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Cyclic Loading Tests of Precast Frames Strengthened by Post-Tensioning

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ABSTRACT

Precast concrete (PC) industry has been remarkably grown because it promises a good quality of construction. Nevertheless, the PC structures have been also blamed for poor joint integrity and weak lateral resistance. Hybrid post-tensioned precast concrete (HPPC) system has been recently developed to improve the joint issues in the PC structures. In this study, a total of three multi-span moment frame specimens were fabricated. The specimens included a reinforced concrete(RC) specimen and two HPPC specimens with the main variables of the partial prestressing ratio. Some seismic indices were addressed to evaluate their seismic performances. The test results showed that the HPPC series specimens had comparable seismic performance to RC specimen designed to be special moment frame which are specified in the ACI 318-19 code.

1. INTRODUCTION

Precast concrete (PC) system has many advantages in that the member quality can be ensured, and that the construction period can be shorten. In the PC system, however, it is not easy to achieve structural integrity between PC members, and thus various PC details have been actively developed to secure the structural integrity (Li et al. 2009; Yan et al. 2018; Choi et al. 2013; Barhrami et al. 2017; Lu et al. 2018). Meanwhile, post-tensioning PC joints had been suggested by the PRESS (PREcast Seismic Structural System) program, and several experimental studies with discontinuous joints (i.e., unit beam-column joints) was conducted. However,

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experimental study of post-tensioning PC frames is very limited. Therefore, in this study, a multi-span frame test for hybrid prestressed precast concrete (HPPC) was conducted, as shown in Fig. 1.

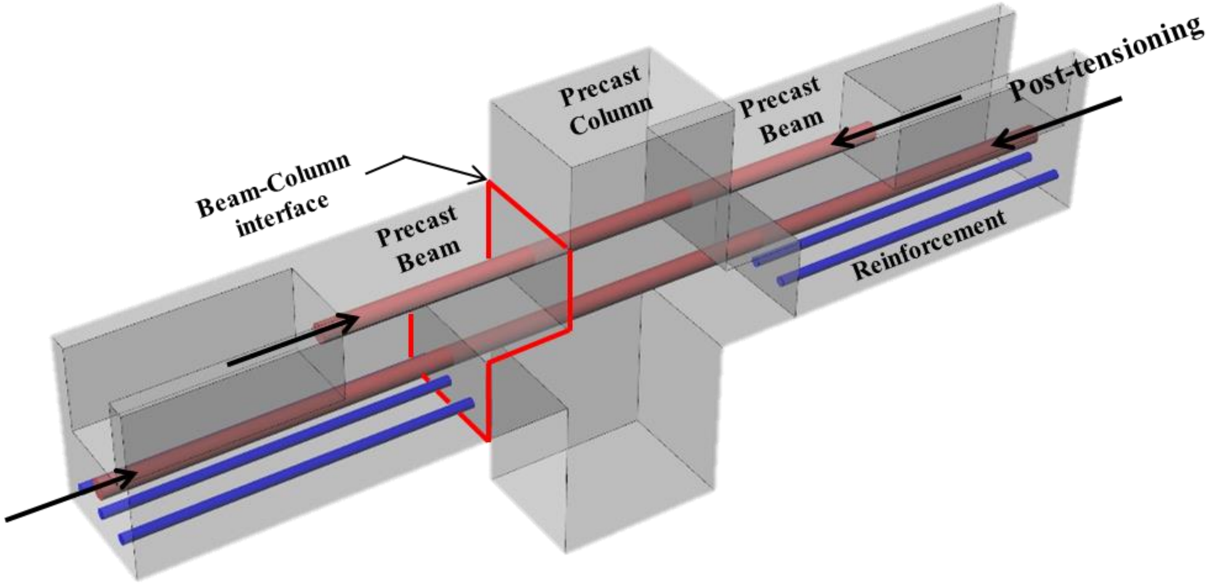
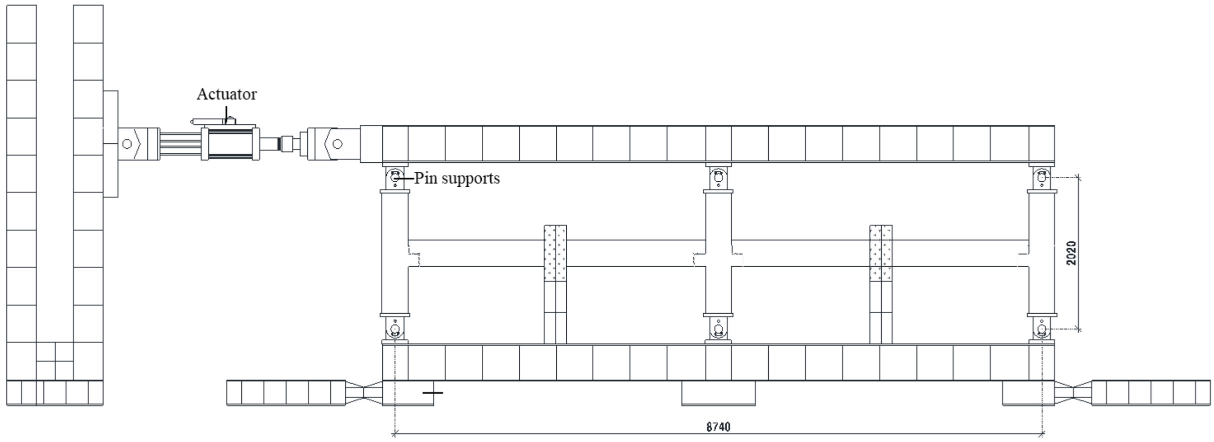


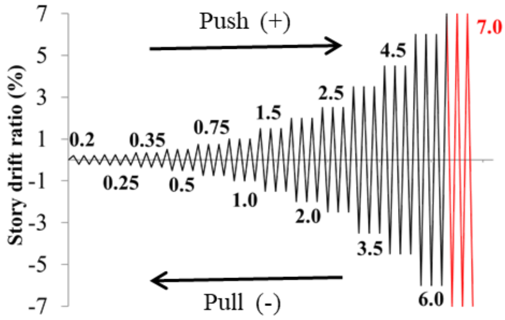
Fig. 1 Description of HPPC system (Kim et al. 2021)

2. EXPERIMENTAL PROGRAM

In this study, HPPC and RC multi-span frame specimens were carefully fabricated, and quasi-static cyclic loading test was conducted. Fig. 2 shows the test rig and loading protocol, and Fig. 3 shows the details of test specimens.

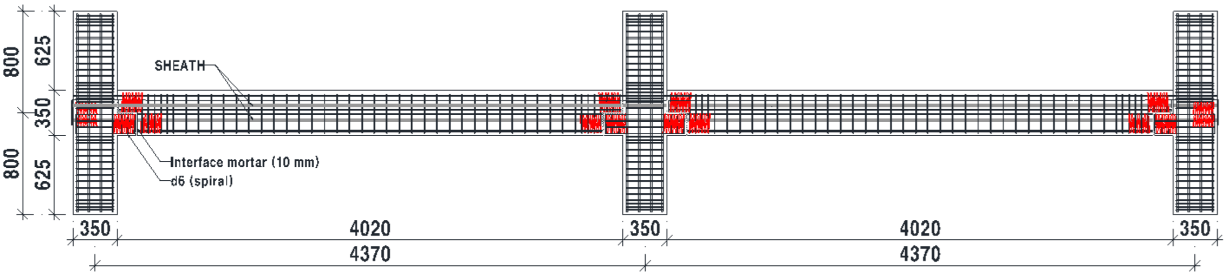


(a) test rig

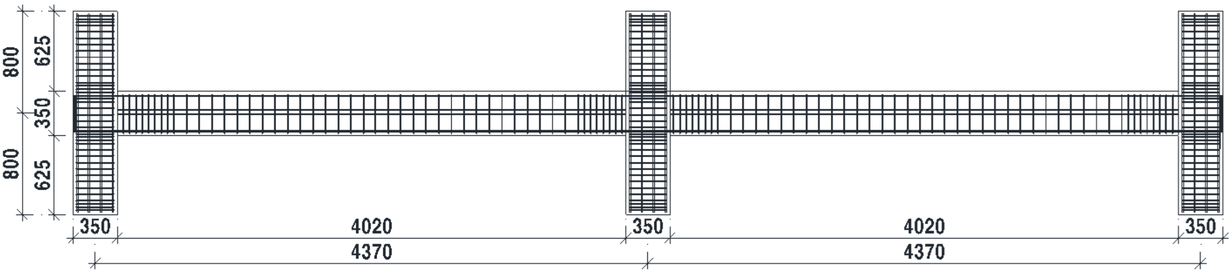


(b) loading protocol

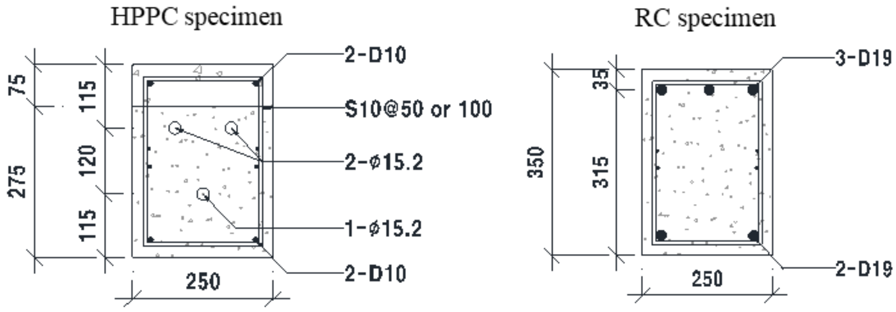
Fig. 2 Test set-up



(a) HPPC specimen



(b) RC specimen

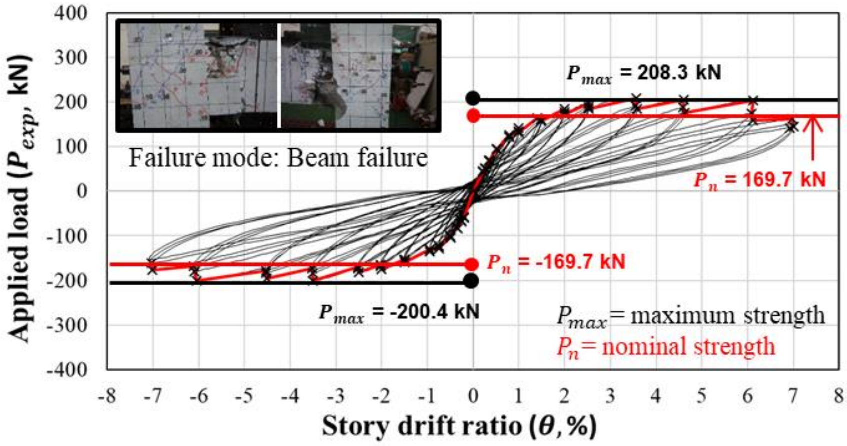


(c) Beam section

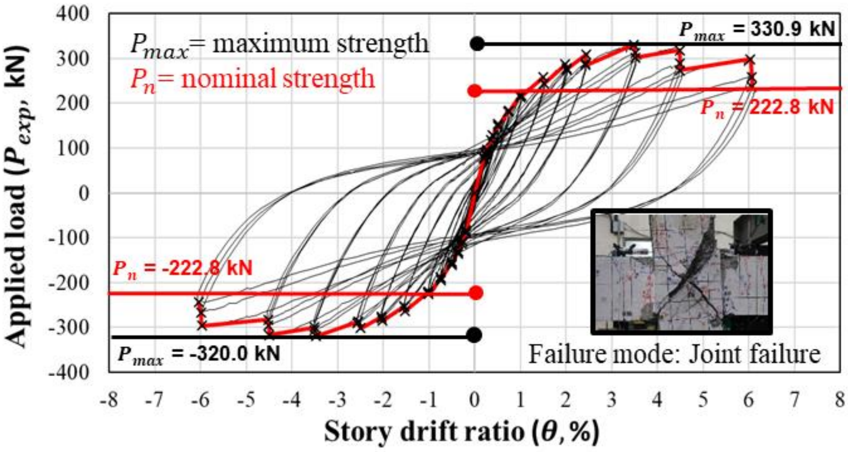
Fig. 3 Details of test specimens (unit: mm)

3. EXPERIMENTAL RESULTS

Fig. 4 shows the load-drift ratio response of each specimen. HPPC specimen reached nominal strength($Q_n = \pm 169.7\ \text{kN}$) at the drift ratio 1.6% and -1.8%, and maximum strength($Q_{\max} = 208.3\ \text{kN}$, $-200.4\ \text{kN}$) at the drift ratio 3.6% and -3.5%. On the other hand, RC specimen showed a relatively high initial stiffness compared to the HPPC specimen and reached nominal strength($Q_n = \pm 222.8\ \text{kN}$) at the drift ratio 1.1% and -1.0%. The maximum strength ($Q_{\max} = 330.9\ \text{kN}$, $-320.0\ \text{kN}$) of RC specimen occurred at the drift ratio 3.5% and -3.5%, which is similar to that of the HPPC specimen. The overstrength factor($\Omega = Q_{\max} / Q_n$) was 1.46 for RC specimen and 1.20 for HPPC specimen, respectively. However, HPPC specimen shown excellent self-centering behavior and underwent failure at a drift ratio of 7.0% due to the beam failure. In the RC specimen, shear failure occurred in the interior joint at a drift ratio of 6.0%.



(a) HPPC specimen



(b) RC specimen

Fig. 4 Load-drift ratio response

4. SEISMIC PERFORMANCE EVAULATION

ACI318 2019 specifies criteria to ensure sufficient seismic performance for the beam-column joints of RC moment-resisting frame. On the other hand, in case of a structural system that does not meet the criteria, such as the HPPC system, its seismic performance should be verified experimentally. In this study, seismic performance evaluation on the HPPC specimen was performed based on the acceptance criteria presented in ACI 374-1.05 report 2005. As shown in Tables 1-5, the HPPC specimens met all the acceptance criteria in the ACI 374.1-05 report, which suggests that the HPPC system has seismic performance (i.e., strength, stiffness, energy dissipation performance, etc.) equivalent to that of the RC special moment frame.

Table 1 Performance evaluation based on ACI 374-1.05 report 9.1.1

Specimen	θ_n (%)		θ_{allow} (%)	Acceptance criteria ($\theta_{allow} \geq \lvert\theta_n\rvert$)	
	+ (push)	- (pull)		+ (push)	- (pull)
HPPC	1.6	-1.8	2.0	accept	accept

*Notations: θ_n = the story drift ratio at the design strength; θ_{allow} = allowable story drift ratio

Table 2 Performance evaluation based on ACI 374-1.05 report 9.1.2

Specimen	Ω_0		λ	Acceptance criteria ($\lambda \geq \Omega_0$)	
	+ (push)	- (pull)		+ (push)	- (pull)
HPPC	1.23	1.18	2.66	accept	accept

*Notations: Ω_0 = overstrength factor, λ = beam to column strength ratio

Table 3 Performance evaluation based on ACI 374-1.05 report 9.1.3-1

Specimen	$P_{3.5\%}$ [kN]		$0.75P_{\max}$ [kN]		Acceptance criteria ($0.75P_{\max} \geq P_{3.5\%}$)	
	+ (push)	- (pull)	+ (push)	- (pull)	+ (push)	- (pull)
HPPC	156.2	-150.3	208.3	-200.4	accept	accept

*Notations: $P_{3.5\%}$ = maximum strength at the drift ratio 3.5% 3rd cycle

Table 4 Performance evaluation based on ACI 374-1.05 report 9.1.3-2

Specimen	β	Acceptance criteria ($\beta \geq 0.125$)
HPPC	0.160	accept

*Notations: β = energy dissipation ratio

Table 5 Performance evaluation based on ACI 374-1.05 report 9.1.3-3

Specimen	$K_{s,3.5\%}$ [kN/mm]		$0.05\,K_I$ [kN/mm]	Acceptance criteria ($K_{s,3.5\%} \geq 0.05K_I$)	
	+ (push)	- (pull)		+ (push)	- (pull)
HPPC	1.914	2.241	0.680	accept	accept

*Notations: $K_{s,3.5\%}$ = secant stiffness at the drift ratio 3.5% 3rd cycle, K_I = initial stiffness

5. DAMAGE INDEX

Damage index (DI) can be used to quantitatively assess the damage status of a structure. The DI can be classified as the non-cumulative DI that cannot consider the effects of cyclic loads, and the cumulative DI that can assess the damage status of structures for repetitive cyclic loads such as seismic loads. In this study, the cumulative DI proposed by Cao et al. 2014 was used to investigate the damage status of all specimens, and the values calculated are shown in Fig. 5.

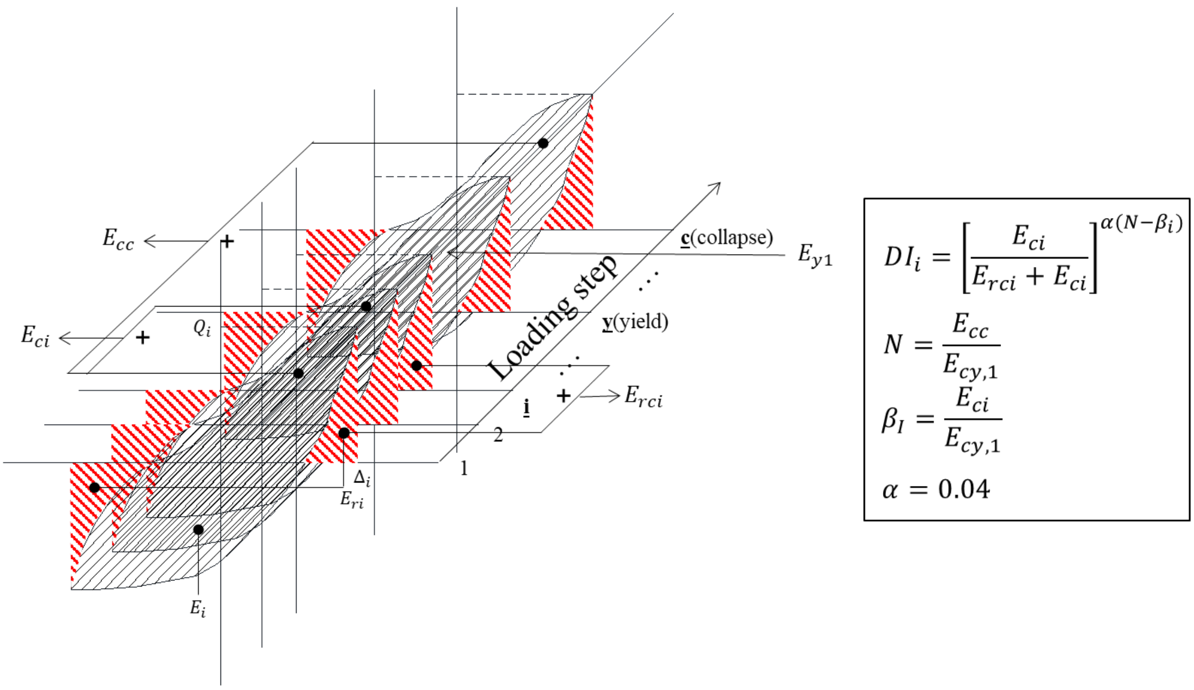


Fig. 5 Characteristic values of the damage index

Fig. 6 compares the DI of each specimen. The RC specimen shows the collapse damage at a permanent drift ratio (i.e., 4.0%) of the collapse prevention performance level (ASCE 2000), while the HPPC specimen shows only moderate damage at the same drift ratio.

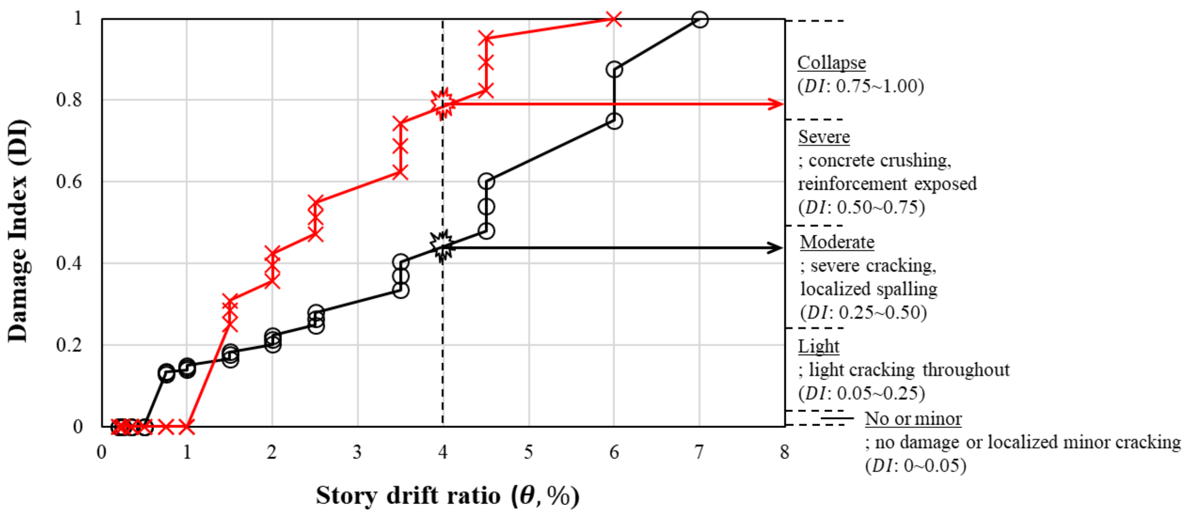


Fig. 6 Damage index

6. CONCLUSIONS

In this study, quasi-static loading tests of HPPC and RC frame specimens were carried out, and their seismic performances were quantitatively evaluated through acceptance criteria specified in the ACI 374-1.05 report and damage index (*DI*) proposed by Cao et al. 2014. The evaluation results showed that the HPPC specimen satisfied all the acceptance criteria and had lower *DI* compared with that of the RC specimen.

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