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STUDY PROGRESSIVE COLLAPSE UNDER GEOMETRIC NONLINEARITY USING ETABS

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Abstract - *The R.C.C building is consisting of elements such as column, beams, Slab, Foundation etc. these elements are also mention as load bearing elements of the structure. However there are mainly two types of load that acts on structure and loads are dead (DL) and live (LL). The dead load consists of the weight of everlasting structure elements such as column; beam whereas the live load incorporates of weight of moving people, furniture etc. A typical model of a 12storey structure is made on ETABS Software. The collapse materialize only on some elements of the building structure, does not arise in the whole structure of the building. The disinterested of this project is to find censorious columns in building which causes maximum damage or collapse after the removal. Column interaction ratios and bending moment of beams are the main factors considered for study. Succeeding this collapse load pattern of building is studied using same software.*

The developments in construction make it compulsory for architects to plan the high-rise structures in RCC. U N fortunately due to some reasons like gas explosion, terrorist attack, fire etc. high-rise structures under goes some major component failure. As the important component fails, sometimes part of the structure or whole structure frequently to collapse. This behaviour of the structure is called as progressive collapse. Progressive collapse may be a vicious circle of failures that circulates either throughout or some of the structure unsymmetrical to the first local failure. The progressive collapse of building structure is beginning when one or more vertical load conveys members are removed. One of the major important characteristics of progressive collapse is that the ultimately damage is not related to the initial damage. In this project it is advice to carry out progressive collapse analysis of regular and irregular structures. Structural model of building has been fabricating din ETABS and loads are appertaining as per guidelines, for the evaluation of progressive collapse nonlinear static method of analysis has been used. The analysis is done using ETABS 16 software and using codes of analysis, IS 1893: 2016, IS 456: 2016. Joint displacements, axial force, bending moment are evaluated. In all demonstration progressive collapse of internal column is more censorious as compared to other censorious.

***Key Words*: Rectangular column, Gravitational load, progressive collapse, Column force, Interaction ratio.**

1.INTRODUCTION

Progressive collapse occurs when relatively little structural damage triggers a chain reaction of structural element failures that outweigh the initial damage, causing the structure to partially or completely collapse.
This study aims to provide the designer engineers with recapitulation on this topic to minimize the repercussion of buildings progressive collapse after the event of column removal system.
The collapse behaviour of the whole structures was analysed by different numerical methods.
The important advantage and intention of using these design and analysis software is that they not only make construction economic but also make it uncomplicated and less time consuming.
More or less all types of loads and geometric disposition can be manipulated by both the software efficiently.
This work aims to consider the progressive collapse and the behaviour of masonry buildings subject to gravitational load. An extensive literature review is carried out.

2. Literature Review

2.1 GENERAL

As the present study deals with the Progressive Collapse failure of RCC column and Beam, a literature review has been conducted on previous studies on Progressive Collapse failure of RCC column and Beam. This Chapter presents various literatures in this area.

PREVIOUS RESEARCH WORKS ON PROGRESSIVE COLLAPSE ANALYSIS OF RCC STRUCTURE

1. **Progressive Collapse Analysis of RC Buildings using Linear Static and Linear Dynamic Method.** International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 8, August – 2014 IJERTIJERT ISSN: 2278-0181.

Corresponding Author: Bhavik R .Patel M.Tech (Civil-STRUCTURAL DESIGN).

- Columns on the entire structure; 12 stores moment Resistant RC buildings are considered.
- The buildings are modelled and analysed for progressive collapse using the structural analysis and design software ETABS.

- Study of the vertical displacement under the column removal locations is carried out for middle one the ccolumn removal.

2. **A Comparison of the Analysis and Design of 12 Story Using ETABS Software.** International Journal of Research (IJR) e-ISSN: 2348-6848, p- ISSN: 2348-795X Volume 3, Issue 05, March 2016. Corresponding Author: Puneet Mittal; Nishant Kad.
    - This paper will check the degree of variations between the results of those obtained by two different design softwares STAAD PRO and ETABS.
    - The analysis results of column, we may conclude that ETABS gave lesser forces as compared to STAAD PRO.
3. **Comparative study of a G+10 storied building using ETABS**. © 2017 IJSRST | Volume 3 Corresponding Author: Ramanand Shukla, Prithwish Saha.
    - The present study is mainly limited to the basic comparison between their analytical results under vertical loadings. The study then further extended and horizontal load is applied and the plan position of lift wall (shear wall) is optimized in terms of developed horizontal base shear at different support positions.
    - The structures are analyzed in both the software and the results are presented below.
4. **Modelling of RC Frame Buildings for Progressive Collapse Analysis** (Received October 29,2015, Accepted January 9, 2016, Published online March 9, 2016) International Journal ofConcrete Structures and Materials Vol.10, No.1, pp.1–13, March 2016DOI 10.1007/s40069-016-0126-yISSN 1976-0485 / eISSN 2234-1315

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- The results presented in this study offer useful guidelines on modelling and simulation of progressive collapse of RC Frame structures within the context of the APM. Using a simple case study of a RC frame structure, various issues in modelling of materials and elements are presented with a view to providing practical insights into progressive collapse simulations.

2.2 OBJECTIVES AND METHODOLOGY

To study of analysis of multi-story building by apply gravitational load. And Study of progressive collapse of a RC building by nonlinear dynamic analysis using ETABS 2016.

2.3 METHODOLOGY

The methodology worked out to achieve the above-mentioned objectives is as follows:

- Review the existing literature in the area of progressive collapse due to sudden column loss in three cases.
- In this project G+12 multi-story building is considered and modelling techniques used in the ETABS 2016.
- Procedure for Progressive Collapse.
- Checking various loads acting on structure.
- Designing structural element in ETABS using IS code.
- Fabricate a model which contains the entire structure, including the column to be removed. Scrutinize this model to procure the internal forces of the column which will be removed.
- Fabricate another model in which the column is separate. Apply the column end forces, acquire during the analysis of model, to simulate the occupancy of the removed column.

Parameter considered: -

- Effect and Loads acting on foundation.
- Effects and Loads acting Beams.

PROGRESSIVE COLLAPSE COLUMN REMOVAL CASES

- Researched the structural fragility of traditional RC constructions due to the lack of corner columns.
- An explosion or a vehicle-column collision can instantly detach the column.
- The current research aims to simulate the gradual elimination of the column.
- The findings would be compared to those obtained in the case of an instantaneous removal of the column.

2.4 MODELING

Modeling in ETABS 2016:

Analyses have been performed using ETABS, which is a structural analysis program used for non-linear dynamic analyses of building structures. In this study, ETABS 2016 Version 16.2.0 has been used.

A description of the modeling details is provided in the below sections. A three-dimensional model of the building structure is created in ETABS to carry out non-linear dynamic analysis. Beam and column elements are modeled as rectangular framed elements with material properties and section properties as mentioned in section III –B. And slab section is considered as membrane section with 120 mm thickness. The structure is loaded as mentioned in III-C accordingly and load combinations are predefined for carrying analysis. The structure is analyzed for non-linear dynamic analysis by creating time history function. Response-spectrum analysis (RSA) is a method in which the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure is measured. Response-spectrum analysis provides insight into dynamic behavior by measuring acceleration. The structure is subjected for loadings such as gravity loadings, seismic loadings, wind loadings and response spectrum loadings as mentioned in below sections and carried out the analysis. The concrete frame design is performed for the structure and all the elements are checked to observe whether all the structural elements are below the failure limit (Demand Capacity Ratios of the elements have been checked and all the DCR's are less than 1).

Building Configuration:

The Details of the building model (G + 10) is shown in figure 4.1 to figure 4.4, with individual story height of 3m is considered for the study. The total height of the building considered is 30m. The building considered also has vertical regularity. All column and beam sections are modeled as rectangular shape elements using frame elements and the slab section is modeled as membrane type. Section properties and material properties are as mentioned as below.

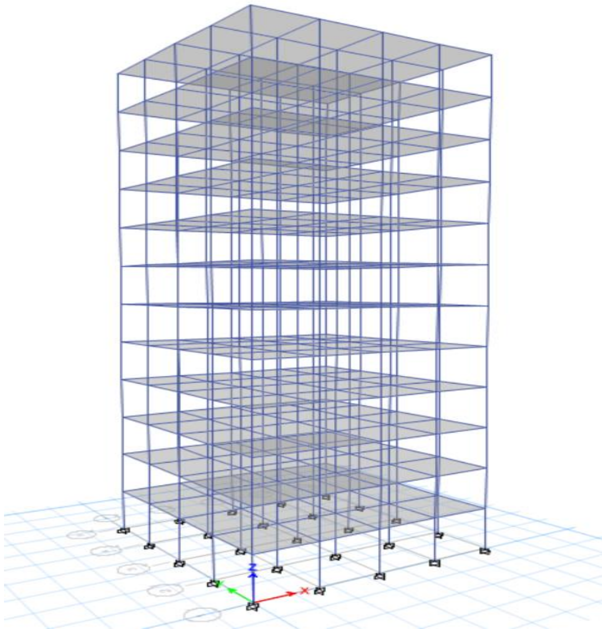


Fig.2.1 3D plan showing beam, column, floor, slab layout of the building in ETABS 2016

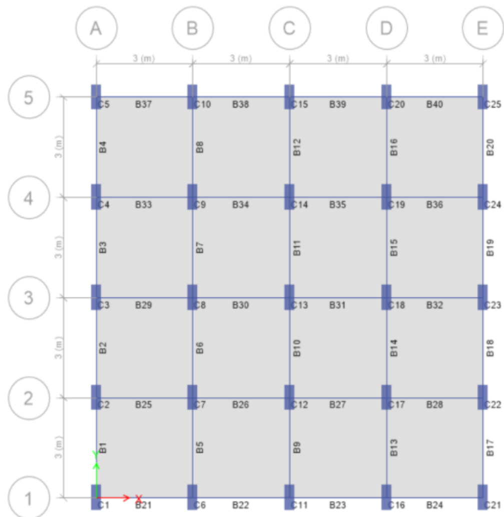


Fig.2.2Plan showing beam layout of the building in ETABS 2016

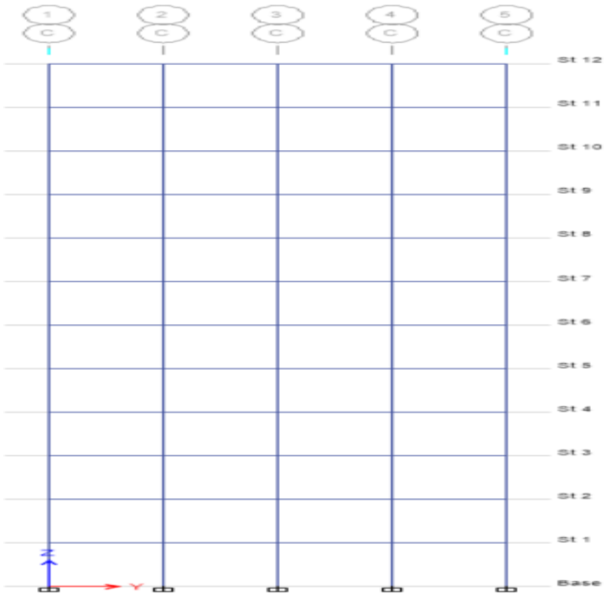


Fig 2.3 Elevation showing beam and column layout of the building in ETABS 2016.

ANALYSIS METHOD

4 The structure is designed to resist progressive collapse using dynamic analysis according to GSA guidelines by using ETABS software. The analyses are carried out to determine the potential for progressive collapse when it is subjected to the instantaneous removal of a primary vertical element. The assessment of the potential for progressive collapse using the results of analysis is achieved by using the acceptance criteria in the form of appropriate Demand-Capacity Ratios. DCR ratio are determined for all the columns and according to GSA guidelines columns with DCR ratio's greater than 1 are identified as critical columns. The critical columns are redesigned using enhanced local resistance method by increasing flexural and shear capacity of the columns.

5 **Non-Linear dynamic progressive collapse analysis**

Analyse G+ 12 models as shown in figure 4.4 using ETABS software considering lateral forces and Time History Function. Perform concrete design and determine the reinforcement to be provided in members. Create column loss scenario by removing ground floor column from the specified location one at a time as shown in figure 4.4. Apply the dynamic load combinations as per GSA 2016 guidelines. Perform Time History Analysis considering acceleration as load type and Time History function. Evaluate the results based on demand-to-capacity ratio (DCR), where demand is taken as the peak value of response from the calculated response spectrum analysis.

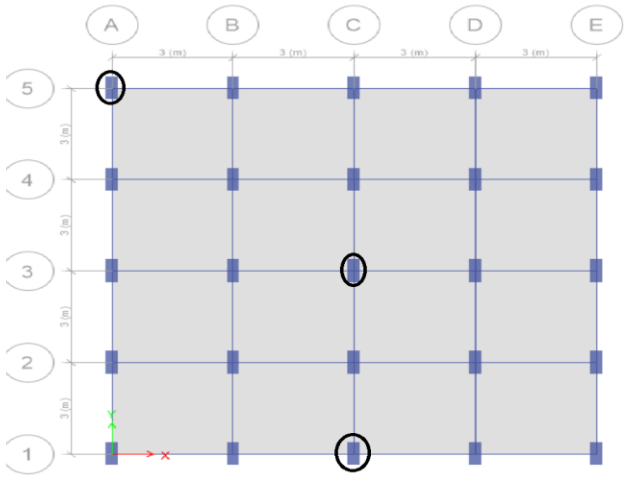


Figure 2.4: plan showing sudden loss of column layout of the building in ETABS 2016

A. Analysis Loading

Increased gravity loads for floor areas above removed column or wall.

GLF = ΩLF [1.2 D + 0.5 L]

GLF = Increased gravity loads for deformation-controlled actions for Linear Static Analysis

D = Dead load including façade loads (lb/ft^2 or kN/m^2)

L = Live load including live load reduction per Section (lb/ft^2 or kN/m^2)

ΩLF = Load increase factor for calculating force-controlled actions for Linear Static analysis=2

For other structural elements in the static analyses, the load combinations are.

Gravity Loads for Floor Areas Away From Removed Column or Wall.

G = [1.2 D + 0.5 L]

Whereas in case of Linear Dynamic Analysis apply the loading as mentioned in equation 2 to the entire structure.

B. Calculating DCR Value

Demand capacity Ratio is defined as the ratio of the force (bending moment, axial force, shear force) in the structural member after the instantaneous removal of a column to the member capacity.

DCR limit values depending on the cross sectional dimensions and on the construction materials. In DCR, demand indicates the Bending moment of the member obtained from the static analysis of frame and the capacity indicates the ultimate moment resistance

capacity of the member i.e. Plastic Moment. DCRs are not used to determine the acceptability of component behaviour, but it is used only to determine the structure's regularity of the building. DCRs for building components are calculated by following Eq. DCR= Mmax / Mp
Mmax: Bending Moment of the member obtained from the analysis
Mp: Expected ultimate moment capacity of the member. (Mp=0.138Fckbd2)
The acceptance criteria for DCR are given below
For typical structure (symmetrical structure) = DCR≤ 2.0

(a)Material Properties

1. Concrete
   - Grade of Concrete, fck = M30
   - Poisons ratio = 0.2
   - Density =30 kN/m3
   - Modulus of Elasticity = 30000 MPa
2. Steel
   - Yield Stress, fy = 500 MPa
   - Modulus of Elasticity = 2 x 105 MPa

(b) Section Properties

1. Different column sizes (1 to 4,5 to 8,9 to 12)
   - 300mmX750mm
   - 300mmX600mm
   - 300mmX450mm
2. Different beam sizes(1 to 4,5 to 8, 9 to 12)
   - 300mmX750mm
   - 300mmX600mm
   - 300mmX450mm
   - Thickness of slab = 140 mm

(C)Loadings

Primary loading considered on the building for the study are as:

Gravity loading:

- Dead load: Self weight of the structural elements
- Live load at typical floor: 6.0 (kn/m^2)
- Live load at terrace floor: 2.0 (kn/m^2)
- Live Load at Parapet Wall: 4.5 (Kn/m)
- Live Load at Partisan Wall: 5.52 (Kn/m)
- Floor finish floor: 1 (kn/m^2)
- Wall load: 12 (kN/m)

3. RESULTS

Table 3.1 Column Removal of a Building in Corner Location

COLUMN REMOVAL OF A BUILDING (WITH CORNAR COLUMN REMOVAL) AXIAL FORCR PU (Kn)			
STOREY	COLUMN	BRFORE	AFTER
St 1	C10	724.5298	2753.553
St 1	C4	671.5096	2668.17
St 2	C10	656.3794	2494.559
St 2	C4	609.6177	2418.834

Table 3.2 Column Removal of a Building in Middle Location

COLUMN REMOVAL OF A BUILDING (WITH MIDDLE COLUMN REMOVAL) AXIAL FORCR PU (Kn)			
STOREY	COLUMN	BRFORE	AFTER
St 1	C18	2646.2	2970.612
St 1	C14	2671.072	3024.864
St 1	C12	2671.072	3024.864
St 1	C8	2646.2	2970.612
St 2	C18	2380.255	2650.356
St 2	C14	2409.967	2704.375
St 2	C12	2409.967	2704.375

Table 3.3 Column Removal of a Building in Side Location

COLUMN REMOVAL OF A BUILDING (WITH SIDE COLUMN REMOVAL) AXIAL FORCR PU (Kn)			
STOREY	COLUMN	BRFORE	AFTER
St 1	C6	2159.366	2706.891
St 1	C12	2671.072	3058.981
St 1	C16	2159.366	2706.891
St 2	C6	1963.438	2440.896
St 2	C12	2409.967	2754.858
St 2	C16	1963.438	2440.896

Table 3.4 Column Removal of a Building in Corner Location show Bending Moment Value

BENDING MOMENT(Kn-m) OF BEAM (WITH CORNAR COLUMN REMOVAL)					
STOREY	BEAM	BRFORE		AFTER	
St 1	B4	0.3095	2.5707	7.4109	9.5984
St 1	B37	1.3668	0.7587	2.7392	12.8664
St 2	B4	1.2586	8.3357	23.1291	20.5274
St 2	B37	4.5983	2.7127	8.2738	53.2584

Table 3.5 Column Removal of a Building in Middle Location show Bending Moment Value

BENDING MOMENT(Kn-m) OF BEAM (WITH MIDDLE COLUMN REMOVAL)					
STOREY	BEAM	BRFORE		AFTER	
St 1	B30	1.1635	0	6.3679	0
St 1	B10	0	3.2819	0	17.6125
St 1	B31	0	3.2819	0	17.6125
St 1	B11	1.1635	0	6.3679	0
St 2	B30	0	12.3018	21.0227	0
St 2	B10	0	12.3018	0	57.9967
St 2	B31	4.8255	0	0	57.9967

Table 3.6 Column Removal of a Building in Side Location show Bending Moment value

BENDING MOMENT(Kn-m) OF BEAM (WITH SIDE COLUMN REMOVAL)					
STOREY	BEAM	BRFORE		AFTER	
St 1	B22	0.9839	8.2127	7.3744	8.7957
St 1	B23	0	3.2819	0	6.3666
St 1	B9	0.9839	8.2127	7.3744	8.7957
St2	B22	4.0236	26.5625	24.3062	21.3979
St2	B23	0	12.3018	0	25.5906
St2	B9	4.0236	26.5625	24.3062	21.3979

Table 3.7 Column Removal of a Building in Corner Location show Interaction Ratio

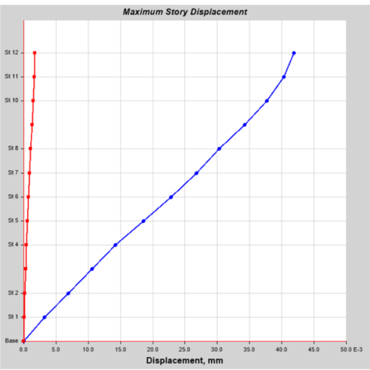
COLUMN REMOVAL OF A BUILDING (WITH CORNAR COLUMN REMOVAL) INTERACTION RATIO			
STOREY	COLUMN	BRFORE	AFTER
St 1	C10	0.923	0.986
St 1	C4	0.838	0.981
St 2	C10	0.832	0.984
St 2	C4	0.759	0.986

Table 3.8 Column Removal of a Building in Middle Location show Interaction Ratio

COLUMN REMOVAL OF A BUILDING (WITH MIDDLE COLUMN REMOVAL) INTERACTION RATIO			
STOREY	COLUMN	BRFORE	AFTER
St 1	C18	0.984	1
St 1	C14	0.985	0.997
St 1	C12	0.985	0.997
St 1	C8	0.984	1
St 2	C18	0.992	0.984
St 2	C14	0.988	0.986
St 2	C12	0.988	0.986

Table 3.9 Column Removal of a Building in Side Location show Interaction Ratio

COLUMN REMOVAL OF A BUILDING (WITH SIDE COLUMN REMOVAL) INTERACTION RATIO			
STOREY	COLUMN	BRFORE	AFTER
St 1	C6	0.923	0.984
St 1	C12	0.985	0.997
St 1	C16	0.923	0.984
St 2	C6	0.832	0.986
St 2	C12	0.988	0.986
St 2	C16	0.832	0.986



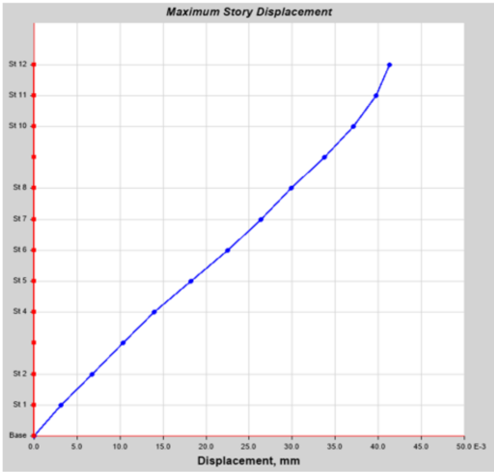
Displacement Graph of Corner Column Removal

Tabulated Plot Coordinates of Corner Column Removal

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
St 12	36	Top	0.042	0.002
St 11	33	Top	0.04	0.002
St 10	30	Top	0.038	0.001
St 9	27	Top	0.034	0.001
St 8	24	Top	0.03	0.001
St 7	21	Top	0.027	0.001
St 6	18	Top	0.023	0.001

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
St 5	15	Top	0.019	0.001
St 4	12	Top	0.014	4.13E-04
St 3	9	Top	0.011	2.964E-04
St 2	6	Top	0.007	1.829E-04
St 1	3	Top	0.003	7.579E-05
Base	0	Top	0	0



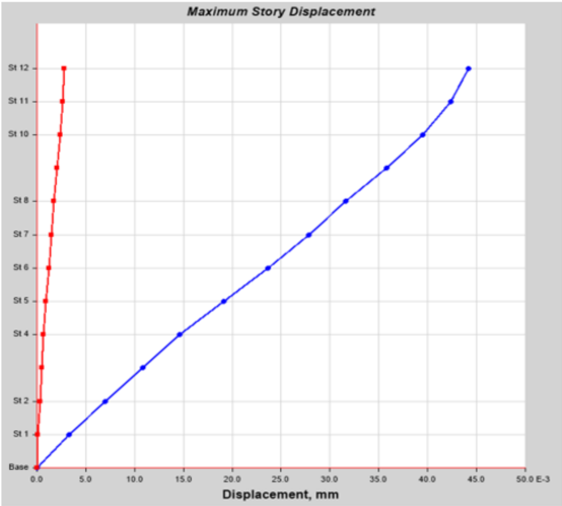
Displacement Graph of Middle Column Removal

Tabulated Plot Coordinates of middle column removal

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
St 12	36	Top	0.041	1.794E-06
St 11	33	Top	0.04	1.241E-06
St 10	30	Top	0.037	1.206E-06
St 9	27	Top	0.034	1.166E-06
St 8	24	Top	0.03	1.27E-06
St 7	21	Top	0.026	7.347E-07

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
St 6	18	Top	0.022	6.354E-07
St 5	15	Top	0.018	5.678E-07
St 4	12	Top	0.014	5.967E-07
St 3	9	Top	0.01	1.67E-07
St 2	6	Top	0.007	1.678E-07
St 1	3	Top	0.003	2.559E-07
Base	0	Top	0	0



Displacement Graph of Side Column Removal

Tabulated Plot Coordinates of Side column removal

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
St 12	36	Top	0.044	0.003
St 11	33	Top	0.042	0.003
St 10	30	Top	0.04	0.002
St 9	27	Top	0.036	0.002

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
St 8	24	Top	0.032	0.002
St 7	21	Top	0.028	0.001
St 6	18	Top	0.024	0.001
St 5	15	Top	0.019	0.001
St 4	12	Top	0.015	0.001
St 3	9	Top	0.011	4.764E-04
St 2	6	Top	0.007	2.88E-04
St 1	3	Top	0.003	1.154E-04
Base	0	Top	0	0

4. CONCLUSIONS

In this study, a procedure to determine the interaction ration of rectangular reinforced Under axial load and bending moment, concrete columns was formulated. The present models result showed good agreement with the data. It is concluded that the present procedure and the software in which it was implemented with ETABS 2016.are viable tools to accurately predict the combined axial load, and bending moment behavior in rectangular concrete columns. In the present work, Non- Linear Dynamic Analysis of RC earthquake resistant building is carried out by using commercial software ETABS 2016. Vulnerability of building against progressive collapse is studied and the conclusion are drawn from the analysis are discussed below.

1. DCR ratio value of beam is more as compare to DCR ratio value of column.
2. For all column is safe with DCR value less than < 2 i.e. GSA criteria.
3. To avoid the progressive failure of the beam and column, caused by failure of particular column, adequate reinforcement is required to limit the DCR within the acceptance criteria.
4. Among three cases of column removal, most damaging collapse occurs when interior column is lost, next is corner column failure, finally middle column failure.
5. Increasing beam size will be more effective in avoiding or delaying collapse rather than increasing column sizes.
6. The size, shape, and importance of the building are major factors used to determine the most suitable analysis approach for each building.
7. The displacement of storey increases with number of storey increases.
8. The time period of storey decreases with number of storey increases.

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