EFFECT OF THE BUILDING HEIGHT ONPROGRESSIVE COLLAPSE

Majid MOHAMMADI
Professor Assistant, International Institute of Earthquake Engineering and Seismology , Tehran, Iran
m.mohammadigh@iiees.ac.ir

Bahram KORDBAGH
Master of Science Student, International Institute of Earthquake Engineering and Seismology, Tehran, Iran
b.kordbagh@iiees.ac.ir

Keywords: Progressive Collapse, Building Height, Steel Moment Resisting Frame, Alternate PathMethod, Nonlinear Dynamic Analysis

ABSTRACT

Progressive collapse is defined as extension of initial collapse, from a part of structure to another one that may result in destruction of structure. Possible risks and abnormal loads that cause progressive collapse are as follows: aircraft collision, design or construction error, firing, gas explosion, random overload, vehicles contusion, bomb blast and etc. such phenomenon are not consider in designing typical structure, since possibility of occurring these risks is very low. However, they should be regarded in very important or special structures.

In this research, effect of the building height on progressive collapse is studied. For this purpose, steel moment resisting structures designed for high seismicity zone areas, with four, eight and twelve- stories are considered and their progressive collapse are studied and compared.

Results indicate that the potential of progressive collapse decreases by increasing building height. The main reason is increasing structure indeterminate degree, and catenary action of members.

INTRODUCTION

Increasing catastrophic events in recent years showed that the prevention or mitigation of progressive collapse must be included as a requirement in design and analysis of important buildings. Many methods have been proposed to mitigate progressive collapse and several building codes, standards, and design guidelines have discussed this issue. General Services Administration (GSA, 2013) and Department of Defence (DoD, 2005) have been used more than the others for designing and analysing of progressive collapse. The alternate path method (APM) is a threat independent approach that is commonly used for analysis of progressive collapse. This approach is based on removing a load-bearing element and evaluating stability of the remaining structure and also its ability to bridge over the removed element.

There are different analysis procedures for the APM that have been suggested in guidelines. These procedures are linear static, linear dynamic, nonlinear static and nonlinear dynamic. In recent decades, many studies have been performed to evaluate the potential of progressive collapse of buildings by computer modelling and also to evaluate the advantages and disadvantages of each four progressive collapse analysis procedures some of these studies have been performed by Marjanishvili (2004); Powell (2005); Marjanishvili and Agnew (2006); McKay (2008). A more complex nonlinear analysis is required to obtain more realistic results but it is better that the static and the dynamic analysis properly be incorporated so that the best results can be achieved for analysis of progressive collapse.Kim and An (2009) investigated the effect of catenary action on the progressive collapse potential of steel structures. Khandelwal et al. (2009) applied a macro analysis model to investigate the resistance to progressive collapse of seismically designed steel braced frames.

In this research, effect of the building height on progressive collapse is studied. For this purpose, steel moment resisting structures designed for high seismicity zone areas, with 4-, 8-, and 12- story are considered and their progressive collapse are studied and compared.

MODELING OF STRUCTURAL ELEMENTS

The columns and beams in the consideredstructures were modelled using the ‘Nonlinear Beam-Column’ element provided by OpenSees(2006). In addition, ‘Steel01’ material model was used for columns and beams. Fig. 1 shows the bilinear load-displacement relationship of the ‘Steel01’ material model. The post-yield stiffness was assumed to be 2% of the initial stiffness.

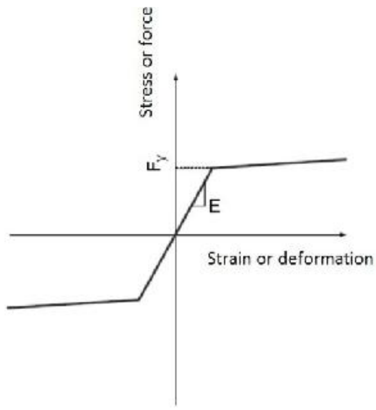


Figure 1. Material modeling for steel members

In this study the panel zones in girder-column joints were assumed to be rigid and the catenary action of girders was not considered. When panel zone is not rigid, the deflection of girders caused by sudden removal of a column will be greater than that of the rigid panel zone case and the progressive collapse potential of the structure will be increased. Therefore for more accurate evaluation of progressive collapse potential it would be necessary to consider connection strength including panel zone effect and the development of catenary action in the analysis. Further study is still required to provide more information about the connection properties of structures and to validate the failure criteria currently recommended in the guidelines.

DESIGN AND ANALYSE OF THE MODEL STRUCTURES

The structures are considered in this study are the four, eight, and twelve- stories, special steel moment frames structures that have been designed in accordance with Iranian Standard No. 2800 (2014) and AISC Load and Resistance Factor Design (2003). It is assumed that the structures located on soil type 3 (with shear velocity of 175-375 m/s) and the structural elements are made of steel, St-37. Height of stories is 3 m and spans of the structures are 5 m. Plan of structures is shown in Fig. 2. The twodimensionalframes indicated by the dotted rectangularbox in Fig. 2 were analysed for progressivecollapse. Designed sections of the considered frames areshown in Table 1.

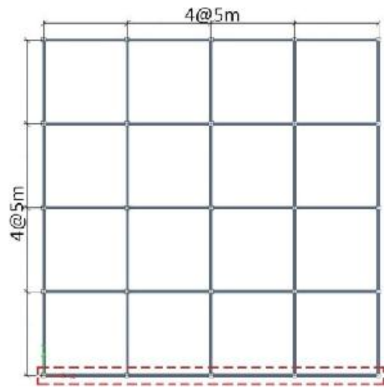


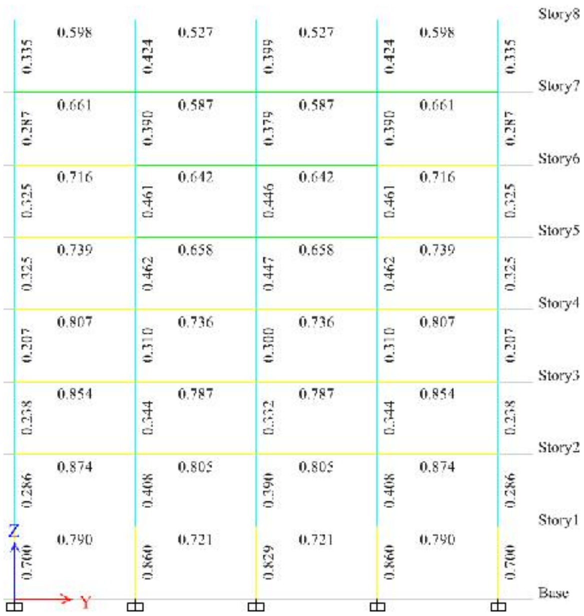
Figure 2. Structural plan of model

Table 1.Member sizes of model structures (mm)

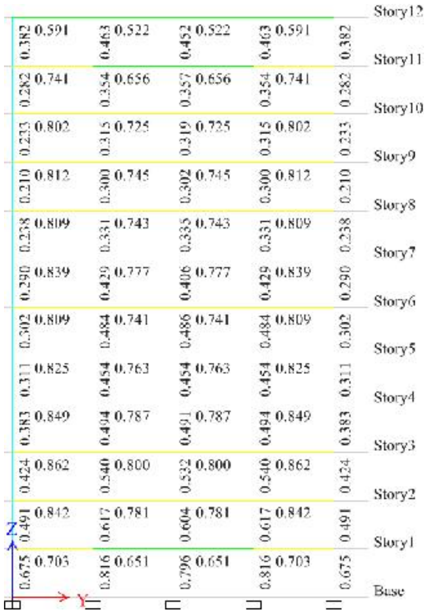
(a) 4-story			(b) 8-story			(c) 12-story		
Story	Columns	Beams	Story	Columns	Beams	Story	Columns	Beams
1	BOX 240x240x17.5	IPE 300	1	BOX 320x320x20	IPE 360	1	BOX 360x360x25	IPE 400
2	BOX220x220x17.5	IPE 300	2~4	BOX 300x300x40	IPE 360	2~5	BOX 340x340x30	IPE 400
3	BOX220x220x17.5	IPE 270	5	BOX 300x300x20	IPE 360	6	BOX 340x340x25	IPE 400
4	BOX180x180x12.5	IPE 160	6	BOX 280x280x20	IPE 330	7~8	BOX 340x340x25	IPE 360
-	-	-	7	BOX 260x260x20	IPE 300	9	BOX 340x340x25	IPE 330
-	-	-	8	BOX 220x220x17.5	IPE 160	10	BOX 320x320x20	IPE 300
-	-	-	-	-	-	11	BOX 260x260x20	IPE 270
-	-	-	-	-	-	12	BOX 220x220x16	IPE 180

Demand capacity ratio for structural elements of frame indicated by the dotted rectangularbox is shown in Fig. 3.

(a) 4-story



(b) 8-story



(c) 12-story

Figure 3. Demand capacity ratio for structural elements

NONLINEAR DYNAMIC ANALYSIS OF THE MODEL STRUCTURES

Nonlinear analysis procedures generally provide a moresophisticated analysis than linear procedures to characterize the performance of a structure.However, advances in computer hardware and generalpurposeanalysis software packages have now made itpossible to employ nonlinear assessment techniques onlarge and complex structures, including nonlinear time history response of high-rise structurescontaining thousands of members and connections. When such procedures are used, the guidelinesgenerally permit less restrictive acceptance criteria recognizingthe improved results that can be obtained from such procedures.The guidelines, however, indicate that potential numerical convergenceproblems may be encountered during the execution ofthe nonlinear analysis, along with sensitivities to assumptions forboundary conditions, geometry and material models, etc.

Progressive collapse is generally initiated by the suddenloss of one, or many, structural members. Once astructural member (usually a column in the first storey) issuddenly removed, the stiffness matrix of the system alsoneeds to be suddenly changed. This may cause difficultyin the analytical modelling process. To avoid this problem,all member forces were first obtained from the fullstructural model subjected to the applied load. Thestructure was then re-modelled with the appropriatecolumn removed and its member forces applied tothe structure as dummy forces to maintain equilibriumas shown in Figures 4 and 5. The preliminary analysis results showedthat the structure became stable after 5 seconds. Themember force was suddenly removed after 7 seconds toinitiate progressive collapse. In this way the progressivecollapse analysis started from the moment that thestructure was already deformed by the applied load, whichreflected the loading situation quite realistically.

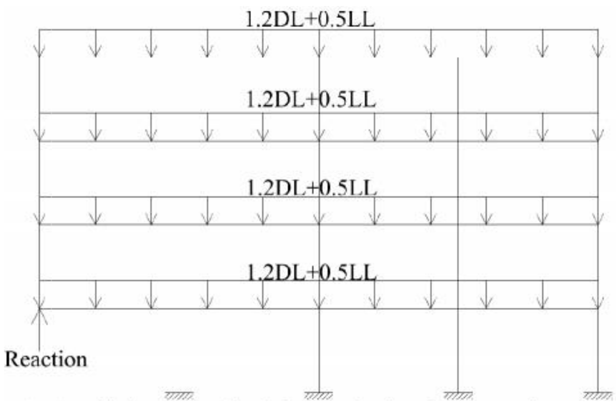


Figure 4. Applied gravity load for analysis of progressive collapse

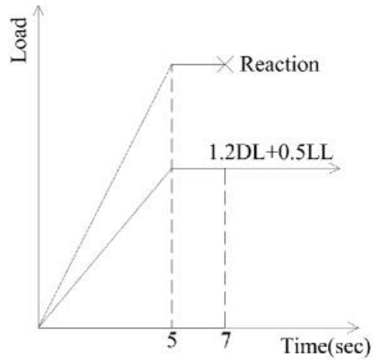
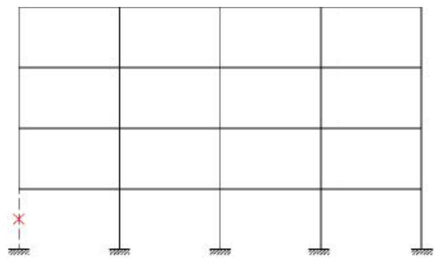
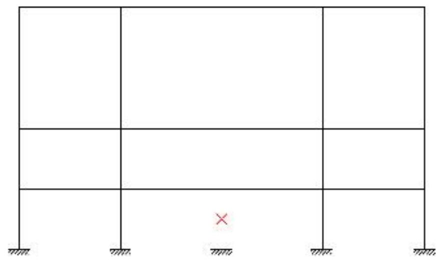


Figure 5. Application of vertical load for dynamic analysis

Nonlinear dynamicprogressive collapse analyses were performed bysuddenly removing the column from the corner and the middle column as shown in Fig.6.



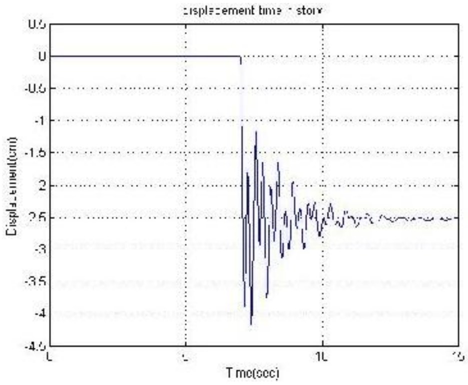
(a) Removing the corner column



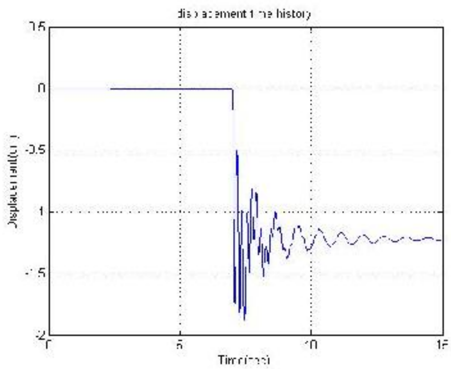
(b) Removing the middle column

Figure 6. Removing external columns

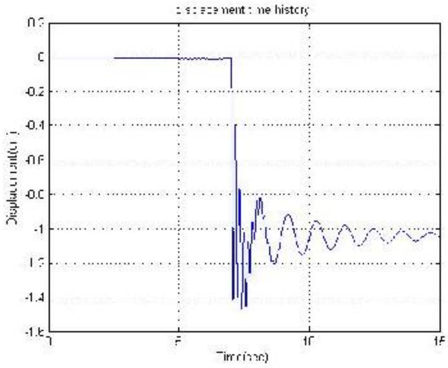
Figures 7 and 8indicate thevertical deflections for the four, eight, and twelve-storieswith removing the corner column and the middle column, respectively.



(a) 4-story

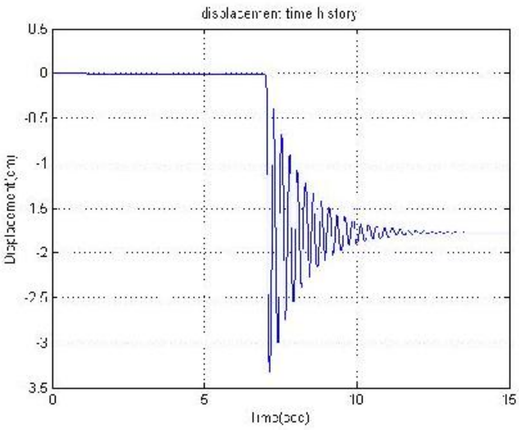


(b) 8-story

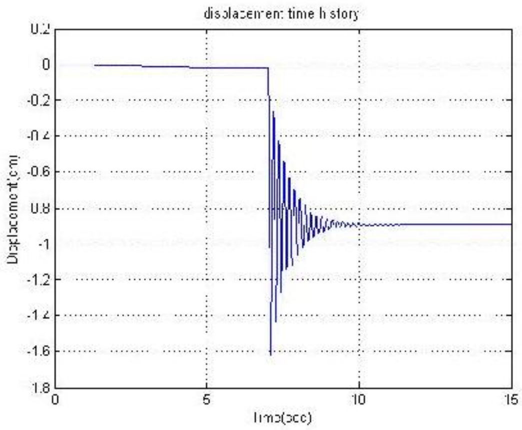


(c) 12-story

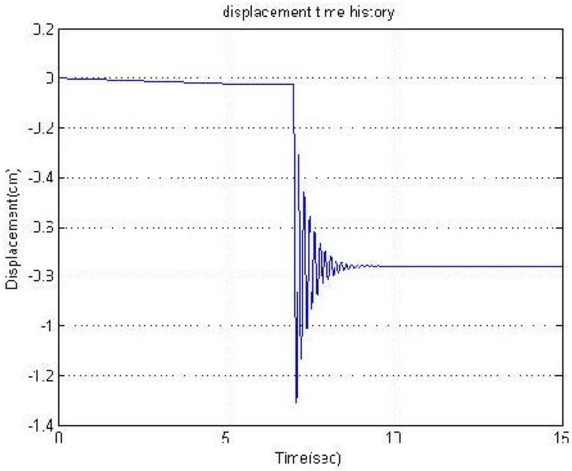
Figure 7. Displacement time history at the joint where the corner column is removed



(a) 4-story



(b) 8-story



(c) 12-story

Figure 8. Displacement time history at the joint where the middle column is removed

Fig.9 compares thevertical deflections of the joint where the corner column is removed for the four, eight, and twelve-storey buildings, and Fig. 10compares them, for the case of removing the middle column.

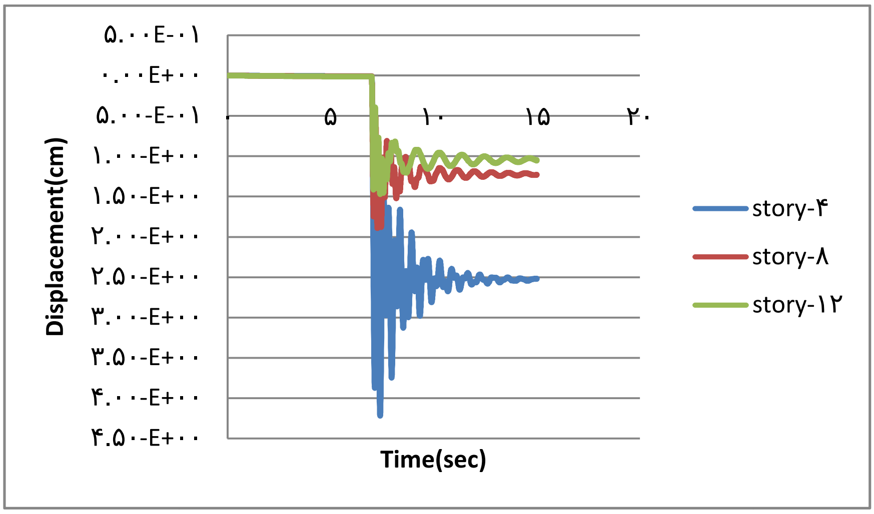


Figure 9.Comparison of the nonlinear dynamic analysis results for the 4-, 8-, and 12-storeyfor the scenario of removing the corner column

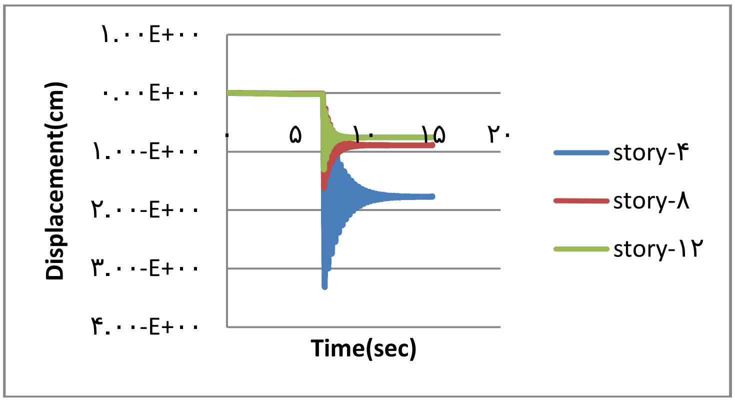


Figure 10. Comparison of the nonlinear dynamic analysis results for the 4-, 8-, and 12-storey for the scenario of removing the middle column

CONCLUSIONS

In this study the progressive collapse potential for the four, eight, and twelve-storiessteelmoment resisting frames was investigated using the nonlinear dynamic analysis proceduresrecommended in the GSA 2013 and the guideline. It wasobserved that,the potentialfor progressive collapse was highest for the scenario of removinga corner column, and that the progressive collapse potentialdecreased as the number of story increased. Results indicate that the potential of progressive collapse decreases by increasing building height. The main reason is increasing structure indeterminate degree, and catenary action of members.Also the dynamic analysis results varied moresignificantly depending on the variables such as locationof column removal, or number of building story.

REFERENCES

AISC (2003)Load and Resistance Factor Design Specification for Structural Steel Buildings, Chicago (IL): American Institute of Steel Construction

DoD(2005)Design of Buildings to Resist Progressive Collapse Unified Facilities Criteria (UFC) 4-023-03, Department of Defense (DoD)

GSA (2013) Progressive Collapse Analysis and Design Guidelines for New Federal Office Buildings and Major Modernization Projects, General Services Administration (GSA)

Iranian Code of Practice for Seismic Resistant Design of Buildings (2014), Standard no. 2800, 4rd edition, Building and Housing Research Center

Khandelwal K, El-Tawil S and Sadek F (2009) Progressive Collapse Analysis of Seismically Designed Steel Braced Frames,*Journal of Constructional Steel Research*, 66(3): 699-708

Kim J and AN D (2009) Evaluation of Progressive Collapse Potential of Steel Moment Frames Considering Catenary Action,*The Structural Design of Tall and Special Buildings*, 18(4): 455-465

Marjanishvili S (2004) Progressive Analysis Procedure for Progressive Collapse,*Journal of Performance of Constructed Facilities*, 18(2): 79-85

Marjanishvili S and Agnew E (2006) Comparison of Various Procedures for Progressive Collapse Analysis, *Journal of Performance of Constructed* Facilities, 20(4): 362-74

Mazzoni S, McKenna F, Scott MH and Fenves GL(2006)*Open System for Earthquake Engineering Simulation,User Command-Language Manual*, Pacific EarthquakeEngineering Research Center, Berkeley, CA

McKay AE (2008) Alternate Path Method in Progressive Collapse Analysis: Variation of Dynamic and Non-linear Load Increase Factor, MS Thesis, Department of Civil and Environmental Engineering, University of Texas, San Antonio, Texas

PowellG (2005) Progressive Collapse: Case Study Using Nonlinear Analysis, Proceedings of the 2005 structures congress and the 2005 forensic engineering symposium. Apr. 20-24, New York, NY