

# **The Effect of Column Axial Load on the Progressive Collapse**

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**ABSTRACT:** When major load carrying structural members are suddenly failed, part or the entire building will collapse because the remaining structural elements cannot support or redistribute the residual loads of the building. The local failure due to abnormal loadings are resulting from natural hazards, explosion, construction errors, and accidents that have induced progressive collapse in buildings. A three dimensional nonlinear finite element method has been used to model the beam-column sub-assembly specimens subjected to gravity loads. The main objective of this study is to investigate the response of two span beams sub-assembly demonstrating continuous beams to the failure of supporting column. In order to study the behavior of beam-column sub-assembly, nonlinear static analysis is used to estimate the effect of axial force on the columns at supports produced from above stories on the ultimate capacity of the models. It is shown that the increase of the axial load in the adjacent columns would increase the ultimate capacity of the bridging beam above the failed interior column.

**KEYWORDS:** Progressive collapse, Column axial load, Finite-element analysis, Reinforced concrete

## **I. INTRODUCTION**

The gradual or instantaneous failure of a column due to explosion, accidental actions, or earthquakes leads to progressive failure. The General Services Administration of the United States (GSA<sup>[1]</sup>,2003) defines this phenomenon as “a situation where local failure of a primary structural component leads to the collapse of adjoining members which, in turn, leads to additional collapse” and denoted as progressive collapse. Also in ASCE<sup>[2]</sup> Standard 7-10: Minimum Design Loads for Buildings and Other Structures, progressive collapse is defined as “the spread of an initial local failure from element to element, resulting eventually in the collapse of an entire structure or a disproportionately large part of it”. The first research in progressive failure was motivated by the partial collapse of 22-story Ronan Point Tower in England in 1968, caused by a gas explosion that bumped the supporting reinforced concrete panels close to the corner of the building. The loss of supporting wall at the eighteenth floor caused the failure of above stories [3].

The second case of progressive collapse was the destructing of Alfred P. Murrah Federal Building in the Oklahoma City in 1995 by a bomb detonated outside of the Building [4].

Several studies have been conducted to get the best design for buildings to mitigate the potentially catastrophic effects of collapse. Sasani and Kropelnicki[5](2008) conducted experimental and analytical investigations on the response of a seven story reinforced concrete building to the instantaneously failure of load-bearing element.

Su, et. al.,[6] (2009) investigated the gravity load-carrying capacity against progressive collapse by experimentally tested twelve specimens representing reinforced concrete sub-assembly beams. Lu, et. al.,[7] (2010) obtained the resistance of reinforced concrete structure subjected to earthquakes to the progressive collapse by using pushdown analysis method. Choi and Kim[8] (2011) Experimentally investigated the effect of removing interior column on the response of beam-column sub-assembly designed with and without considering the seismic loads.

Kai and Li[9] (2012) experimentally investigated the dynamic performance of beam-column sub-assembly subjected to the failure of corner-column of ground-floor. Marchis, et. al.,[10] and Marchis and Ioani[11] (2013) investigated the performance of the reinforced concrete building designed for seismic load to get better resistance for the progressive collapse.

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In this study, the response of two span beams sub-assembly demonstrating continuous beams to the failure of supporting column is investigated. The main goal of the study is to investigate the effect of axial force on the columns at support produced from above stories. It is assumed there are two, four and six stories above the columns and variable beam lengths for parametric investigations.

## II. THE SPECIMEN DESCRIPTION

The RC beam specimen that considered in the analysis is designed as part of multi-story reinforced concrete ordinary moment frame building according to ACI-318[12] (2011) subjected to gravity loads. Figure (1) shows the elevation and the plane layout of the adopted multi-story RC building and the considered beam-column sub-assembly. In this study the effect of axial force on the columns at support produced from the above stories is discussed. It is assumed there are two, four and six stories above the columns for discussions.

The imposed live load of (2 KN/m<sup>2</sup>) is considered. Dead load used in the design is including partitions load (1 KN/m<sup>2</sup>), floor finishing and ceiling (1.3KN/m<sup>2</sup>) in addition to self-weight of the beam and slab. Material properties include the yield strength of steel reinforcement  $f_y=414\text{MPa}$ , the compressive strength of concrete  $f'_c=30\text{MPa}$ , modulus of elasticity of steel  $E_s=200\text{GPa}$ , and for concrete  $E_c=25.7\text{GPa}$  are adopted. The total depth and width of the beams are 600mm and 300mm, respectively while for column are (300 mm ×300 mm).

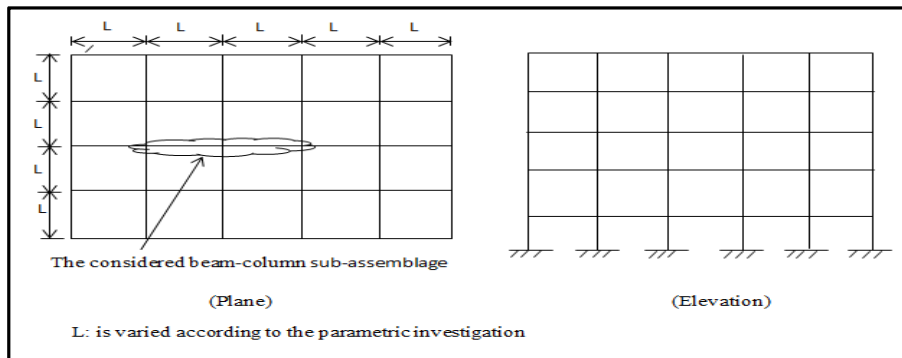


Figure (1) The elevation and plane of the multi-story RC building.

The span length is varied considering 5, 6 and 7 m to investigate their effects with equal steel reinforcement details for all lengths as shown in figure (2).

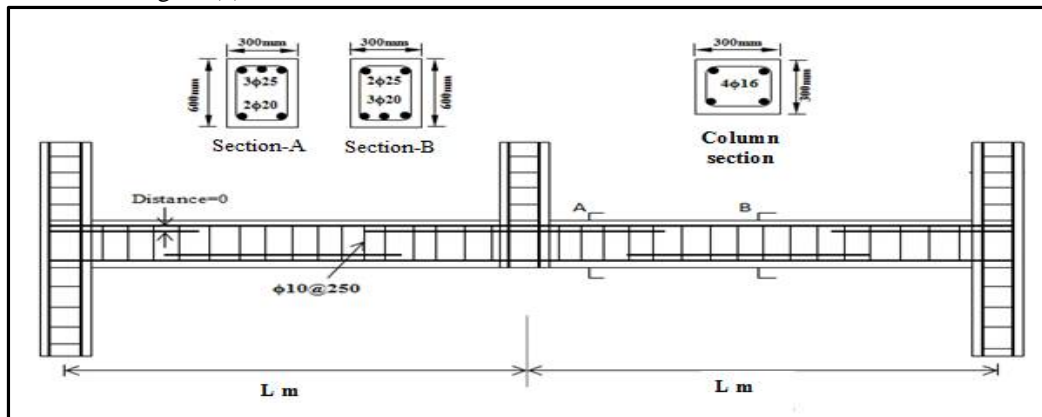


Figure (2) Reinforcement details of sub-assembly specimen.

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## III. MODELING AND ANALYSIS

The ANSYS 11.0 software is utilized for modeling and analysis. A solid element, SOLID 65, is used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node translations in x, y, and z directions [13]. Steel reinforcements (both longitudinal and stirrups) are represented by using 2- node discrete representation (LINK8 in ANSYS). LINK8 is a truss element that may be used in different of engineering applications [13]. An eight-node solid element, SOLID45, is used for the steel plates at loading locations in the finite element models so as to avoid the problems of stress concentration [13].

By taking advantage of symmetry of beam-column sub-assembly, a quarter of full model is adopted. This approach leads to reduce the computational time and the space of computer disk requirement. Figure (3) shows the quarter of the entire model. The boundary condition are applied at support and plane of symmetry to constrain the nodes. At supports the boundary condition is represented as fixed support at exterior columns and as roller perpendicular to the plane of symmetry.

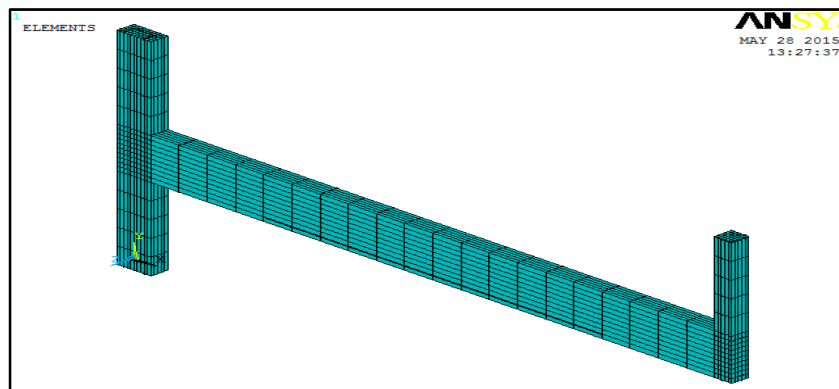


Figure (3) Finite element model of quarter subassembly

The column loads are applied as a surface pressure distributed on the top cross sectional area of the column. Figure (4) shows the boundary conditions and the applied load.

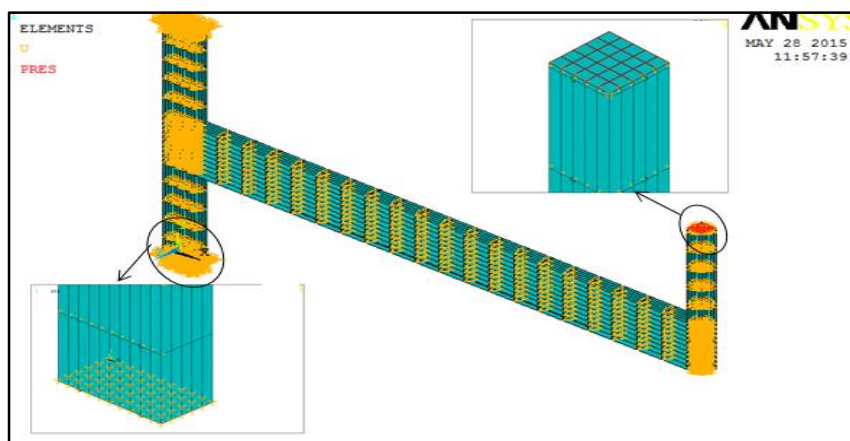


Figure (4) Boundary condition and loads of quarter subassembly model

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The flexural and shear reinforcement are illustrated in figure (5). The area of main reinforcement and stirrups are one half of the normal area because of symmetry of the subassembly

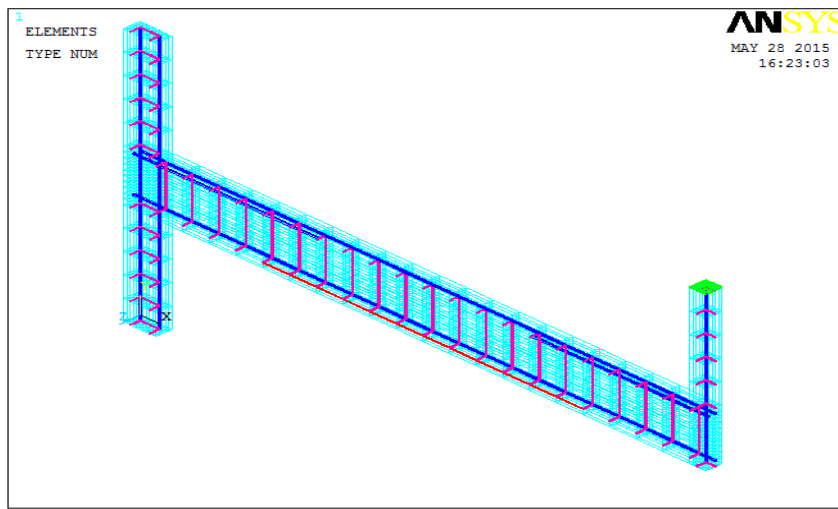


Figure (5) Reinforcement details of a quarter subassembly.

The nonlinear static method that considers for both geometric and material nonlinearities. In this method the vertical load is increased gradually until the maximum ultimate load is reached or the structure is failed. The load combination used in this method which recommended by GSA[1](2003) guidelines for progressive collapse analysis is:

$$\text{Load combination} = \alpha (D.L + 0.25L.L)$$

Where D.L = Dead Load , L.L = Live Load and the factor  $\alpha$  is represent the dynamic amplification factor that equal to (2) as recommended by GSA[1](2003) guideline for static analysis.

Figures (6), (7) and (8) illustrated the response of the selected beam-column sub-assembly in the nonlinear static analyses conducted for beam lengths 5m, 6m and 7m, respectively.

Figures show the load factor which is the ratio of the ultimate applied load to the recommended load by the GSA (2003) guidelines considering the dynamic amplification factor ( $2 \times [\text{Dead load} + 0.25 \times \text{Live load}]$ ) with the resulted deflection at the location of removed column for beam lengths 5m, 6m and 7m. Its shown that the load factor increased with the increase in the number of stories above the columns at supports for all beam length values.

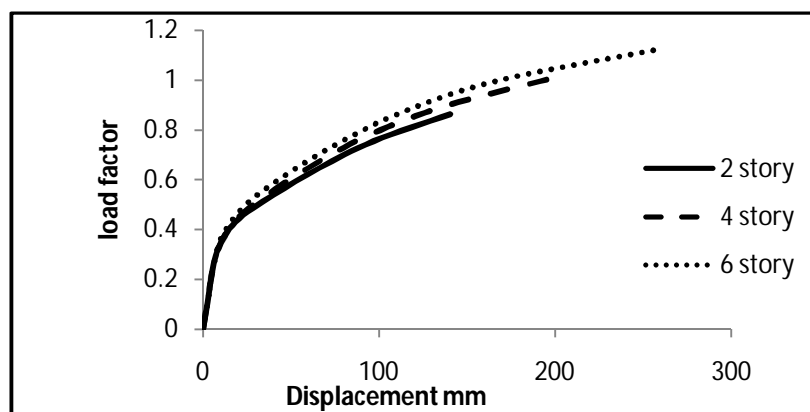


Figure (6) Load-Displacement Relationships of specimen (beam length=5m)

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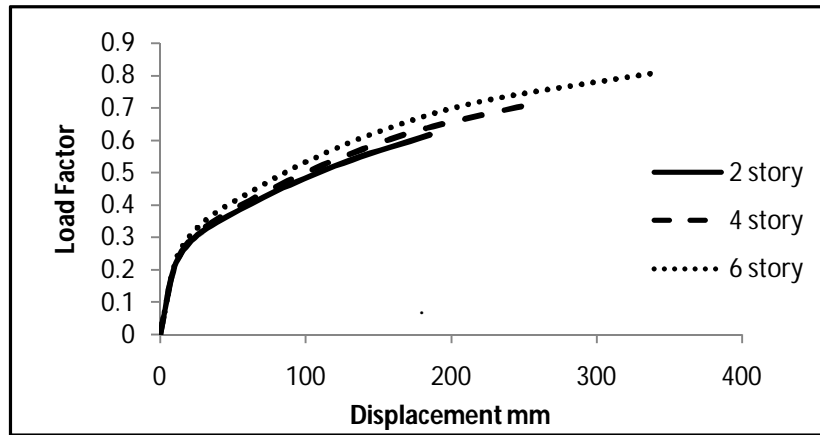


Figure (7) Load-Displacement Relationships of specimen (beam length=6m).

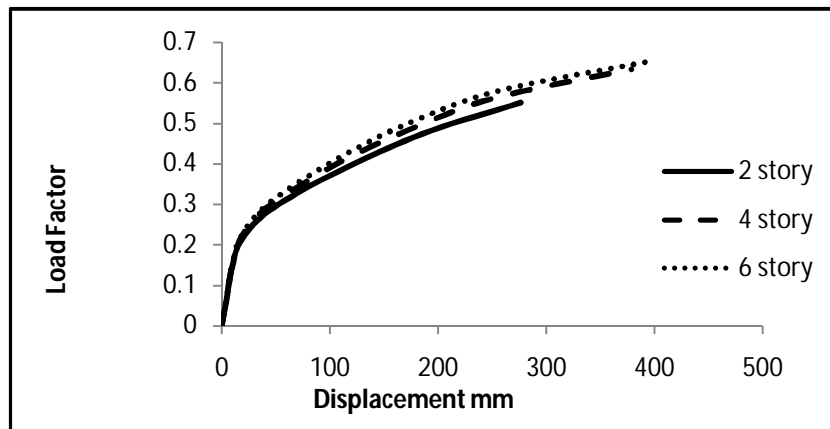


Figure (8) Load-Displacement Relationships of specimen (beam length=7m).

## IV. ANALYSIS RESULTS

In case of beam length equal to 5m (figure 6), it can be noted that the load factor is varied from the smallest value of 0.86 to the greatest value of about 1.12 corresponding to 2-story and 6-story above the beam floor, respectively. In addition, it can be noted that the ultimate deflections were varied from 140.3 mm to 257.6 mm corresponding to 2-story and 6-story above the beam floor, respectively.

While in case of beam length equal to 6m (figure 7), it can be noted that the load factor is varied from the smallest value of 0.62 to the greatest value of about 0.81 corresponding to 2-story and 6-story above the beam floor, respectively. In addition, it can be noted that the ultimate deflections were varied from 185.6 mm to 343.7 mm corresponding to 2-story and 6-story above the beam floor, respectively.

Also in case of beam length equal to 7m (figure 8) it can be noted that the load factor is varied from the smallest value of 0.55 to the greatest value of about 0.66 corresponding to 2-story and 6-story above the beam floor, respectively. In addition, it can be noted that the ultimate deflections were varied from 276.0 mm to 400.8 mm corresponding to 2-story and 6-story above the beam floor, respectively.

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From the above, it can be concluded that the progressive collapse resistance of floor bridging beam above the failed column will increase with increasing the number of stories above that floor of bridging beam. This increase in bridging resistance is expected by increasing the concrete confinement at the ends of the bridging beam due to increasing in number of stories.

## V. CONCLUSIONS

This study investigated the response of two span beams sub-assembly demonstrating continuous beams to the failure of supporting interior column. The effect of axial force on the columns at support produced from above stories is discussed. It is assumed there are two, four and six stories above the columns with different beam length values for investigations.

The results indicated that the load factor increased with increase the number of stories above the columns at supports for all beam length values, also the displacement increased with increase the number of stories above the columns at supports for all beam length values. Also noticed that the increase of the number of stories will increase the progressive collapse resistance of the building.

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