

# NON-LINEAR STATIC PROGRESSIVE COLLAPSE ANALYSIS OF HIGH RISE R.C.C. STRUCTURE

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**Abstract** - As per recent developments in construction, the architects required to plan the high rise structures in RCC. Unfortunately due to some reasons such as gas explosion, terrorist attack, fire etc. high rise structures undergoes some major component failure. Because of the failure of major component, sometimes part of the structure or whole structure tend to collapse. In other words this behaviour of structure is called as progressive collapse

In this project it is proposed to carry out progressive collapse analysis of 12 storey RC frame building by removing different column one at a time as per the GSA guidelines. Building consists of 6 X 5 bay 3 m in X and Y-direction and designed by Indian code. Structural model of building has been created in ETABS and loads are applied as per GSA guidelines, for evaluation of progressive collapse nonlinear static method of analysis has been used. As per given in GSA, three column removal cases for 1st floor has studied like corner column C1, interior column C43 and exterior column C47. For these cases non linear static analysis has done and joint displacements for three column removal cases are evaluated. Also, PMM ratio and axial force for adjacent columns and bending moments for adjoining beams are evaluated.

Results are obtained that, for progressive collapse of interior column is more critical than other two locations ie. Corner and exterior column.

**Key Words:** Progressive Collapse, non linear static analysis, Etabs 2015.

## 1. INTRODUCTION

Progressive collapse is a term now a days used worldwide. progressive collapse phenomenon is initiated by the failure of one or more load carrying members. At the time of failure, to transfer excessive load, structural elements structure will seek alternate load paths. sometimes structure may not be designed to resist additional loadings. Failure of overloaded structural elements will cause further redistribution of loading, this process will continue till the equilibrium is reached. when elements may reached equilibrium already a large part of structure has already collapsed. The resulting overall damage may be disproportionate to the damage in the local region near the lost member.

The American Society of Civil Engineering (ASCE, 2005) is the only mainstream standard which addresses the issue of progressive collapse in some detail. 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 have provided a methodology to diminish the progressive collapse potential in structures based on Alternate Path Method (APM). It defines scenarios in which one of the building's columns is removed and the damaged structure is analyzed to study the system responses. With the current scenario of increasing reasons for disaster like situation at industrial or residential workplace. The main objective of this study is to implement GSA guidelines for RCC structure in three dimensional, which are designed according to Indian standard codes to assess the vulnerability behaviour. The procedure have been carried out is Non Linear Static (NSL) according to the guidelines, and analyzed by using by finite element software Etabs 2015.

## 2. LITURATURE SURVEY

Progressive collapse study is in picture after Ronan point apartment building and after that incident progressive collapse is studied by various researchers. There are lot of research carried out on many aspects of progressive collapse of RCC structure. R. Shankar Nair (March 2004) describes in paper previous structural collapse and observation on progressive collapse and description of proportionate and disproportionate collapse [1]. Wibowo, H. and Lau, D.T. (2009) summaries the merits and limitations of available analysis methods for assessment of progressive collapse of structures and paper concluded that seismic progressive collapse of structures can be analyzed by modifying the current analysis procedures[2]. Three researchers Bruce R. Ellingwood Robert Smilowitz Donald O. Dusenberry Dat Duthinh H.S. Lew Nicholas J. Carino (2007) discussed three methods in this document indirect method, specific local resistance method and alternate load path method to reduce progressive collapse. The methodology for evaluating the progressive collapse potential of existing buildings is also discussed[3]. Halil Sezen (PI) and Kevin A. Giriunas (May 2009)

investigates the existing structure’s potential to fail due to progressive collapse. Author concluded that the existing building is unique because second floor was collapsed at the initial stage of experiment[4]. Authors Yanchao Shi , Zhong-Xian Li , Hong Hao (2010) studied RC structure under blast loading prone to progressive collapse. A new method for progressive collapse analysis of reinforced concrete (RC) frame structures by considering nonzero initial conditions and initial damage to adjacent structural members under blast loading is proposed And it is found it gives better prediction[5]. Weifeng Yuan and Kang Hai Tan (2011) to incorporate the pancake type progressive collapse of multistory structure. This paper concludes that the local member failure in a multi-storey structure may lead to a global progressive collapse[6]. In this present study by A.R. Rahai, M. Banazadeh, M.R. SeifyAsghshahr& H. Kazem (2012) progressive collapse in RC structures resulting from both instantaneous and gradual removal of columns is observed[7].Rakshith K G, Radhakrishna (2013) studied RCC structure of 12 story. Paper concludes that, 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) describes linear static analysis of a multi-storeyed building, authors concludes that seismically designed building having good resisting capacity to progressive collapse[9].Ram Shankar Singh, Yusuf Jamal, Meraj A. Khan (2015) studied five storey reinforced concrete framed structure symmetrical and Unsymmetrical by geometry and conclude that to avoid progressive collapse, adequate reinforcement is required to limit the DCR within the acceptance criteria[10]. authors A. Choubey and M.D. Goel (2015) studied RCC building designed based on Indian standard code of practice is considered and concludes that the effect of transferring the load is more on the nearest member of the removed member and negligible when moved away from removed column[11]. Ram Shankar Singh,Yusuf Jamal, Meraj A. Khan (2015) states that seismically designed building columns have inherent ability to resist progressive collapse. 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].

**3. MODELLING OF STRUCTURE**

To observe the structural behavior of RCC building for progressive collapse it is necessary to build up 3D model by using finite element model, analyse and design that model by using ETABS(15) . Here are some tables related to modeling of structure

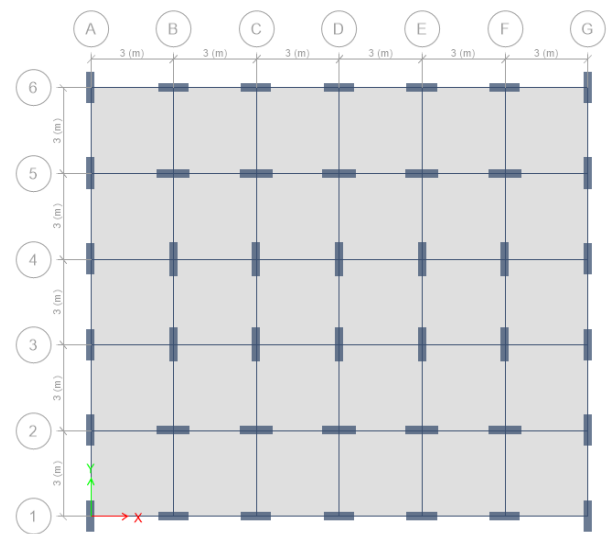


Fig.1. Typical Plan layout of ETABS model

TABLE 1. MODELLING DETAILS FOR IRREGULAR STRUCTURE

Sr. no.	Particulars	Description
1	Type of Structure	RCC Framed structure
2	Type of Building	Commercial Building
3	Number of stories	G+12
4	Height of Building	42m
5	Spacing in X-Direction	18m
6	Spacing in Y-Direction	15m
7	Material	M30, Fe500
8	Thickness of Slab	150mm
9	Codal Provision	IS456:2000,IS1893:2002,GSA2003

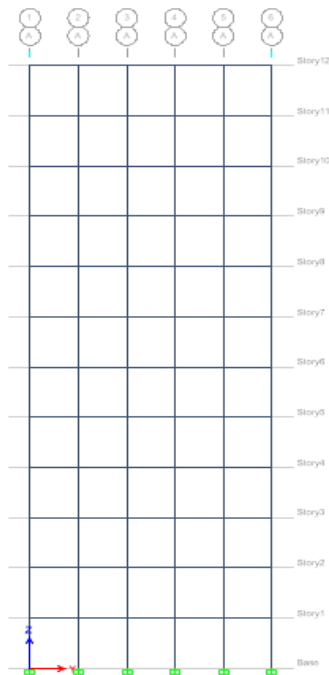


Fig.2 .2D Elevation of ETABS Models

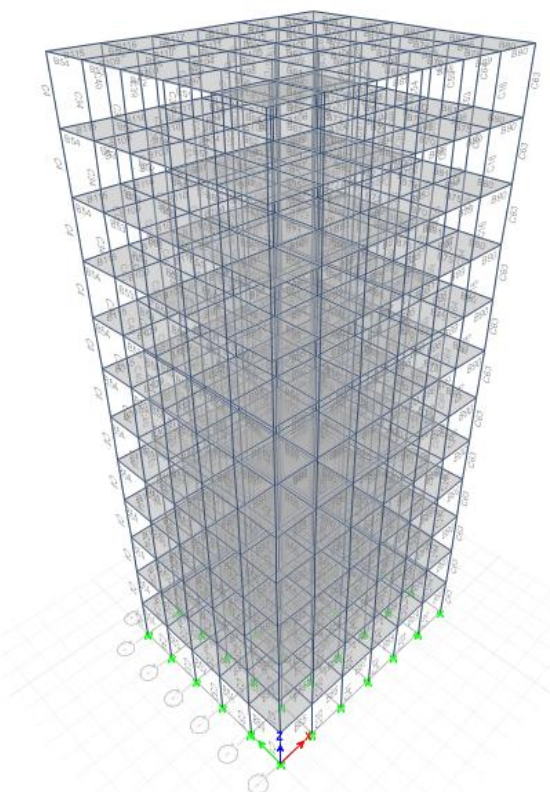


Fig. 3. 3D Elevation of Model

#### 4. METHODOLOGY

This Study is based on analysis of RCC structure for progressive collapse, Considering Sudden Loss of Column as a design Scenario and considering different locations for sudden loss of column and its effect on progressive collapse. There are many codes and Guideline available worldwide but most of the research work uses the GSA guideline. For this research work, there are various methods to analyse the structures and investigate their response to the progressive collapse phenomenon, we used GSA for further guideline. The aim of this work is to study Progressive Collapse over the sudden loss of a column, to study 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, Non linear static analysis, linear dynamic analysis, Non linear dynamic analysis are given as per GSA guidelines. But for our research work we are analysing model for non linear static analysis.

##### 4.1 Non Linear static analysis procedure

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

To model, analyze, and evaluate a building, employ a three-dimensional assembly of elements and components. Create one model for framed structure. Apply non linearity conditions and Dynamic Increase Factor. Apply plastic hinges as per ASCE 41 and FEMA. Then apply loadings as per GSA guidelines. Then run non linear analysis and find out results as per our considerations.

##### 4.2 Load Cases for Non Linear static analysis

Case I: Force Control action  $Q_{uf}$  for linear static

$$G LF = \Omega LF [1.2 D + (0.5 L \text{ or } 0.2 S)] \quad (1)$$

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  $Q_{uf}$  for non linear static  
Apply the following increased

$$GN = \Omega N [1.2 D + (0.5 L \text{ or } 0.2 S)] \quad (2)$$

Where,

GN = 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 GN

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

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

### 4.3 Loading data used for modeling

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

### 4.4 Progressive collapse analysis

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

Case1 : analyzed for sudden loss of corner column C1

Case2 : analyzed for sudden loss of middle column C43

Case3 : analyzed for sudden loss of centre column C47

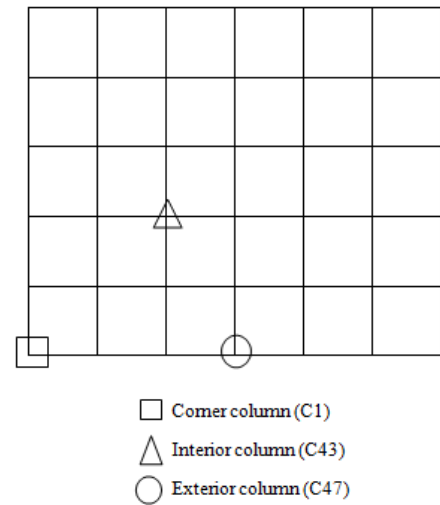


Fig.4 Detail Description of Model

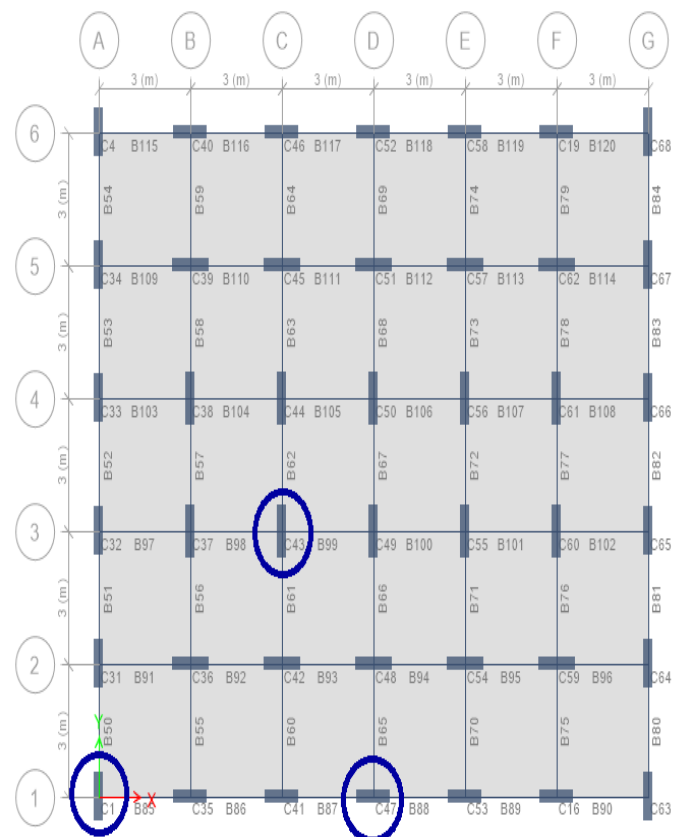
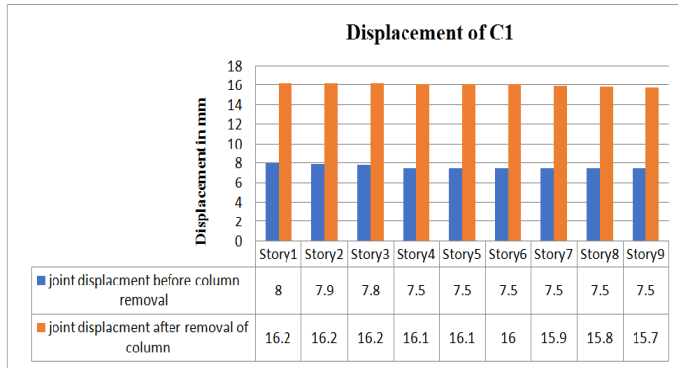


Fig.5. Location of Column Removal

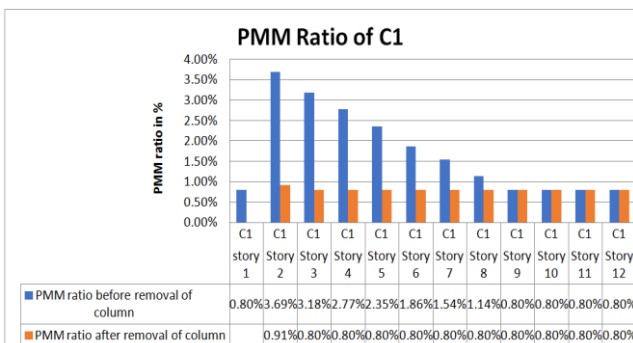
## 5. RESULTS AND DISCUSSION

### 5.1 RESULTS FOR REMOVAL OF COLUMN C1



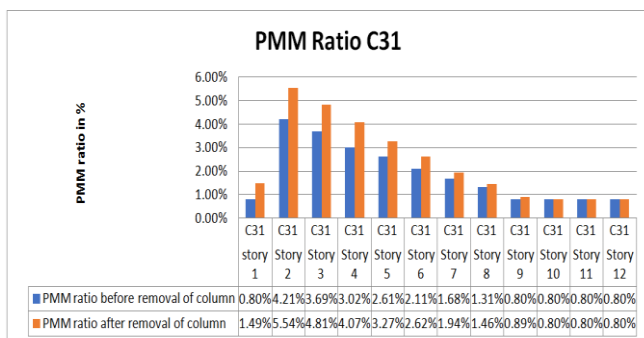
Graph. 1. Joint displacement of column C1

Joint displacement of column C1 before column removal was 8mm but due to sudden loss of column C1 and after Non Linear Static Procedure carried out, joint displacement was suddenly increased to 16.2mm due to less load carrying elements carries extra load.



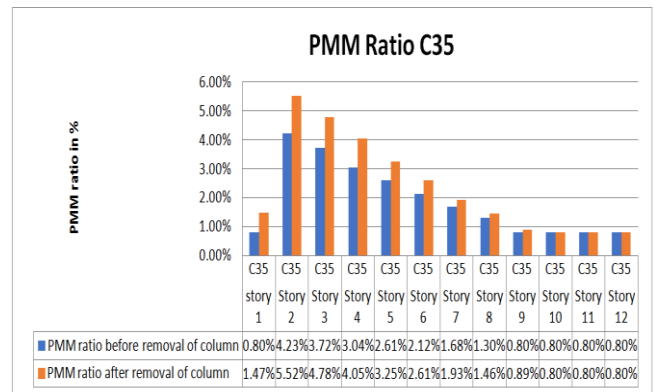
Graph. 2. PMM ratio For column no C1

From graph 2, PMM ratio or % rebar of original structure is in a range of 0.8 to 3.7. initially column had two supports but due to sudden loss of column it transform into cantilever and PMM ratio (%rebar) minimized to 0.8.



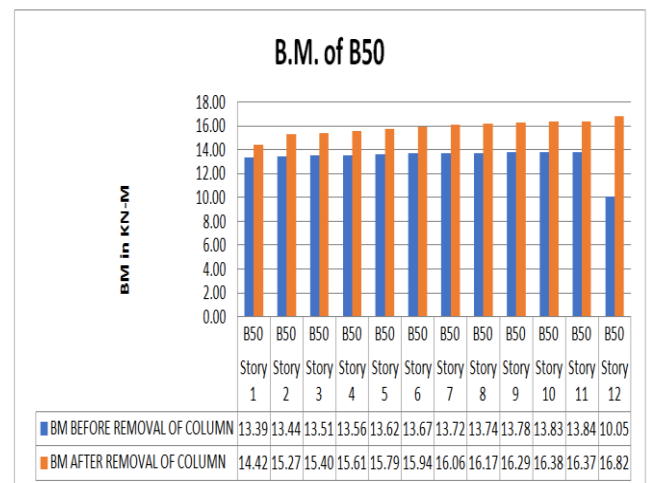
Graph. 3. PMM ratio For column no C31

PMM ratio of original structure is in a range of 0.8 to 4 but due to sudden column removal load distributed to nearest member and the PMM ratio is suddenly increases above the removal location max upto 5.54



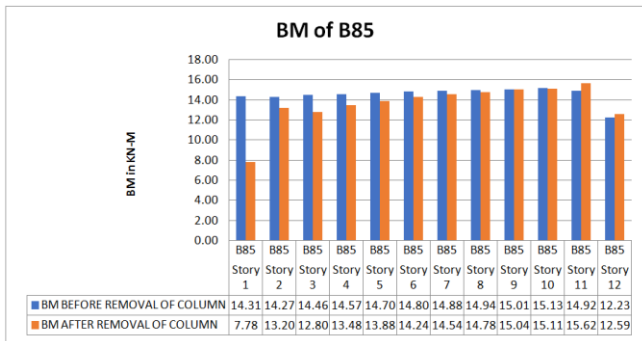
Graph. 4. PMM ratio For column no C35

PMM ratio of original structure is in a range of 0.8 to 4 but due to sudden column removal, load distributed to nearest member and the PMM ratio is suddenly increases above the removal location max upto 5.52.



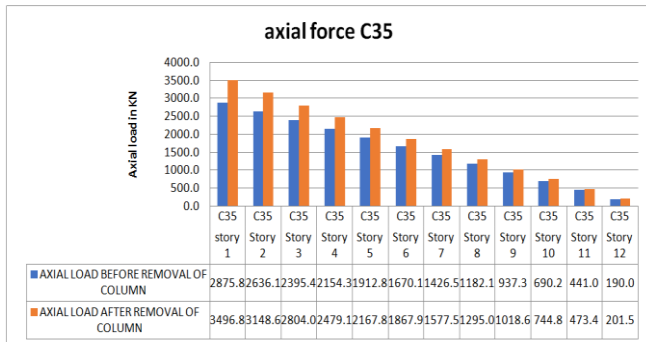
Graph. 5. Bending Moment For beam no B50

After removal of column C1, adjacent beams transform their form from simply supported to cantilever beams. From above graph, bending moments before removal of column and after removal of column are varies from min.10 and max.13.78 to 16.3. bending moments are increased after column removal.



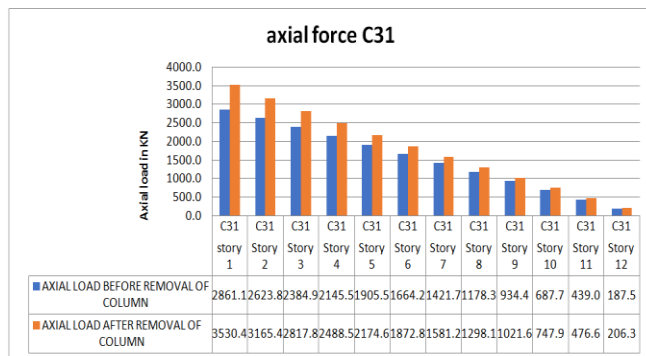
Graph. 6. BM of beam no. B85

From graph it is observed that after removal of first floor column BM value of B85 changes largely near the column removal location after that effect is neutralized.



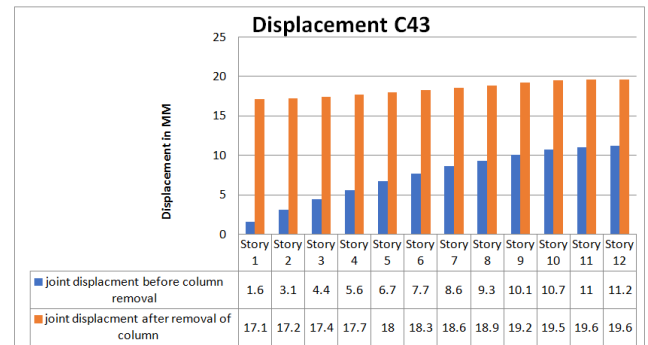
Graph. 7. Axial Force of column no C35

Axial force is important factor to check column is safe or not. After removal of column the force taken by this member is transfer to column C35 and C31. Hence axial forces on that column after removal of column C1 is suddenly increased. Values of increased loads are given in graph.7 and 8.



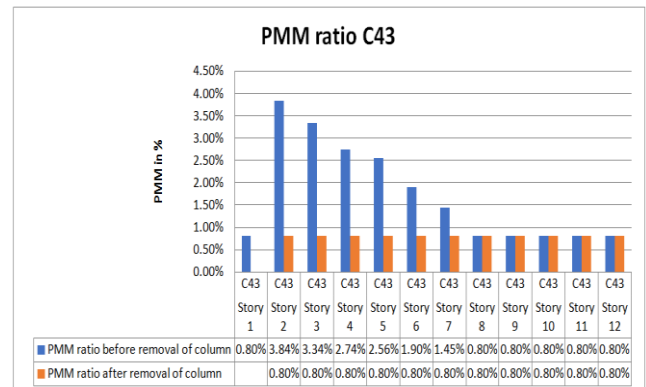
Graph. 8. Axial Force of column no C31

## 5.2 RESULTS FOR REMOVAL OF COLUMN C43



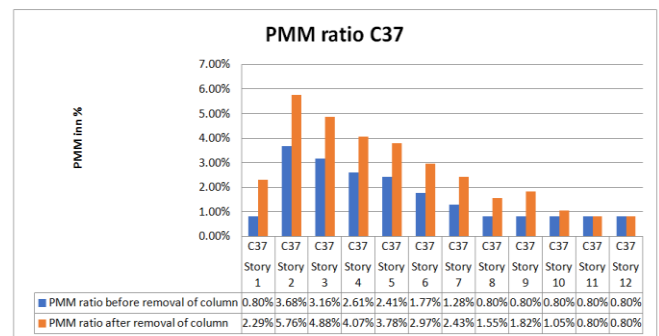
Graph .9. joint displacement of column no C43

Displacement at node 43 is changes after removal of column is considerable. Before removal of column initial displacement was min. 1.6mm and max. 11.2, after removal of column max displacement is 19.6mm.



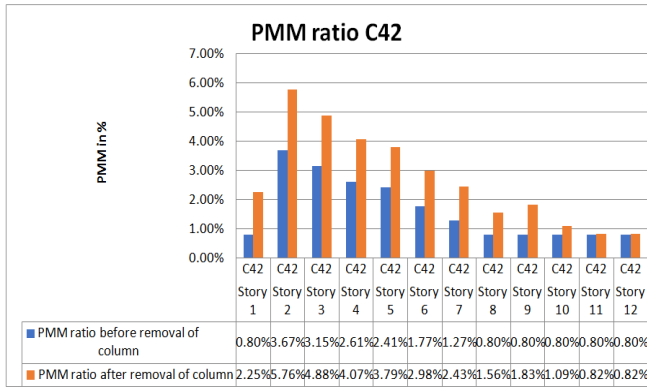
Graph. 10. PMM ratio of column no C43

From graph of PMM ratio or % rebar of original structure is in a range of 0.8 to 3.84. initially column had two supports but due to sudden loss of column is converted into cantilever and PMM ratio (%rebar) minimized to 0.8 for all above stories.



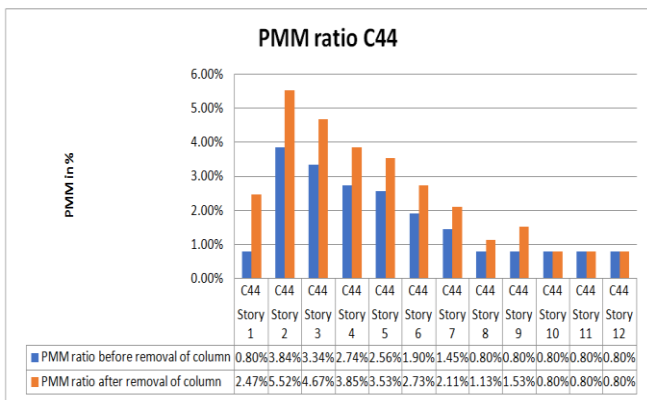
Graph. 11. PMM ratio of column no C37

Initially PMM ratio of original structure is in a range of 0.8 to 3.16 but due to sudden column removal, load distributed to nearest member and the PMM ratio is suddenly increases above the removal location max upto 5.76.



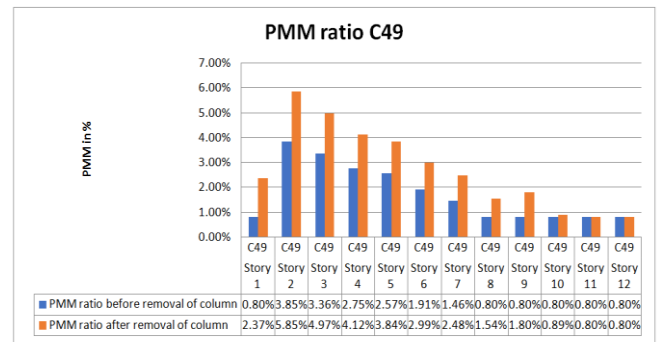
Graph. 12. PMM ratio of column no C42

PMM ratio of original structure is in a range of 0.8 to 3.67 but due to sudden column removal, load distributed to nearest column and the PMM ratio is suddenly increases above the column removal location max upto 5.76.



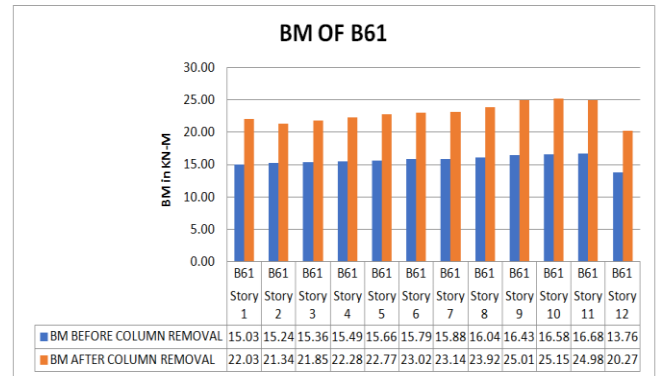
Graph. 13. PMM ratio of column no. C44

Initially PMM ratio of original structure is in a range of 0.8 to 3.84 but due to sudden column removal, load distributed to nearest member and the PMM ratio is suddenly increases above the removal location max upto 5.52.



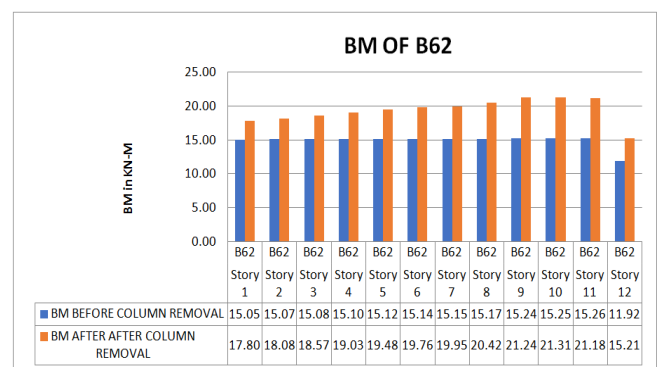
Graph. 14. PMM ratio of Column no. C49

From graph no.14 PMM ratio of original structure is in a range of 0.8 to 3.36 but due to sudden column removal, load distributed to nearest member and the PMM ratio is suddenly increases above the removal location max upto 5.85.



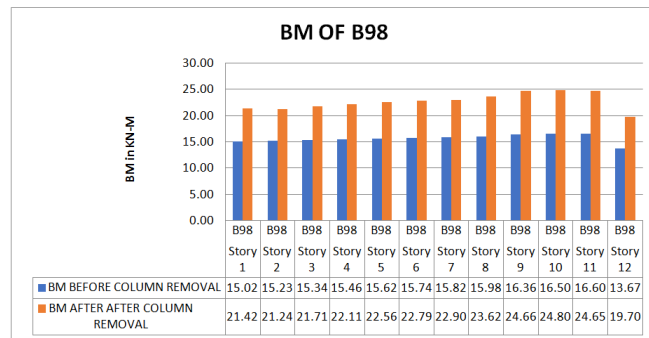
Graph. 15. Bending Moment of beam no. B61

After removal of column C43, adjacent beams transform their form from simply supported to cantilever beams. From above graph, bending moments before removal of column and after removal of column are varies from 15 to 25.15. bending moments are increased after column removal.



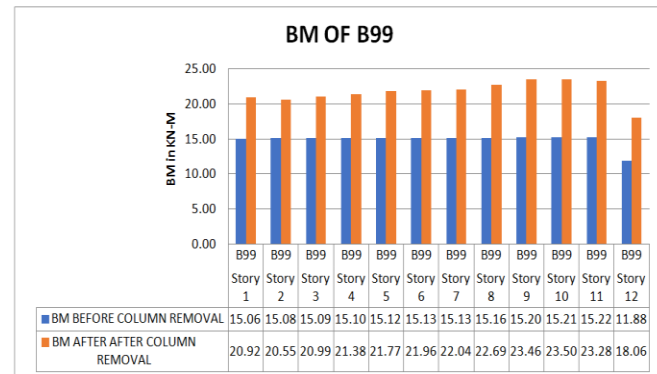
Graph. 16. Bending Moment of beam no. B62

From graph it is observed that after removal of first floor column BM value of B62 changes largely near the column removal location after that effect is neutralized.



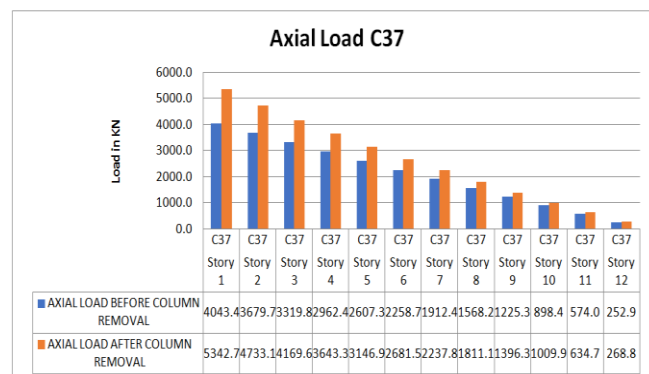
Graph. 17. Bending Moment of beam no. B98

After removal of column C43 it is observed that after removal of first floor column, BM value of B98 changes largely than before.



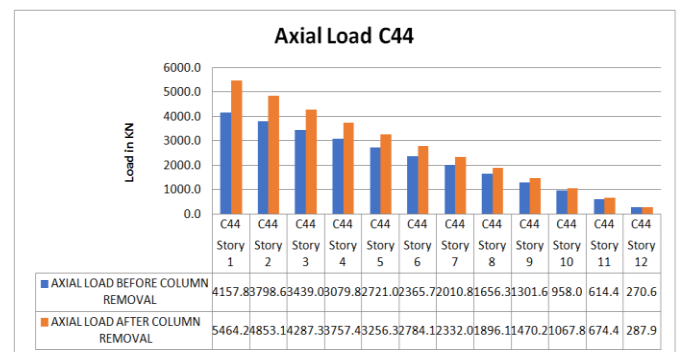
Graph. 18. BM of beam no B99

After removal of column, simply supported beams act like a cantilever beams. Bending moments increased suddenly after column removal.



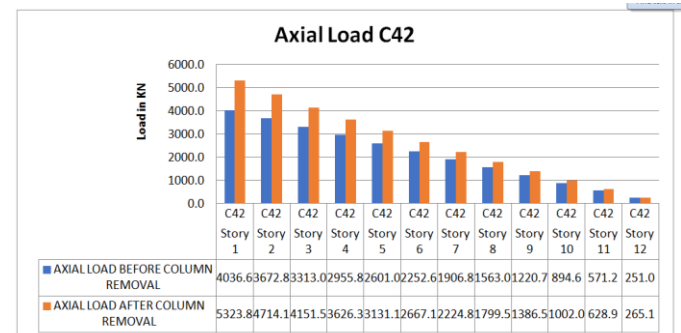
Graph. 19. Axial load on column no C37

After removal of column C43 the force taken by the column is transfer to adjacent columns. Hence axial forces on that column after removal of column C43 is suddenly increased.



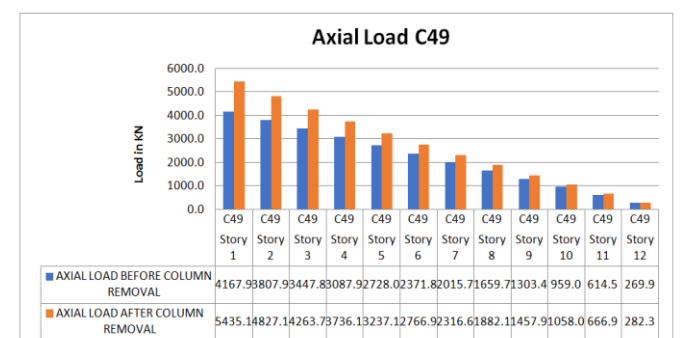
Graph. 20. Axial load on column no C44

After removal of column C43 the force taken by this member is transfer to adjacent column C37, C44, C42 and C49. Hence axial forces on that column after removal of column C43 was suddenly increased.



Graph. 21. Axial load on column no C42

When column C43 is removed, load on column is distributed to the columns of vicinity. C43 is interior column and surrounded by 4 columns. After removal of column load is transfer to the surrounded columns and axial load on the columns is suddenly increased.

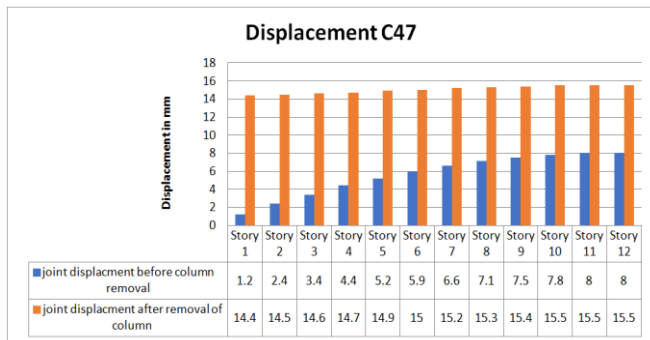


Graph. 22. Axial load on column no C49

After removal of column C43 the force taken by the column is transfer to adjacent columns. Hence axial forces on that column after removal of column C43 is suddenly increased.

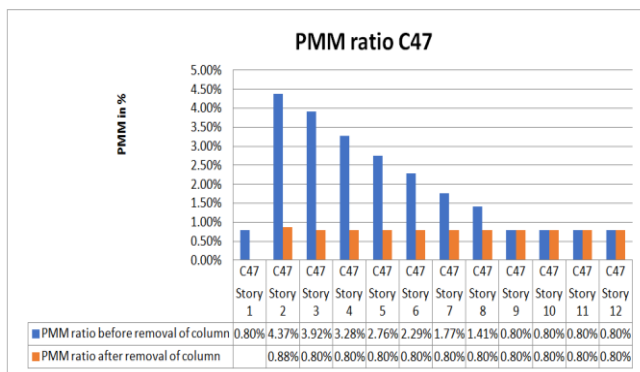


### 5.3 RESULTS FOR REMOVAL OF COLUMN C47



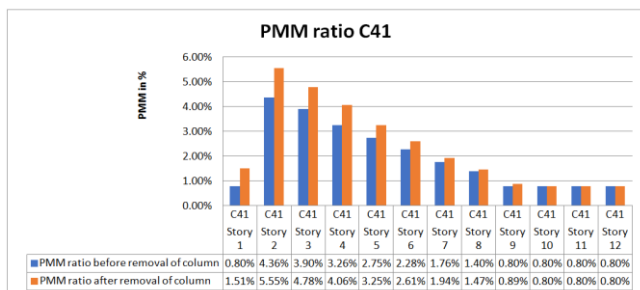
Graph. 23. Displacement of column no. C47

Displacement at column C47 is changes after removal of column is considerable. Before removal of column initial displacement was min. 1.2mm and max. 8, after removal of column max displacement is 15.5 mm.



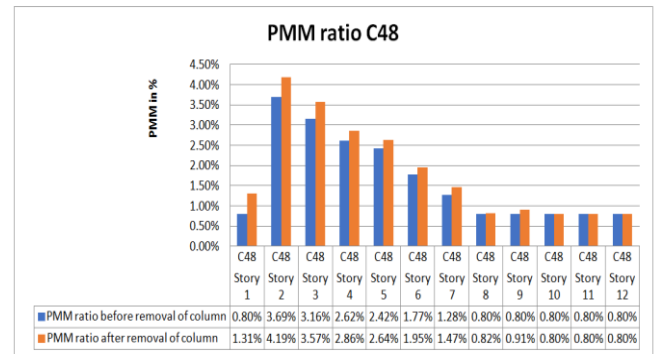
Graph. 24. PMM ratio of column No.C47

From graph of PMM ratio or % rebar of original structure is in a range of 0.8 to 4.37. initially column had two supports but due to sudden loss of column is converted into cantilever and PMM ratio (% rebar) minimized to 0.8 for all above stories.



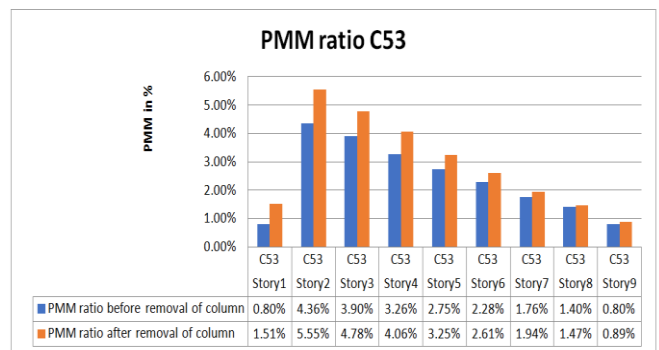
Graph. 25. PMM ratio of column No.C41

PMM ratio of original structure is in a range of 0.8 to 4.36 but due to sudden column removal, load distributed to nearest column and the PMM ratio is suddenly increases above the column removal location max upto 5.55.



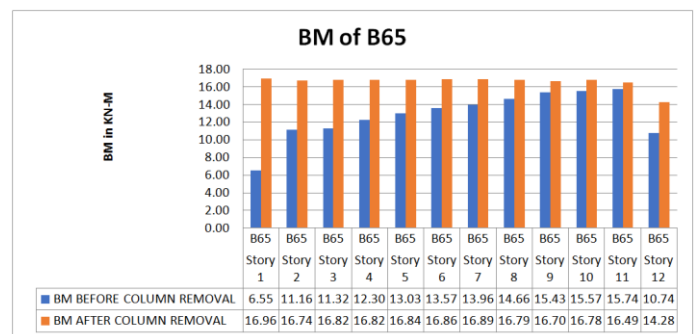
Graph. 26. PMM ratio of column No.C48

From graph no.14 PMM ratio of original structure is in a range of 0.8 to 3.69 but due to sudden column removal, load distributed to nearest member and the PMM ratio is suddenly increases above the removal location max upto 4.1.



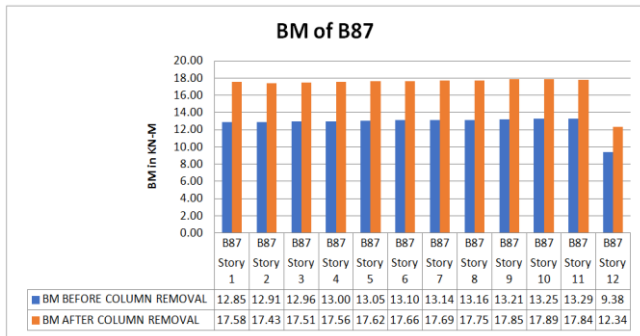
Graph. 27. PMM ratio of column No.C53

PMM ratio of original structure is in a range of 0.8 to 4.36 but due to sudden column removal, load distributed to nearest column and the PMM ratio is suddenly increases above the column removal location max upto 5.55.



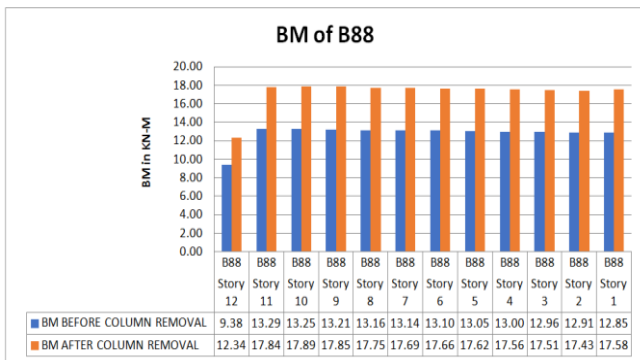
Graph. 28. Bending Moment of beam no.B65

After removal of column C47, bending moment of adjacent beams increased suddenly. Min bending moment at 1st story is 6.55KN-m after removal of column C47 bending moment it reaches 16.96 KN-m. At all stories bending moment increases suddenly.



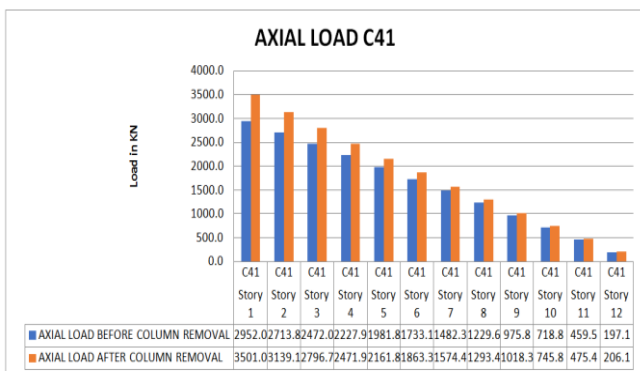
Graph. 29. Bending Moment of beam no.B87

After removal of column, simply supported beams act like a cantilever beams. Bending moments increased suddenly after column removal. Initially BM is max. 13.3KN-M after removal of column it reaches 17.8KN-M .



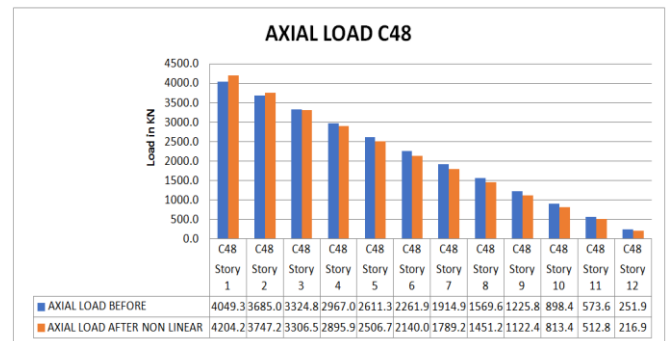
Graph. 30. Bending Moment of beam no.B88

After removal of column, simply supported beams act like a cantilever beams. Bending moments increased suddenly after column removal. Initially BM is max. 13.1KN-M after removal of column it reaches 17.89KN-M .



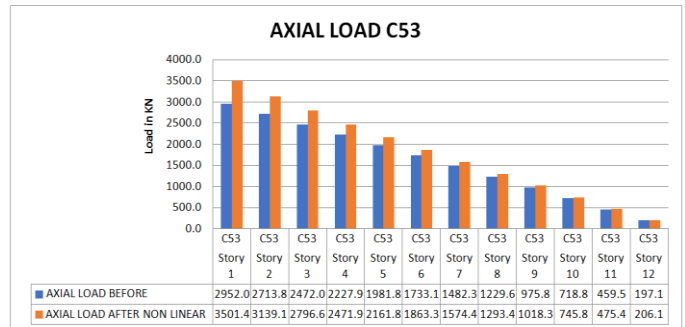
Graph.31. Axial load of column C41

When column C47 is removed, load on column is distributed to the columns of vicinity. C47 is exterior column and surrounded by 3 columns. After removal of column load is transfer to the surrounded columns and axial load on the columns is suddenly increased.



Graph. 32. Axial load of column C48

After removal of column C47 the force taken by the column is transfer to adjacent columns. Hence axial forces on that column after removal of column C47 is suddenly increased.



Graph. 33. Axial load of column C48

After removal of column C47 the force taken by this member is transfer to adjacent column C41, C48 and C53. Hence axial forces on that column after removal of column C47 was suddenly increased.

## 6. SUMMURY AND CONCLUSION

In this study we analyze G+12 structure for non linear progressive collapse. Following observations are made.

- 1.for removal of C1, C43 and C47, joint displacement is larger in C43 ie. at Interior column.
- 2.PMM ratio (% rebar) is suddenly increasing at interior column location as compare to corner and exterior column locations.
- 3.BM values of beam are largely increasing at interior column than other two locations because these beams get affected more.
- 4.Axial forces are increased in locations near to interior column, after removal of exterior column C43.

From this study it is observed that maximum readings are obtained for interior column removal and out of three

locations, middle central location ie. Interior location (C43) shows the effects of progressive collapse larger than other two cases. And that column location is critical for progressive collapse.

When interior column is failed due to some reasons then building undergoes major collapse than corner or any exterior column.

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