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EXTENDED ABSTRACT

Effect of Composite Floors on Progressive Collapse Control in the Steel Moment Frame Structures

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1. Introduction

According to ASCE 7 (2016), Progressive collapse is described as the distribution of an initial local failure from element to element, resulting finally in the collapse of an entire structure or an extremely large part of it. Now, it has become evident that abnormal loads need to be considered in the design of structures to prevent progressive collapse. Building collapse such as Ronan Point, Alfred P. Murrah, and World Trade Center have shown the catastrophic nature of the progressive collapse, and with an increasing trend towards more terrorist action in the future, it is clear that structural design must include progressive collapse (Starossek, 2018).

2. The importance and aim of the research

Generally, progressive collapse triggers by the failure of the main member of the building, such as a column or a bearing wall. This event creates a super load in the members and the connections in the vicinity of the failed one. This super-loading may cause new failures and consecutively, the failure spreads across the entire structure. Composite floors of buildings play a key role in possible structural damages. Composite floors transfer the floor loads to the main structural members. Moreover, as a rigid body and with horizontal movement, composite floors integrate lateral displacements of the floors during earthquakes. Considering progressive collapse, composite floors can steel have an integrating effect and also decrease deformations of stories .At the end of the study, the reaction of composite floors was obtained with bilinear spring elements.

2. Methods of Analysis

In order to study the building's structure performance against progressive collapse using the alternative path method in DOD code, there are three analyses (LS, NS, and ND) to control the behavior of main members such as beams and columns which are destroyed suddenly (GSA, 2016).

2.1. Linear static approach

In this method, as the simplest one, to check the member's susceptibility against progressive collapse, to rectify the effects resulting from member geometry and dynamic load in gravity loading of upper members of removed column a factor called m_{LIF} is applied. Regarding the type of structure, whether steel, concrete, etc.,

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and also the kind of joints, a factor called magnifying coefficient (m) is extracted. It is necessary to mention that m_{LIF} is the smallest magnifying coefficient (m) of elements that are joined to the beam. In the current research, the amount of m has been taken into account regarding the improved rigid joint. The loading coefficient (Ω) is calculated concerning the m_{LIF}.

2.2. Nonlinear static approach

In Nonlinear Static Method (NS), the factor which resulted from the dynamic loading effect is added to the gravity loading of the removed column's upper members. This coefficient is calculated and extracted based on the defined tables in the code regarding the type of structure and joints.

2.3. Nonlinear dynamic approach

In Nonlinear Dynamic Method, to evaluate members, first, the existing interior forces in the nodes of the removed column are calculated. Then the mentioned column is removed from the numerical modeling and analogous reactions in the mentioned node are applied. To calculate displacement and specify the condition of plastic joints of the members' elements, the incoming reactions are removed from the structure in the form of an impact load. It is necessary to mention that the time period of removing the load is a time history algorithm.

3. Design against progressive collapse

Design measures for ensuring progressive collapse can be classified into event control, indirect and direct methods (Starossek, 2018).

3.1. Event Control method

In this method, for provided objective with a predicted event or removed it or find ways of structure protection against progressive collapse. For example, with the implementation of protective barriers against the impact of vehicles and etc. can protect structure against possible events. Another two following methods are used to provide resistance versus progressive collapse.

3.2. Direct method

In this method, explicit consideration of resistance to progressive collapse during the design process through either. Alternate Path Method: A method that allows local failure to occur but seeks to provide alternative load paths so that the damage is absorbed and major collapse is averted.

Specific Local Resistance Method: A method that seeks to provide sufficient strength to resist against failure from accidents or misuse.

3.3. Indirect method

In this method, implicit consideration of resistance to progressive collapse during the design process through the provision of minimum levels of strength, continuity, and ductility.

4. Description of the structure

The studied structure was of steel moment frame type with intermediate ductility. The usage of steel intermediate moment frame buildings is very common in earthquake-prone areas. However, there are only a few studies on this system and most of the studies are about steel special moment frames (Khandelwal & El-Tawil, 2007; Kim & Kim, 2009). The structure was a 3-story and 4-bay. The height of each story was 3.2 m and the bays were 6 m and 5 m long.

4.1. Materials

Steel: Steel is an isotropic material that has good ductility and strength. It generates significant deformation prior to failure. In this paper, steel was considered as an elastoplastic material. The values of steel properties are shown in Table 1.

Concrete: In order to describe the nonlinear damage and the fracture characteristics of the concrete, the HJC constitutive equation, and the damage model were adopted. The axial compressive strength of the concrete is 25 MPa. Other values of the concrete specifications are presented in Table 2.

Table 1. Material properties of steel (units: Cm, Kgf, Sec)

ρ (Density)	E (Young's modulus)	μ (Poisson's ratio)	Fy (Yield stress)	Fu (Ultimate stress)
7.85e-3	2.1e6	0.3	2400	3700

Table 2. Material properties of concrete (units: Cm, Kgf, Sec)

ρ (Density)	E (Young's modulus)	μ (Poisson's ratio)	f_c' (Yield stress)
2.5e-3	2e5	0.15	250

4.2. Loading of structure

The assumed gravity Loads for the design of structures have been presented in Table 3.

Table 3. The assumed gravity Load (units: m, Kgf, Sec)

Story	Dead load (uniform)	Live load (uniform)	Dead load of the Surrounding beams
1 & 2	585	200	550
floor	550	150	190

4.3. Structural elements

For this purpose, three steel intermediate moment frame buildings with three stories were designed (INBC Part 6th, 2013; INBC Part 10th, 2013; IBCS, 2013), modeled, and analyzed using ETABS software. The structural members and the slab members of the three-story model structures are presented in Table 4.

Table 4. Dimension of structural members (units: mm)

Story	Columns	Main beams	
		X Direct	Y Direct
1 & 2	BOX 300*300*12	H 300*200*10 *12	H 300*200*8*10
3	BOX 250*250*10	H 300*150*10 *12	H 300*150*8* 12
Girder beams of composite slab		IPE 200	IPE 180

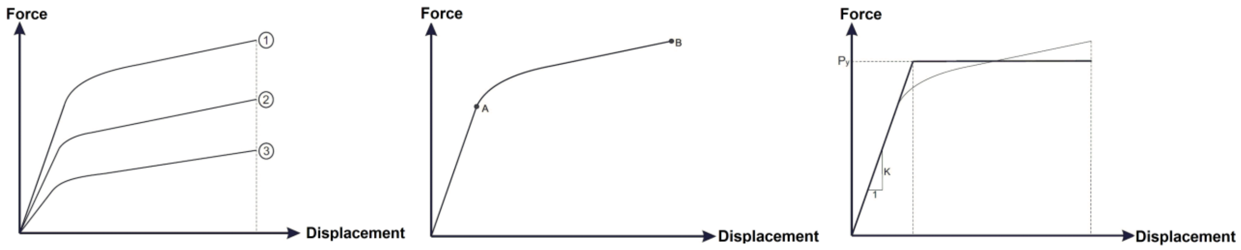
5. Load combinations of progressive collapse

According to GSA (2016): In the event of progressive collapse gravity load is applied to the structure. The gravity load on the members is a combination of Dead Load (DL) and Live Load (LL). The load combination for the progressive collapse was assumed as DL+0.25LL.

6. Results and discussion

6.1. Spring of equivalent composite floor

According to Fig. 1-a, in this part to simplify and obtain the equivalent spring of the composite floors; First, the force-displacement curve of the main beams, girder beams, and the deck has been obtained (curve 1), second, the force-displacement curve of the main beams has been obtained (curve 2) and in the third step, the difference between the curves 1 and 2 is obtained that this curve is equivalent to the slab. Curve 3 alone is shown in Fig. 1-b and this curve with a bilinear curve has been replaced (Fig. 1-c).



(a) (b) (c)

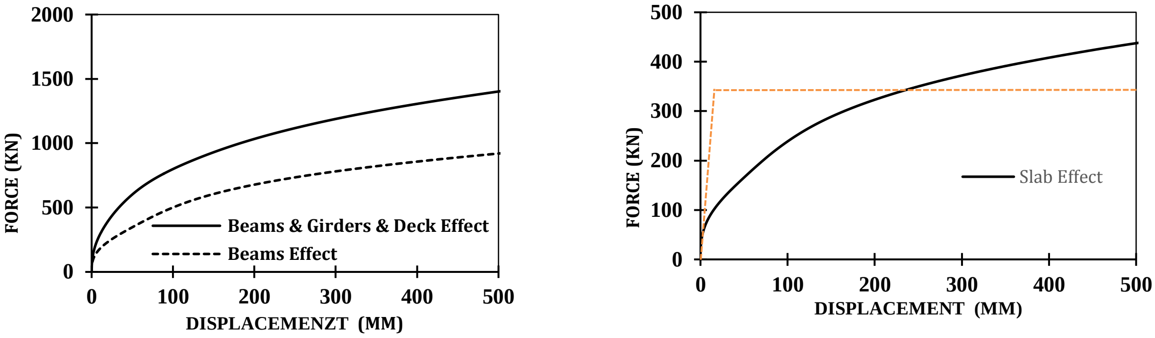
Fig. 1. Force-displacement curves: a) Force-displacement relationship, b) Force-displacement relationship equivalent of slab, c) Idealized to force-displacement relationship equivalent of slab

6.2. Simulation

Analyzing various scenarios of removing columns in this study. The simulations were done using the finite element method in a three-dimensional macro-modeling approach by ABAQUS software. The fixed end condition of panels is similar to the research of Kong et al. (2020) and Ren et al. (2020). Both non-linearity of geometry and material were considered in the models. In order to simulate composite floors, their equivalent stiffness and resistance in the vertical direction were calculated (Table 6). For example, the curves of scenario 15 are shown in Fig. 2.

Table 5. Results of stiffness and resistance equivalent of composite floors

State of Scenario	Number of removed column	Column named	k (N/mm)	P_y (N)
1	1	A	3994	79877
2	1	A	4685	93697
3	1	A	6216	217577
4	1	A	7687	230610
5	1	A	12148	485912
6	2	A	3707	111208
		B	2003	100162
7	2	A	3963	122865
		B	2209	110468
8	2	A	2721	95218
		B	1387	76295
9	2	A	3128	109491
		B	1898	49907
10	2	A	3865	21260
		B	3865	21260
11	2	A	3440	154807
		B	3440	154807
12	2	A	4016	150646
		B	4016	150646
13	2	A	4365	152763
		B	4365	152763
14	2	A	10344	475841
		B	10344	475841
15	2	A	9096	341122
		B	9096	341122



(a) (b)

Fig. 2. a) Force- displacement relationship for scenario 15, b) Force- displacement relationship equivalent of slab for scenario 15

7. Conclusions

It was shown that the hardness of the composite floors in the corner panels is less than the corresponding values in the central and edge panels. Based on the results, to obtain an acceptable estimation of the behavior of the building against the progressive failure, it is necessary to include composite floors in the modeling and analysis.

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