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Dynamic Column Removal: An Analytical Approach

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Abstract – Progressive collapse triggers due to change in loading pattern or boundary conditions of some members, when they are loaded beyond their intended capacities. Pushover analysis is used to analyze for a lateral load. Nonlinear dynamic time history technique is used here to simulate the scenarios of column removal. Time history analysis of different cases like long side column removal, short side column removal and corner column removal were performed in SAP 2000.

***Key Words*: Pushover analysis, Dynamic column removal, SAP 2000, Acceptance criteria, Mitigation techniques**

1. INTRODUCTION

Progressive collapse occurs when a structure has its loading pattern or boundary conditions changed such that some members are loaded beyond their intended capacities. The residual structure is then forced to seek alternate load paths to redistribute the out-of balance loads from damaged members. As a result, other neighboring members surrounding the residual structure may also fail shedding some applied loads. The redistribution of loads is a dynamic process and will continue until a new equilibrium position is reached by the residual structure, either through finding a stable alternate load path or through further shedding of loads as a consequence of collapsed members.

2. PROGRESSIVE COLLAPSE CATEGORIES

a) PANCAKE-TYPE COLLAPSE

When the capacity of a member carrying vertical load is inadequate it can lead to the collapse of an entire section of a structure. The upper part of the damaged structure starts to fall and accumulate kinetic energy. The impact force due to the falling part of the structure commonly exceeds the design load of the remaining structure. If the floor underneath is not able to resist the impact, the collapse will continue one floor at a time.

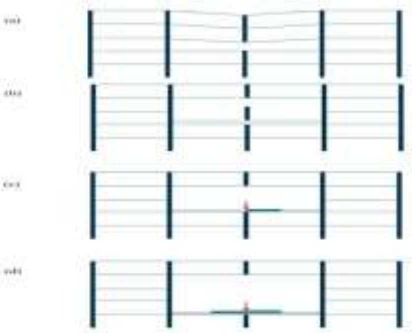

Fig-1: The stages of pancake-type progressive collapse

b) ZIPPER TYPE COLLAPSE

The loss of a single load bearing member redistributes the force to the other members situated transverse to the failure direction. If the resistance of the remaining members is exceeded, due to the extra load or its dynamic character, the failure will be increased. For this kind of collapse, the failure of elements may be connected with any local failure mode, which contains instability (buckling).

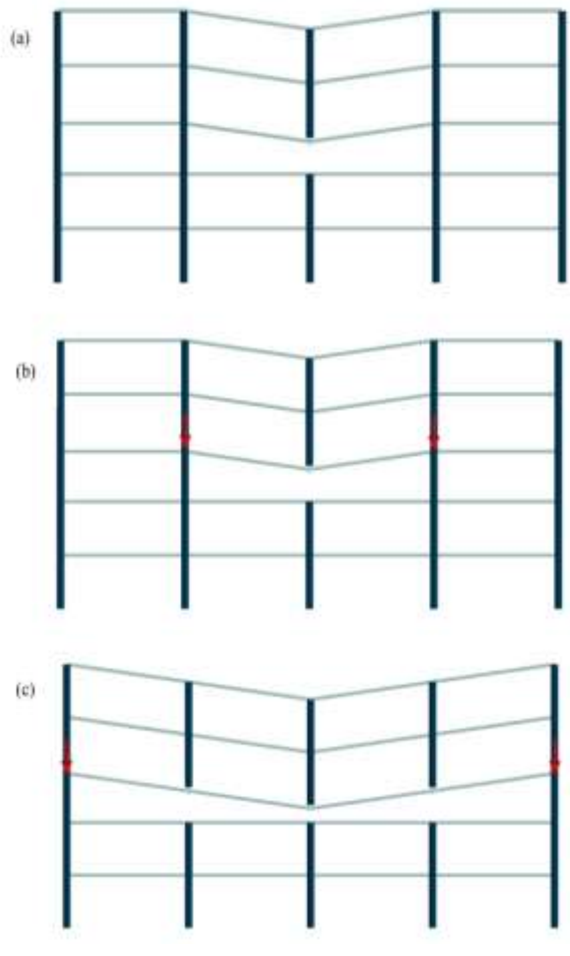

Fig-2:.The stages of zipper-type progressive collapse,

c) DOMINO-TYPE COLLAPSE

The characteristic of a domino-type collapse is the initial overturning of one element. Then the unexpectedly overturning of involved elements next to the first damaged element of the structure. And if the elements which were impacted lose their stability overturns the failure is progressing in the horizontal direction.

The height of the overturning element has to be bigger than the distance to the next element or the elements have to be connected to each other with some horizontal load transferring member.

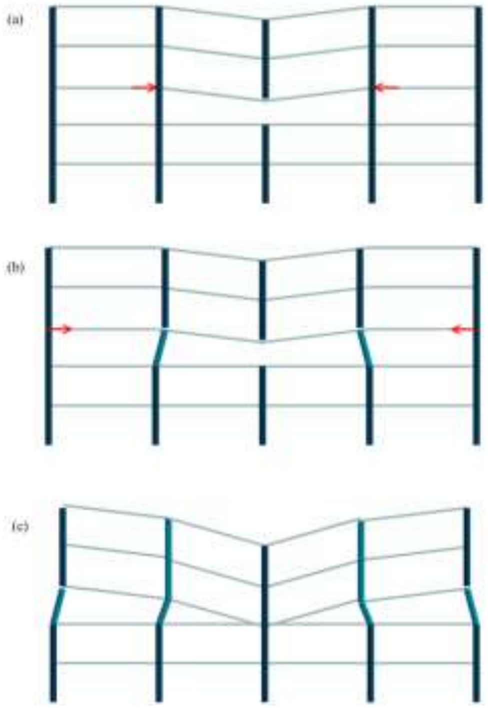

Fig-3: The stages of domino-type progressive collapse,

d) INSTABILITY-TYPE COLLAPSE

If the initial failure occurs in a critical member stabilising the entire structure a collapse due to instability can occur. Instability type collapse´s initial disruption is minor and critical due to its direction, as a lateral impact load on bracings, or position, as in the corner of the member stabilizing the structure. The instability-collapse often occurs in compressed members where the initial disruption can for example lead to large deformation and then to collapse. If the initial failure leads to a disproportional collapse immediately then the progression of the collapse is problematic to define.

e) SECTION-TYPE COLLAPSE

In the section-type of collapse a beam under a bending moment or a bar under axial tension is taken into account. When a part of the corresponding cross section is cut, the inner forces transmitted by that part are redistributed into the remaining cross section. The corresponding increase in stress at some locations can be the destruction of further of cross sectional parts and a failure progression throughout the whole cross section. A section-type collapse appears similar to a zipper-type collapse.

3. CAPACITY FOR RESISTING LOAD REVERSALS

It is recommended that both the primary and secondary structural elements be designed such that these components are capable of resisting load reversals for the case of a structural element(s) failure.

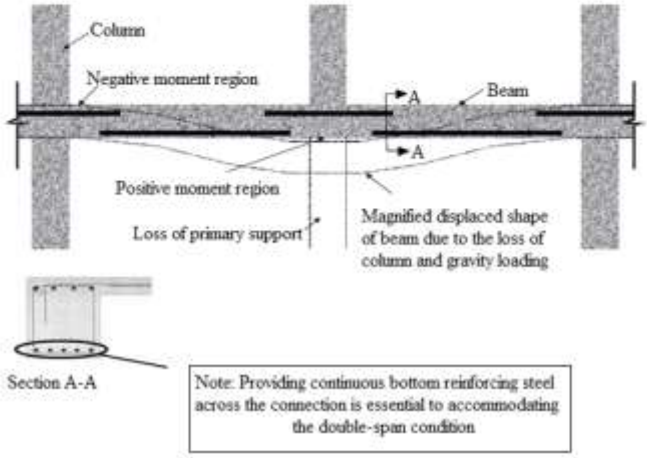

Fig-4: Response of the beam after the loss of primary column support, shows the inability to protect against progressive collapse

4. CAPACITY FOR RESISTING SHEAR FAILURE

It is essential that the primary structural elements maintain sufficient strength and ductility under an abnormal loading event to preclude a shear failure such as in the case of a structural element(s) failure. When the shear capacity is reached before the flexural capacity, the possibility of a sudden, non-ductile failure of the element exists which could potentially lead to a progressive collapse of the structure.

5. VERTICAL ELEMENT REMOVAL

The vertical element (i.e., the column, bearing wall, etc.) that is removed should be removed instantaneously. While the speed at which an element is removed has no impact on a static analysis, the speed at which an element is removed in a dynamic analysis may have a significant impact on the response of the structure. Because of this, it is recommended for the case where a dynamic analysis is performed, the vertical supporting element should be removed over a time period that is no more than 1/10 of the period associated with the structural response mode for the vertical element removal. Also the vertical element removal shall consist of the removal of the vertical element only. This removal should not impede into the connection/joint or horizontal elements that are attached to the vertical element at the floor levels. It is critical that the user understand that the sketch is not representative of damage due to any specific threat.

6. NONLINEAR STATIC PROGRESSIVE COLLAPSE ANALYSIS

Nonlinear static analysis is widely used to analyze a building for a lateral load and is known as ''pushover analysis.'' It increases applied loads step-by-step until maximum load is attained (load controlled) or maximum displacement is attained (displacement controlled). This method can be used to determine the ductility measure of the structure for lateral loading. Ductility is measured as a ratio of maximum displacement and yield displacement.

Generally, the ability of the structure to attain large ductility results in better performance under earthquake loading. For nonlinear analysis automatic hinge properties and user-defined hinge properties can be assigned to frame elements. When automatic or user-defined hinge properties are assigned to a frame element, the program automatically creates a generated hinge property for each and every hinge.

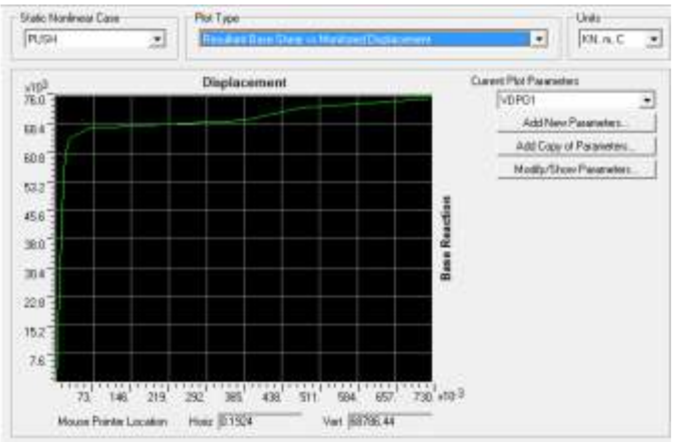

Fig-5: Pushover curve: 3D Frame without column removed case

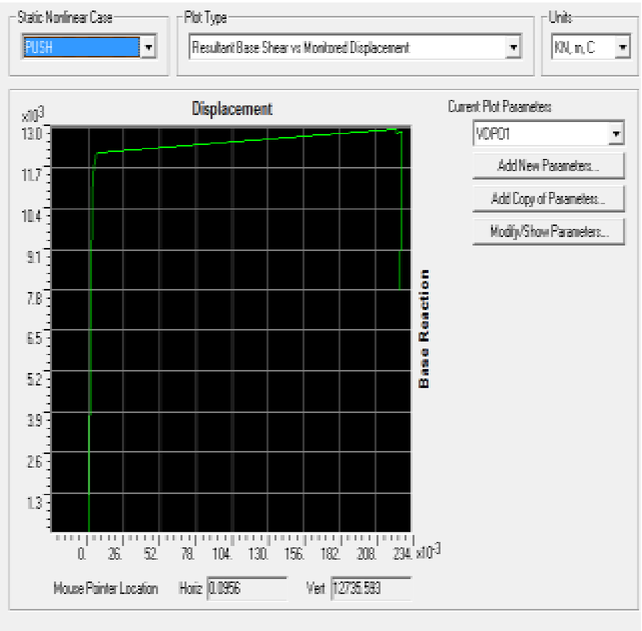

Fig-6: Pushover curve: 3D Frame when long side column removed

Figure 22 and 23 indicates two push over curves obtained from nonlinear analysis. It could be observed from comparing two acquired graphs, that damaged model has less stiffness than the primary one.

7. DYNAMIC COLUMN REMOVAL ANALYSIS

Nonlinear dynamic time history technique is used here to simulate the scenarios of column removal. Time history analysis of different cases like long side column removal, short side column removal and corner column removal were performed in SAP 2000.The primary structure were subjected to time history analysis using the data of Altadena earthquake. The maximum displacement was noted as 8.401e-05 m at the node on the top of the long side column removal point. When the long side column in first storey was removed suddenly, the node on the top of the removed column reached a maximum vertical displacement of 1.919e-03 m.

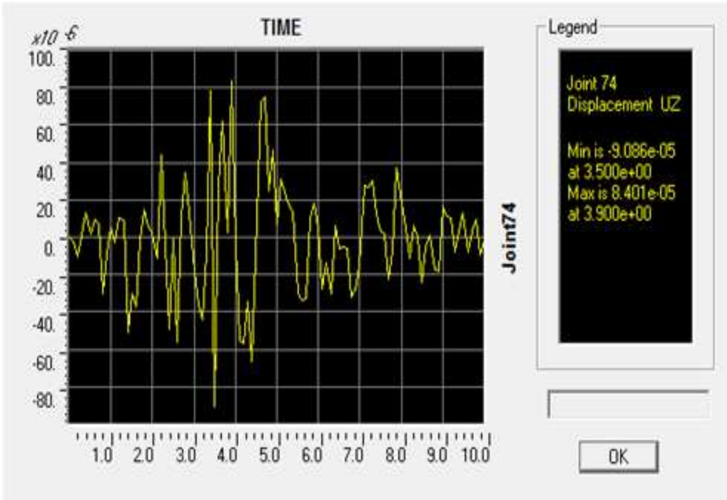

Fig-7: At the point of column removal before column removed case-long side column

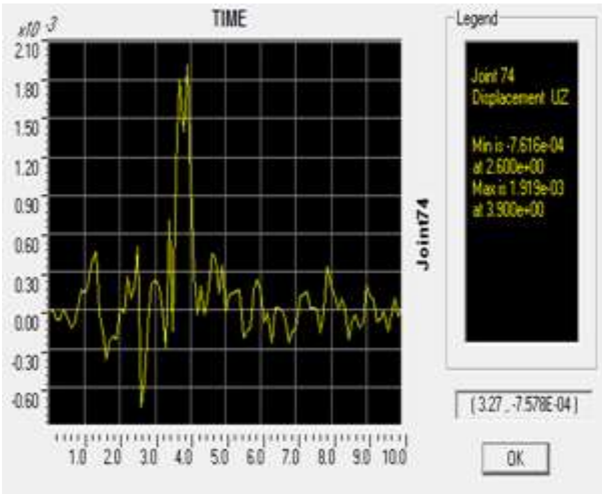

Fig-8: At the point of column removal when column removed-long side

Similarly the displacements of short side column removal point and corner column removal point were calculated after time history analysis.

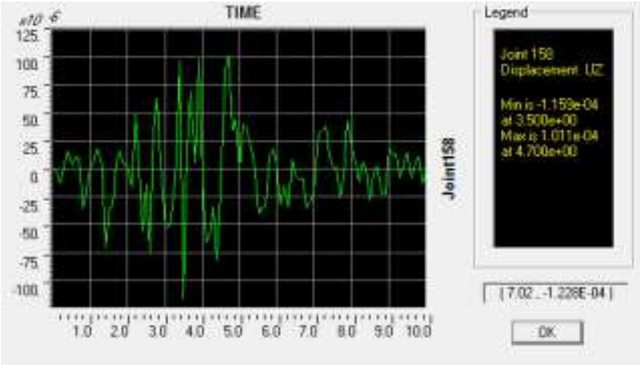

Fig.-9: At the point of column removal before column removed case-short side column

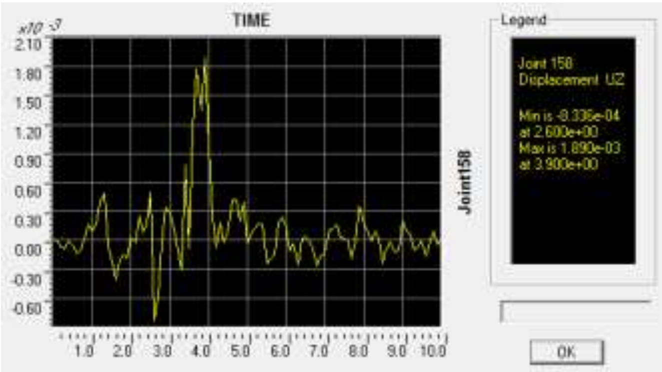

Fig-10: At the point of column removal when column removed-short side

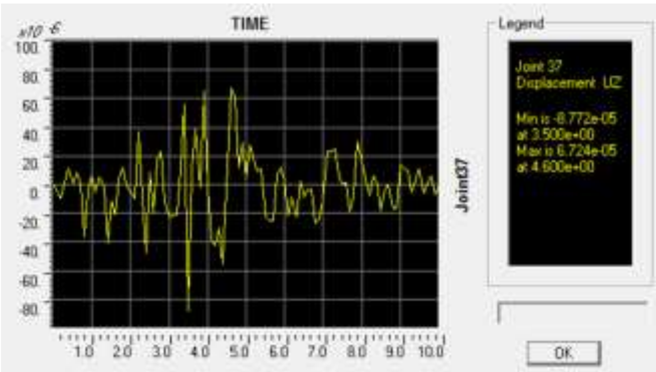

Fig-11: At the point of column removal before column removed case-corner column

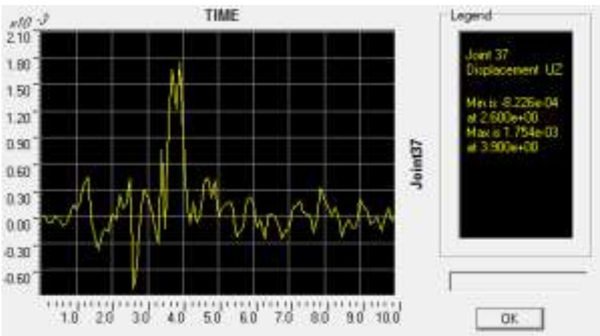

Fig-12: At the point of column removal when column removed-corner column

From the results it is clear that there is a huge difference between the maximum displacements at the column removal point before and after column removing.

8. ACCEPTANCE CRITERIA IN DYNAMIC ANALYSIS

In nonlinear dynamic column removal analysis, the General Service Administration guideline specify maximum plastic hinge rotation as acceptance criteria for progressive collapse potential (Table 2.1 of GSA guidelines). Rotation angle is obtained by dividing the maximum displacement to the length of the member .The acceptance criteria for plastic hinge rotation for reinforced concrete column and beam is 0.105 radian. According to current results the limit state for rotation is not exceeded in the considered cases of column removal.

9. MITIGATION TECHNIQUE

It is observed that demand capacity ratio (DCR) in beams and columns are exceeding the allowable limit for the building in zone II. This indicates the building considered for study is having high potential of progressive collapse when it is not designed as per seismic considerations. In order to limit the DCR value within the acceptable limit, as per GSA guidelines progressive collapse mitigation techniques have to be provided in the structure.

10. CONCLUSION

.Nonlinear static analysis reveals that hinge formation starts from the location having maximum demand capacity ratio.. Providing extra columns emerges as the most effective approach for mitigating the potential of progressive collapse. Time history analysis of different cases of column removal were carried out and current results shows that the limit state for rotation is not exceeded in the considered cases of column removal.

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