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Evaluation of Eccentrically Braced Steel Frames with Double Vertical Link Beam under Progressive Collapse

H. Alimadadi[1], S. Sh. Emamzadeh*[2]

[1] Department of Civil Engineering, Azad University, Estahban, Iran
[2] Faculty of Civil Engineering, Kharazmi University, Tehran, Iran

ABSTRACT: In this article, the performance of Eccentrically Braced Frames with Vertical Shear Links against progressive collapse has been investigated based on GSA guidelines and the alternative path method. For this purpose, three frames of 5, 10, and 15 floors have been investigated, and their performance was estimated by the method of nonlinear dynamic analysis with SAP2000 software. By removing the middle column for all three frames, it was observed that the displacements are regular and perform well in progressive collapse. However, with the removal of the corner column, the five-story frame collapsed, and for the 10-story frame, an increase of about 3 times the floor displacement was observed. But for the 15-story frame, the behavior of the frame under progressive collapse is very suitable. The removal of the corner column in the frames creates a more critical condition than the removal of the middle column. In the scenario of removing the middle column, the maximum vertical displacement on the last floor of the 5-story frame was equal to 9.21cm, in the 10-story frame it was equal to 6.37cm and in the 15-story frame, it was equal to 4.25cm. For comparison, in the scenario of removing the corner column, the maximum vertical displacement obtained on the last floor of the 5-story frame was unknown due to collapse, and in the 10-story frame it was equal to 21.88cm and in the 15-story frame, it was equal to 7.65cm. Results show that as structure height increases, system behavior will improve against progressive collapse.

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1- Introduction

After the September 11 events and with the increase in terrorist attacks around the world, the study of progressive collapse has expanded among researchers. In 2000, research was started to prepare a guideline in this field, an example of which was the GSA guide, the last edition of which was published in 2013 [1]. In this guide, ASCE41 guidelines were used for nonlinear analysis and definition of plastic joints [2]. According to GSA, to apply the dynamic effects of explosive charges in quasi-static analysis, a resonance factor of two is considered. Makki (2012) and colleagues showed that the coefficient of two is sometimes conservative and sometimes non-conservative and presented new values for it that were determined based on the structural system [3]. Gomels-Kaya (2014) fully investigated the load intensification factor for bending frames [4]. Mahmoudi *et al*. (2015) showed that the intensification coefficients presented by Mackey [3] are appropriate and also proposed several new relationships based on ductility [5]. In this research, the effect of the force intensification factor of structural members was investigated and the appropriateness of Makki *et al.*'s relations [6] was proved. In this research, various dynamic and static analysis methods were investigated and SAP software was used to model plastic joints. In esearch by Adnan *et al.* (2014) with SAP software and GSA guide, they investigated the behavior of seismically designed bending frames under progressive failure [7]. One of the proposed methods in braced frames is the use of vertical link beams in the place where the braces are connected to the main beam. Implementation details of this method are provided by Fling *et al*. (1992) [8].

By reviewing the conducted research, it can be seen that the performance of the vertical link beam, which is used in steel frames for seismic control in progressive damage, has been less investigated, and therefore, in this research, the capability of this system in controlling progressive collapse in frames with different number of floors investigated. For this purpose, the introduction of the vertical beam is first discussed, then the basics of progressive failure analysis are presented, and after defining the performance levels, the analysis of three frames of 5, 10, and 15 floors as Fig. 1 and Table 1-3 under two scenarios of removing the corner and middle columns on the ground floor is discussed.

2- Methodology

2- 1- Progressive failure analysis

The nonlinear dynamic analysis of progressive failure

*Corresponding author's email: shemamzadeh@khu.ac.ir

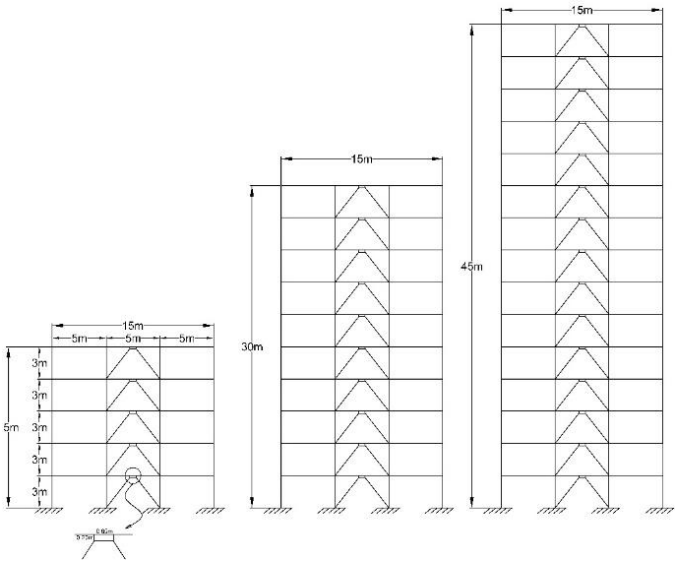

Fig. 1. The studied frames of 5, 10 and 15 story

Table 1. Sections used in the 5-story frame

Story	1-2	3-4	5
Floor Beam	IPE330	IPE330	IPE300
Link Beams	IPE270	IPE240	IPE240
Bracing	2UPN140×20	2UPN120×20	2UPN120×20
Outer Column	IPB240	IPB220	IPB220
Inner Column	IPB320	IPB280	IPB280

Table 2. Sections used in the 10-story frame

Story	1	2-4	5-7	8-10
Floor Beam	IPE360	IPE360	IPE360	IPE330
Link Beams	IPE330	IPE330	IPE300	IPE240
Bracing	2UPN160×30	2UPN160×30	2UPN160×25	2UPN140×25
Outer Column	IPB400	IPB400	IPB280	IPB220
Inner Column	TUBO380×380×28	IPB900	IPB400	IPB280

Table 3. Sections used in the 15-story frame

Story	1-3	4-6	7-9	10-12	13-15
Floor Beam	IPE360	IPE360	IPE360	IPE330	IPE330
Link Beams	IPE330	IPE330	IPE300	IPE240	IPE240
Bracing	2UPN160×30	2UPN160×30	2UPN160×25	2UPN140×25	2UPN140×25
Outer Column	TUBO380×266×20	TUBO380×266×20	IPB400	IPB340	IPB220
Inner Column	TUBO400×400×40	TUBO400×400×40	IPB700	IPB450	IPB340

is similar to the nonlinear static analysis method, with the difference that there is no intensified load combination and the load intensification factor is considered equal to unity. In the dynamic analysis, the applied force starts from zero and increases step by step until the structure reaches the final equilibrium state (the column has not been removed yet). After that, the column should be removed, and the duration of its removal should be less than 10% of the period of the structure without the removed column. The duration of the analysis of the structure is determined in such a way that the structure reaches the maximum displacement and performs at least one complete Oscillating motion in the vertical direction. There are different methods for modeling progressive failure and column removal. GSA2013 regulation [1] recommends to use of SAP2000 software and step-by-step execution capability.

3- Results and Discussion

In this article, the performance of 10, 5, and 15-story frames was investigated with the help of GSA2013 guidelines and the method of defining plastic joints against progressive collapse, and the following results were obtained:

In the 5-story frame under progressive failure, collapse occurs and the behavior of the structure is not appropriate. In the 10-story frame, in addition to the fact that the structure does not collapse and has sufficient behavior against progressive damage, the L.S. performance level (life safety) is provided, which is very suitable. In the 15-story structure, all the joints provide the I.O performance level, except for one joint at the foot of the column, which is at the border of the L.S performance level and has crossed it. This joint is located at the foot of the first-floor column. Therefore, with a little strengthening of this column, the level of I.O performance can also be provided. In general, with the increase in height, the behavior of the structure improves. Improving the behavior of the structure with height in the case of bending frames has also been suggested by Adnan *et a*l [4]. In the 15-story frame, by increasing the total height related to 5 and 10-story, the behavior of the structure improved that provide the I.O performance level in this case. In the scenario of removing the middle column, the maximum vertical displacement in the last floor and in the 5-story frame was equal to 21.9 cm. In the scenario of removing the middle column in the 10-story frame, the maximum vertical displacement on the last floor was 6.37 cm. In the scenario of removing the middle column in the 15-story frame, the maximum vertical displacement on the last floor was 4.25 cm. To compare the scenario of removing the corner column, the following results were obtained:

In the scenario of removing the corner column in the 5-story frame, the maximum vertical displacement was unclear due to the collapse. In the scenario of removing the corner column, the maximum vertical displacement in the 10-story frame was 21.88 cm.In the scenario of removing the corner column, the maximum vertical displacement was obtained in the 15-story frame equal to 7.65 cm.

4- Conclusion

It can be said that link beams and braces have a significant load in progressive failure and create integrated performance in the members and are also effective in improving behavior. The results of progressive collapse analysis in 5,10 and 15 story frames, indicated that with the increase of floors, the plastic hings will not be formed, which means that the seismic capacity provided in their design is very suitable for progressive damage. The special configuration and short length of the link beams ensure their shear behavior by comparing the above results, it is clear that the most deformation occurred at the highest point and also the scenario of removing the corner column is more critical than the scenario of removing the middle column .According to the research results, no plastic joints were observed in the 10th and 15th floor frames in the connecting beams and braces. But in the 5-story frame, plastic joints were observed on the first and second floors in the scenario of removing the middle corner column.

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