The 2021 World Congress on
Advances in Structural Engineering and Mechanics (ASEM21)
GECE, Seoul, Korea, August 23-26, 2021

Structural Behavior of Precast Concrete Moment Frames Subject to Progressive Collapse

Fei-Fan Feng[1)] *Hyeon-Jong Hwang[2)] and Wei-Jian Yi[3)]

[1), 3)] College of Civil Engineering, Hunan University, Changsha 410082, China
[2)] School of Architecture, Konkuk University, Seoul 05029, Republic of Korea
[2)] hwanghj@konkuk.ac.kr

ABSTRACT

To investigate the progressive collapse behavior of conventional PC moment frames, quasi-static tests were performed on four PC moment sub-frames. As test parameters, the effects of PC beam connection details, beam section size, and rebar ratio on the progressive collapse resistance of the PC sub-frames were studied. On the basis of the test results, a simplified analytical model was developed to predict the progressive collapse resistance of the moment sub-frames. The proposed method applied to the test results for comparison, and directly estimated the load-displacement relationship including the CAA and CTA stages, without iterative calculations.

1. INTRODUCTION

All types of building structures can be affected by extreme events, such as explosions, vehicle impacts, fires, earthquakes, tsunamis, and human error, or even terrorist attacks (Adam et al., 2018). These events usually cause local damage to the building structure, leading to partial or even total collapse of the structure.

To investigate the progressive collapse performance of frame structures, extensive experimental studies have been conducted (Yi et al., 2008; Qian and Li, 2013; Lew et al., 2017). However, the existing studies mainly focused on RC structures. The discontinuity of the conventional PC structure using wet connection may increase the progressive collapse risk. Thus, an alternative load transfer path for anti-progressive collapse in PC structures under extreme failure conditions is worth investigation.

In this study, four static loading tests were performed to evaluate the progressive collapse resistance of conventional PC moment frames. Further, a simplified analytical model was developed to estimate the progressive collapse resistance of the moment

---

[1)] Graduate Student

[2)] Assistant Professor

[3)] Professor

sub-frames. The validity of the proposed model was verified by comparing with the test results.

2. EXPERIMENTAL PROGRAM AND RESULTS

Figure 1 shows the test specimen and test setup. Table 1 shows the detailed information of four specimens. Vertical load was applied on the mid-column. Pin and fixed boundary conditions were adopted at the top and bottom of exterior columns, respectively. Guide rail was installed at the front and back sides of the mid-column to address the in-plane and out-of-plane constraint due to the slab and top columns.

Figure 2 presents the load-displacement relationships of specimens (Feng et al., 2020). Specimen PCF-1 showed the peak strength P_{CAA}= 50.5 kN in CAA stage, and the peak strength P_{CTA}= 127.4 kN in CTA stage. The 2nd peak strength was 153% greater than the 1st peak strength of CAA. In specimen PCF-2, the peak strength at CAA stage was P_{CAA}= 54.0 kN. After the peak strength, the top bars at the both beam ends in the exterior beam-column joints were gradually fractured with the increase of the mid-column displacement. For this reason, CTA was not effectively developed. In specimen PCF-3, the peak strength at CAA stage was P_{CAA}= 62.5 kN and the 2nd peak strength of CTA was 28% greater than the 1st peak strength of CAA. This result indicates that tensile stress of reinforcing bars can be sufficiently developed in large deformation when the minimum bar development length is satisfied. Specimen PCF-4 exhibited the peak strength P_{CAA}= 45.8 kN in CAA stage and the peak strength P_{CTA}= 105.4 kN in CTA stage. The 2nd peak strength was 130% greater than the 1st peak strength of CAA.

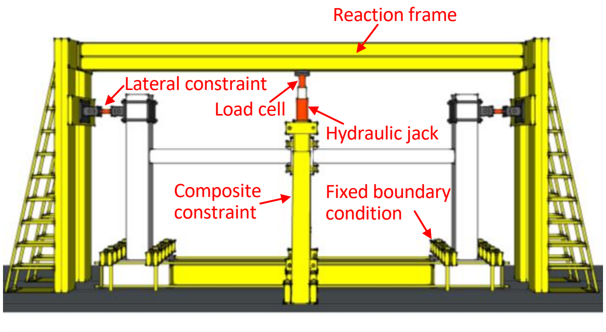

Fig. 1 Test setup

Table 1 Reinforcement and joint details of specimens (Feng et al., 2020)

Specimen	Beam					Interior joint		Exterior joint	
	Cross section ($b \times h$) (mm)	Clear span (L_n) (mm)	Flexural bars: Top	Flexural bars: Bottom	Stirrups	Anchorage method	Hook length (Weld length) (mm)	Anchorage method	Hook length (mm)
PCF-1	150 × 250	2600	2T16 (1.24%)	2T12 (0.69%)	R6@100(50)	135°hook	360	135°hook	360
PCF-2	180 × 300	2600	4T10 (0.65%)	1T10+2T8 (0.37%)	R6@100(50)	135°hook	360	135°hook	360
PCF-3	180 × 300	2600	4T10 (0.65%)	1T10+2T8 (0.37%)	R6@100(50)	135°hook	195	135°hook	195
PCF-4	150 × 250	2600	2T16 (1.24%)	2T12 (0.69%)	R6@100(50)	Welding	120	135°hook	360

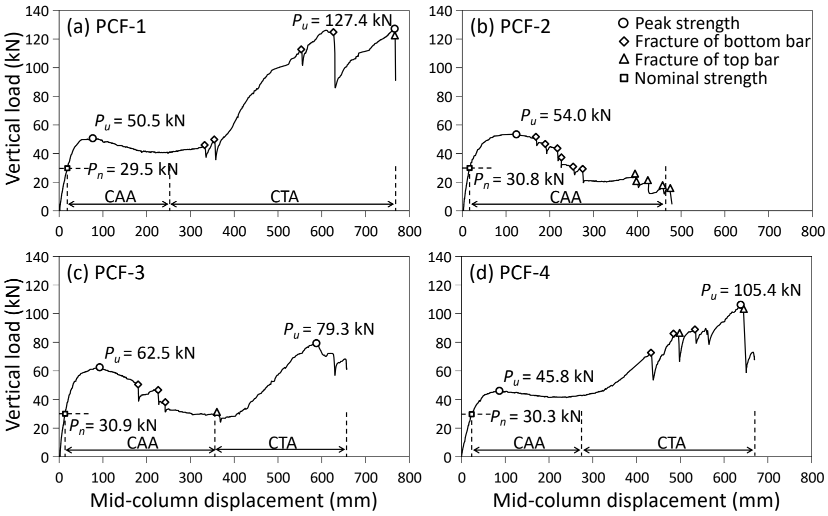

Fig. 2 Load-displacement relationships of test specimens (Feng et al., 2020)

3. ANALYTICAL MODEL AND COMPARISON

Figure 3(a) shows the simplified piecewise multi-linear curve to evaluate the collapse response of moment sub-frames. Addressing the actual boundary condition and rebar bond strength, the proposed method directly estimates the load-displacement relationship including the CAA and CTA stages, without iterative calculations. In the curve, point A represents the beam flexural action where axial force on the beam section is negligible. Point B represents the peak strength of CAA. Point C represents the strength degradation of CAA, or the development of CTA. Point D represents the peak strength of CTA. For simple calculations of the progressive collapse resistance of the sub-frame, the four points are derived from each mechanism, and each point is linearly connected. Figure 3(b~e) compares the predictions with the test results in the load-displacement relationship. In general, except for specimen PCF-2, the proposed method predicted well the test results. In specimens PCF-1, PCF-3, and PCF-4, the average prediction-to-test result ratio of the peak strength at CAA and CTA was 1.02 and 1.11, respectively, with COV being both 0.09. In the case of the ultimate displacement at CTA, the average prediction-to-test result ratio of three specimens was 0.95 and COV was 0.04.

4. CONCLUSIONS

In this study, four static loading tests were performed and a simplified model was developed. Compared to PCF-4 with weld connection, the use of 135° hooked bars increased the peak strength due to CAA and CTA by 10.3% and 20.9% in PCF-1. Although the development length of 135° hooked bars satisfied the minimum requirement, PCF-3 showed CAA and subsequent CTA. In the beams designed to develop the same flexural moment, large cross-sectional area is beneficial to improve the contribution of CAA by 6.9–23.8%, and high rebar ratio increases the contribution of CTA by 32.9–60.7%. The proposed simplified model predicted well the test results. The average prediction-to-test result ratio at the peak strength of CAA and CTA was 1.02 and 1.11, respectively, and COV were both 0.09. For the ultimate displacement, the average ratio was 0.95, and COV was 0.04.

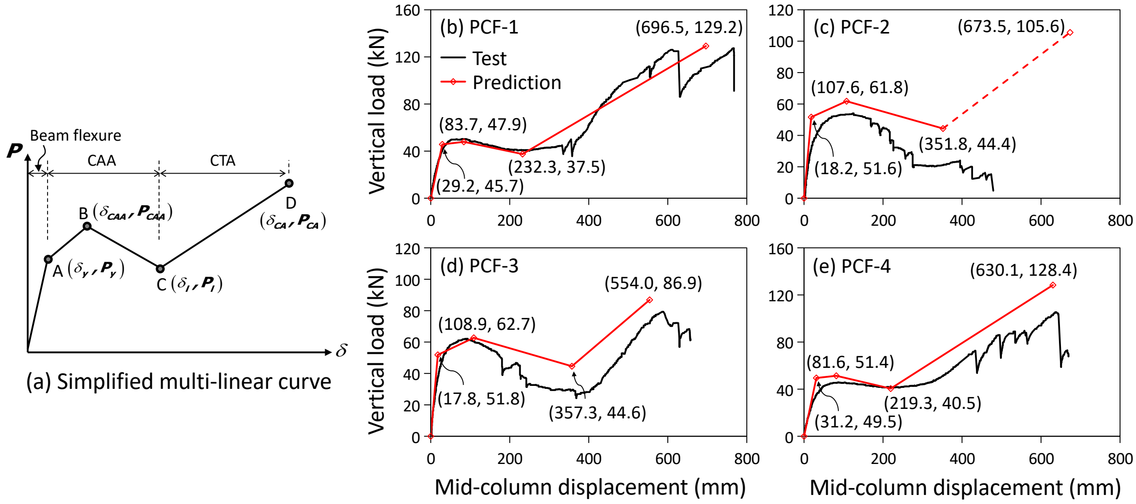

Fig. 3 Simplified multi-linear curve and comparisons

REFERENCES

Adam JM, Parisi F, Sagaseta J, Lu X. (2018), "Research and practice on progressive collapse and robustness of building structures in the 21st century", Eng. Struct., **173**, 122–149.

Yi WJ, He QF, Xiao Y, Kunnath SK. (2008), "Experimental study on progressive collapse-resistant behavior of reinforced concrete frame structures", ACI Struct. J., **105**(4), 433–439.

Qian K, Li B. (2013), "Performance of three-dimensional reinforced concrete beam column substructures under loss of a corner column scenario", J. Struct. Eng. **139**(4), 584–594.

Lew HS, Main JA, Bao Y, Sadek F, Chiarito VP, Robert SD, et al. (2017), "Performance of precast concrete moment frames subjected to column removal: part 1, experimental study", PCI J. (Sept–Oct):35–52.

Feng FF, Hwang HJ, Yi WJ. (2020), "Static and Dynamic Loading Tests for Precast Concrete Moment Frames under Progressive Collapse", Eng. Struct. **213**:110612

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT)(No. 2021R1A4A3030117).