7th International Conference on Seismology & Earthquake Engineering
18-21 May 2015

EFFECT OF THE ASSUMED DESIGNINGSEISMIC COEFFICIENT ON SAFETYMARGIN AGAINST PROGRESSIVECOLLAPSE OF STEEL, MOMENT RESISTINGFRAME BUILDINGS

Majid MOHAMMADI
Assistant Professor, 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, Steel Moment Resisting Frame, Nonlinear Dynamic Analysis, Different Seismic Zones

ABSTRACT

Progressive collapse began with local destruction of one or more parts of structure. Then, it extends into significant part of building, being no proportional to initial collapse. Usually, buildings are designed for normal loads, such as, dead, live, wind and earthquake. Nevertheless, there are other possible risks and loads, including firing, vehicle collision, explosion and etc. having less occurring possibility, but, they shall cause terrible collapse, in case of occurring.

Some structures should be safe against progressive collapse; therefore sufficient safety margin should be regarded in the designing phase. It is generally clear that considering higher base shear for a structure, leads to greater safety margin against progressive collapse. In this study, the effect of the considered seismic base shear in increasing safety margin, against progressive collapse is quantitatively studied for a four-story, steel moment resisting frame building. Different structures are designed for the building, for low- to – very high seismic hazard regions, and investigated for sudden removal of critical members, in first floor.

Subsequently, relation of the assumed seismic base shear and potential of the progressive collapse is shown quantitatively for different seismic zone of Iran.

INTRODUCTION

For designing structures to resist progressive collapse, generally the alternate path method, among different methods, has been recommended by guidelines. In this method, a structure is designed in such manner that if one element failed, the alternate paths would be exist to carry loads and the structure would be able to bridge over the removed element and disproportionate collapse of whole or a large part of the structure would not occur. Simplicity and directness are some of the advantages of this approach. There are different analysis procedures for the alternate path method that have been suggested in guidelines. This procedures are linear static, linear dynamic, nonlinear static and nonlinear dynamic.The linear static procedure is the simplest analysis option and often offers conservative assessment of the progressive collapse potential.The nonlinear static procedure, as an intermediate analysis option, involves modeling of both geometrical and material nonlinearities but for conducting progressive collapse analysis, it is not required to perform time history analysis. The nonlinear dynamic procedure is the most accurate option that is also the most computationally expensive procedure. Marjanishvili and Agnew (2006) evaluated and compared these methods and mentioned that, though these four procedures had their own advantages individually, 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.Khandelwal and El-Tawil (2007) presented a calibrated micromechanical constitutive model for steel to investigate a number of key design variables that influence the formation of catenary action in special steel moment resisting frame sub-assemblies. 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 study, the progressive collapse potential of steel moment frames is evaluated for the four-story buildings that designed per Iranian building and seismic codes (2014) in four different seismic zones of Iran; low level of risk to very high level of risk of seismic zones. The resistance of seismic designed structures to progressive collapse has been investigated using the alternate path method in accordance with GSA (2013) and UFC (2009).

MODELING OF STRUCTURES

The structure, considered in this study, is afour-story special steel moment frame that has beendesigned in accordance with Iranian Seismic Code 2800 (2014) and the AISC Load and Resistance Factor Design (2003). It is assumed that the structure located onsoil type 3 and type of the applied steel is St-37. Height of stories is 3 m and spans of the structure are 5 m. The structure isdesigned forfour different seismic zones of Iran; low, moderate, high, and very high seismic hazard zones with designing acceleration of 0.2g, 0.25g, 0.3g, and 0.35g, respectively.Plan of the building is shown in Fig. 1. The twodimensionalframe indicated by the dotted rectangularbox in Fig. 1isanalysed separately for progressivecollapse. Dimensions of the selected members in low, moderate, high, and very high seismic zones areshown in Table 1. It is worth mentioning that vertical component of earthquake is not required to be considered in the designing phase, except for the structure in very high seismic zone.

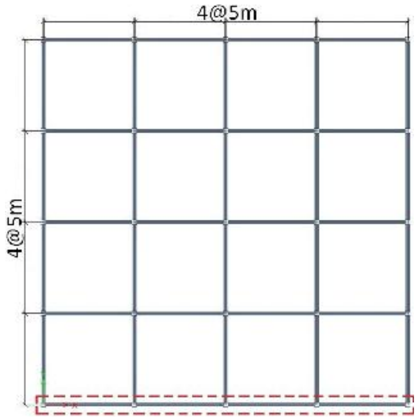


Figure 1. Structural plan of model

Table 1.Member sizes of model structures in different seismic zones(mm)

(a) Very high seismic zone			(b) High seismic zone		
Story	Columns	Beams	Story	Columns	Beams
1	BOX 240x240x17.5	IPE 300	1	BOX220x220x17.5	IPE 270
2	BOX220x220x17.5	IPE 300	2	BOX220x220x17.5	IPE 270
3	BOX220x220x17.5	IPE 270	3	BOX 200x200x12.5	IPE 270
4	BOX180x180x12.5	IPE 160	4	BOX 160x160x12.5	IPE 180

(c) Moderate seismic zone			(d) Low seismic zone		
Story	Columns	Beams	Story	Columns	Beams
1	BOX200x200x17.5	IPE 270	1	BOX200x200x17.5	IPE 240
2	BOX200x200x17.5	IPE 240	2	BOX180x180x17.5	IPE 220
3	BOX 180x180x12.5	IPE 240	3	BOX 160x160x16	IPE 180
4	BOX 160x160x10	IPE 140	4	BOX 140x140x12.5	IPE 140

NONLINEAR DYNAMIC ANALYSIS OF MODEL STRUCTURES

Progressive collapse is generally initiated by sudden loss of one, or many, structural members. Once a structural member (usually a column in the first storey) is suddenly removed, the stiffness matrix of the system needs to be suddenly changed. This may cause difficulty in the analytical modelling process. To carry out dynamic analysis, the axial force acting on a column is computed before it is removed. Then the column is replaced by point loads equivalent of its member forces as shown in Fig. 2. To simulate the phenomenon that the column is abruptly removed,the member forces are removed after a certain time is elapsed as shown in Fig. 3. In this study the forces were increased linearly for five seconds until they reached their full amounts, kept unchanged for two seconds until the system reached stable condition, and the upward force was suddenly removed at the seven second to simulate the dynamic effect caused by sudden removal of the column.

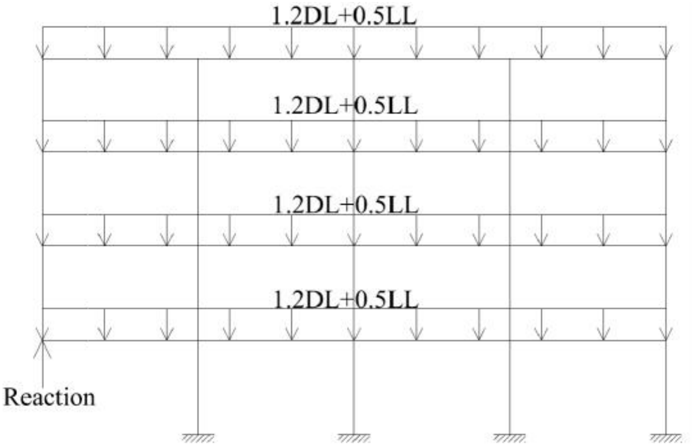


Figure 2. Applied gravity load for analysis of progressive collapse

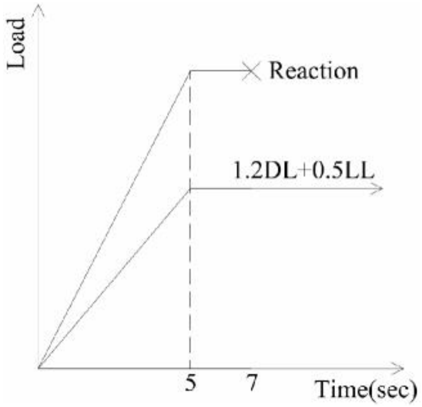
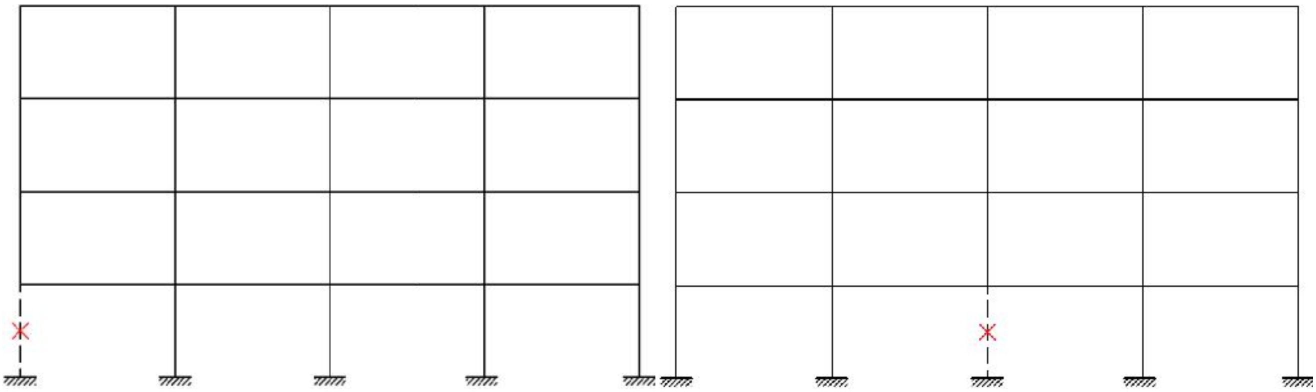


Figure 3. Application of vertical load for dynamic analysis

Nonlinear dynamicprogressive collapse analyses were performed bysuddenly removing the column from the corner and the middle column as shown in Fig.4 as proposed by GSA (2013).

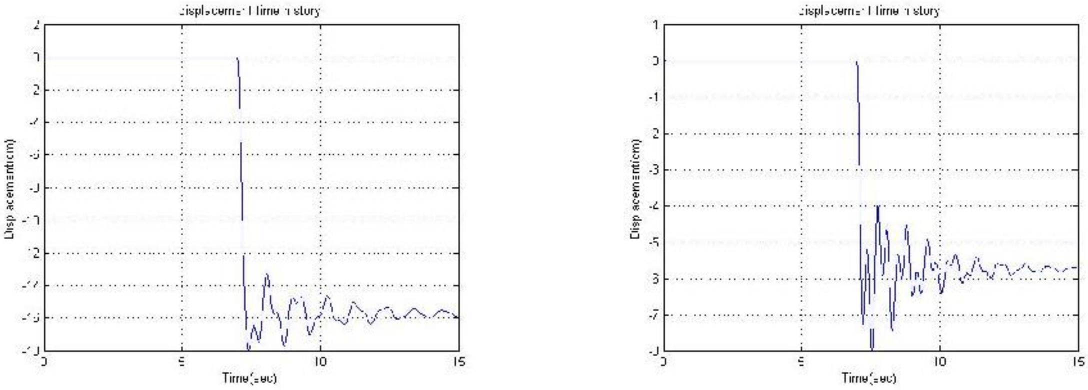


(a) Remove the corner column

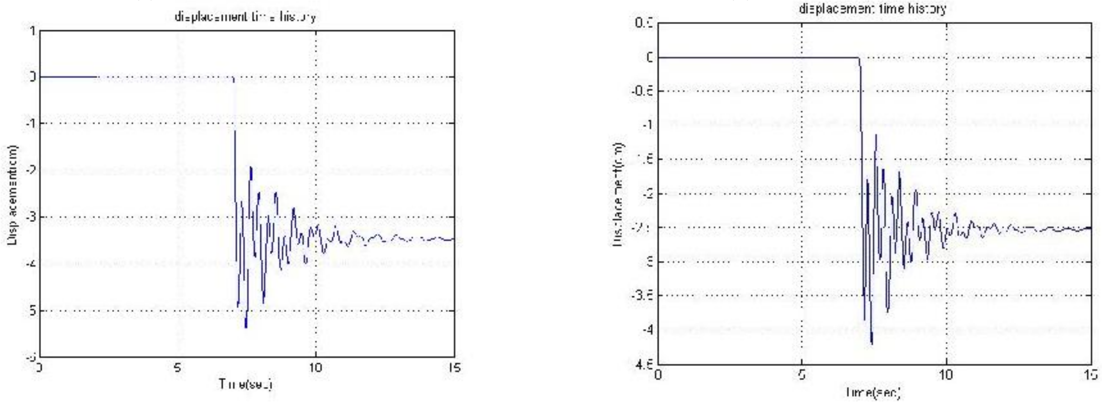
(b) Remove the middle column

Figure 4. Remove external columns

Figures 5 and 6indicate thevertical deflections for the four-story buildings that designed in four different seismic zones of Iran; low to very high seismic hazard zones with removing the corner column and the middle column, respectively.

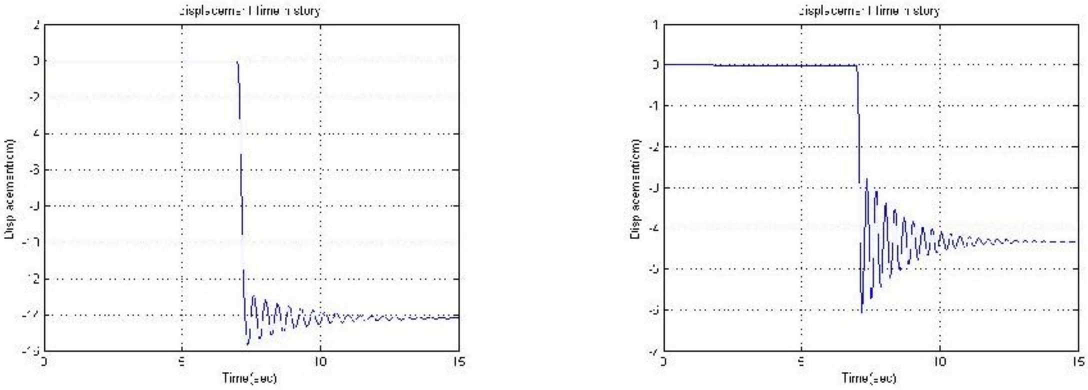


(a) Low seismic zone (b) Moderate seismic zone

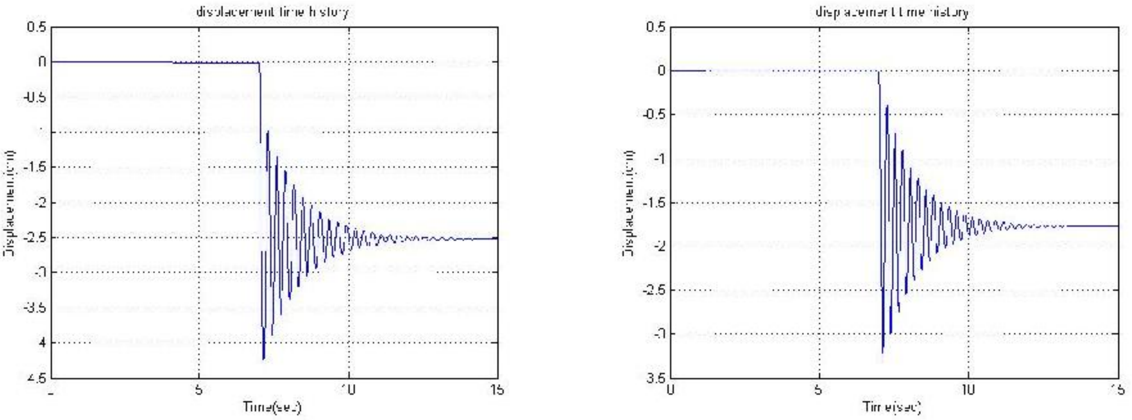


(c) High seismic zone (d) Very high seismic zone

Figure 5. Displacement time history at the joints when the corner column is removed



(a) Low seismic zone (b) Moderate seismic zone



(c) High seismic zone (d) Very high seismic zone

Figure 6. Displacement time history at the joints when the middle column is removed

As shown in different parts of Figures 5 and 6, structures in higher seismic zones behave with higher frequencieslower displacements.

Table 2 illustrates seismic coefficient and permanent displacement for different seismic zones. Figures 7 and 8 show the effect of designing seismic coefficient on potential of progressive collapse with removing the corner column and the middle column, respectively. Vertical axis shows permanent vertical displacement and horizontal axis illustrates the designing seismic coefficient.

Table 2. Seismic coefficient and permanent displacement for different seismic zone

scenario of removing the corner column				
Seismic zone	(a) Very high seismic zone	(b) High seismic zone	(c) Moderate seismic zone	(d) Low seismic zone
C	0.128333333	0.11	0.091666667	0.073333333
Permanent disp.(cm)	2.51743	3.45471	5.72992	15.8964
scenario of removing the middle column				
Seismic zone	(a) Very high seismic zone	(b) High seismic zone	(c) Moderate seismic zone	(d) Low seismic zone
C	0.128333333	0.11	0.091666667	0.073333333
Permanent disp. (cm)	1.76747	2.5147	4.32636	14.1998

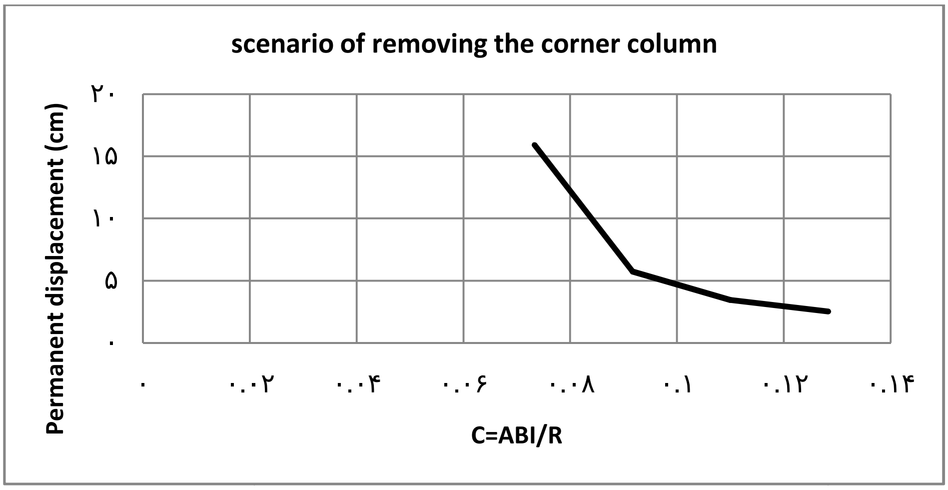


Figure 7.Effect of designing seismic coefficient on potential of progressive collapsefor the scenario of removing the corner column

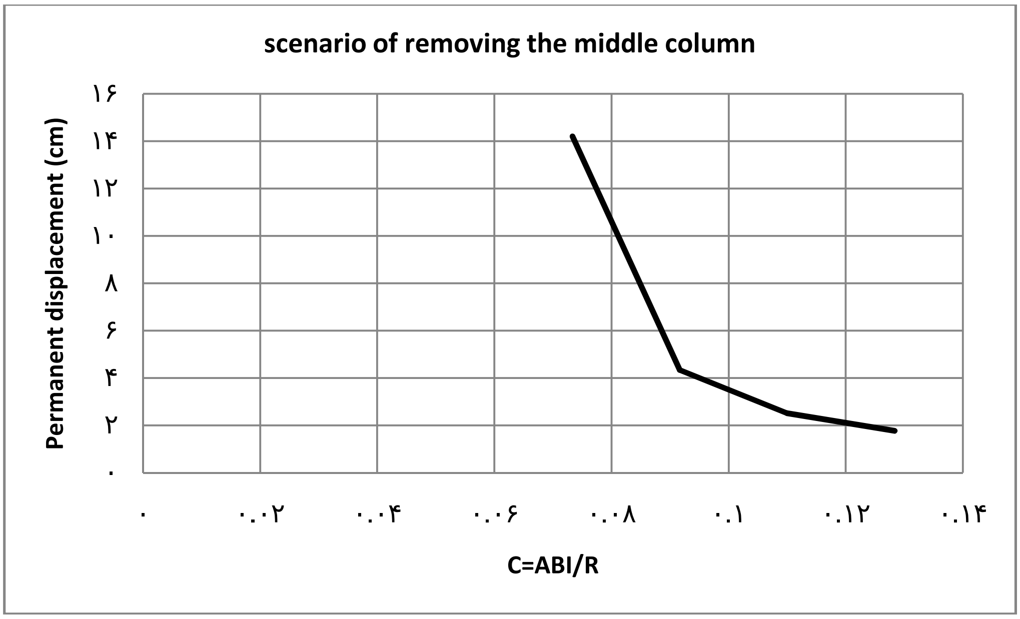


Figure 8.Effect of designing seismic coefficient on potential of progressive collapsefor the scenario of removing the middle column

CONCLUSIONS

In this study the progressive collapse potential for the four-storysteelmoment resisting frames in different seismic zones was investigated using the nonlinear dynamic analysis proceduresrecommended in the GSA (2013)guideline. In this paper, relation of the designing seismic coefficient with the potential of the progressive collapse is investigated for a four-story special moment resisting frame. The frame is designed for low, moderate, high, and very high seismic zones of Iran.

The obtained results show that the potential of progressive collapse decreases by increasing the designing seismic coefficient; the main reason is increasing capacity of members. It is also observed that the potential for progressive collapse is highest when a corner column was suddenly removed.

REFERENCES

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

DoD(2009)Design of Buildings to Resist Progressive Collapse Unified Facilities Criteria (UFC) 4-023-09, 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 and El-Tawil S (2007) Collapse Behavior of Steel Special Moment Resisting Frame Connections, *Journal of Structural Engineering, ASCE*, 133(5): 646-655

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