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RESEARCH ARTICLE

DETAILED ASSESSMENT OF PROGRESSIVE COLLAPSE OF STEEL STRUCTURE

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ABSTRACT

Progressive collapse in a structure occurs when structure demise the load carrying capacity to resist the specific demand of earthquake and major structural load carrying members get failed due to sudden change in configuration of structure. Progressive collapse can be triggered by manmade, natural, intentional, or unintentional causes. Fires, explosions, earthquakes, or anything else causing large amounts of stresses and the failure of a structure's support elements can lead to a progressive collapse failure. Progressive collapse is a complicated dynamic process where the collapsing system redistributes the loads in order to prevent the loss of critical structural members. For this reason beams, columns, and frame connections must be designed in a way to handle the potential redistribution of large loads. Progressive collapse assessment helps to improve the design of structure based on concerned response steel structure under dynamic loading. This research should be provide insight into the structural configuration to achieve a demand to capacity ratio of appropriate quantity and prevent collapse in the event of a single column loss. Several relationships shall be developing between bending moments, shear forces, column loading etc. Ultimately, all this information can be use in design codes where there are currently very limited or no specific rules or guidelines directed towards prevention of progressive collapse.

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INTRODUCTION

The progressive collapse of building structures is initiated when one or more vertical load carrying members (typically columns) are removed. Once a column is removed due to a vehicle impact, fire, earthquake or any other man-made or natural hazards, the building's weight (gravity load) transfers to neighboring columns in the structure. If these columns are not properly designed to resist and redistribute the additional gravity load that part of the structure fails. The vertical load carrying elements of the structure continue to fail until the additional loading is stabilized. As a result, a substantial part of the structure may collapse, causing greater damage to the structure than the initial impact. The concept of progressive collapse came into attention of structural engineers after the collapse of the Ronan Point Apartment building in England in 16May1968; a gas leak caused an explosion in an apartment of the 18th floor of the building. The explosion blew out an exterior wall panel. The loss of an exterior wall triggered the collapse of the upper floors, followed by the collapse of the floors below due to the impact of the falling upper floors.

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Buildings are vulnerable to progressive collapse if one or more columns are lost due to extreme loadings; which underlines the importance of establishing the likelihood of progressive collapse of structures in order to avoid catastrophic events. Published design guidelines and codes are now available to design engineers for mitigating progressive collapse or minimizing the damages caused by progressive collapse of a structure. Sasani and Kropelnicki (2008) made a 3/8 model of a building was produced and tested and compared with a detailed finite element model of the structure. Many different details were analyzed to determine the adequacy of the structure. The finite element model (FEM) was compared to a demand capacity ratio (DCR) method and determined that the DCR method is overly conservative. Giriunas (2009) did a study involving the comparison of real building behavior to that of a computer model he developed on the computer program SAP2000. Giriunas placed strain gauges throughout various places in the structure to gather physical data of the building's response to the loss of a sequential set of columns. While his experiment dealt with a steel framed structure, the information provided by his study gives great insight into the steps used to gather experimental data and how to use it to determine the credibility and accuracy of a specific analysis method. This paper presents important specification of GSA guidelines for progressive collapse analysis. Linear static, linear dynamic methods have been followed for progressive collapse analysis.

GSAguidlines

The Progressive Collapse Analysis and Design Guidelines for New Federal Office Building and Major Modernization Projects" is developed by the United State General Service Administration to evaluate the potential of progressive collapse for new and existing reinforced concrete as well as steel framed building. The guidelines are based on alternative load path method and removal of vertical load carrying member.

Analysis of loading

For progressive collapse analysis, the following load combination shall be applied after the removal of load carrying member:

For liner static analysis: 2 (D.L. + 0.25 L.L.)
For linear dynamic analysis: (D.L. + 0.25 L.L.)

Where:
D.L. = Dead Load and L.L. = Live Load In static analysisload case, dynamic amplification factor 2 is provided.

Calculation of Demand Capacity Ratio (DCR)

In order to determine the susceptibility of the building to progressive collapse, Demand Capacity Ratio should be calculated based on the following equation:

$$DCR=Q_{UD}/Q_{CE} \quad \text{….(1)}$$

In which:

Q_{UD}= Acting force (Demand) determined or computed in element or connection/joint
Q_{CE}= Probable ultimate capacity (Capacity) of the component and/or connection/joint

Referring to DCR criteria defined through static as well as dynamic approach, different elements in the structures and connections with quantities value less than 1.5 or 2 are considered not collapsed as follows:

- DCR < 2.0: for regular structural configuration
- DCR < 1.5: for irregular structural configuration
- Cases which have been chosen for this study have regular structural configuration as well as irregular structural configuration.

Consideration for columns removing for progressive collapse analysis

To calculate DCR according to GSA guidelines, structures should be analyzed as below

Exterior consideration:(a) Analyzing the sudden removal of a column in one floor above the ground (1st story) which is located at or near the middle of the short side of the building.(b) Analyzing the sudden removal of a column in one floor above the ground (1st story) which is located at or near the middle of the long side of the building.(c) Analyzing the sudden removal of a column between the ground floor and the floor above the ground level (1st story) which is located at the corner of the building.

Interior consideration: (a) Analyzing for the loss of a column that extend from the floor of the underground parking area or uncontrolled public ground floor area to the next floor.

Analysis of steel structure

The building considered for the study is a G+15 steel moment frame structure, four bays in longitudinal direction and three in transverse direction. The longitudinal direction spacing is 3m and transverse direction is column spacing is 4m.Floor to floor height is 3m and plinth height is 2m.Also vertical irregularity is provided to same structure for analysis purpose.

Loadings

Dead load includes self weight of structure. It is automatically generated by the software based on element volume and material. Thickness of slab is considered 125mm. For seismic loading, the building is located in zone IV with importance factor 1, soil type 2 and response reduction factor 3.

Column and Beam scheduled

Beam: ISMB 600.
Column: ISMB 600.

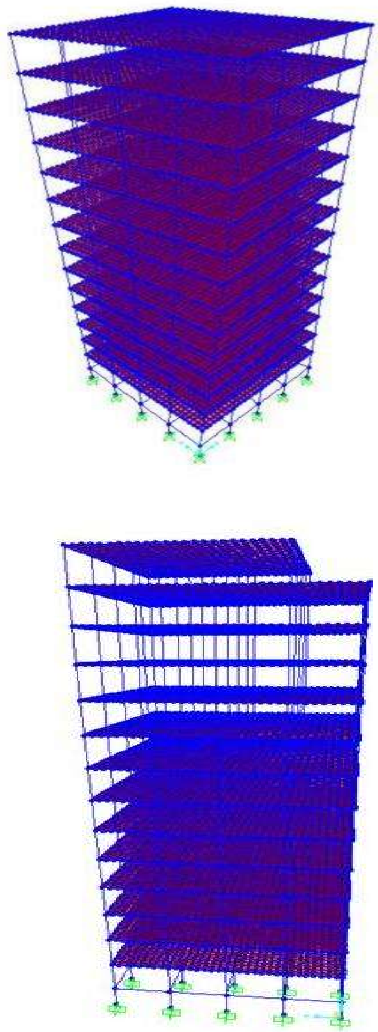


Fig.1. Elevation of regular and irregular building

3.2 Analysis of regular building

3.2.1Analysis of regular building with central column of longitudinal direction remove

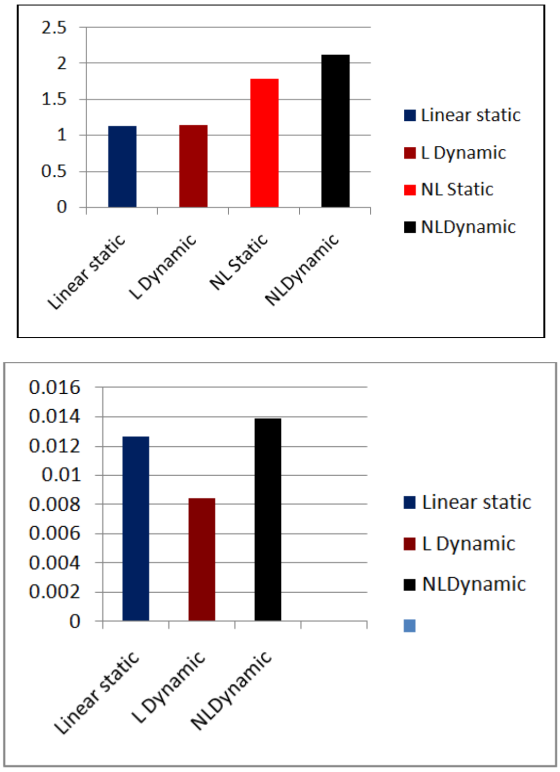


Fig.2. Demand-Capacity ratio and Roof displacement for column of longitudinal direction remove

3.2.2 Analysis of regular building with central column of transverse direction remove

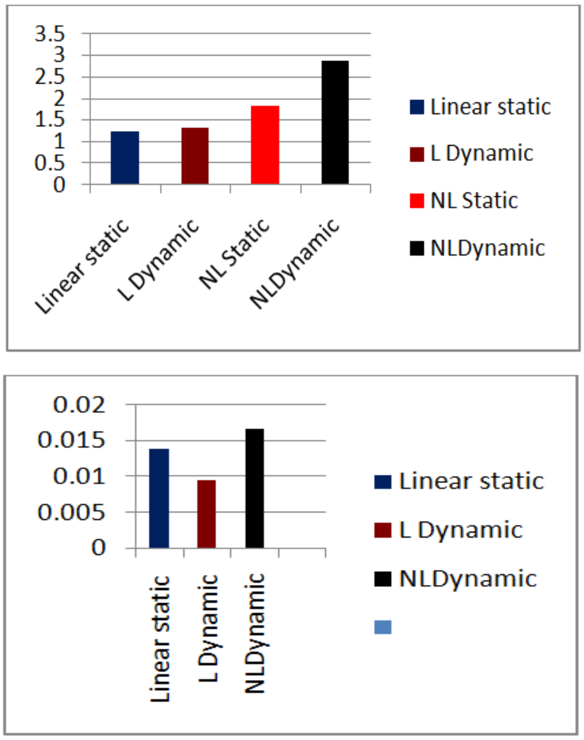


Fig.3. Demand-Capacity ratio and Roof displacement for column of transverse direction remove

3.2.3 Analysis of regular building with corner column remove

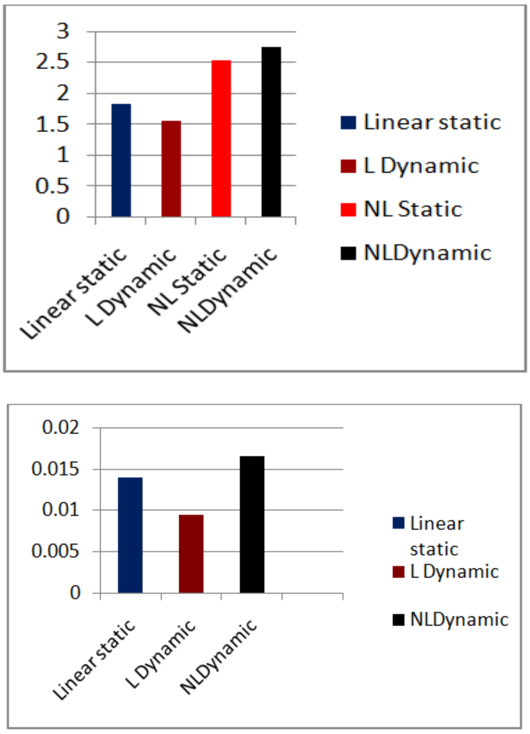


Fig.4. Demand-Capacity ratio and Roof displacement for central column remove

3.3 Analysis ofir regular building

3.3.1Analysis of regular building with central column of longitudinal direction remove

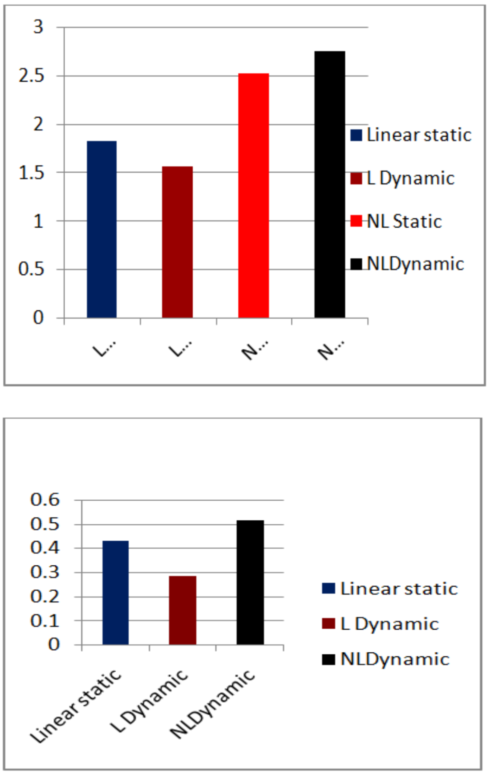
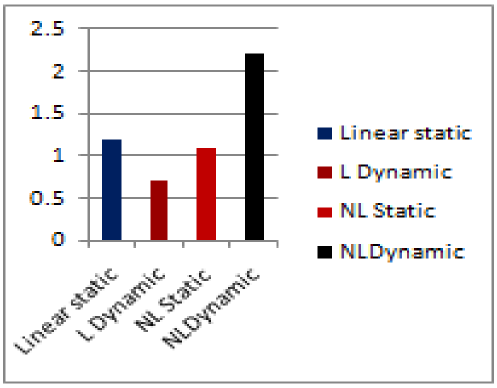


Fig.5. Demand-Capacity ratio and Roof displacement for column of longitudinal direction remove

3.3.2 Analysis of irregular building with central column of transverse direction remove



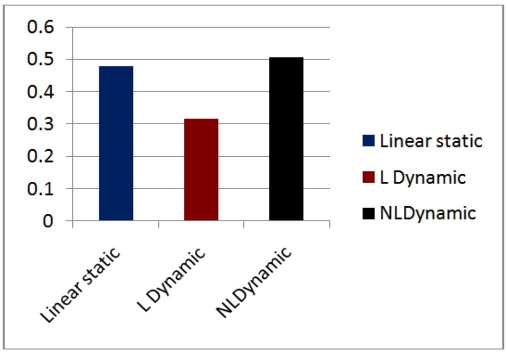
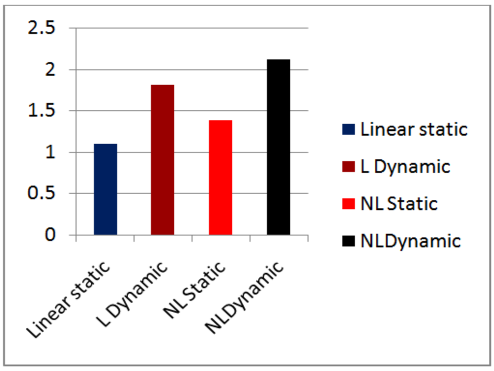


Fig.6. Demand-Capacity ratio and Roof displacement for column of transverse direction remove

3.3.3 Analysis of irregular building with corner column remove



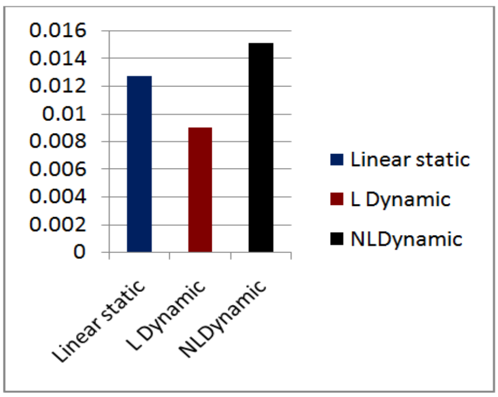


Fig.7. Demand-Capacity ratio and Roof displacement for central column remove

Conclusion

- DCR found from linear static analysis is lower than compared to linear dynamic analysis for left and right side of the column removal location in regular structure. So it can be concluded that to obtain the better result along with linear static analysis procedure, linear dynamic procedure should also be carried out.
- DCR found from linear static analysis is lower than compared to linear dynamic analysis for left and right side of the column removal location in irregular structure. So it can be concluded that to obtain the better result along with linear static analysis procedure, linear dynamic procedure should also be carried out. Effect of vertical irregularity on structural configuration will be calculated.
- Maximum displacement calculated by linear static analysis and linear dynamic analysis are 470mm and 300mm respectively in case of transverse direction middle column is remove.
- Maximum displacement calculated by linear static analysis and linear dynamic analysis are 80mm and 120mm respectively in case of longitudinal direction middle column is remove. So it can be concluded that displacement is much higher in case of transverse direction column removal as compared to longitudinal direction.
- DCR found in irregular structure is higher than regular one in all cases. So it is concluded that irregular building is more affected by progressive collapse than regular one.

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