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# Pushover Progressive Collapse Analysis of High-Rise RC Structure

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**ABSTRACT:** The Construction industry is gaining momentum not only in India but also globally. Obviously, this fact demands planning of high-rise Structures in R.C.C. Due to certain reasons such as fire, gas explosions, terrorist attack, flaw in design, etc., the major components of these high-rise structures may undergo failure which may tend to the collapse of either part of the structure or whole of it. This kind of behavior of the structure, in structural engineering, is termed as progressive collapse.

The present project aims at the progressive collapse analysis of a 12 storeyed RC building by way of removing columns one at a time by following the GSA Guidelines. The building consists of 6 x 5 Bays of 3m in X and Y-directions which is designed by Indian code. For evaluation of progressive collapse non-linear static method of analysis, the structural model of the building is created using software E-TABS whereas, loads are applied as per GSA guidelines. Three column removal cases for 1st floor are taken into consideration. Columns such as corner column C6, Interior Column C16, and exterior column C40 are removed according to GSA Guidelines. Nonlinear static analysis has been done in the above cases followed by the evaluation of joint displacements, Rebar percentage, axial force for adjacent columns and bending moments for adjoining beams for these three cases of column removal.

Results of the study shows that progressive collapse of corner column is more critical as compared to that of interior and exterior columns.

**KEYWORDS:** Progressive Collapse, nonlinear static analysis, E-tabs 2018, GSA Guidelines

## I. INTRODUCTION

The term “Progressive Collapse” is widely used in structural engineering it involves the failure of one or more load carrying members. To transfer excessive load at the time of failure, structural elements will seek Alternate load paths.

Sometimes the structure is so designed that it may not bear additional loadings. Failure of overloaded structural elements will result into further redistribution of loading. This process continues till the equilibrium is reached. By the time equilibrium is attained, the major part of the structure gets collapsed. The effect of overall damage may be disproportionate to that of the local region near affected member. The issue of progressive collapse is critically addressed by the American Society of Civil Engineering (ASCE, 2005).

The guidelines for progressive collapse resistant design are noticeable in US Government Documents, General Service Administration (GSA, 2003) and Unified Facility Criteria (UFC, 2009). The GSA Guidelines provide us with a methodology that diminishes the progressive collapse potential in structures based on Alternate Path Method (APM). Under these methodologies one of the columns of a building is removed and the analysis of the damaged structure is done to examine the system responses. The main objective of this study is to analyse a high-rise RC Structure with the application of GSA Guidelines in order to assess the vulnerability behaviour of the three-dimensional RC Structure designed according to Indian Standard codes the procedure has been carried out in nonlinear static as per GSA Guidelines and Its Analysis is done by using finite element software E-TABS 2018.

## II. RELATED WORK

Progressive collapse, for the first time, came into limelight after Roman point apartment disaster at Newham, East London in the year 1968. Since then, the study on progressive collapse has been highly focused by the researchers and a lot of research is carried out on various aspects of progressive collapse of RC structure. Some of the significant Studies on this topic have been contributed by the following researchers.

R.Shankar Nair (March 2004) describes In his research paper previous structural collapse, progressive collapse and proportionate and disproportionate collapse [1]

Wibowo, H. and Lau, D. T. (2009) summarizes the merits and limitations of available analysis methods for progressive collapse of structures. The paper was concluded by stating the fact that analysis of seismic progressive collapse of structures can be done by modifying the current analysis procedures [2]. A group of three researchers Bruce R. Ellingwood Robert Smilowitz Donald O. Dusenberry Dat Duthinh H.S. Lew Nicholas J. Carino (2007) discussed three methods -indirect method, specific local resistance method and alternate load path method in order to reduce progressive collapse in their research paper. The paper also includes the discussion on methodology for evaluating the progressive collapse potential of existing buildings is [3]. Halil Sezen (PI) and Kevin A. Giriunas (May 2009) examines the existing structure's potential to fail because of progressive collapse. It is also stated at the end of the paper that the existing building is unique because the second floor collapsed at the initial stage of the experiment [4]. Authors Yanchao Shi, Zhong-Xian Li, Hong Hao (2010) studied RC structure under blast loading which was prone to progressive collapse. A new method was proposed for the progressive collapse analysis of reinforced concrete (RC) frame structures by considering non zero initial conditions and initial damage to adjacent structural members under blast loading for better prediction [5]. Weifeng Yuan and Kang Hai Tan (2011) incorporated the pancake type progressive collapse of multistorey structure in their study. The fact that the local member failure in a multi-storey structure may lead to a global progressive collapse was stated in the conclusion [6]. A.R. Rahai, M. Banazadeh, M.R. Seify Asghshahr & H. Kazem (2012) Studied progressive collapse in RC structures resulting from both instantaneous and gradual removal of columns [7]. Rakshith K G, Radhakrishna (2013) studied a 12 storey RC Structure and concluded that, in order to avoid the progressive failure of beams and columns, caused by failure of particular column, adequate reinforcement is required to limit the DCR within the acceptance criteria [8]. Shefna L Sunamy, Binu P, Dr. Girija K (2014) describe linear static analysis of a multi-storeyed building, wherein they have concluded that seismically designed building have good resisting capacity to progressive collapse [9]. Ram Shankar Singh, Yusuf Jamal, Meraj A. Khan (2015) A five storey RC Framed Structure which was symmetrical and unsymmetrical by geometry and concluded that in order to avoid progressive collapse, adequate reinforcement is required to limit the DCR within the acceptance criteria [10]. A. Choubey and M.D. Goel (2015) studied RCC building designed on Indian standard code of practice and concluded that the effect of transferring the load is more on the nearest member of the removed member and it becomes negligible when moved away from removed column [11]. Ram Shankar Singh, Yusuf Jamal, Meraj A. Khan (2015) in their studies states that seismically designed building columns have inherent ability to resist progressive collapse. Moreover, to avoid the progressive failure of beams and columns, caused by failure of particular column, adequate reinforcement is required to limit the DCR within the acceptance criteria [12].

### III. METHODOLOGY

The present study is aimed at the analysis of RC structure for progressive collapse, in view of Sudden Loss of Column as a design Scenario and considering different locations for sudden loss of column and its effect on progressive collapse. Despite of many Codes and Guidelines available globally, the GSA Guidelines are widely accepted by the researchers. For this research work, various methods to analyse the structures and to investigate their response in the progressive collapse phenomenon are used besides GSA guidelines. The aim of this work is to study Progressive Collapse over the sudden loss of a column, the Limiting Extent of damage to a localised area and comparative study of collapse as per column locations.

There are many methods to analyse progressive collapse such as linear static analysis, nonlinear static analysis, linear dynamic analysis, nonlinear dynamic analysis as per GSA guidelines. As far as our research work is concerned, we are analysing model for nonlinear static analysis.

#### Non Linear static analysis procedure

Nonlinear static analysis procedure is effective for structures with more than 10 stories. For structures less than 10 stories, once the nonlinear model, both materially and geometrically is modelled, the loads are increased with a Dynamic Increase Factor (DIF) by taking into account the inertia effects only. Then the column is eliminated and the consequent load is applied to the model.

To model, analyse, and evaluate a building, a three-dimensional assembly of elements and components is employed. One model for framed structure is created. Non linearity conditions and Dynamic Increase Factors and plastic hinges as per ASCE 41 and FEMA are applied. GSA Guidelines are followed for application of the loads. Finally, nonlinear analysis is carried out and results are obtained as per our considerations.



**Load Cases for Non Linear static analysis**

Case I: Force Control action Quf for linear static

$$G_{LF} = \Omega_{LF} [1.2 D + (0.5 L \text{ or } 0.2 S)] \tag{1}$$

Where,

$G_{LF}$  = Increased gravity loads for force-controlled actions for Linear Static analysis.

$\Omega_{LF}$  = Load increase factor for calculating force-controlled actions for Linear Static analysis; use appropriate value for framed or load-bearing wall structures.

Case II: Force Control action Quf for nonlinear static

Apply the following increased

$$G_N = \Omega_N [1.2 D + (0.5 L \text{ or } 0.2 S)] \tag{2}$$

Where,

$G_N$  = Increased gravity loads for Nonlinear Static Analysis

D=Dead load

S= Snow Load

$\Omega_N$  = Dynamic increase factor for calculating deformation-controlled and force controlled actions for Nonlinear Static analysis.

Gravity Loads for Floor Areas Away from Removed Column or Wall. Apply the gravity load combination in below Equation to those bays not loaded with  $G_N$

$$G = 1.2D + (0.5 L \text{ or } 0.2 S) \tag{3}$$

For those bays not immediately adjacent to the removed element the load combination is the same for both deformation and force- controlled action.

**Loading data used for modelling**

Table 2. Loading Data

Sr.no.	Particulars	Description
1	Dead load	Self weight of structure
2	Live load	5
3	Floor Finish	2
5	Wall load	17
6	Wall load on roof	8.5
7	Seismic load	IS1893:2002
8	Importance factor	1
9	Zone	5
10	Soil type	Medium
11	Type of structure	RCC framed structure
11	Response reduction factor	5

**Progressive collapse analysis**

In this analysis, we are considering 3 different cases of column removal. Each of them from 1st story

Case1 : analyse for sudden loss of Corner column, Interior column and Exterior Column at First Floor.

Case2 : analyse for sudden loss of Corner column, Interior column and Exterior Column at Fifth Floor.

Case3 : analyse for sudden loss of Corner column, Interior column and Exterior Column at Tenth Floor.

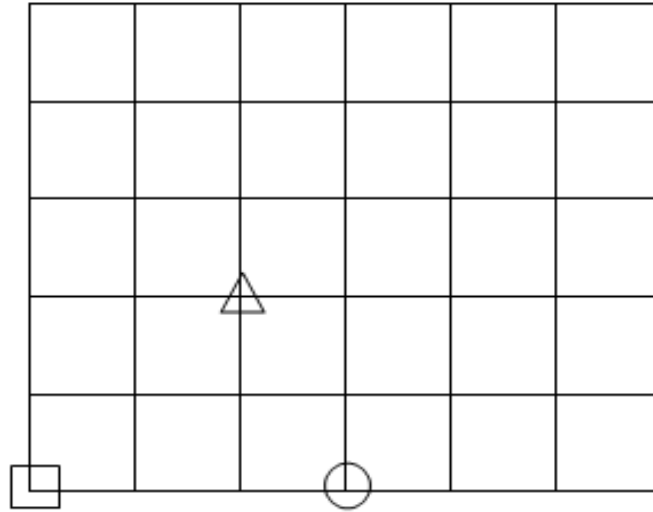


Fig.4 Detail Description of Model

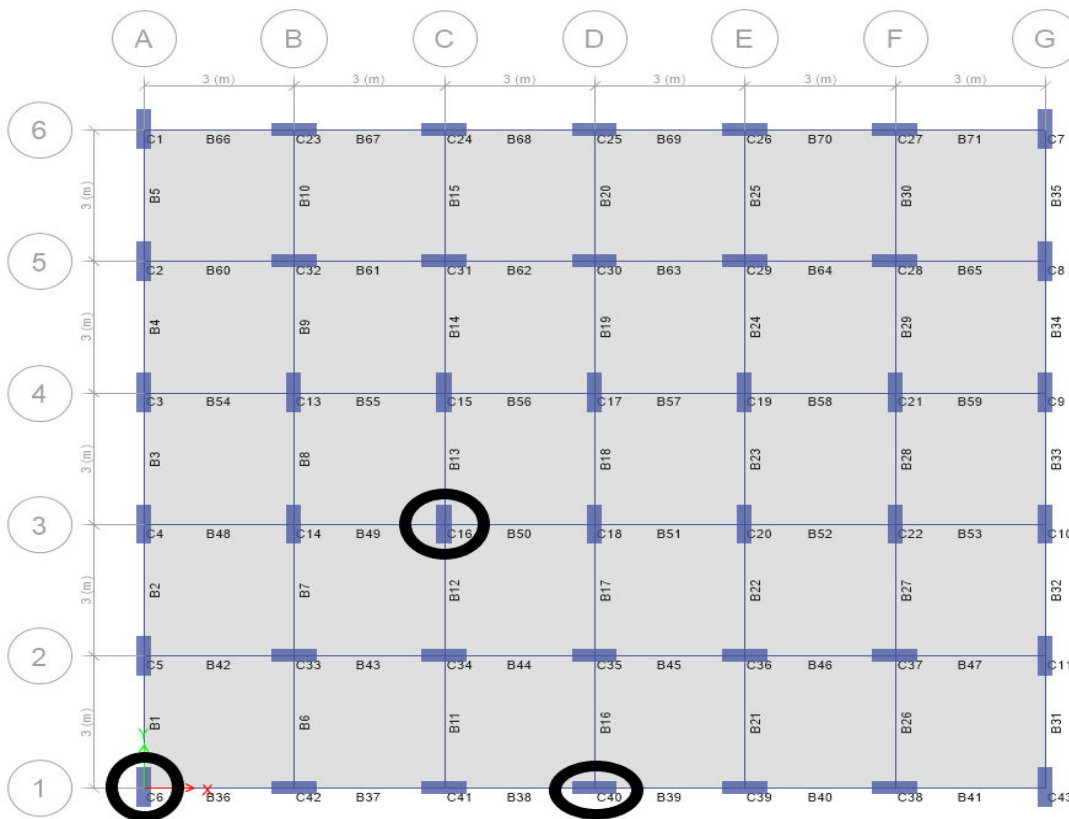
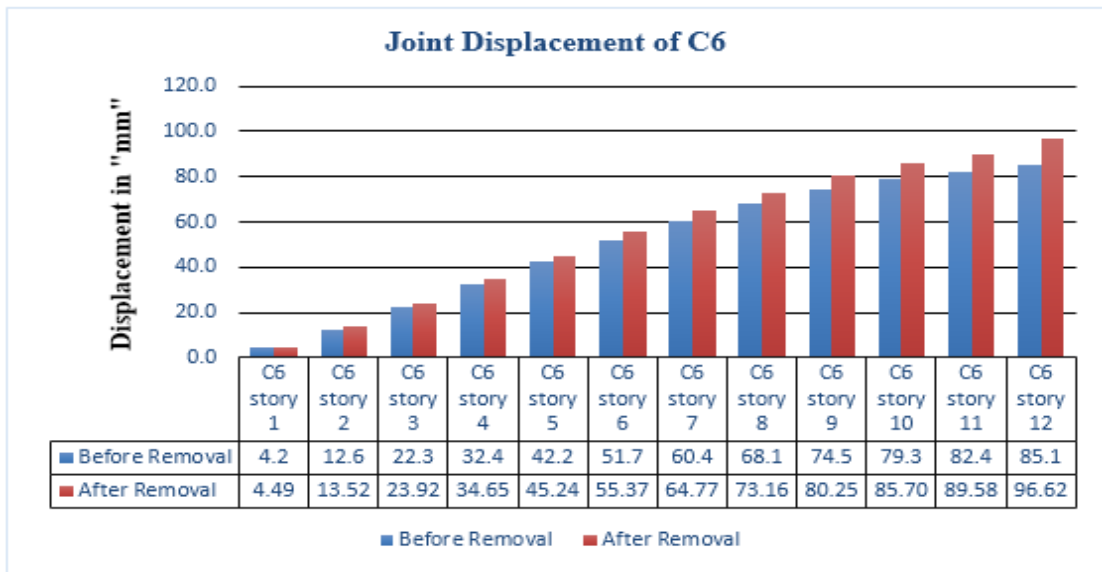


Fig.5. Location of Column Removal



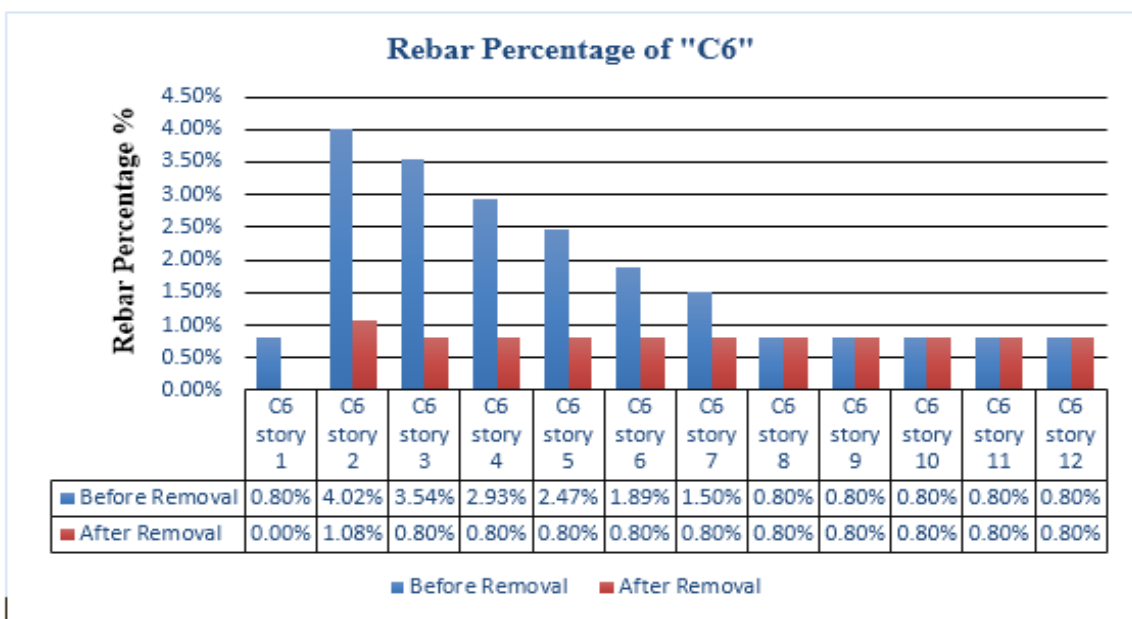
IV. EXPERIMENTAL RESULTS

RESULTS FOR REMOVAL OF COLUMN C6



Graph. 1. Joint Displacement of C6

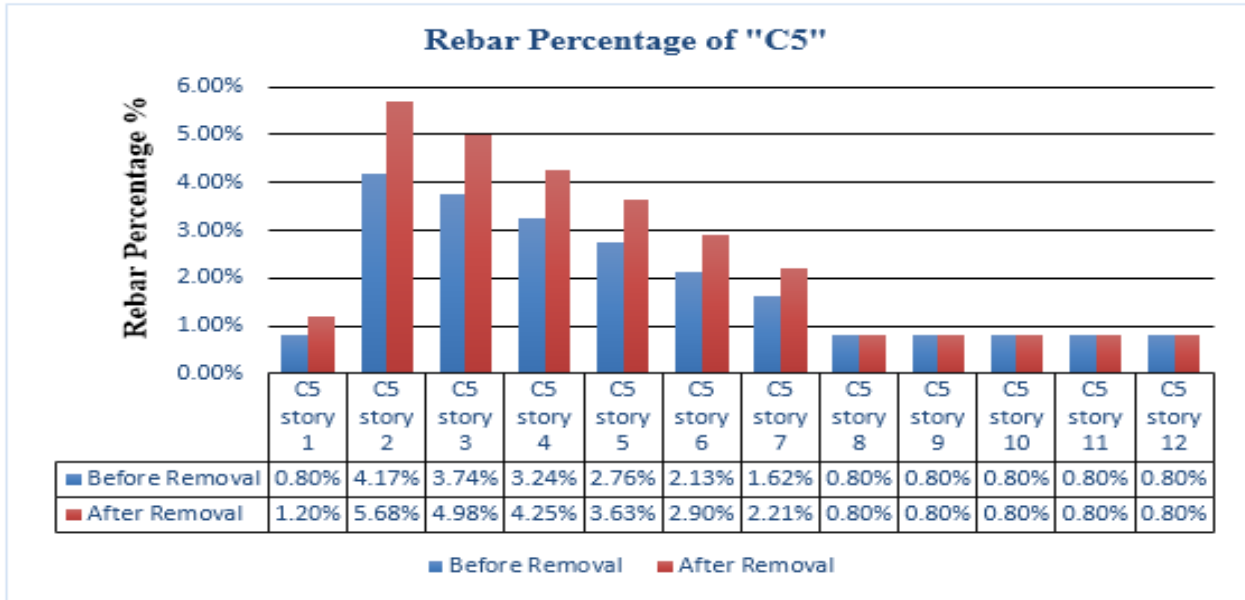
Maximum Joint Displacement before and after removal of Column C6 varies from 85.1mm to 96.62mm.



Graph. 2. Rebar Percentage of Column C6

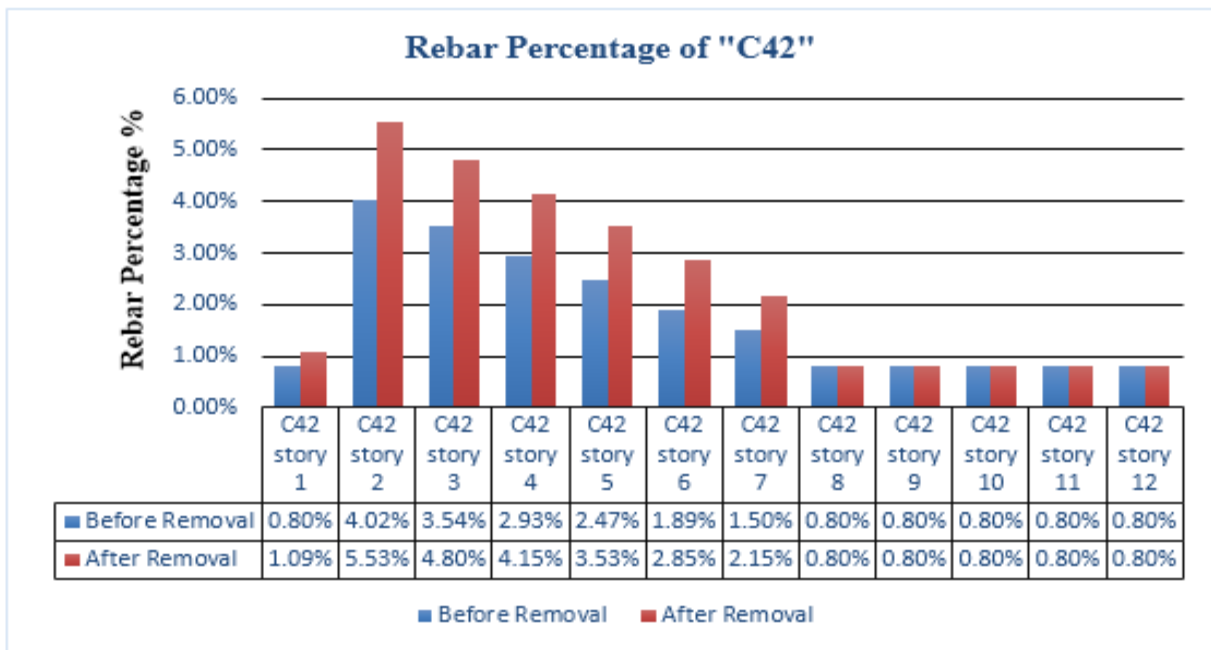


From Graph 3. Rebar Percentage of original structure is in a range of 0.8% to 4.02%. Initially column had two supports but due to sudden removal of column it becomes cantilever and Rebar Percentage for bottom minimized to 0.8% to 1.08%. It is observed that in progressive collapse analysis, Rebar Percentage above column removal location is reduced.



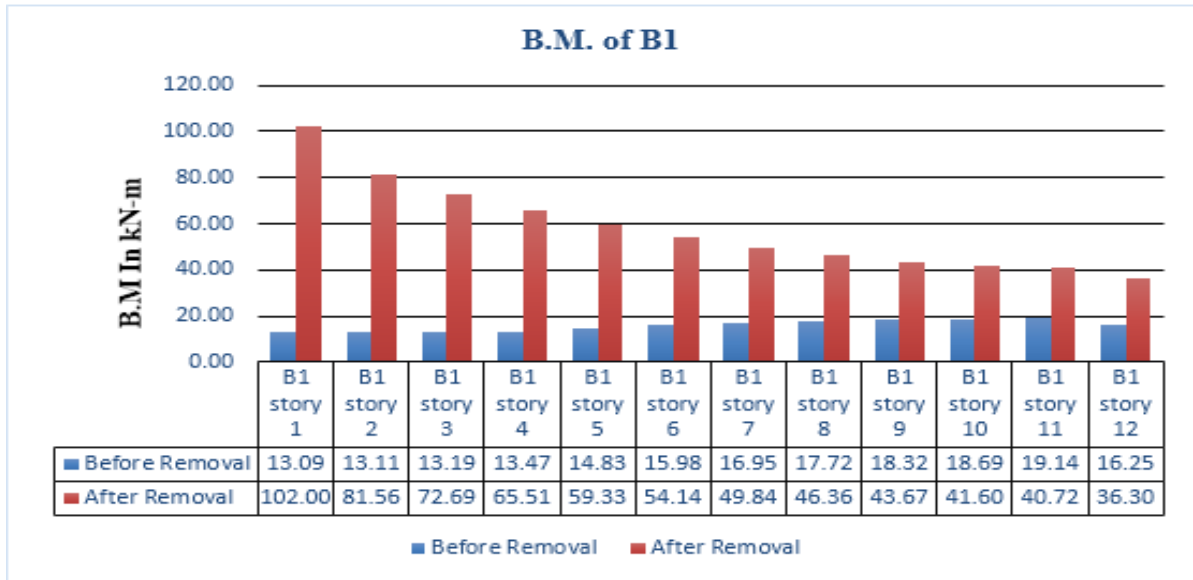
Graph. 3. Rebar Percentage for column C5

Rebar Percentage of original structure is in a range of 0.8% to 4.17% but due to sudden column removal, load distributed to nearest member and the Rebar Percentage is suddenly increases above the removal location max up to 5.68%.



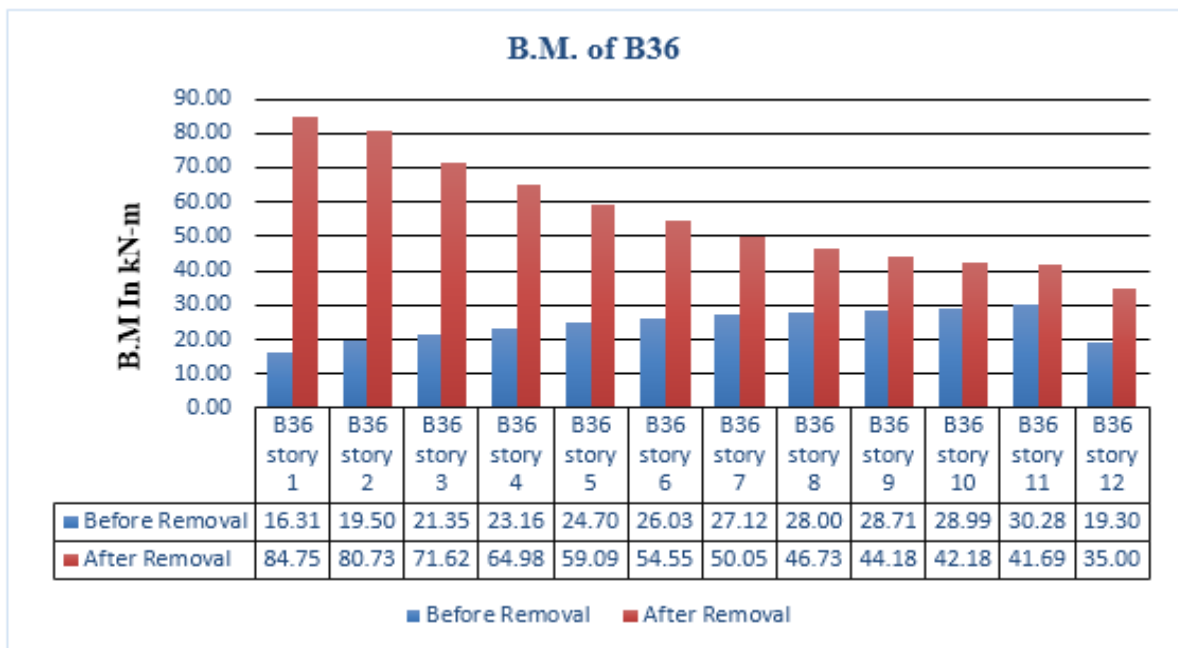
Graph. 4. Rebar Percentage of column C42

Rebar Percentage of original structure is in a range of 0.8% to 4.02% but due to sudden column removal, load distributed to nearest member and the Rebar Percentage is suddenly increases above the removal location max up to 5.53%.



Graph. 5. BM of beam no. B1

After removal of column C6, adjacent beams transform their form from simply supported to cantilever beams. From above graph, maximum bending moments before removal of column and after removal of column are varies from 13.09kN-m to 102kN-m.

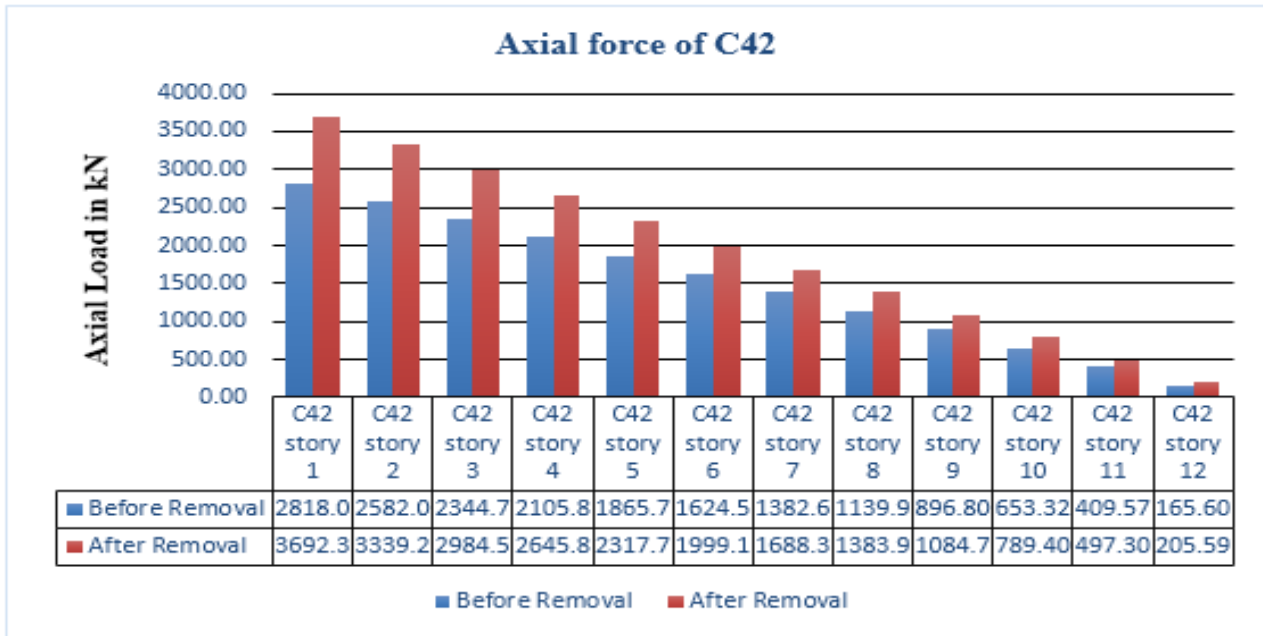


Graph. 6. BM of beam no. B36



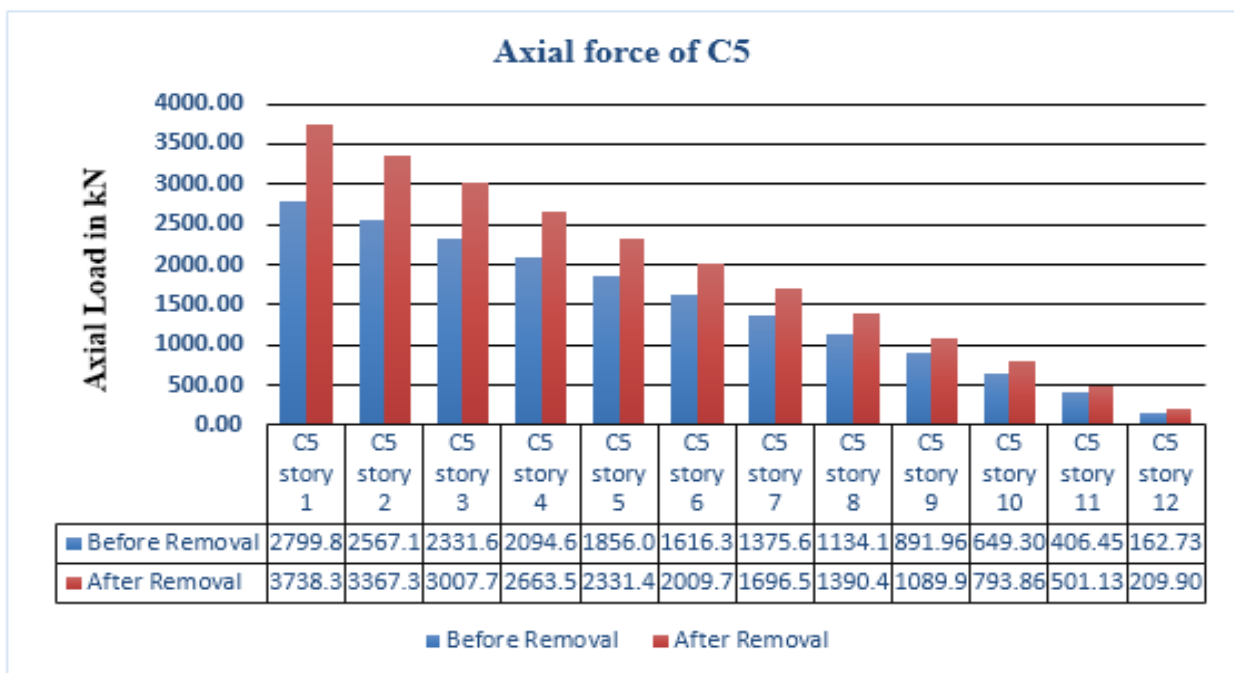


From Graph 6 It is observed that after removal of first floor column BM value of B36 changes largely near the column removal location after that effect is minimized.



Graph. 7. Axial Force of column no C42

After removal of column the force taken by this member is transfer to column C42 and C5. Hence axial forces on that column after removal of column C6 is suddenly increased.



Graph. 8. Axial Force of column no C5

After removal of column the force taken by this member is transfer to column C42 and C5. Hence axial forces on that column after removal of column C6 is suddenly increased.

## V. CONCLUSION

In this research study, the researcher has analysed G+12 structure for nonlinear progressive collapse. The observations of the study are made as follows:

From the study, and Software analysis following conclusions are drawn out:

1. After the removal of Corner Column C6, Interior Column C16 and Exterior Column C40, due to less load carrying capacity after column removal the loads are transferred to adjacent columns hence, Joint displacement is largely increased and after removal of columns at different locations
2. Rebar Percentage of all adjacent columns is increased in all column removal cases i.e. Corner Column C6, Interior Column C16 and Exterior Column C40, but corner column removal case observes more increment in rebar percentage because of less alternative paths for redistribution of loads as compared to other two locations of column removal.
3. Bending Moment values of beam are largely increasing at Corner column i.e. Column C6 than other two locations because of less scope of redistribution of moments to adjacent members as compared to other two locations of column removal.
4. Axial forces in columns are increased more in the column Adjacent to corner column because of the small number of alternative ways to redistribute the efforts, in contrast with the other cases i.e. to interior and exterior column.
5. From this study it is observed that maximum readings are obtained for corner column removal and out of three locations, Corner column i.e. corner location (C6) shows the effects of progressive collapse larger than other two cases. And that column location is critical for progressive collapse.

Progressive collapse is seen maximum for ground floor location as compared to higher storey removal location. When interior column is failed due to some reasons then building undergoes major collapse than corner or any exterior column.

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