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Progressive Collapse Induced by Column Removal in Reinforced Concrete Frames

M. Taavoni Taromsari, A. Massumi*, H. Hoseini Lavasani

Faculty of Engineering, Kharazmi University, Tehran, Iran

ABSTRACT: Progressive collapse occurs when a sudden event such as a blast or an impact load influences a structure. Wherein, loss of continuity and low ductility of the remaining structural members result in total collapse of it. Alternate Path Method (APM) is an efficient method to study progressive collapse that is recommended in common guidelines such as GSA and UFC. APM check outs alternate paths in remained structure to resist progressive collapse due to key elements loss. This research surveys different scenarios of column elimination in planar regular and irregular frames by conducting non-linear dynamic analysis. Verification of the selected methods is conducted via analyzing an experimental model. Generally removal of corner column leads to significant responses compared with other scenarios. Moreover, eliminating a column in irregular frame causes large displacements and beam rotations which could be attributed to uneven distribution of forces in structural members; so regularity is an important factor to resist collapse.

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1- Introduction

In structures with lack of continuity and ductility local damage caused by abnormal load, spreads in horizontal and vertical directions and finally total collapse occurs [1]. The most popular method to evaluate progressive collapse potential is Alternate Path, wherein, by eliminating a column, progressive collapse resistance of the remaining elements and their capability to redistribute induced forces are assessed. By adopting APM and conducting non-linear dynamic time history analysis, different column removal scenarios are investigated and the most critical ones are identified. Verification of the selected methods is conducted via analyzing an experimental model.

2- Verification of analytical method

The test specimen represents quarter-scale sections of two bays and two stories from the center of the long side of the building. Figure 1 gives the reinforcement design of the test specimen [2, 3].

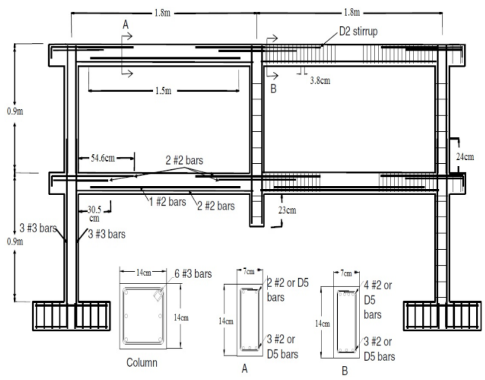


Figure 1. Reinforcement design of test specimens

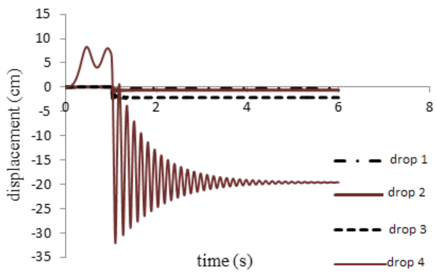
The load the beam is reqsuired to carry for collapse resistance is 1.2DL0.5+LL according to the UFC guidelines [4]. On the basis of a previous static test of the frame, this load was deemed to be too great. It was decided to start at a load corresponding to 25% of total load. Table 1 gives applied loads in each drop of test.

For each drop the frame was reset to the same original position while the damage caused by the last drop was preexisting. Figure 2 and Table 2 give information about test and analysis results.

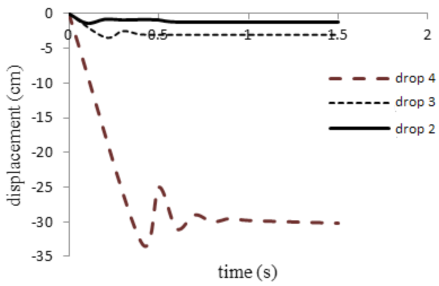
Corresponding author, E–mail: massumi@khu.ac.ir

Table 1. Applied load

Drop	Load (kN)
1	14.4
2	14.4
3	21.4
4	24.6



A - analytical results



B - test results

Figure 2. Results of test and analysis

Table 2 reveals that there is a good agreement between the results obtained by the adopted method and experimental data.

Table 2. Experimental and analytical results

Vertical displacement (cm)		Peak	Static
Drop 1	test	-	-
	analysis	0.56	0.36
Drop 2	test	1.37	1.20
	analysis	1.22	0.7
Drop 3	test	3.04	3.05
	analysis	2.95	2.18
Drop 4	test	32.82	30.20
	analysis	29.18	20.57

3- Methodology

To study progressive collapse potential of reinforced concrete frames two regular and one irregular planar frame are chosen. Figure 3 gives a view of frames and position of removed columns. Similar to tested frame, 40% of recommended load combination applied to beams. Dead, live and partition load are 5.2 kN/m^2, 1.96 kN/m^2 and 1.47 kN/m^2 respectively. Column removal time is 0.1T and T represents modal period of removed column span as recommended in GSA guidelines [5].

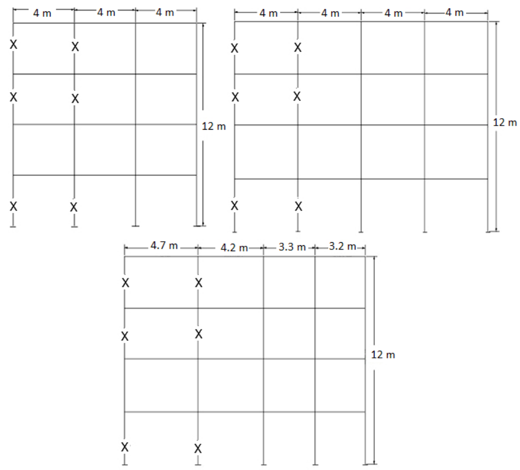


Figure 3. Studied frames and position of removed columns

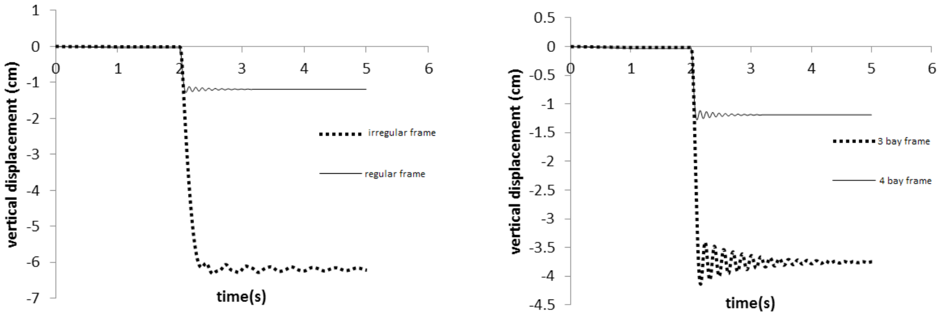
A non-linear analysis in SAP2000 is conducted and time history of vertical displacement beneath the removed column, beam rotation and axial force of adjacent column are reported.

4- Discussion and results

Figure 4 represents time history of vertical displacement beneath 1st story corner column in frames.

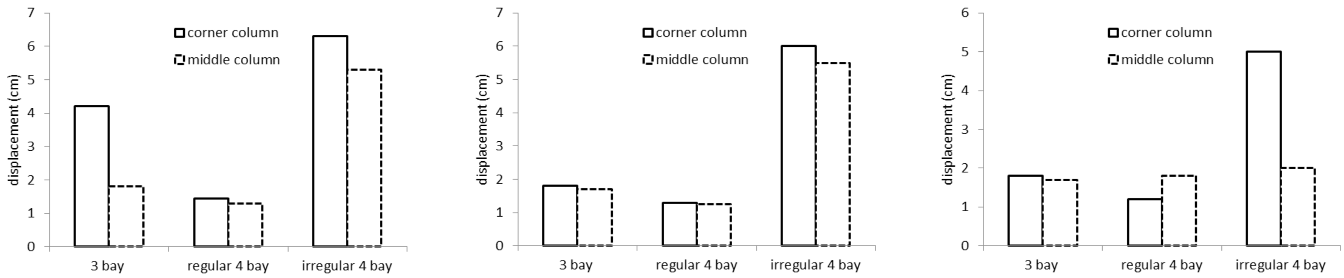
To compare the difference between corner and middle column removal in 1st, 3rd and 4th story, Figure 5 is prepared.

By increasing number of spans in regular frames, structural response to column removal will decrease and it's obvious that removing the corner columns cause greater response. There is a large difference between vertical displacement in regular and irregular 4 bay frames. So regularity is an important factor in collapse resistance. To perceive residual elements role in distributing forces, induced axial force and rotation in adjacent members can be convenient. Axial force ratio (peak dynamic response after column removal to initial static axial force) and beam rotation are collected in Table 3.



A – Regular and irregular 4 bay frames B – Regular 3 bay and 4 bay frames

Figure 4. Vertical displacement time history – 1st story corner column removal



A - 1st story column removal B - 3rd story column removal C - 4th story column removal

Figure 5. Peak vertical displacement

Table 3. Axial force ratio and beam rotation

Frame	Computational parameters	1st story corner column	1st story middle column	3rd story corner column	3rd story middle column	4th story corner column	4th story middle column
3 bay	Axial force ratio	1.45	2.30	1.50	2.13	1.66	1.60
	Beam rotation	0.0103	0.0046	0.0048	0.0046	0.0045	0.0043
Regular 4 bay	Axial force ratio	1.60	1.72	1.66	1.66	1.60	1.73
	Beam rotation	0.0032	0.0037	0.0030	0.0030	0.0030	0.0023
Irregular 4 bay	Axial force ratio	1.86	2.10	1.64	1.64	1.63	1.75
	Beam rotation	0.0134	0.0122	0.0110	0.0140	0.0106	0.0048

5- Conclusions

To evaluate behavior of reinforced concrete frames while key element removal, a dynamic Alternate Path analysis is conducted. Three RC frames are selected and results are as follows:

1. Removing the corner columns cause great response due to lack of alternate paths to resist collapse.
2. Eliminating a column in upper floors causes large displacements and beam rotations which could be attributed to the lack of alternate paths.
3. Amount of vertical displacement and beam rotation in irregular frame reveals uneven distribution of forces and inability to resist progressive collapse.

4. Span length has an essential impact on collapse resistance, small spans are more consistent.
5. Axial force ratio in middle column exclusion is great in all states but Beam rotation in corner column elimination is greater than middle column removal.

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