Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 3, 353-359
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i3.1660

The 3D plan analysis under progressive collapse for RC buildings through demand capacity ratio (DC) for three levels of damage

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Abstract: The progressive collapse presents a sudden load may cause initial failure in local parts at the frame which could lead to sequence reactions in the elements of the structure. A building of seven storeys was chosen to designed under gravity load according ACI 318 Code. This building is analyzed under progressive collapse condition for two columns damage cases; edge damage, corner damage. The building needs to be loaded as specified according (GSA) General Services Administration requirements through linear static analysis. The results of linear analysis show the variation in ((DC)) demand capacity ratio for the columns. The aspects of damage action in this study regarding section size and damage cases with 100% damage column loss (full damage), 60% damage (0.6 section size), 80% damage (0.8 section size). A GSA guideline to typical building with (DC) values bigger than 1.5 refer to critical potential damage conditions at the columns of the frame. It can be seen of the results the effect of size reduction for the building. This effect is clear to be decreased along distance from any plan. The((DC)) for columns which exceeded 1.5 value which show risky damage condition could actually happened that present serious threat possibility specially for nominated columns C22, C29 and C23 at plans A and B which show middle columns at lower position of the building.
Keywords: *3D analysis Demand capacity ratio, Levels of damage, Progressive collapse.*

1. Introduction

Many events like bombs, gas explosion, vehicles impact, the failure of foundation, that may occur due to design or construction errors etc. usually are not consider in the normal design practice. According to these reasons, several government authorities worked to develop special design guideline to prevent this progressive collapse.

The progressive collapse presents a sudden load may cause initial failure in local parts at the frames which may lead sequence reaction in the elements of the structure, result in full or partial collapse of the structure. The damaged column will act like some external effects as blast loading. The path of loads through the building is transferring to the closest columns in the frame. At U.S. the GSA (General Services Administration) [1] gives guideline to prevent the progressive collapse. The criteria of GSA include independent threat due to the progressive collapse action which described in the steps for the analysis with the benefit of using of Demand Capacity Ratio ((DC)). According to GSA guideline (DC) value for typical building should be less than (2) while atypical building has a value not less than (1.5). (DC) values the range from 1-1.5 show low potential collapse while value more than 1.5 has high potential collapse. [2] Marjanishvili predicted the effect of progressive collapse on the buildings and classify the action as a dynamic event that shows vibration in building elements. The disturbance for this load leads to equilibrium of external and internal loads because of member loss. The dynamic nonlinear Analysis show more complexity with accurate results, [3] study RC building of 6 stories in San Diego. These experimental tests analysis reveals that damage of column lead to partial or complete failure through progressive collapse. This building was a hotel which is equipped with several strain

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gauges used to measure strain value on the exterior column that was removed. However, (DC) values present pure field data without simulation techniques are adopt. [4] Sasani carried out a comparison between (DC) method results and finite element analysis for a model building. The conclusion was the (DC) method is over estimated. [5] Sezen conducted a study to test the potential of progressive collapse at Ohio State Union building that is planned for demolition in 2007. It was unique building because some of the floors were collapsed before the beginning of the experiment. The (DC) values with few a little analysis results by sap software [6] give excessive high values because of the special properties of the building, this lead to inaccurate recorded data. [7] Feng used ABAQUS package to study the behavior of steel composite building for a 20 storey frame under column removal using a 3-D model. [8] Hibbitt used Abaqus to investigate the behavior a parametric study are achieved to the variations in: concrete strength, reinforcement mesh size. The result of the parametric study gives measures of the reduction action through progressive collapse design that can be recommended [9].

The U.S. (GSA) developed "Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects" to make sure that the potential for progressive collapse is involved in the design, constructions and planning for new buildings and major projects. The term \progressive collapse" is used in structural engineering to describe the spread of an initial local failure in a manner analogous to a chain reaction that leads to partial or total collapse of a building [10].

In general, the tests of laboratory under progressive collapse are conducted to verify the effects of many different parameters for the structure collapse condition, particularly to frame boundary constraints, which may be expensive, time wasting and complicated. However, the simulation in term of numerical approach beside analytical method is adopted sufficiently to solve this type of problem [11].

Out of these guidelines, US (GSA) General Services Administration illustrated the procedure to minimize the progressive collapse, issued in 2000 and revised in 2003. The structural engineers must consider the serious consequences related to progressive collapse that would affect property and people of the entire building.

Progressive collapse is defined as situation that local failure for a primary structural component lead to the collapse of close members which leads to extra collapse. A failure of one or many primary loads carrying elements lead to overloading of adjoining other structural elements because the change of the load pattern leads to failure of these members. Finally total or partial collapse of that structure element occurs, which have the term of progressive collapse.

This research studies a seven-story frame building. This frame was loaded according to the GSA criteria and the analysis for two damage cases that include corner column beside edge column damage. A ((DC)) value for columns in linear analysis for the critical section of frame that lie at lower stories which have the critical value. The analysis cases with 60%, 80% and fully damaged columns according to section size. The edge column case having long bays is critical in the action of the progressive collapse and this type of collapse occurs suddenly.

2. Building Configuration

The effect of column removal, 60% and 80% column size section on RC building is studying through a 7storeys RC building which considered as (Hypothetical Case). The analysis of Progressive collapse is done according to the GSA guideline. Residential building is considered as the structure in this analysis, which is designed based on (ACI 318 code). Bay size is taken as 4m in one direction and 4m, 6m, 8m respectively in the other direction. Building size in plan is 12m x 36m. Height of typical floor is 3m, 230mm walls thickness was assumed for all beams.

3. Model Description

A building frame consists of seven stories with 6 bays in long direction and 3 bays in short direction. It is selected to carry out progressive collapse analysis. The load detail are dead load, live load applied on the slab are 3 kN/m^2 and 3 kN/m^2 respectively with uniform load 6.5 kN/m to present walls loads. The details of the frame are shown in Table 1 and its plan view with the front elevation that show member designation is illustrated in Figure.1

The beam section details for section A front view are B1-7 (350x300mm), B36-42 (350x300mm) B8-14 (350x350mm) and B28-35 (350x350mm), while the columns section size are C1-14 (350x300mm), C15-36 (450x400mm) and C37-49 (400x350mm). These details are the same of perpendicular sections B, C, D. The concrete fc is 27.4 MPa and steel fy is 413.7 MPa.

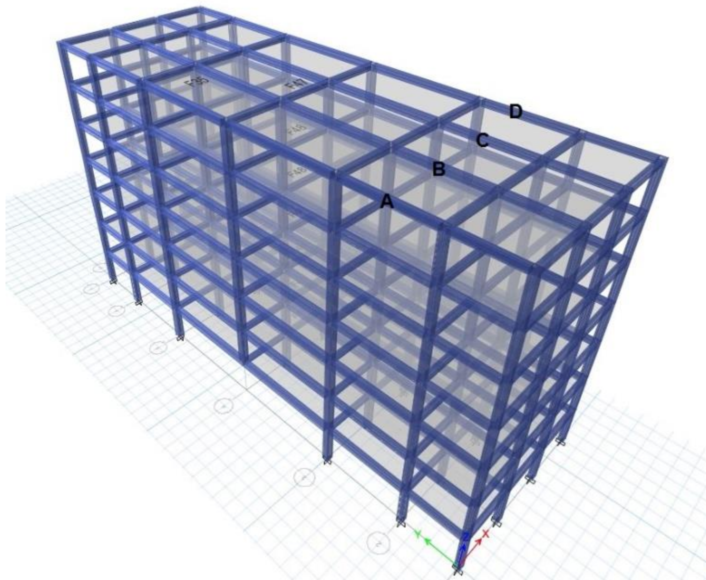

Figure: 1a).
The detail plans of the frame section.

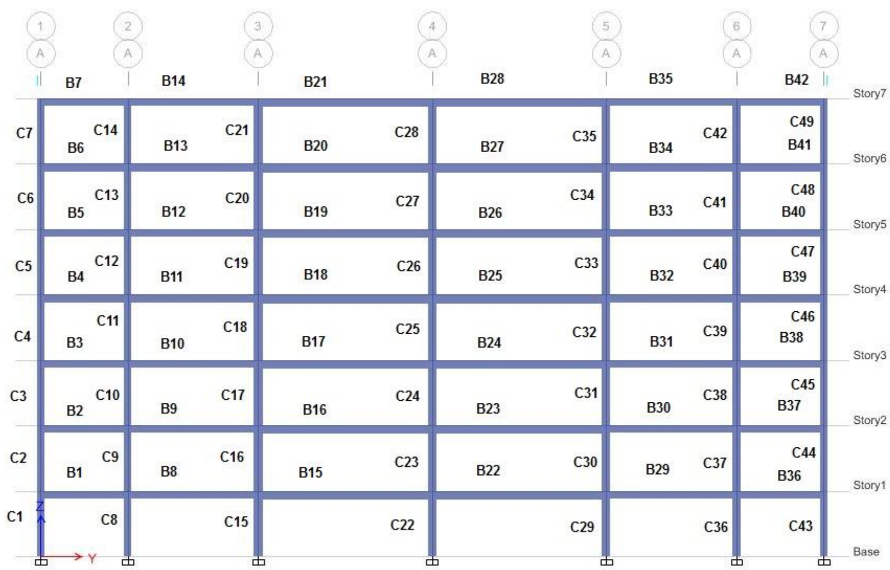

Figure: 1b).
The detail of the frame section at front view (A section).

ISSN: 2576-8484
Vol. 8, No. 3: 353-359, 2024
DOI: 10.55214/25768484.v8i3.1660

4. Progressive Analysis Aspects

The Column Damage Is Considered According to GSA Guideline Through the Linear Static Analysis for Columns. The load combination is carried out of this guideline to the building analysis. The slab is modeled in the ETABS provision using re-fined meshing. Slab thickness is 200mm it is modelled as a shell element. The corner columns and internal columns have reinforcement detail 12#8, 14#8 bars respectively. Demands capacity ratios ((DC)) are calculated to assess the stability for different degree of column damage. When the (DC) value for the member exceeds the criteria of acceptance the column is considered failed. The (DC) values define potential progressive collapse for a structure. For case 1 column is considered with damage occurred at the corner and the (DC) values are shown in figure 1. The (DC) value more than 0.9 were shown for all columns. The GSA guideline for atypical frame building with (DC) values more than 1.5 shows that the element is severely damaged that may have extra damage potential. It is clear from the Tables from 2 to 7 the ((DC)) value exceeds the acceptance limit in green color which shows collapse condition. Primary these columns have (DC) greater than 1.5. It also observed that these damaged elements reflect the actual risk possibility also give a technique to provide continuity and redundancy of the frame beside the deflection and load carrying capacity for the structural elements. This damage permits the designer to make the frame strong also to prevent of the progressive collapse. In the next discussion two floors until the mid-column C22 will be analyzed because it presents the critical part of the frame.

5. Frame Analysis Detail

The frame analysis consists of 4 sections analysis (A, B, C, and D) as appeared in Figure 3. Which present the longer direction and for each section there are two cases; corner column and mid column. For every column 3 conditions, column removal (loss column), 80% column size (0.8-S) and 60% column size (0.6-S). The detail of all these states is listed below in terms of tables and graphs.

5.1. Plan a Analysis

The data of analysis for plan A are summarized in Table 1 for corner case that show the full size of column (origin) C43, 0.8 of section size (0.8-S), 0.6 of section size (0.6-S) and the column removal (loss). The same way of data analysis is done for mid column C22.

Table 1.
Corner column (C43) case A(front view) plan (Demand Capacity ratio DC).

Column Location	Origin	0.8-S)	0.6-S	Loss (C43)	0.8-S%	0.6-S%	Loss (C43)%
C43	0.435	0.493	3.788	----------	13.3	770.8	NON
C36	0.869	0.872	0.891	1.116	0.3	2.5	28.4
C29	1.037	1.037	1.037	1.042	0.0	0.0	0.5
C22	1.191	1.166	1.166	1.173	-2.1	-2.1	-1.5
C44	0.408	0.409	0.37	0.759	0.2	-9.3	86.0
C37	0.786	0.788	0.804	0.995	0.3	2.3	26.6
C30	0.922	0.922	0.923	0.43	0.0	0.1	-53.4
C23	1.068	1.033	1.035	1.05	-3.3	-3.1	-1.7

(DC) greater than 1.5	(DC) increments greater than 50%	(DC) increments from 25-50%	(DC) increments greater than 10%

Note: 0.8-S: 0.8 section size (C43), 0.8-S%: 0.8 section size(C43) increments% with origin
0.6-S: 0.6 section size (C43), 0.8-S%: 0.8 section size (C43) increments% with origin
Loss (C43): Column loss (C43), Loss (C43) %: Column loss (C43) increments% with origin

ISSN: 2576-8484
Vol. 8, No. 3: 353-359, 2024
DOI: 10.55214/25768484.v8i3.1660

In this case plan A corner case, the most critical column is C43 for 0.6 section size it was 770% the increment value of (DC) the other critical cases are C44 and C30. The columns C43 and C44 have positive increments which mean the (DC) increased but the column C30 has negative (DC) that means the (DC) was decreased. In another word there was redistribution for the load that made column C30 had less load and columns C43 and C44 have higher load. The other increments were less than 10% so it is assumed negligible. The (DC) increments according to the color explained in Table 1 is adopted for all the next graphs, the detail of plan A corner case is shown in Figure 2.

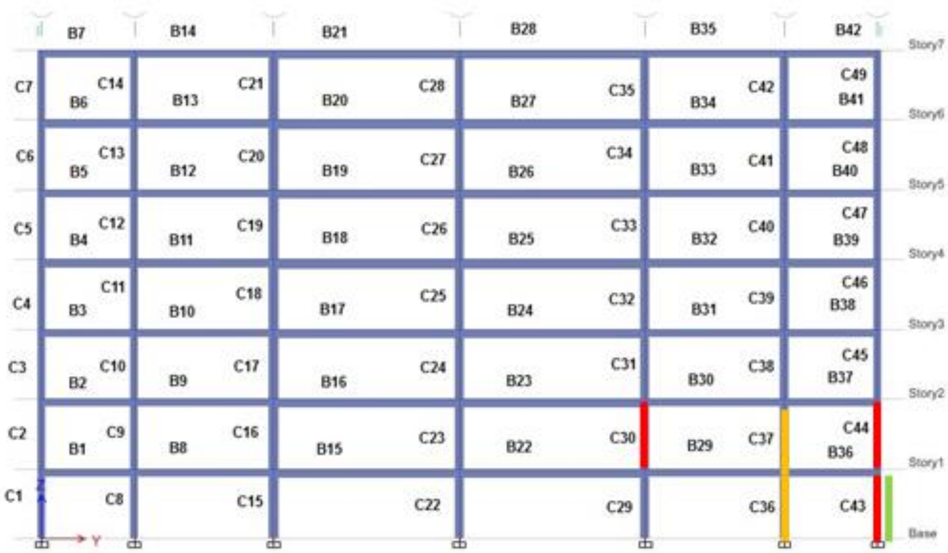

Figure 2.
The plan A corner case detail according to the adopted color criteria.

In the case of plan A mid column case the most critical column is C23 for 0.6 and 0.8 section size the increment value of (DC) were 67.5%, 70.8% respectively. In less degree of risk, the columns C29, C44 and C30 with (DC) are 22.7%, 17.2%, 34.2% respectively. All the critical cases are have positive increments except the column C23 has negative (DC) which refer to a redistribution for the loads that made column C23 had less load and columns C29, C22, C44, C30 and C23 have higher load. The other increments which have less than 10% are assumed negligible.

1.1. Plan b Analysis

The data of analysis for plan B to present the effect of C43 cases in plan A on columns in this plan for corner case that show the full size of column C43, 0.8 of section size, 0,6 of section size and the loss of the column. The same way of data analysis is done for mid column C22

In the case of plan B corner case the critical column is C43 and C44 for lost column with value of (DC) are 35% and 31.9% respectively. In the second hand the mid column column case critical cases are C22 and C23 for lost column. The critical columns in plan B for corner and mid column case columns have positive increments. It can notice that the values of (DC) in plan B less than the case of plan A. The other increments of (DC) with less than 10% value are assumed negligible.

1.2. Plan c Analysis

The data of analysis for plan C to present the effect of C43 cases in plan C on columns for corner case that show the full size of column C43, 0.8 of section size, 0,6 of section size and the loss of the column. The same way of data analysis is done for mid column C22.

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In this case plan C corner case and mid column case all the increments of (DC) values are less than 10% and it is neglected according to our assumption. It is clear in this case all the increments are negative that mean the loads were start to decrease for all columns in small value and expect these values are increased in negative values for plan D.

1.3. Plan d Analysis

The data of analysis for plan D to present the effect of C43 cases in plan A on columns for corner case that show the full size of column C43, 0.8 of section size, 0,6 of section size and the loss of the column. The same way of data analysis is done for mid column C22.

In this case plan D corner case and mid column case all the increments of (DC) values are less than 10%. It is clear in this case all the increments are negative have higher values from previous case (plan C) as it is expected but still less than 10% except one column C37 with value 10.3%. When compare corner case with mid column case it is clear that mid column case had the bigger value of (DC).

The concerning researches demonstrate that the columns should be designed with efficient strength using the direct design method, resistance versus the risk of progressive collapse is given through improvement the strength of the key structural parts to overcome failure under atypical loads. (G. E. Tsai & Lin, 2010; R. Y. Tsai & Huang, 1984) state the shear failure is not considered, the columns were assumed to stay at elastic even when regarding as local damage. (McCann, 2007) express that even design always leads to a "Strong Column Weak Beam" approach with the purpose that beam failure is preferred compared column failure.

6. Comparison Between Mid-Column Action and Edge Column Action

The comparison between middle column action and edge column action can be discussed through many points. First point is the number of critical columns. From Table 10 which present the columns with (DC) value greater than 1.5 and more than 0.5 values it can see that the critical columns in plan B and C are the same (C22-23-29) for the two cases corner column case and mid column case. The action of the two cases is vanished at plan D. in the other hand the increments% with respect to original value show that corner case only A plan had 3 columns are exceeding 50%. the mid column increments% more than 50% are speeded for two plans A and B as illustrated in Table 2.

Table 2.
A comparison between corner column and Midlle column.

Plan corner column action	**Columns (DC) value >1.5**	**Columns (DC) increments% >0.5**
A	C43	C43-44-30
B	C22-23-29	-----------
C	C22-23-29	-----------
D	-----------	-----------
Mid column action	Columns (DC) >1.5	Columns (DC) >0.5
A	C22-23	C22-23
B	C22-23-29	C23
C	C22-23-29	-----------
D	-----------	-----------

7. Conclusion

It is observed the flexural (DC) values in columns regarding the effect of reduction of column section size for corner and mid column.

- The size of column (column section reduction) effect is decreasing to plan distance for specific plan especially A plan.

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- The no. of critical column cases (more than 50% increment with origin) are 3 columns in case of corner column condition to 2 in mid column condition.
- The effect of the corner case and mid column case in plan A is vanished in plan C and D.
- There is redistribution in the other columns and plans
- The columns (DC) exceeded 1.5 show damaged condition represent actual threat possibility and they are (C22), (C29) and (C23) in plans A and B which present mid column lower part of the frame
- The columns (DC) exceeded 1.5 in plan A are (C43) in corner case and (C22), (C23) in mid column case.
- Hence the mid column case has the most critical condition for that it is recommended a check for potential progressive collapse is required to the building through a failure of primary load carrying members.

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