Progressive Collapse Analysis of R.C.C. Framed Structure using Etab's

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Abstract - *A structure experiences progressive collapse when a primary structural member (generally column) fails due to manmade or natural causes. The failure of a member in the primary load resisting system leads to redistribution of forces to the adjoining members and if redistributed load exceeds member capacity it fails. This process continues in the structure and eventually the building collapses. This phenomenon is referred as progressive collapse of the structure. In the present study progressive collapse potential of 15-storey symmetrical concrete framed building is evaluated. Linear static and dynamic analysis is performed by following the General Service Administration (GSA-2003) guidelines for evaluating progressive collapse potential. Modeling, analysis and design of the buildings are performed using ETABS 2019 for three different threat-independent column removal conditions by following the alternate load path method. It is observed that demand capacity ratio (DCR) in beams and columns are exceeding the allowable limit for all the cases. This indicates the building considered for study is having high potential of progressive collapse. To reduce the potential of progressive collapse various approaches for mitigation of the progressive collapse are implemented in this research. Different approaches like providing bracing at floor level, moderate increase in the size of beam at all the storey levels. Comparison between the approaches is presented in this study by analyzing progressive collapse of G+15 RCC Framed structure.*

***Key Words*: Progressive Collapse, ETABs, IS Code, DCR, PMM Ratio, story displacement, story drift.**

INTRODUCTION

The progressive collapse of building structures is a complicated mechanical behavior of entire structural systems under large deformation. However, limited researches have been conducted to investigate this issue at the last century due to the lack of the experimental technique and numerical simulation for entire structural systems under large deformation. In recent years, with the development of the experimental technique and numerical simulation, the progressive collapse of building structures is studied in depth and the exciting progresses have been reported. A progressive collapse of a building is initiated by an unexpected event that causes local damage and subsequently propagates throughout the structural system, leading to a final damage state in large-scale or entire collapse of the building. A progressive collapse can be triggered by accident actions, including fire hazard, gas explosion, terrorist attack, vehicle collision, design and construction errors, and environmental corrosion. With the development of industrialization, the buildings with multi-function and high complication become more common of which the safety and stability are far more concerned. However, the current ultimate limit state design based on the structural reliability theory is commonly used for regular structures to ensure their safety. On the other hand, during the long-term use, the structure may suffer unexpected accidental actions, causing local damage or failure. Hence if the remaining structural system cannot absorb or contain the internal force variation caused by the initial failure, it will lead to a further damage even the collapse of whole structure, causing huge loss of life and property.

Stages in Structural Design

Every structure follows a specific path from its initiation to ultimate design as follows:

1) Structural planning of the building.
2) Calculation of applied loads.
3) Structural analysis of the building
4) Design of the building as per analysis.
5) Drawing and detailing of the structural members.
6) Preparation of tables and graphs.
7) It is the responsibility of the structural engineer to construct the building structurally good, considering all the loads acting on the building. There are so many methods of conducting these design we use E-tab software.

Introduction to E-tab

ETABS-Extended 3D analysis of Building Systems", is a product of Computers and Structures Inc. It is an engineering software that is used in construction. It has highly efficient structure analysis and design programs developed for catering to multi-story building systems. It is loaded with an integrated system consisting of modeling tools and templates, code-based load prescriptions, analysis methods, and solution techniques. It can handle the largest and most complex building models and associated configurations. ETABS software is embedded with CAD-like drawing tools with an object-based interface and grid representation. Integration, productivity and technical innovation.

ETABS software has the following implications in the construction, designing, and modeling industry:

1. It is a software used in construction. It analyses and assesses seismic performance and checks the load-bearing capacity of building structures.
2. Using this software, you can view and manipulate the analytical model with great accuracy. Plans and elevation views are auto-generated at every grid line.
3. ETABS software is used for the analysis of concrete shear walls and concrete moment frames. It is highly acclaimed for static and dynamic analysis of multi-storey frame and shear wall buildings.
4. It is the most popular civil designing tools used in the building industry and increases the productivity of structural engineers. It also prevents the investment of unnecessary time and money in general-purpose programs.
5. The input, output and numerical solution techniques of ETABS are particularly designed to take an upper hand of the unique physical and numerical characteristics associated with building type structures. As a result, this analysis and design tool accelerates data preparation, output interpretation, and overall execution.

1. LITERATURE REVIEW

6. Suyash Garg, Vinay Agrawa, Ravindra Nagar (2021)(1)This Presents the Previous studies have shown that RC flat slab buildings are highly vulnerable to progressive collapse because no beams could help redistribute the loads previously carried by the lost columns. The necessary strengthening methods should, therefore, be adapted to reduce the occurrence of progressive collapse. In this paper, the progressive collapse behaviour of five-storey R.C flat slab building is assessed by removing columns from the first-storey and dynamic analysis is conducted in compliance with GSA guidelines (2016). The results are analyzed in terms of vertical displacement and chord rotation at the location of removed columns and compared with the allowable limits as specified in DoD guidelines (2009). Different sized perimeter beams are used as strengthening methods to increase the progressive collapse resistance of the studied flat slab building. Since building strengthening uses structural elements that consume natural resources, sustainability criteria should be explicitly included in the strengthening requirements. These performance enhancement methods are then evaluated from structural, cost and environmental aspects and the results are examined. A strengthening alternative is then proposed which not only satisfy the progressive collapse code requirements but also requires less cost and emits less CO2 gas.
7. Adrian G. Marchisa, Mircea D. Boteza(2)(2019) This paper presents the results of a numerical investigation into the influence of the number of stories on the progressive collapse resistance of reinforced concrete planar frames. Starting from the specifications provided by Yi et al. (2008) in their experimental program, an initial numerical model was developed in Midas FEA software package. To assure a high results accuracy for the current and the following investigations based on this set-up, this initial numerical model was successfully validated against the data's revealed by the experimental test. To achieve the proposed objective, five numerical models are developed starting from the initial one by increasing/decreasing the number of structure's stories. To simulate the gradual failure of the first story column caused by the abnormal loadings such as explosions or impact, a target displacement of 50mm is imposed and a nonlinear static "push-down" analysis is conducted in each case. As a result, the ultimate load carrying capacity to progressive collapse for each numerical model is determined and the additional capacity of the RC frames with respect to the number of stories is assessed. The activation of the supplementary resisting mechanisms (Compressive Arch Action – CAA and Catenary Action – CA) of the planar frames to better resist progressive collapse is also discussed. The obtained results indicate that, as expected, the structure's load carrying capacity increases with the number of stories but, when expressed in terms of percentage with respect to the activation of the initial failure mechanism (three-hinge mechanism) the value decreases. Also, based on the results obtained herein, a simplified approach is proposed to estimate the peak load that can be sustained by the planar RC frames without collapse.
8. Hamed Yavari, Mohammad Soheil Ghobadi (3)(2019), Mansoor Yakhchalian This paper evaluates the effects of severity of Torsional Irregularity (TI) and In- plane Discontinuity in Vertical Lateral force-resisting element Irregularity (IDVLI) together with seismic strength of the building on the progressive collapse potential of steel Special Moment-Resisting Frames (steel SMRFs),which were designed based on common seismic codes. In order to investigate the progressive collapse potential according to GSA 2013 guidelines, an interior or exterior column is removed in 3D modeled building using nonlinear dynamic analysis. Various TIs by defining the ratio of maximum relative lateral displacement of the story to average relative lateral displacement of the story between 1 to 1.6 and IDVLIs by disconnecting one or two columns in the first and second stories are selected. Buildings are 3, 6 and 9 stories high, and Los Angeles, California andGeorgia sites with high, moderate and low levels of seismicity, respectively, are considered. All corresponding buildings have similar seismic mass and are designed for approximately equal values of earthquake base shear, so the comparison process can be possible due to the comparison of equivalent-designed buildings. Gravity and seismic loads of buildings are applied based on ASCE 7-05, and steel design is carried out based on AISC 2010. The results show that buildings designed with greater TI have greater resistance to the progressive collapse phenomenon. Furthermore, buildings in a site with higher seismicity level have less progressive collapse potential. In IDVLI, the buildings located in a site with low seismicity are always rejected against progressive failure based on GSA 2013, whereas buildings located in a site with high seismicity are always acceptable. In addition, in a system with IDVLI, the scenario of external column removal always creates more critical conditions.
9. Jinkoo Kim and Young-Ho Lee(4): In this Study the progressive collapse potential of Tube type buildings such as Diagrid & Tubular Structures, composed of lateral load-resisting perimeter frames and internal pin connected gravity frames was evaluated by non-linear static & dynamic

analyses. In this study 36 and 54 storey framed tube and diagrid structures with the same plan shape and storey heights were prepared. The analysis results showed that tube type buildings generally had high resistance to progressive collapse caused by the sudden loss of external members. If perimeter column corresponding to 11% of all vertical columns were removed from a side of diagrid and tubular structures then progressive collapse of tube type building tended to occur. From the result it was observed that progressive collapse capacity of 54 storey diagrid structures were higher than that of 36 storey structures

10. Rakshith K G, Radhkrishna(5): This presents the progressive collapse analysis of structures is initiated by one or more vertical load carrying members are removed due to man-made or natural hazards. In this paper the linear static analysis of 12-storeyRC building of height 37.5m is done and to evaluate the progressive collapse analysis of 12-Storey RC building four column removal conditions is considered and the demand capacity ratio of members are calculated as per U.S. General Service Administration (GSA) Guidelines. As per GSA, if the Demand capacity Ratio values of Column are less than Two, then the column is safe for progressive collapse analysis. In this study three column removal case does not exceed the acceptance criteria of GSA for DCR values and hence the column is safe for all three case but in fourth case the acceptance criteria value of beam adjacent to column removal is exceed so the beam is unsafe for progressive collapse analysis. To avoid the progressive collapse failure of beams and columns cause by failure of particular column, adequate reinforcement is required to limit the DCR within the acceptance criteria.
11. Bhavik R. Patel(6): In this paper to study the effect of failure of load carrying element i.e. columns on entire structures, nonlinear static (vertical pushover analysis) and non-linear dynamic analysis is carried out for 15-storey RC Buildings for external bay column removal case as per GSA Guidelines by using SAP2000.To understand the hinge formations at yield and at collapse, Nonlinear static analysis is carried out. Displacement and support rotations are found out using nonlinear static and dynamic analysis. The nonlinear dynamic procedure for progressive collapse analysis is the most efficient method of analysis in which a primary load bearing structural element is removed dynamically and structural material is allowed to undergo nonlinear behaviour.
12. Niloufar Mashhadiali and Ali Kheyroddin(7): This paper presents progressive collapse capacity of Hexagrid structures and diagrid structures corresponding to local failure of structural elements in the first storey. The collapse behaviour is evaluated by two different nonlinear static and dynamic analysis methods. To design two type of 28-storey and 48-storey building models this study was conducted to withstand wind load for both structural systems. The Targeted 28-Storey and 48-Storey buildings were studied for five removal members from the corner of the buildings. Various load factors were evaluated to estimate the dynamic effect and to achieve the comprehensive results. The analysis results show that hexagrid has enough potential of force redistribution to resist progressive collapse due to its special configuration and show that dynamic amplification factor could be larger than 2. Pushdown curves report that Hexagrid is ductile and diagrid is brittle. [4] Progressive Collapse Analysis of an RC structure.

2. OBJECTIVES

The main objective of this paper is to study progressive collapse analysis of G+15 RC framed on E-Tab. The objectives have been specified as follows:

1. Generation of building model on E-Tab.
2. To study various design and drawings of RC building.
3. High rise R.C.C. structure (building) is analyzed and design by conventional method for dead load, live load, and earthquake load in ETAB software.
4. To study of causes of progressive collapse.
5. To find story max over average story drift in Y-direction.
6. To find story max over average story displacvement in Y-direction.

3. METHODOLOGY TO UNDERTAKE ANALYSIS AND DESIGN OF G+15 BUILDING ON E-Tab.

A progressive collapse analysis is required to determine the capability of a structure to resist abnormal loadings. The proposed progressive failure analysis method is threat independent, in the sense that it is initially assumed that some type of short duration abnormal loading has caused local damage represented by the removal of one or more critical members. When a multi storey building is subjected to sudden column failure. the resulting structural response is dynamic. typically characterized by significant geometric and material nonlinearity. Analysis methods used to evaluate the possibility of progressive collapse widely varies, it is ranging from the simple two dimensional linear elastic static procedures to complex three dimensional nonlinear dynamic analyses.

Steps for analysis

Step1. First, the building is designed in ETABS 2019 for the IS 1893 load combinations and the output results are obtained for moment and shear without removing any column.

Step2. A vertical support (column) is removed from the position under consideration and linear static and dynamic analysis is carried out to the altered structure with loading combinations as per GSA 2003 Guidelines.

Step3. The load combinations are entered into the ETABS 2019 V15.0 program. An ETABS 2015 computer simulation is executed for each case of different Column removal location on the model and the results are reviewed.

Step4. Further, from the analysis results are obtained and if the DCR for any member exceeds the allowable limit based upon moment and shear force, the member is expected as a failed member.

Step5. If DCR values surpass its criteria then it will lead to progressive collapse.

It is important to check that both stages (before and after column removal) of every analysis case converge. lf the analysis does not converge there is a problem with the model that must be fixed prior to proceeding with the analys

Project Statement

A structure considered here is a residential building with plan dimension. For wind load IS 875(1987) part-3 is used and IS:1893 (part -1) 2002 is used for seismic loading.

Location of building	Aurangabad
Dimension of building	15.9m x 13.5m
Number of stories	G+15
Height of base story	1.5m
Size of beam : Main beam	0.4 X 0.5
Main beam	0.35 X 0.45
Secondary beam	0.3 X 0.35
Height of building	53m
Floor to floor height of building	3.5m
Main Column	0.6 X 0.6
Secondary Column 1	0.3 X 0.4
Secondary Column 2	0.3 X 0.38

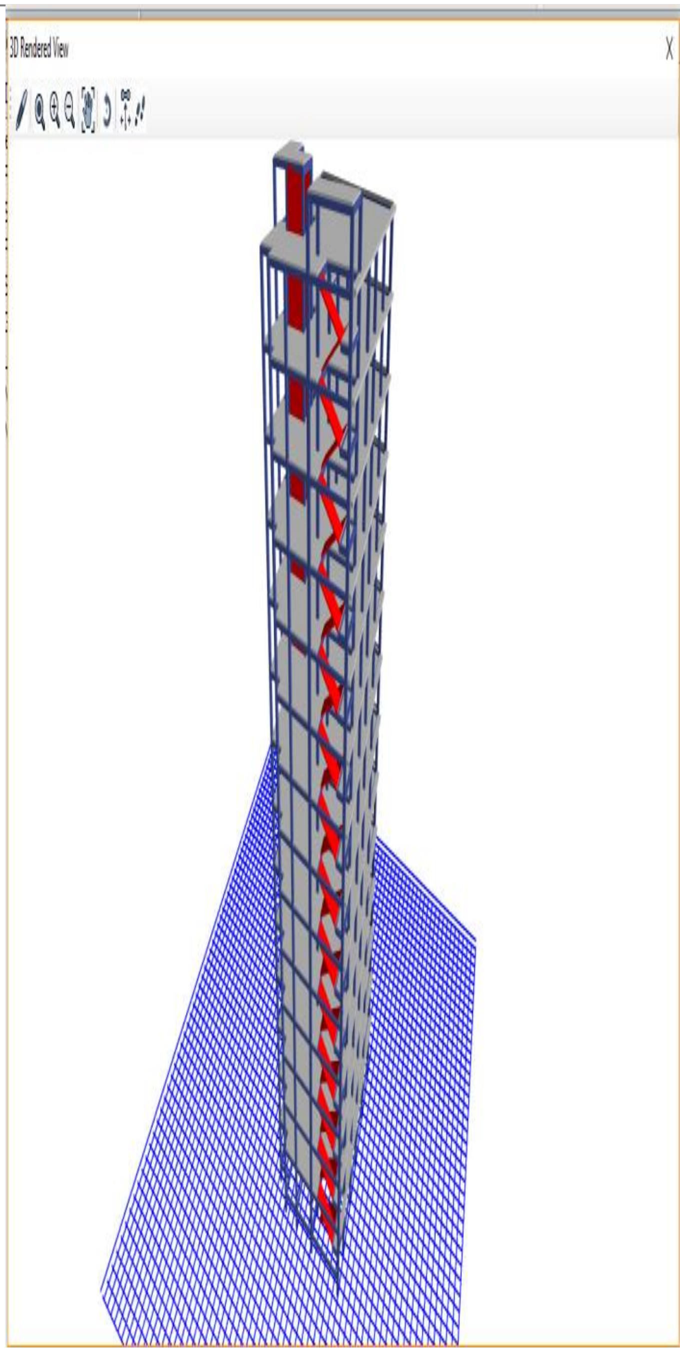


Figure 1: 3D View Of G+15 Storied Building

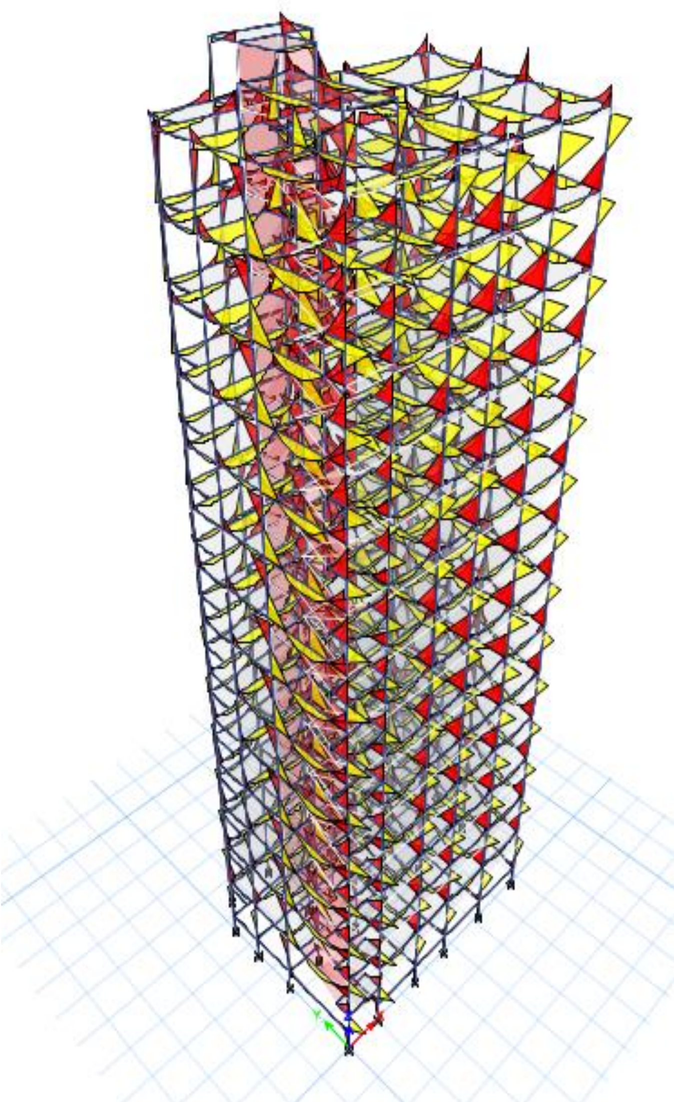


Figure 2: Bending Moment Diagram From Analysis

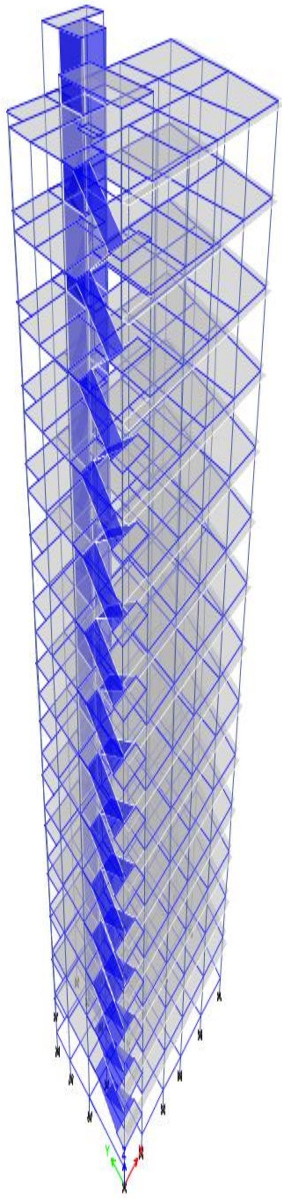


Figure 3 : 3D View Of G+15 Storied Building

4. RESULT AND DISCUSSION

Story data

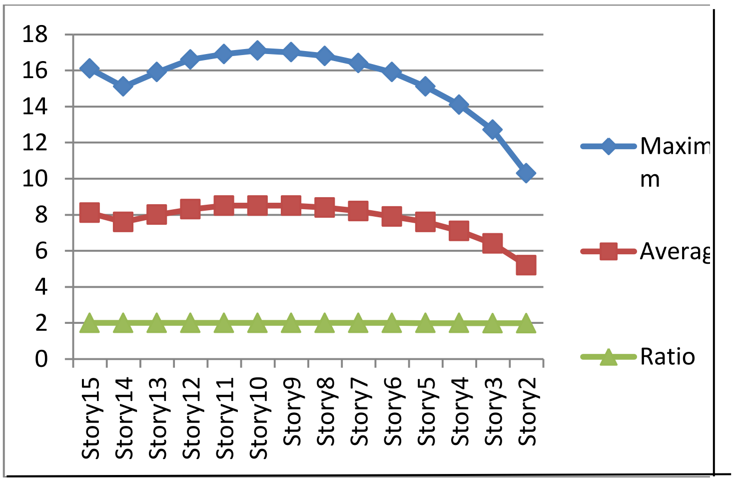
Table no 1: Story Data Values

Name	Height mm	Elevation mm	Master Storey	Similar To	Splice Storey
Storey16	2500	53000	Yes	None	No
Storey15	3500	50500	Yes	None	No
Storey14	3500	47000	No	Storey15	No
Storey13	3500	43500	No	Storey15	No
Storey12	3500	40000	No	Storey15	No
Storey11	3500	36500	No	Storey15	No
Storey10	3500	33000	No	Storey15	No
Storey9	3500	29500	No	Storey15	No
Storey8	3500	26000	No	Storey15	No
Storey7	3500	22500	No	Storey15	No
Storey6	3500	19000	No	Storey15	No
Storey5	3500	15500	No	Storey15	No
Storey4	3500	12000	No	Storey15	No
Storey3	3500	8500	No	Storey15	No
Storey2	3500	5000	No	Storey15	No
Storey1	1500	1500	No	Storey15	No
Base	0	0	No	None	No

Story Max Over Avg Displacements In X direction Values Given In Following Table:

Table no.2 : Story Max Over Avg Displacements In Y direction

Story	Output Case	Step Type	Direction	Maximum	Average	Ratio
Story15	ENVELOPE	Max	Y	16.1	8.1	2.001
Story14	ENVELOPE	Max	Y	15.1	7.6	2.001
Story13	ENVELOPE	Max	Y	15.9	8	2.001
Story12	ENVELOPE	Max	Y	16.6	8.3	2.001
Story11	ENVELOPE	Max	Y	16.9	8.5	2.001
Story10	ENVELOPE	Max	Y	17.1	8.5	2.001
Story9	ENVELOPE	Max	Y	17	8.5	2.001
Story8	ENVELOPE	Max	Y	16.8	8.4	2.001
Story7	ENVELOPE	Max	Y	16.4	8.2	2
Story6	ENVELOPE	Max	Y	15.9	7.9	2
Story5	ENVELOPE	Max	Y	15.1	7.6	1.998
Story4	ENVELOPE	Max	Y	14.1	7.1	1.991
Story3	ENVELOPE	Max	Y	12.7	6.4	1.985
Story2	ENVELOPE	Max	Y	10.3	5.2	1.984

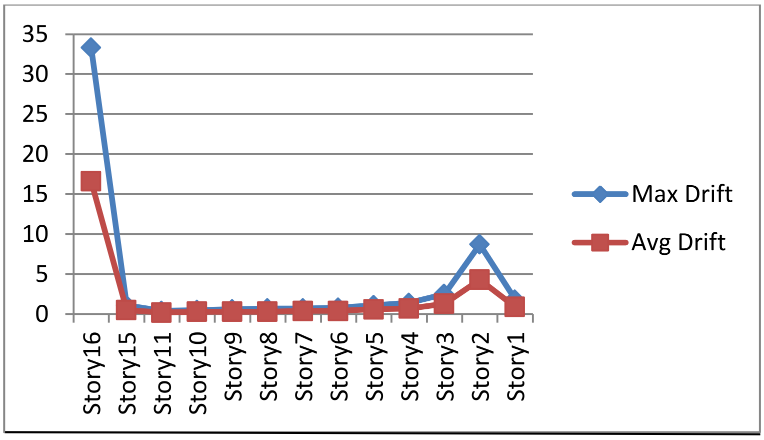


Graph No:01:-Story VS Story Max Over Avg Displacement In Y Direction

Story Max Over Avg Drifts In X direction Values Given In Following Table.

Table no.3 : Story Max Over Avg Drifts In Y direction

Story	Output Case	Step Type	Direction	Max Drift	Avg Drift	Story
Story16	ENVELOPE	Max	Y	33.3	16.6	Story16
Story15	ENVELOPE	Max	Y	1.1	0.5	Story15
Story11	ENVELOPE	Max	Y	0.4	0.2	Story11
Story10	ENVELOPE	Max	Y	0.5	0.3	Story10
Story9	ENVELOPE	Max	Y	0.6	0.3	Story9
Story8	ENVELOPE	Max	Y	0.7	0.3	Story8
Story7	ENVELOPE	Max	Y	0.7	0.4	Story7
Story6	ENVELOPE	Max	Y	0.8	0.4	Story6
Story5	ENVELOPE	Max	Y	1.1	0.6	Story5
Story4	ENVELOPE	Max	Y	1.4	0.7	Story4
Story3	ENVELOPE	Max	Y	2.5	1.3	Story3
Story2	ENVELOPE	Max	Y	8.7	4.3	Story2
Story1	ENVELOPE	Max	Y	1.8	0.9	Story1



Graph No:02:-Story VS Story Max Over Avg Drift In Y Direction

5. CONCLUSIONS

1. In this paper A design model is generated on E tab software to analyze progeressive collapse of RC framed structure .
2. Table no 2and graph no. 1 shows that story vurses story max over average displacement in Y direction.
3. Table no 3 and graph no.2 shows that Story Max Over Average Drifts In Y direction.
4. It was observed that Column D5 at story 1 is critical column and when this column loss the adjacent column has not capacity to resist the progressive collapse.
5. It was also observed that when Column D22 from Storey 4 is removed then the Columns adjacent to the removed columns does not exceeds Demand Capacity Ratio which is 2 suggested by U.S. General Services Administration for progressive collapse.
6. When Column D31 from Storey 7 is removed then the Columns adjacent to the removed columns does not exceeds Demand Capacity Ratio which is 2 suggested by U.S.
7. General Services Administration for progressive collapse When Column D32 from Storey 2 is removed then the Columns adjacent to the removed columns does not exceeds Demand Capacity Ratio which is 2 suggested by U.S.

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