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"Evaluation of the Structure's Progressive Collapse Subjected to Sudden Column Removal"

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ABSTRACT- Progressive collapse is a chain reaction of failures that propagates either throughout or a portion of the structure disproportionate to the original local failure. The progressive collapse of building structure is initiated when one or more vertical load carrying members are removed. Once a column is removed or made weak, due to man-made or natural hazards, load carried by column removed is transferred to neighboring columns in the structure, if the neighboring column is incapable of withstanding the extra load, leads to the progressive failure of adjoining members and finally to the failure of partial or whole structure. When a multi-story building experiences sudden damage to a column, the structural response is dynamic and usually contains geometric non-linear and important materials. The analytical methods used to estimate the probability of a Progressive collapse are very different, from simple two-dimensional static elastic methods to complex three-dimensional non-linear dynamic analyses. In the present study the four methods for progressive collapse analysis are compared by analyzing a reinforced concrete eight storey frame structure, by employing analytical procedures: linear-elastic static, nonlinear static, linear-elastic dynamic, and nonlinear dynamic methodologies.

Keywords- Progressive collapse, Column removal, Alternate path method, Demand Capacity Ratio, Linear analysis, Nonlinear analysis.

I.INTRODUCTION

The explosion caused damage to the structure almost immediately. Direct exposure to a high intensity explosion on the surface of a building can damage major structural elements, like columns or walls. Damage may occur in the form of loss of unstructured elements, errors in structural elements or destruction of structural elements, which may lead to the gradual destruction of parts or the entire building. If an element is rejected by the support system, the neighboring elements are forcibly redistributed and an error occurs if the redistributed load exceeds the element's throughput. This process continues in the structure and, finally, the structure collapses. This phenomenon is known as progressive collapse of the structure. When a multi storey building is subjected to sudden column loss, the resulting structural response is dynamic, typically characterized by significant geometric and material nonlinearity.
Most civil engineering infrastructures are not specifically designed for unforeseen expenses. Because of this, they tend to collapse. On the other hand, threats to private infrastructure have increased, as the frequency of terrorist bombings has increased in recent years. Over the past 20 years, many embassies, shopping centers, government buildings, industrial plants and residential buildings have been subjected to explosives. As a result, in recent years, folding structures have become more important to minimize structural damage and safety risks. Progressive failure analysis is an independent threat analysis regardless of the cause of the incident. Some events that cause gradual destruction include abnormal loads, internal gas explosions, external explosions, car accidents, earthquakes, grounding, design errors, and design errors.

II ANALYSIS APPROACHES

G.S.A GUIDELINES

For buildings of 10 stories or less in height with relatively simple layouts, both the U.S. General Services Administration [GSA 2013] and the Interagency Security Committee [ISC 2001] recommend the alternate load path method be used to assess the vulnerability of new and existing buildings to progressive collapse.
For static analysis procedure:

Load = 2 [1.2DL + 0.5LL] ----1

For dynamic analysis procedures:

Load = 1.2DL + 0.5LL ----2

From the analysis results demand at critical points are obtained and from the designed section the capacity of the member is determined. Check for the Demand Capacity Ratio (DCR) in each structural member is carried out. The DCR of each member of the alternate load path structures is calculated from the following equation.

$$DCR = \frac{QUD}{QCE} \quad \text{----3}$$

QUD = Acting force (demand) determined in member or connection (moment, axial force, shear)

QCE = Expected ultimate, un-factored capacity of the member and connection (moment, axial force, shear)

If the DCR of a member in flexure exceeds 2 for symmetric configuration and 1.5 for asymmetric configuration, the member is considered as failed.

III PROGRESSIVE COLLAPSE ANALYSIS

A. MODEL CONFIGURATION

Structure considered in this analysis is assumed to be a G+7 residential building, which is designed for an importance factor 1 (IS code 1893-2002).

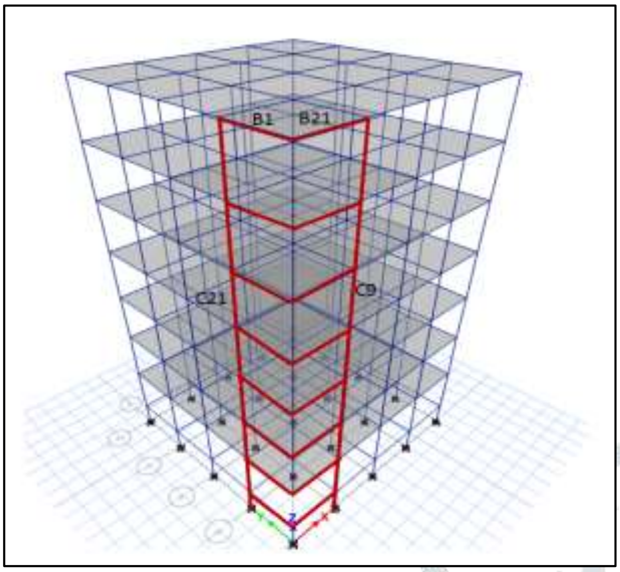
1. Bay size is taken as 3m in x-direction and 3m in y-direction.
2. Building size in plan is 12m x 12m.
3. Typical floor height - 3m.
4. Wall thickness - 300 mm
5. Concrete grade- M25
6. Steel grade- Fe415
7. Live load on floor - 3 kN/m2
8. Live load on roof - 3 kN/m2
9. Floor finish - 1.5 kN/m2
10. Beam size - 300mm X 450mm
11. Column size - 450mm X 600mm

Fig 1 shows Structural model with corner column removed and elements whose DCR values should be found out

B. LINEAR STATIC ANALYSIS (LS)

This analysis procedure is the simplest and easiest to perform. However, it is limited to relatively simple structures where both nonlinear effects and dynamic response effects can be easily and intuitively predicted. In the linear static analysis column is removed from the location being considered and linear static analysis with the gravity load imposed on the structure has been carried out. This analysis procedure involves the following steps:

1. Build a finite-element computer model;
2. Apply the amplified static load combination as defined by Eq. 1
3. Perform static linear analysis, a standard analysis procedure
4. Evaluate the results based on demand to capacity ratios DCR. Now that the member forces are known, the DCR can be found by Eq 3



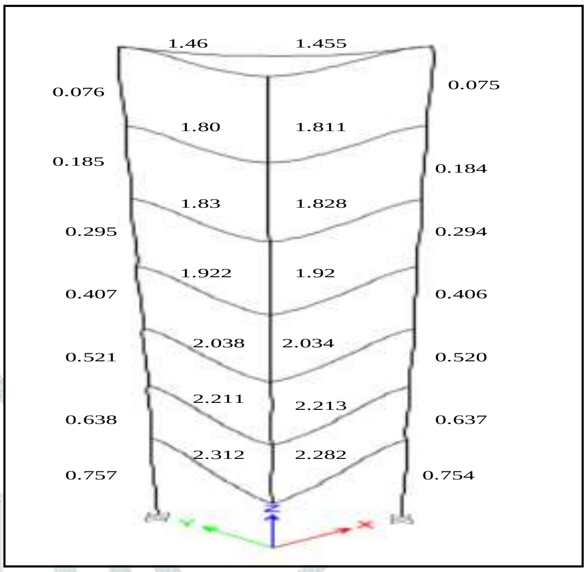


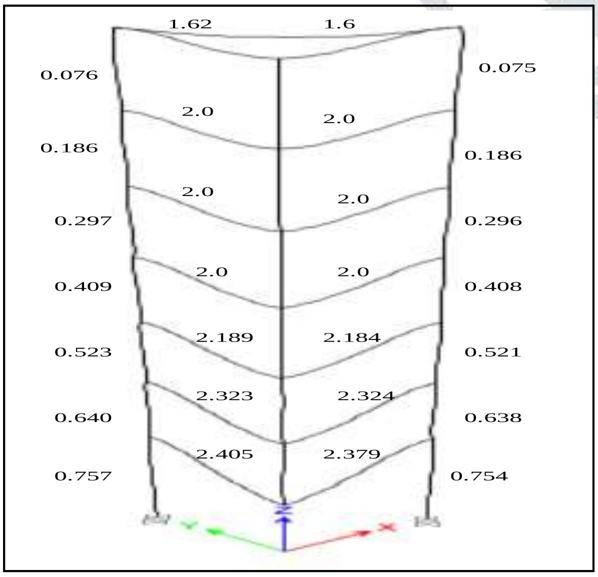
Fig 1: Model with DCR calculation elements

Fig 2 : DCR values for LS

C. NONLINEAR STATIC ANALYSIS(NLS)

Nonlinear Procedure implies the use of static or dynamic finite element analysis methods that takes into consideration, both material and geometric nonlinearity. Nonlinear static analysis is widely used to analyze a building for a lateral load and is known as "pushover analysis". The pushover analysis consists of the application of gravity loads and a representative lateral load pattern. Nonlinear static analysis procedure is carried out in the following steps using

1. Build a finite-element computer model.
2. Define and assign nonlinear plastic hinge properties, to beams and columns.
3. Apply static load combination 2(1.2DL+0.5LL).
4. Perform nonlinear static analysis.
5. Verify and validate the results based on hinge formation



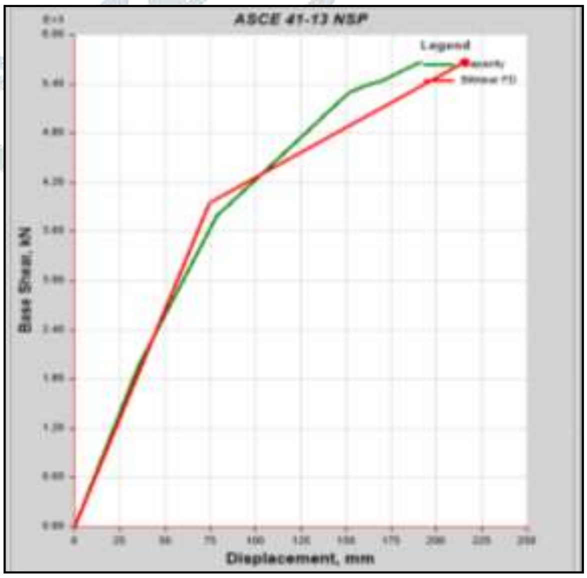


Fig 3 : DCR values for NLS

Fig.4: Capacity spectrum curve

D. LINEAR DYNAMIC ANALYSIS(LD)

Dynamic analysis procedures either linear or nonlinear are usually avoided, as they are perceived to be excessively complex. But compared to static analysis procedures, their accuracy is much higher since dynamic procedures inherently incorporate dynamic amplification factors, inertia, and damping forces. This sets the initial conditions as the deflected shape of the undamaged structure under normal service loads. This analysis includes the following analysis steps:

1. Build a finite-element computer model;
2. Apply the dynamic load combination as defined by Eq. 2.
3. Perform time history analysis with zero initial conditions..
4. Evaluate the results based on demand-to-capacity ratio DCR, where demand is taken as the peak value of the calculated time–history response

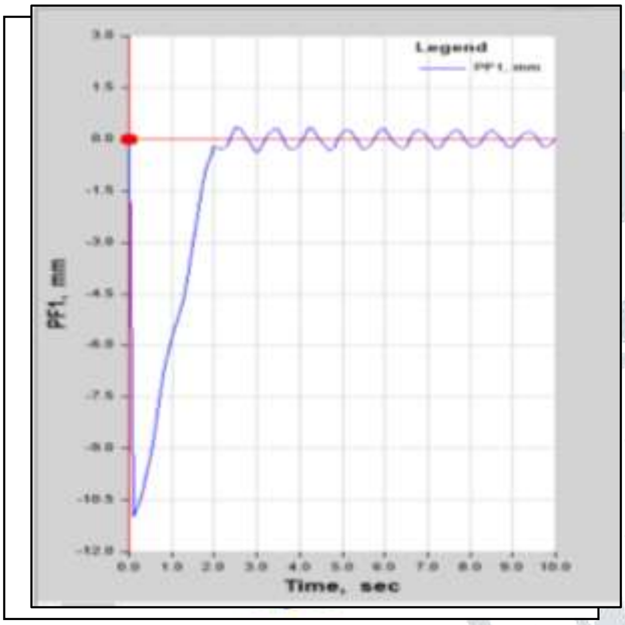
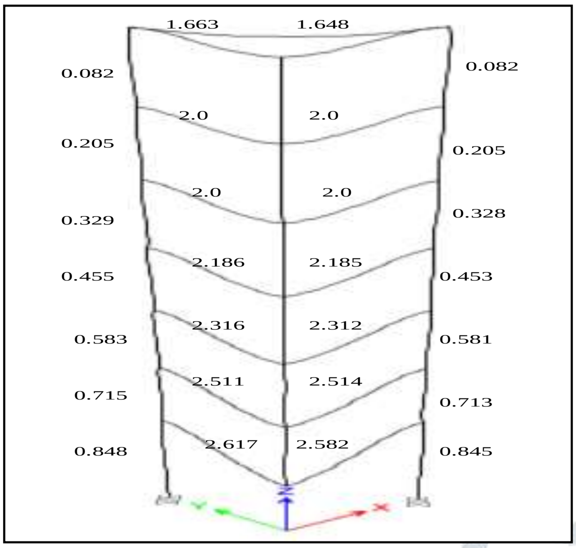


Fig 5: DCR values for LD Fig.6: Time vs Displacement curve of joint 1

E. NONLINEAR DYNAMIC ANALYSIS(NLD)

Nonlinear dynamic analysis (NLD) is the most accurate method of analyzing the response of the building. Nonlinear dynamic, are usually avoided due to the complexity of the analysis. Additionally, evaluation and validation of the results can be very time-consuming, making this analysis procedure even less attractive. Nonlinear dynamic analysis is performed similarly to linear dynamic analysis with the exception that now the structural elements are allowed to enter their inelastic range. The following steps are involved:

1. Build a finite-element computer model.
2. Find the deflected shape of the loaded, undamaged structure. This involves static analysis of the undamaged structure i.e., with missing column present.
3. Apply dynamic load combinations as defined by Eq 2.
4. Perform nonlinear time history analysis with initial conditions.
5. Verify and evaluate the results based on the maximum ductility and rotation values



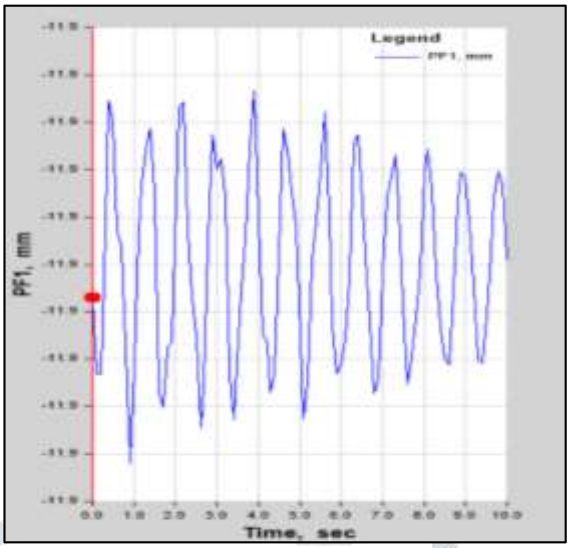


Fig 7 : DCR values for NLD

Fig.8: Time vs Displacement curve of joint 1

F. DCR VALUES FOR MOMENTS DCR VALUES FOR MOMENTS

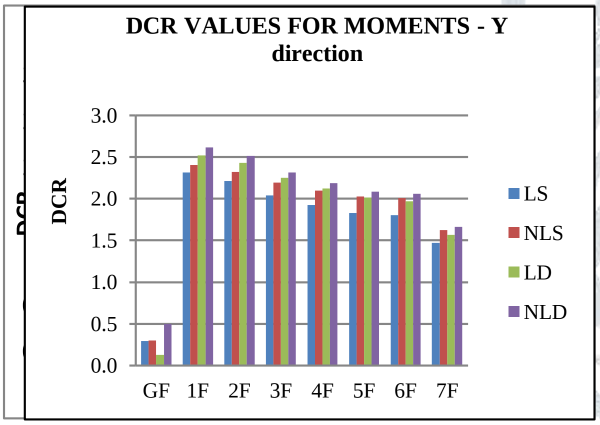


Chart no 1: Comparative chart of DCR values for moments in X directions

Chart no2 : Comparative chart of DCR values for moments in Y directions

G. DCR VALUES FOR AXIAL LOADS OF ADJACENT COLUMNS

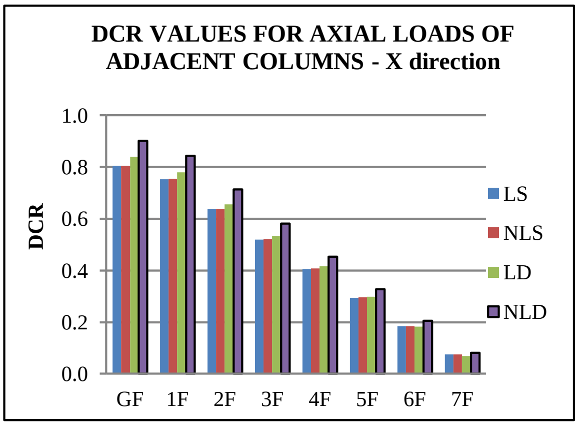


Chart no 3: Comparative chart of DCR values for column in X directions

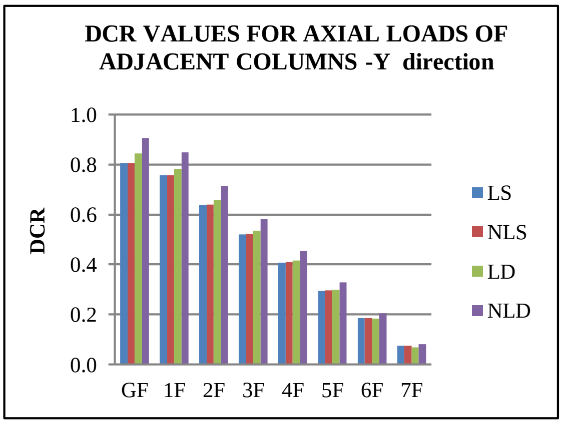


Chart no 4 : Comparative chart of DCR values for column in Y directions

H. DISPLACEMENT AT JOINT 1 WITH VARIOUS ANALYSIS

Displacement at joint 1 for various analysis studied and observed as follows,

10.5 mm in Linear static analysis, 10.7 mm in Non linear static analysis , 11 mm in Linear dynamic analysis, 11.9 mm in Non linear dynamic analysis.

Comparative chart

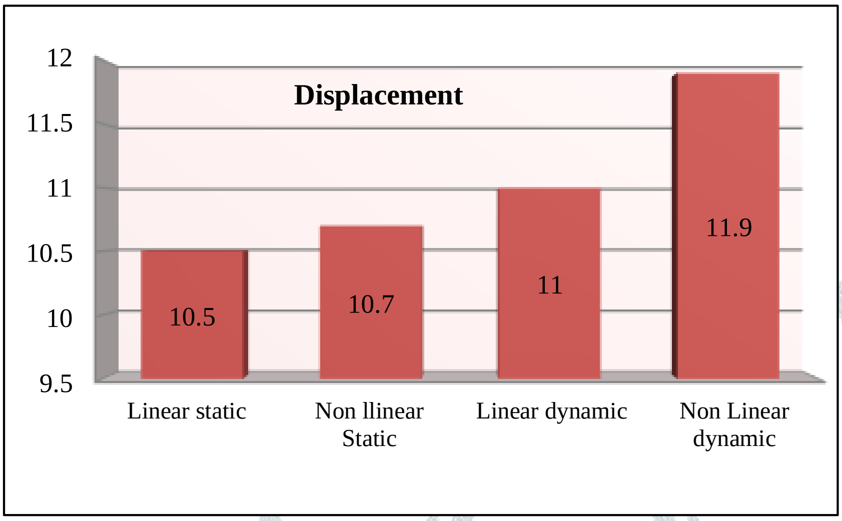


Chart no5: of displacement of joint 1

Chart no5: Comparative chart of displacement of joint 1

IV.RESULTS AND DISCUSSION

1. The three analysis LS, NLS, NLD showed DCR values are exceeding limits for some members in flexure for column removed from corner where as LD showed DCR values are within limits for flexure
2. The DCR values in axial force of adjacent columns are safe for the condition of corner column removed as showed by all four analysis.
3. Hinge status studied is formed in the I-O level. The performance level require minor repair for functional or safety reason.
4. Displacement at joint 1 for various analysis is studied and observed as follows,

10.5 mm in Linear static analysis, 10.7 mm in Non linear static analysis , 11 mm in Linear dynamic analysis, 11.9 mm in Non linear dynamic analysis.

V.CONCLUSION

1. From this study it is observed that to avoid the progressive failure of beams and columns, after failure of particular column due to extreme loading from blast, adequate reinforcement to limit the DCR within the acceptance criteria and adequate detailing can be useful.
2. Nonlinear static analysis reveals that hinge formation starts from the location having maximum demand capacity ratio. Then formation of hinge continues through the locations having higher DCR in various displacement levels.
3. From demand capacity curve it is concluded that both the demand curve intersects the capacity curve. Therefore, it can be concluded that the margin safety against collapse is high and there are sufficient strength and displacement reserves.
4. DCR values , Deflection at joint 1 studied in all four analysis showed nearly same results, hence we can conclude Progressive collapse of structure under consideration will not happen on failure of corner column, Minor repairs will be required for some beams whose DCR values exceeds 2.

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