Analysis of steel structure against Progressive collapse

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Abstract— A building undergoes progressive collapse when a primary structural element fails, resulting in the failure damage is disproportionate to the original cause, so the term disproportionate collapse is also used to describe this collapse type. Progressive collapse can be triggered by manmade, natural, intentional, or unintentional causes. Explosion, fires, earthquakes creates large amounts of stresses and the failure of supporting structural members 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. This research provides 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 developed between various analysis procedure against shear forces. Ultimately, all this information can be used in design codes where there are currently very limited or no specific rules or guidelines.

Keywords— Progressive collapse, Demand capacity ratio, Base shear, GSA(General Service Administration), Dead load, Live load, Dynamic analysis.

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. In the United States and other Western nations, progressive collapse is a relatively rare event. But after the remarkable partial collapse of the Ronan Point apartment tower in 1968 initiated an intellectual discussion among the engineering community on the possible ways to design buildings against such catastrophic progressive types of failure. While there have been several notable building collapses with similar characteristics in the years since Ronan Point, the debate considerably intensified after the World Trade Center disaster on 11 September 2011.

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.

GSA GUIDELINES

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:

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

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.

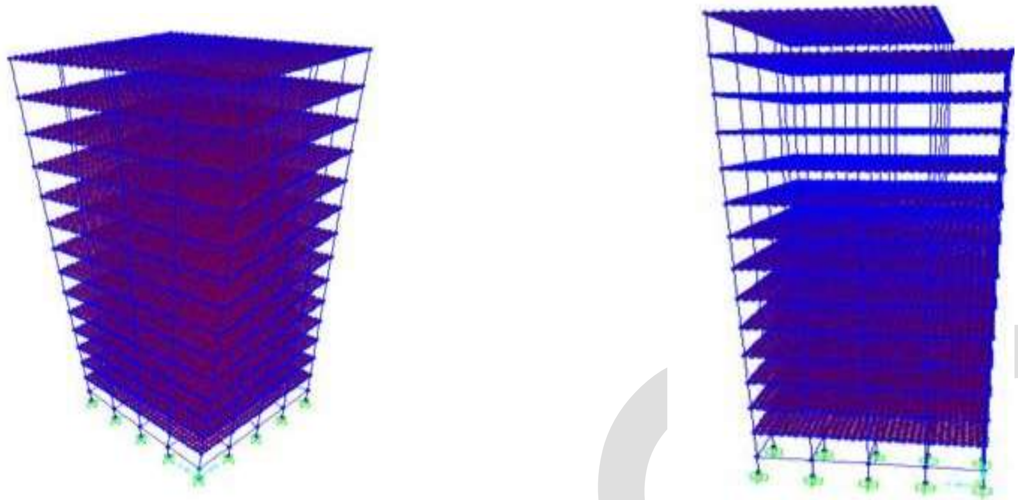

Fig.1. Elevation of regular and irregular building.

ANALYSIS OF REGULAR BUILDING

ANALYSIS OF REGULAR BUILDING WITH CENTRAL COLUMN OF LONGITUDINAL DIRECTION REMOVE.

A graph is plotted taking analysis methods as abscissa and base shear as ordinate for central column removed of longitudinal direction as shown fig.2.

From the fig.2 it can be seen that base shear for linear static analysis is larger than linear dynamic as well as non linear dynamic analysis. Base shear increases in linear static analysis by 6% than non linear dynamic analysis.

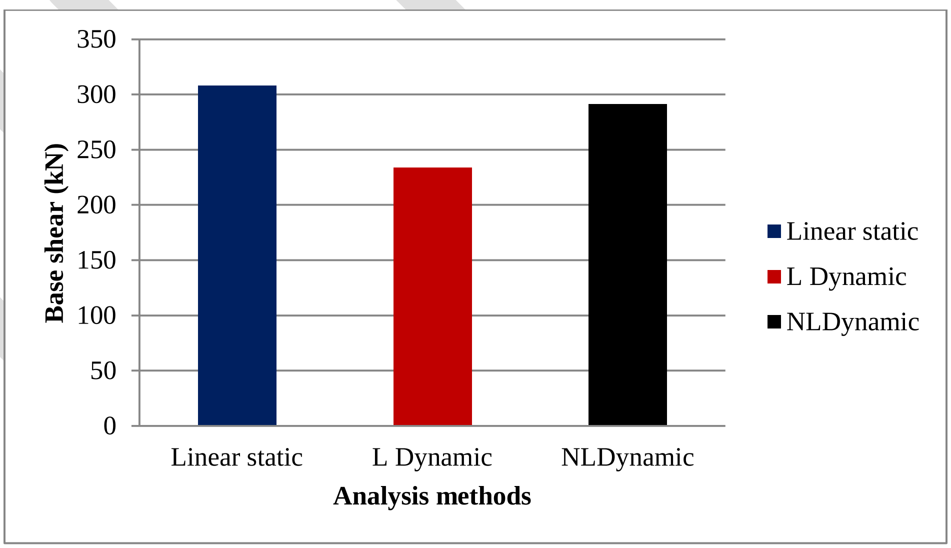

Fig.2 Base shear.

ANALYSIS OF REGULAR BUILDING WITH CENTRAL COLUMN OF TRANSVERSE DIRECTION REMOVE.

From the fig.3 it can be seen that base shear for non linear dynamic analysis is larger than linear static as well as linear dynamic analysis. Base shear increases in non linear dynamic analysis by 51.15 times than linear dynamic analysis.

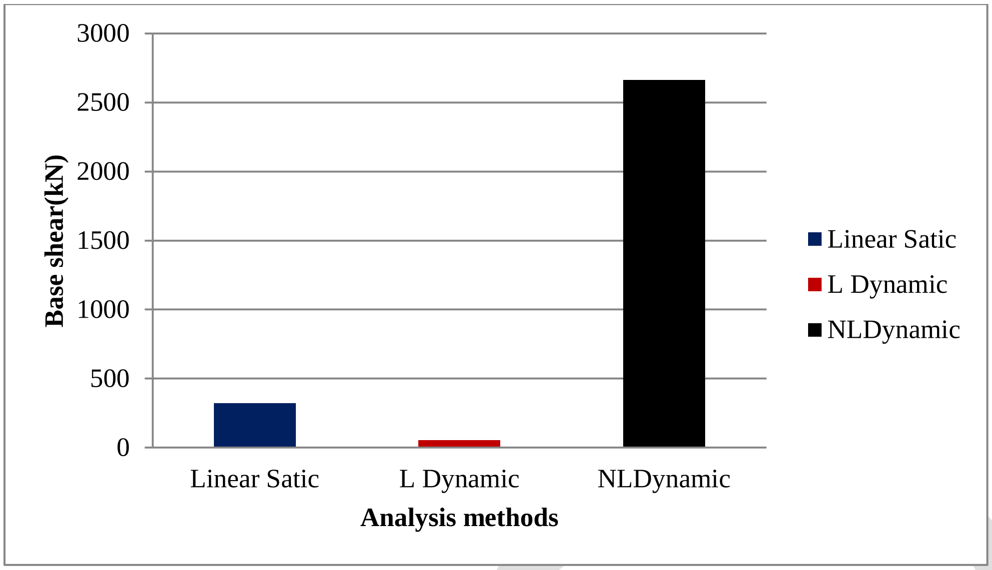

Fig.3 Base shear.

ANALYSIS OF REGULAR BUILDING WITH CORNER COLUMN REMOVE.

From the fig.4 it can be seen that base shear for linear static analysis is larger than linear dynamic as well as non linear dynamic analysis. Base shear increases in linear static analysis by 34.78% than linear dynamic analysis.

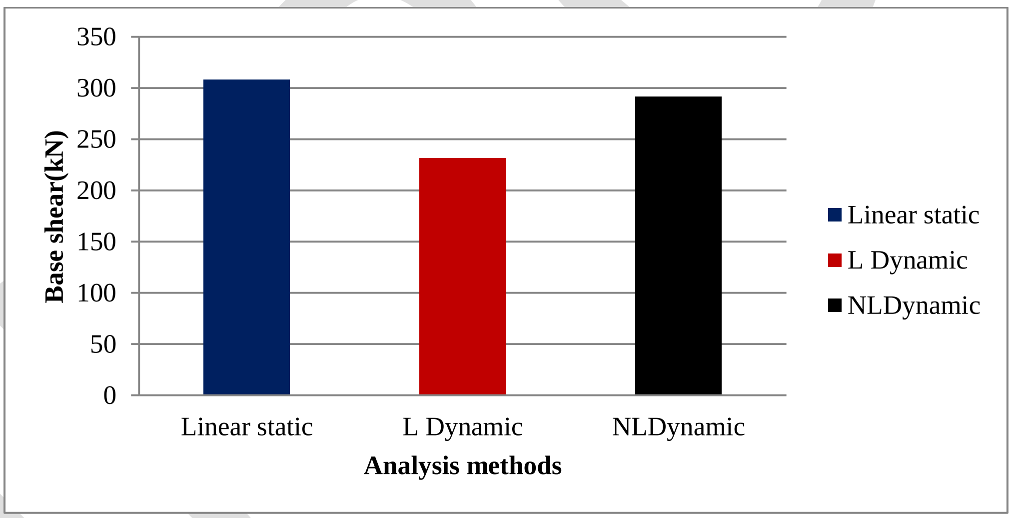

Fig.4 Base shear.

ANALYSIS OF IRREGULAR BUILDING

ANALYSIS OF REGULAR BUILDING WITH CENTRAL COLUMN OF LONGITUDINAL DIRECTION REMOVE.

From the fig.5.it can be seen that base shear for non linear dynamic analysis is larger than linear static as well as linear dynamic analysis. Base shear increases in non linear dynamic analysis by 2.8 times than linear dynamic analysis.

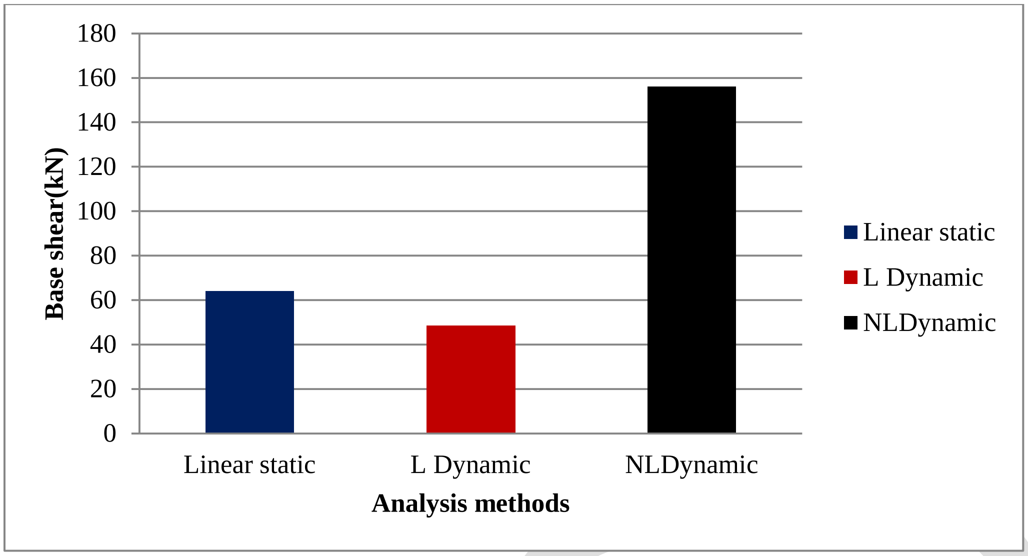

Fig.5 Base shear.

ANALYSIS OF IRREGULAR BUILDING WITH CENTRAL COLUMN OF TRANSVERSE DIRECTION REMOVE.

From the fig.6 it can be seen that base shear for linear static analysis is larger than linear dynamic as well as non linear dynamic analysis. Base shear increases in linear static analysis by 50% than linear dynamic analysis.

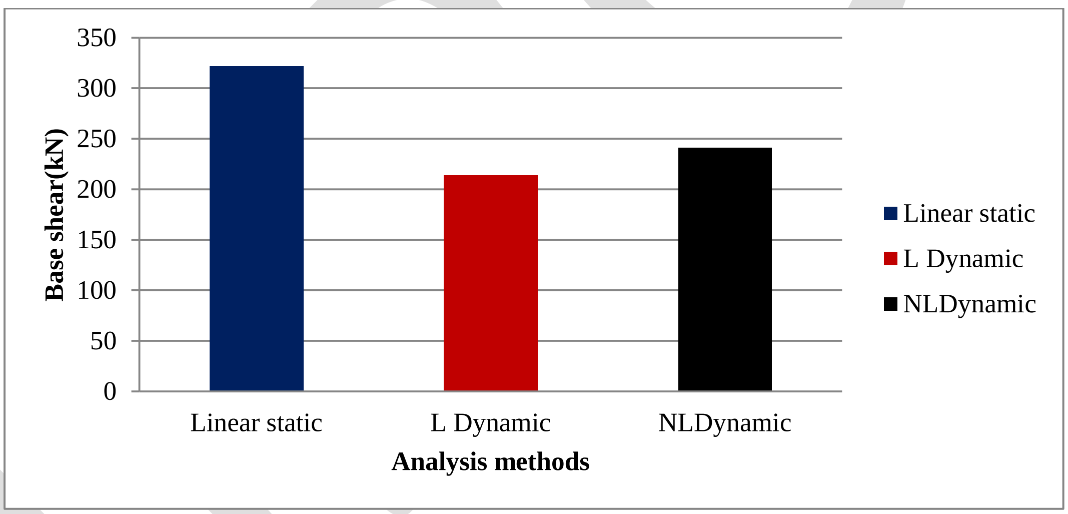

Fig.6 Base shear.

ANALYSIS OF IRREGULAR BUILDING WITH CORNER COLUMN REMOVE.

From the fig.7 it can be seen that base shear for linear static analysis is larger than linear dynamic as well as non linear dynamic analysis. Base shear increases in linear static analysis by 26% than linear dynamic analysis.

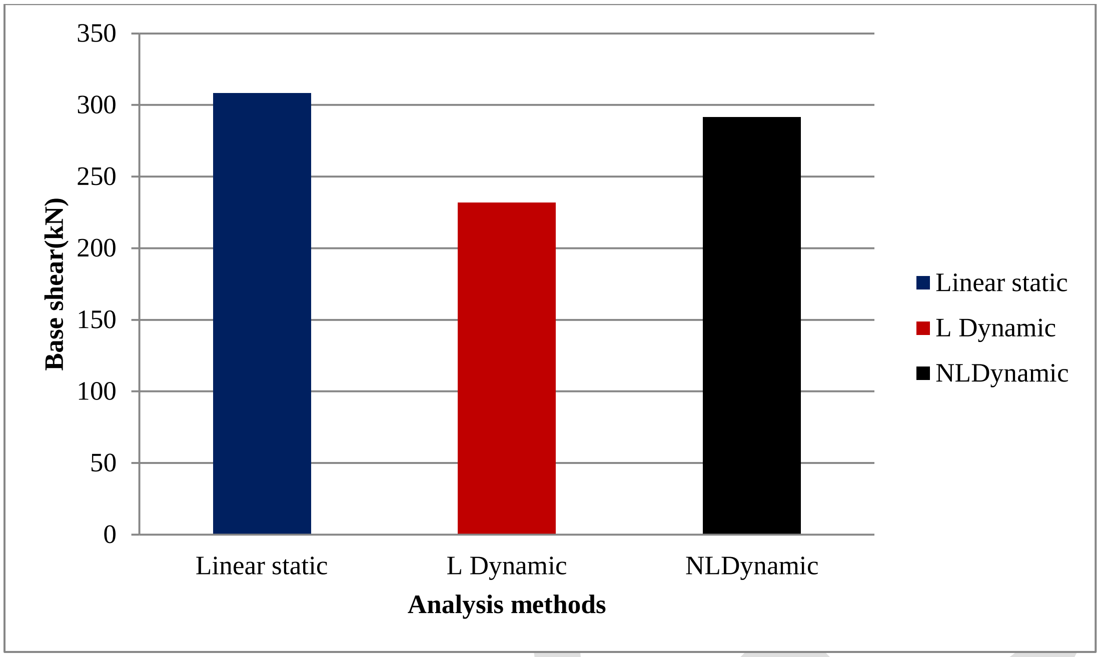

Fig.7 Base shear.

CONCLUSION

1) The variation in the linear static analysis and non linear static analysis seemed to be only 6% in whole structure.
2) The variation in the linear dynamic analysis and non linear dynamic analysis is seemed to be 20% for middle column of longitudinal direction is get removed in whole structure.
3) The variation in the linear dynamic analysis and non linear dynamic analysis is seemed to be 23% for middle column of transverse direction is get removed in whole structure.
4) The variation in the linear dynamic analysis and non linear dynamic analysis is seemed to be 20% for corner column is get removed in whole structure.
5) From above point it can be concluded that to obtain the better result along with linear dynamic analysis procedure, non linear dynamic analysis procedure should also be carried out.
6) Maximum base shear is obtained 2650Kn in regular structure when transverse direction middle column is removed where as in irregular structure when corner column is removed base shear is 330Kn.
7) For regular structure base shear is maximum when transverse direction middle column is removed. So, it can be concluded that regular steel structure is most vulnerable to progressive collapse when transverse direction middle column is get removed.
8) For irregular structure base shear values is maximum when transverse direction middle column is removed. So, it can be concluded that irregular steel structure is most vulnerable to progressive collapse when transverse direction middle column of building is get removed.

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