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Assessment of Progressive Collapse of Steel Structure

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Abstract:
The objective of the present study is to analyse the progressive collapse of regular and irregular steel structure. For this G+15 regular as well as irregular building with missing column at different locations has been taken . For this linear static analysis, linear dynamic analysis, non linear static and non linear dynamic analysis of structure has been carried out. To compare the progressive collapse responses 2D and 3D models are prepared. Percentage change in the values of base shear , demand capacity ratio and roof displacement considering progressive collapse effect of structures has been carried out. This analysis is done by using SAP2000.

Keywords: Progressive collapse, Base shear, Demand capacity ratio and roof Displacement, SAP2000.

I. INTRODUCTION

The progressive collapse of structures starts when one or more vertical load carrying members (specially columns) are removed. Once change in structure is made by removing a column due to man-made or natural hazards like vehicle impact, fire, earthquake etc the building's weight (gravity load) get transferd 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.

II .LITERATURE REVIEW

Miss. Preeti K. Morey, Prof S.R.Satone / "Progressive Collapse Analysis of Building", International Journal of Engineering Research and Applications. Vol. 2, Issue 4, June-July 2012 In the present paper the two different analysis procedure on G+4 R.C.C. structure has been performed. It was observed that dynamic amplification factor of 2 used in linear static equation is a good estimate for static analysis procedure since linear static and linear dynamic analysis procedure yield approximately the same maximum moment. Static analysis have low DCR value compare dynamic procedure this may be due to dynamic amplification factor of 2 used in linear dynamic analysis. Linear dynamic analysis gives more conservation results than static analysis.

Jinkoo Kim† and Junhee Park "Design of steel moment frames considering progressive collapse", Steel and Composite Structures, Vol. 8, No. 1 (2008) 85-98 In this study the progressive collapse potential of three- and nine-story special steel moment frames designed in accordance with current design code was evaluated by nonlinear static and dynamic analyses. It was observed that the model structures had high potential for progressive collapse when a first story column was suddenly removed. Then the size of beams required to satisfy the failure criteria for progressive collapse was obtained by the virtual work method; i.e., using the equilibrium of the external work done by gravity load due to loss of a column and the internal work done by plastic rotation of beams. According to the nonlinear dynamic analysis results, the model structures designed only for normal load turned out to have strong potential for progressive collapse whereas the structures designed by plastic design concept for progressive collapse satisfied the failure criterion recommended by the GSA guideline.

Mojtaba Hosseini , Nader Fanaie and Amir Mohammad Yousefi "Studying the Vulnerability of Steel Moment Resistant Frames Subjected to Progressive Collapse", Indian Journal of Science and Technology, Vol 7(3), 335–342, March 2014. In this study, the vulnerability of an official 10-story steel moment resistant frame, designed according to Iranian National Building Codes (INBC) is assessed. The following nonlinear dynamic analysis procedure is recommended by the UFC 4-023-03 guideline, which provides technical guidance for mitigation and protection of progressive collapse. Alternate Path (AP) method has been applied to evaluate the structure that can bridge over notionally removed column and nonlinear dynamic analysis procedure conducted. The investigated cases emphasize on the removal of a corner column in the ground floor, fifth floor, eighth floor, and just below the roof floor. Based on the results obtained in this research, steel moment resistant frames, designed according to Iranian National Building Codes, do not satisfy UFC acceptance criteria and have high potential for progressive collapse in corner column removal scenarios. Therefore some modifications have been conducted on the codes to satisfy the UFC limits.

M. A. Hadianfard, M. Wassegh M. and Soltani Mohammadi. "Linear and nonlinear analysis of progressive collapse for seismic designed steel moment frames."14 th international conference on computing in civil and building Engineering. Moscow, Russia 27- 29 june 2012. In this paper, the intermediate steel moment frames structures with different levels of height designed for moderate and very high level of seismic zones of Iran are studied. For evaluating the potential of progressive collapse, the alternate path method in accordance with both GSA and UFC guidelines is used in two different methods; linear static analysis and nonlinear static analysis. The results show that, generally, for the steel structures designed for higher seismicity there is higher capacity for progressive collapse and in the low height steel structures, there is not enough redundancy to redistribute loads of the failed elements so, the potential of progressive collapse increases with decreasing the height of the structure.

III. METHODOLOGY

For carry out present dissertation following methodology has been used.

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.

ANALYSIS OF LOADING-

For progressive collapse analysis, the following load combination has been 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.)
In static analysis load case, dynamic amplification factor is taken as two.

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=QUD/QCE ….(1)

In which:

QUD= Acting force (Demand) determined or computed in element or connection/joint.

QCE= 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

1.Beam: ISMB 600.
2.Column: ISMB 600.

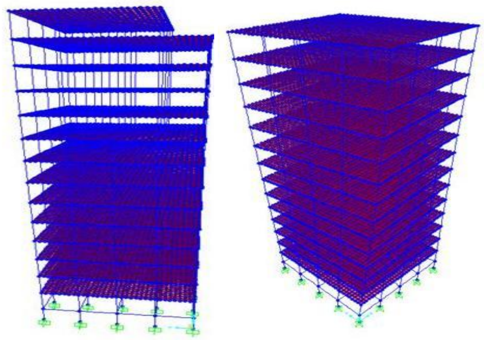

Figure.1. Elevation of regular and irregular building.

IV.TEST RESULT AND DISCUSSION

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 . 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 7% than non linear dynamic analysis.

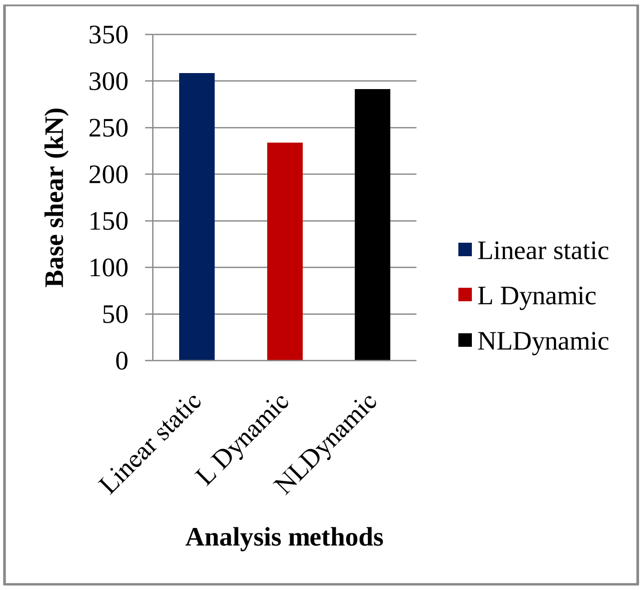

Figure.2. Base shear

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

For this 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.

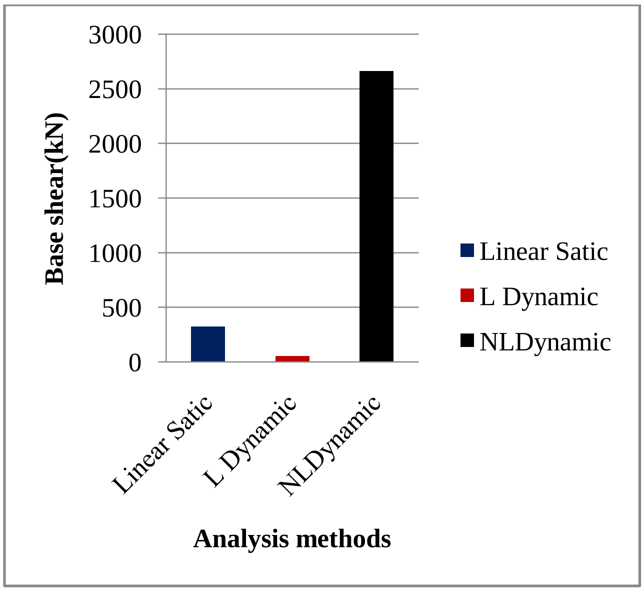

Figure.3. Base shear.

ANALYSIS OF REGULAR BUILDING WITH CORNER COLUMN REMOVE.

For this 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.

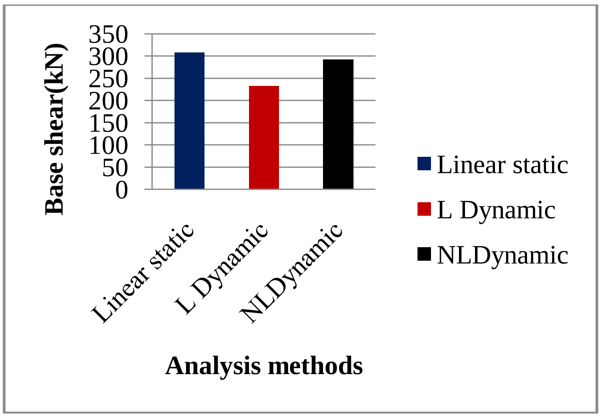

Figure.4. Base shear

ANALYSIS OF IRREGULAR BUILDING - ANALYSIS OF IREGULAR BUILDING WITH CENTRAL COLUMN OF LONGITUDINAL DIRECTION REMOVE.

For this 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.

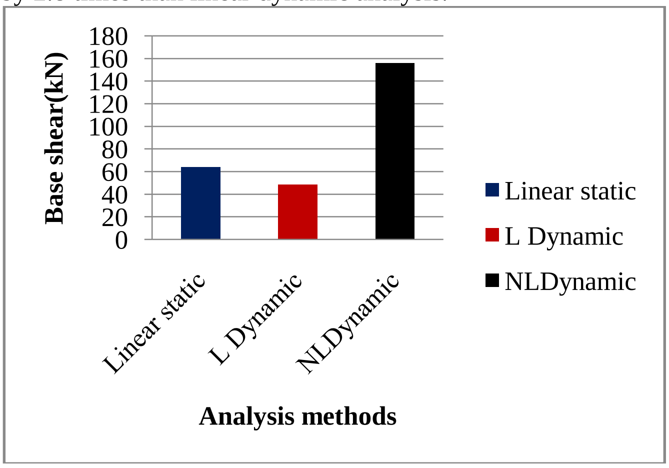

Figure.5. Base shear.

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

For this 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.

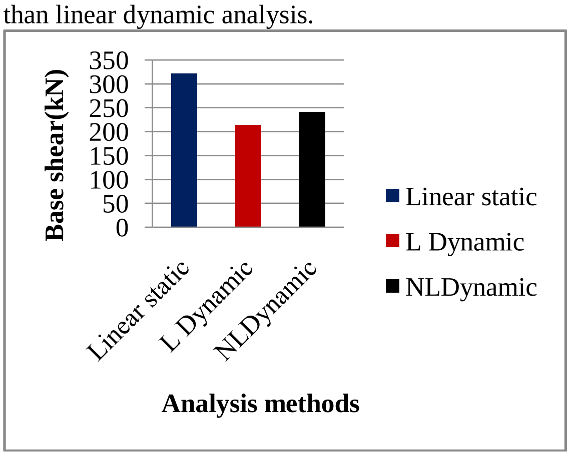

Figure.6. Base shear.

ANALYSIS OF IRREGULAR BUILDING WITH CORNER COLUMN REMOVE.

For this 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.

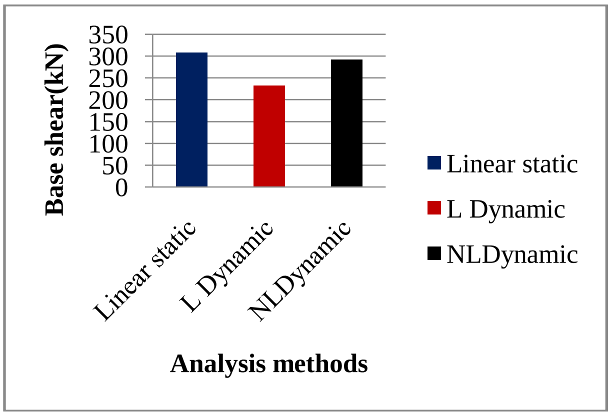

Figure.7. Base shear.

VI. CONCLUSION

1) The variation in the linear static analysis and non linear static analysis seemed to be only 7% 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) Maximum demand capacity ratio is obtained 2.9 in regular structure when corner column is removed where in irregular structure when transverse direction middle column is removed demand capacity ratio is 2.74.
8) Maximum roof displacement is obtained 16.5mm in regular structure when corner column is removed where as in irregular structure when transverse direction middle column is removed roof displacement is 510mm.
9) 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.
10) 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.

VII. REFERENCES

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