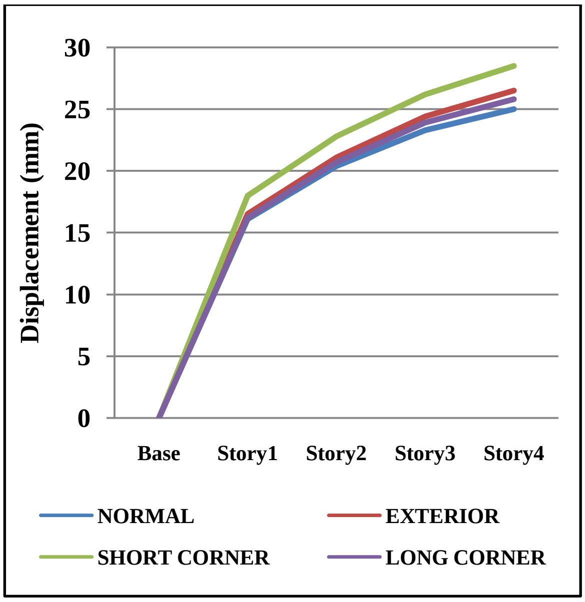

Fig 12: Comparision of Max.Story Displacements

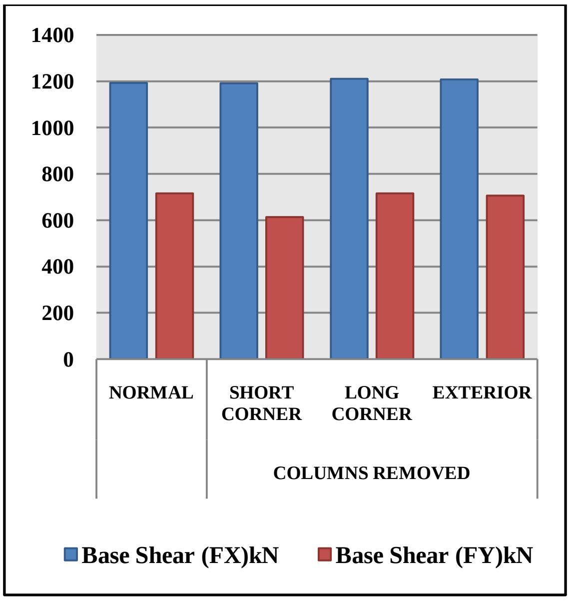

Fig 9: Comparision of Base Shear

E. Non-linear Dynamic analysis Results of 20 Degree sloped Building:

The maximum storey displacements before and after removal of column have been obtained from the non-linear dynamic analysis are shown in the figure below:

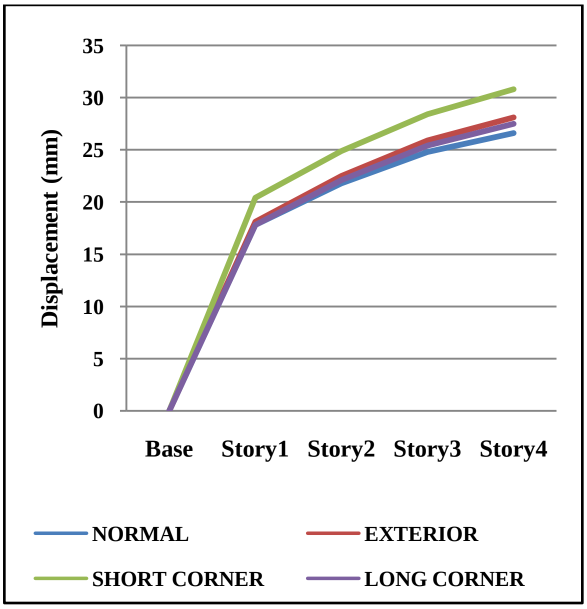

Fig 12: Comparision of Max.Story Displacements

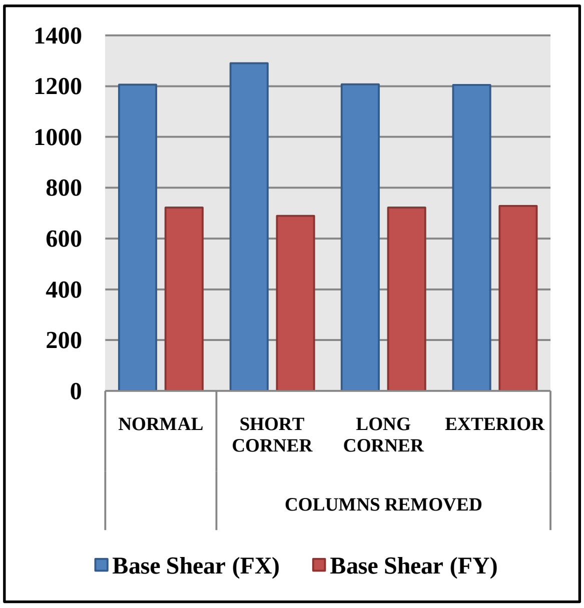

Fig 13: Comparision of Base Shear

VI. CONCLUSION

- As the Demand Capacity Ratio (DCR) of the beams of buildings on 0 degree, 10 degree, 15 degree and 20 degree are greater than 2.0, which means the buildings constructed on these slopes are highly vulnerable and has high potential to progressive collapse. Hence they require additional reinforcement and need to be redesigned in order to resist the progressive collapse.
- Since demand capacity ratio (DCR) values of the adjacent columns are not much greater than 2.0 and they are less susceptible to progressive collapse, but removed columns in all the stories need to be redesigned.
- For building on 0 degree slope, It is observed that maximum story displacement is 20mm has been occurred when the corner column removed. Hence when the exterior column is removed the maximum story displacement is 19.6mm, whereas before removal of columns (normal) the maximum story displacement is 17.8mm has been shown in the figure 6.The maximum base shear for the time history X direction ground data of Bhuj Eartquake is 1507.53 kN at 43.495 seconds, has been occurred when corner column removed and the maximum base shear for the time history Y direction ground data of Bhuj Eartquake is 1409.34 kN at 43.63 seconds, has beeen occurred before removal of columns (i.e; normal) as shown in the figure 7.
- For building on 10 degree slope, It is observed that maximum story displacement is 25.9mm has been occurred when the short corner column removed. Hence when the long corner column is removed the maximum story displacement is 23.7mm and when exterior column is removed the maximum story displacement is 24.4mm, whereas before removal of columns (normal) the maximum story displacement is 22.9mm has been shown in the figure 8.The maximum base shear for the time history X direction ground data of Bhuj Eartquake is 1164.9 kN at 46.69 seconds, has been occurred before removal of columns (i.e; normal). Similarly the maximum base shear for the time history Y direction ground data of Bhuj Eartquake is 854.17 kN at 43.83 seconds, has beeen occurred of columns (i.e; normal) as shown in figure 9.
- For building on 15 degree slope, It is observed that maximum story displacement is 28.5mm has been occurred when the short corner column removed. Hence when exterior column is removed the maximum story displacement is 26.5mm and when the long corner column is removed the maximum story displacement is 25.8mm, whereas before removal of columns (normal) the maximum story displacement is 25mm has been shown in the figure 10.The maximum base shear for the time history X direction ground data of Bhuj Eartquake is 1211.13 kN at 42.7 seconds, has been occurred when long corner column removed. Similarly the maximum base shear for the time history Y direction ground data of Bhuj Eartquake is 716.50kN at 40.87 seconds, has beeen occurred of columns (i.e; normal) as shown in figure 11.
- For building on 20 degree slope, It is observed that maximum story displacement is 30.8mm has been occurred when the short corner column removed. Hence when exterior column is removed the maximum story displacement is 28.1mm and when the long corner column is removed the maximum story displacement is 27.5mm, whereas before removal of columns (normal) the maximum story displacement is 26.6mm has been shown in the figure 12.The maximum base shear for the time history X direction ground data of Bhuj Eartquake is 1290.82 kN at 42.75 seconds, has been occurred when short corner column removed. Similarly the maximum base shear for the time history Y direction ground data of Bhuj Eartquake is 728.26kN at 39.19 seconds, has beeen occurred when exterior column is removed as shown in figure 13.
- Since many researches have concluded that the additional reinforcement required in order to resist the progressive collapse is little expensive in the project, but structures constructed by considering the effect of progessive collapse are efficient and safe.
- It is very important for us to include the effect of progressive collapse in our Indian Standard (IS)Codes, since so many international codes like American standards, Euro Standards,etc have been following the effect of progressive collapse.
- So many case studies on RC buildings of Hill stations have concluded that the present constructed buildings are inefficient and vulnerable to withstand the heavy earthquakes, which may result in the loss of life and economy. With the increasing population on hill stations it is very essential to repair the present structures and therefore to overcome these problems the GSA 2003 guidelines also helpful to design and remould the existing structures to make them withstand the progressive collapse.

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