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Probabilistic Progressive Collapse Analysis of 3D Steel Moment Frame Using Fragility Curves and Double-column-damage Approach

E. Mohammadi Dehcheshmaeh[1], V. Broujerdian[1*], G. R. Ghodrati Amiri[2]

[1]School of Civil Engineering, Iran University of Science and Technology
[2]Natural Disasters Prevention Research Center, School of Civil Engineering, Iran University of Science and Technology

ABSTRACT: In this research, a method of probabilistic analysis of progressive collapse has been introduced based on the concept of fragility curves. In order to develop the fragility curves, the stiffness of two columns is considered as the random variable and the displacement at the top of the removed columns is considered as the Damage Index (DI). Based on these measures, the fragility curves of a 4-story steel structure with Intermediate Moment Frame (IMF) system were developed. Six scenarios of progressive collapse were investigated, including the removal of the corner, perimeter, and middle double-columns. The simulations were performed using OpenSees software. The structural analyses were performed using nonlinear time history approach in a three-dimensional framework. The results showed that the IDA capacity curve of the lower stories is weaker than the upper stories. According to the results, at each considered DI and assumed performance level, damage to the removed double-columns occurs at more stiffness in the upper stories compared to the lower ones. The results showed that considering the floor slab can reduce the probability of fragility of structures. The effect of the floor on the lower stories of the structure is more than on the upper stories. The increasing effect of the floor on the structural fragility corresponding to the first to fourth stories are 13, 9, 6, and 2%, respectively. The probability of exceedance of the performance levels of IO, LS and CP is almost zero until the reduction of the double-column stiffness is 50, 70 and 75%, respectively

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1- Introduction

Progressive Collapse refers to the spread of damage to a structure due to an initial localized failure. In this phenomenon, the redistribution of forces in each path causes the structural members of that path to fracture. Then the load transfer path is changed. This process continues until the collapse of the whole structure or the collapse of a major part of the structure [1].

Qian et al. [2] have surveyed the removal of single-column and double-column columns in the corner of an experimental of the one-story concrete structure. Finally, a simple method for estimating the vulnerability behavior of structures under progressive collapse by column removal is presented. Nassir et al. [3] have evaluated the removal of single-column corner and perimeter and compared with the removal of a double-column removal in an 8-story moment concrete structure. Furthermore, it was shown that the double-column removal scenarios are more critical than the single-column removal in terms of creating vertical displacements as well as DCR members in the structure. In the study [4], the progressive collapse has been considered in two forms including: sequential, and non-sequential double-column removal. In concrete moment frames, sequential double-column removal due to the delay in the removal of columns can have a positive and negative effect on the moment capacity of the frames. Zhang et al. [5] have investigated the removal of several columns in a system of 6-story steel moment frames.

The effect of structural floors can also affect the potential for progressive collapse. Fu et al. [6] investigated composite floors with different dimensions of slab span. Then they showed that the load-bearing capacity of the floor with smaller span dimensions was higher, but the ductility capacity of the roof with larger span dimensions was higher. Exact finite element modeling of floors is often time-consuming and volume of computational files. In terms of the effects of floors in the study [7], a simplified method of roof effects in the form of bilinear springs has been proposed.

2- Methodology

The use of intermediate steel moment frame (IMF) structures is very common in earthquake prone zones. However, there are few studies on this system and there are most of the studies on special steel moment frames [8, 9]. In this study, a 4-story IMF structure is investigated. Using

*Corresponding author's email: Broujerdian@iust.ac.ir

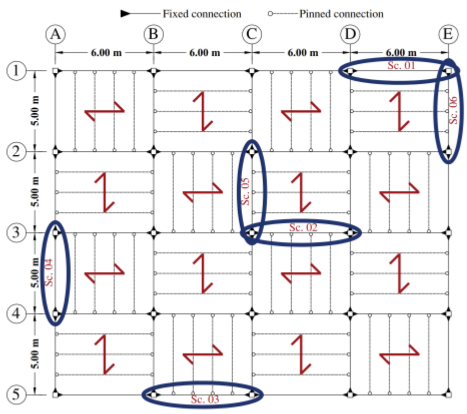

Fig. 1. Plan of the studied structure

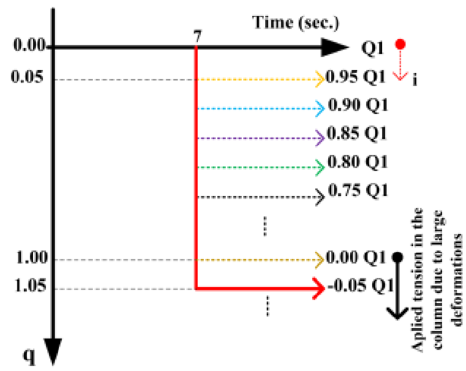

Fig. 3. Column stiffness reduction method for IDA analysis

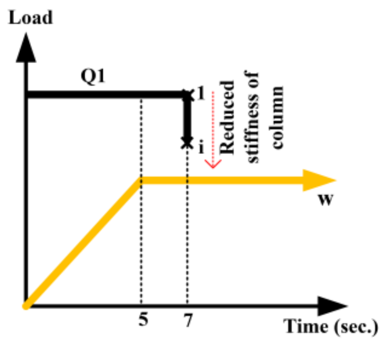

Fig. 2. Applied gravity load [11] and change in stiffness of the column analyzed by IDAm

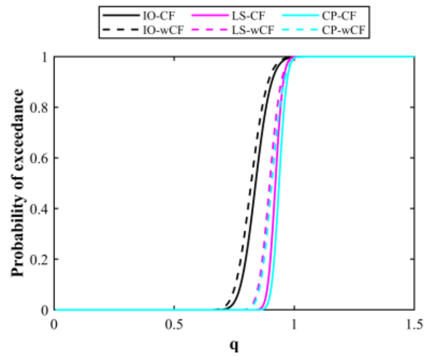

Fig. 4. Fragility curves for the entire structure with and without CF composite floor

ETABS 2016 software and conventional sections in steel structures, buildings were designed by the LRFD method [10]. The plan view of the studied structure is shown in Figure 1. In this research, six scenarios of double-column damage were considered according to Figure 1.

The gravitational load in this study gradually increases from zero, according to Figure 2 (curve w). Then, at the moment of the 5th second, it is completely applied to the structure [11]. In this research, changes in column stiffness have been considered as an intensity measure (IM). In Figures 2 and 3, the column stiffness is reduced at 7 seconds. In this research, column removal has not been done directly. Stiffness reduction in structural columns is done dynamically. This reduction in stiffness, according to GSA is done in a time equal to 10% of the mode 1 time of the structure. In these figures, the column stiffness is shown with Q and the initial stiffness of the column with Q1 is shown. IDA analysis continues until the final stage of structural beam collapse.

When applying lateral load to the column, first bending deformations occur in the column and then due to the increase in the length of the column. Therefore, a tensile force is created in the column. The loading coefficients of the IDA in this section in Figure 3 are therefore considered negative (i.e., inverse and tensile loading). The axis of the vertical Figure 3 is denoted by q. the q value is equal to the difference between Q1 and iQ1 (i.e., q = (1-i) Q1).

3- Results and Discussion

Figure 4 shows the fragility curves of the entire structure in the case of double-column damage. According to this figure, the probability of collapse in wCF is less than CF case. The effect of the composite floor can reduce the probability of structure collapse.

Figure 5 shows the percentage reduction stiffness of the mean scenarios of different floors and the entire structure to achieve performance levels with a 50% probability of collapse. According to this figure, with less reduction in stiffness at the lower floors than the upper floors of the structure, it reaches performance levels sooner. The floor effect on increasing the failure resistance is different in different classes. The effect of the floor on the lower stories of the structure is more effective than on the upper stories.

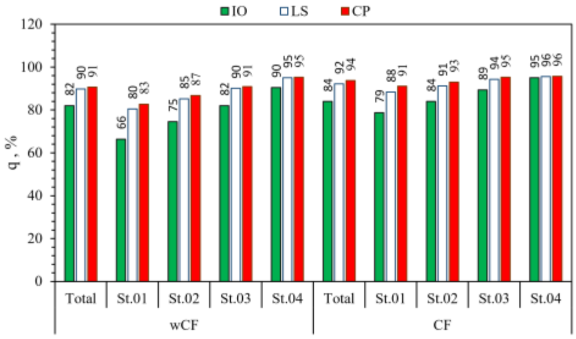

Fig. 5. Reduction of stiffness of entire and stories structures to reach different performance levels

4- Conclusions

The conclusions of this research include the following:

The lower stories are more probability of fragility than the upper stories. With reducing stiffness in the column members, the probability of collapse in the lower stories is higher than in the upper stories.

IDA capacity curves for the structure with the composite floor are greater than the case of without it.

The effect of the roof on the lower stories of the structure is more effective than on the upper stories under double-column vulnerability.

In a constant double-column stiffness reduction, the middle column scenarios (scenarios 2 and 5) are critical compared to the other scenarios.

The maximum effectiveness of the floor in increasing the failure resistance of structures has been in scenarios 2 and 5.

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