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INTERIOR BEAM-COLUMN JOINTS WITH WIRE STRANDS SUBJECTED TO REVERSE CYCLIC LOADS

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ABSTRACT

In this study, new moment-resisting precast concrete(PC) beam-column joint system is proposed for the use in moderate seismic regions. It is attempted to devise connection details which improve workability and provide effective stress transfer mechanism in the region of connection. The interior beam-column connection is made of precast column and precast beam. The precast beam is the type of half PC beam which is embedded 7-wire strands in the bottom part of it. The experimental study was carried out to investigate the behavior of the interior joints subjected to reverse cyclic loading and constant axial compressive load. The test variables were the number of strands and transverse reinforcements in connection. A structural performance of interior joint is evaluated on the basis of connection strength, stiffness, energy dissipation, and drift capacity. Based on the test results, the precast connection is proved to be capable of matching the performance of the monolithic connection and thereby provides the sufficient moment-resisting behavior to be applicable for moderate seismic regions.

Introduction

PC frame buildings in Korea utilize the PC beams at beam-column joints in order to secure effective stress transfer and workability. A typical PC beam is shown in Figure 1. In this structure, ends of the stirrups protrude from the top of the beam to enable installation of the top reinforcements, whereas the bottom reinforcements project from both ends of the beam as 90 degree hooks at the joint. Continuity of the semi PC structure is secured by the continuously placed top reinforcements and hook shaped bottom reinforcements at the joints. However, there are a lot of reinforcements such as the reinforcements from beams and columns and the transverse reinforcements concentrated at beam-column joints for semi PC systems. This system requires not only careful placement of reinforcements at the joints but also producing and installing plans of PC members, since the position of the hook shaped bottom reinforcements changes as order of the beams' installment changes.

In order to solve this issue, hook shaped bottom reinforcements are replaced with U-shaped strands (Alcocer et al. 2002). This settles the problem in two ways. First, by changing the bottom

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reinforcements to strands, placement of reinforcements at the joints is simplified. Second, since strands are more flexible than reinforcements, interference problems of reinforcements at the joints during construction can be easily fixed (Alcocer et al. 2002; Khaloo et al. 2003). Therefore, workability of the semi PC system is improved. Also, since strands are four times stronger than reinforcements, better structural performance can be expected.

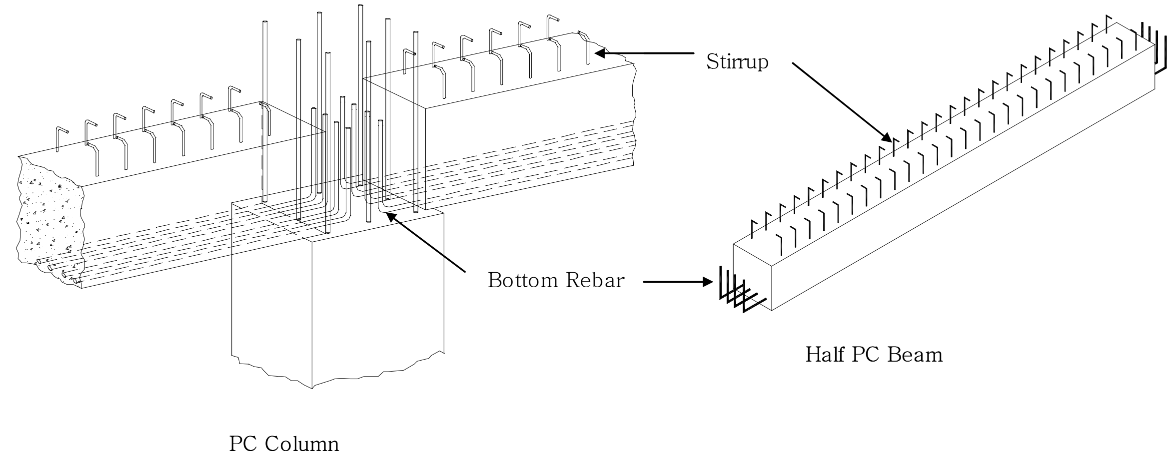

Figure 1. Half PC beam-column connection

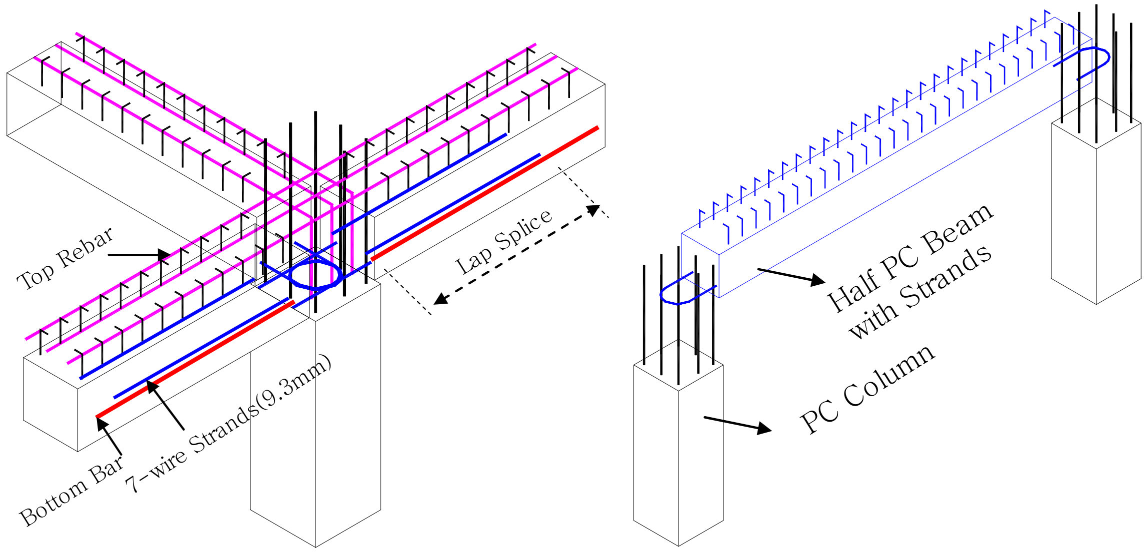

Figure 2. Half PC beam-column connection with strands

A semi PC beam with U-shaped strands is shown in Figure 2. As shown in the Figure, one U-shaped strand consists of two strands at the end of the beam. The strands are lap spliced with the bottom reinforcements of the PC beam and transfer the load applied to the beam to the joint. In order to transfer this load effectively proper lap splice length which prevents slippage between the reinforcements and the strands is required. When non-prestressed strands are installed to the PC joints, improvement in the workability of PC construction is expected, but continuity at the joint and the structural performance of the system should be carefully examined before using the system in practice. Therefore, the experimental study of semi interior PC beam-column joints with U-shaped strands is executed in this research.

Experimental Program

Details of Test Specimens

An experimental study on three two thirds-scale semi PC beam-column connections, which were S3-1, S3-2, and S3-3, subjected to lateral cyclic load was conducted in this research. The lap splice length of 1600 mm between strands and bottom reinforcements was decided based on the results of the preceding splice test. One side of the strands was placed inside the PC beams equal to the length of the lap splice length and the other side was left exposed from the ends of the beams as U-shaped strands. As shown in Figure 3, U-shaped strands from each side of the beams are placed in an alternating overlap so that they form a circle at the joint, thus confining the concrete at the joint once concrete is put in place.

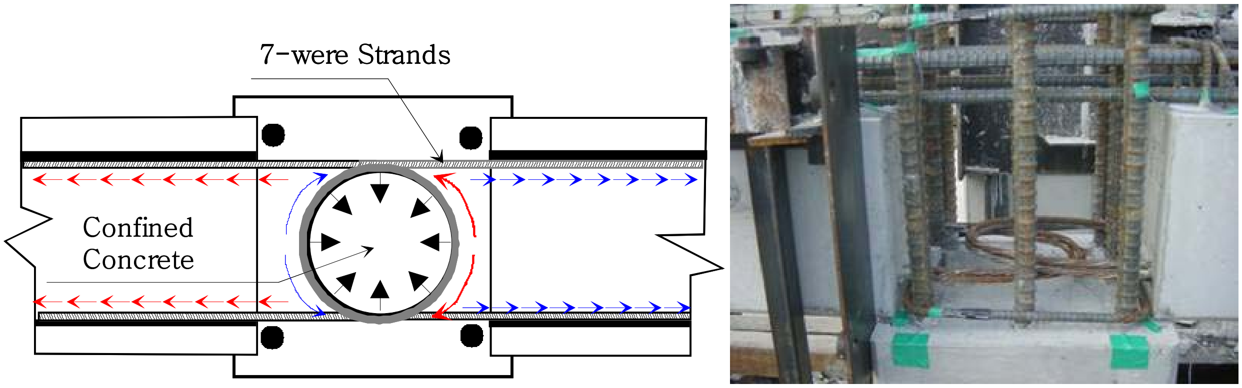

Figure 3. Confined concrete by strands

Details of all the test specimens are specified in Table 1. Specimens used the number of strands and the presence or absence of the transverse reinforcements at the connection as testing parameters.

Table 1. Description of half PC beam-column joint specimens

Specimens	Joint	Beam			
	Transverse Reinforcement	Top Rebars	Bottom Rebars	Number of Strands	Stirrups
S3-1	N/A	6-D19	3-D19	2	D10@80
S3-2	D13@100			2	
S3-3	N/A			3	

S3-1, which is a standard specimen for the interior connection, has two U-shaped strands consisting of four strands at the end of the beam, but it does not have transverse reinforcements. Four strands are placed in the standard specimen since the strength of four strands is equal to the tension strength of the bottom reinforcements in the PC beam. Figure 4 shows size and details of S3-1. S3-2 is equal to S3-1 except for the presence of the transverse reinforcements, and S3-3 is equal to S3-1 with the exception that it encases six strands instead of four strands.

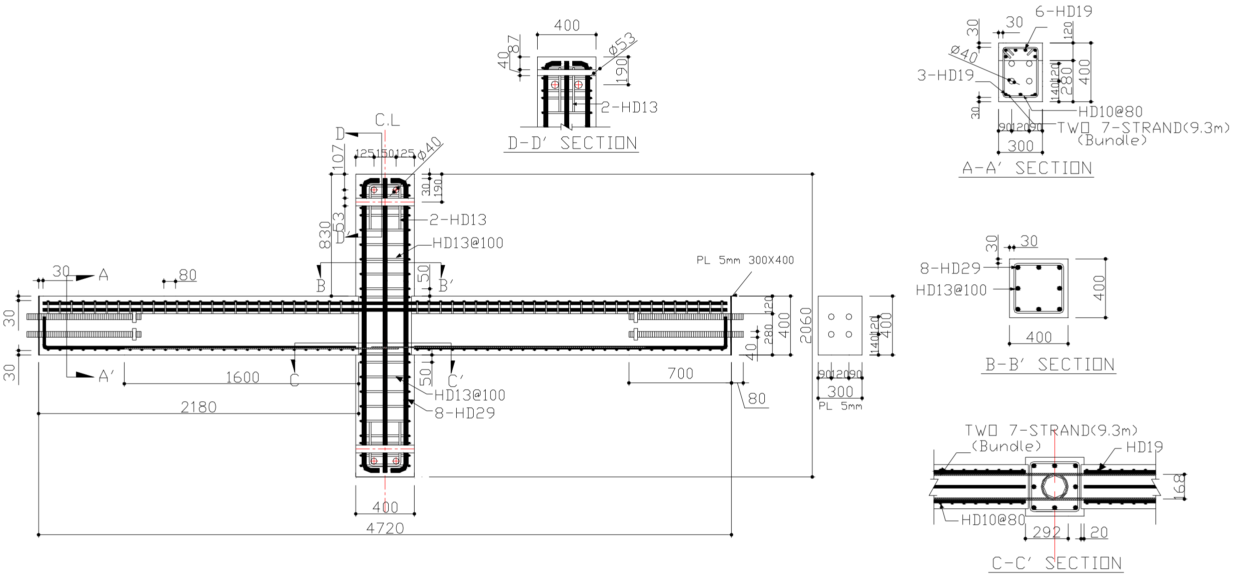

Figure 4. Details of interior joint test

Testing of Material Properties

Compressive strength of concrete used for the PC beams, columns, and the cast-in-place concrete was 33.5 MPa, 34.1 MPa, and 28.1 MPa, respectively. Six sizes of reinforcements and seven-wire standard strands with a diameter of 0.93 mm were used for the test. The results of the coupon test are summarized in Table 2.

Table 2. Material properties for test specimens

Reinforcement , Strands	f_y (MPa)	ϵ_y ($\times 10^{-6}$)	f_u (MPa)	E_s (GPa)	Elongation (%)
D10	504.1	2,482	685.0	204.0	16.3
D13	501.1	2,543	637.0	196.1	17.5
D19	467.9	2,186	667.0	213.8	19.1
D29	603.4	2,948	786.9	205.0	23.3
7-wire Strands (SWPC7A)	1,851.2	9,988	2,086.6	187.3	-

Test Setup

The test setup for specimens is shown in Figure 5. Constant axial force of “0.1f'cAg” was applied to the column using a 300 kN hydraulic jack and cyclic load was applied to both ends of the PC beam asymmetrically using two 250 kN actuators. The specimen was setup on the floor of the lab and the hydraulic jack and actuators were installed at the reaction wall. Displacement controlled lateral cyclic load was used for the test. Drift angles of 0.2%, 0.25%, 0.35%, 0.5%, 0.75%, 1%, 1.5%, 2%, 2.75%, 3.5%, and 4.25% were applied gradually and each step was applied three times cyclically using the actuators. LVDTs were installed to measure displacements at the end of the beams and columns.

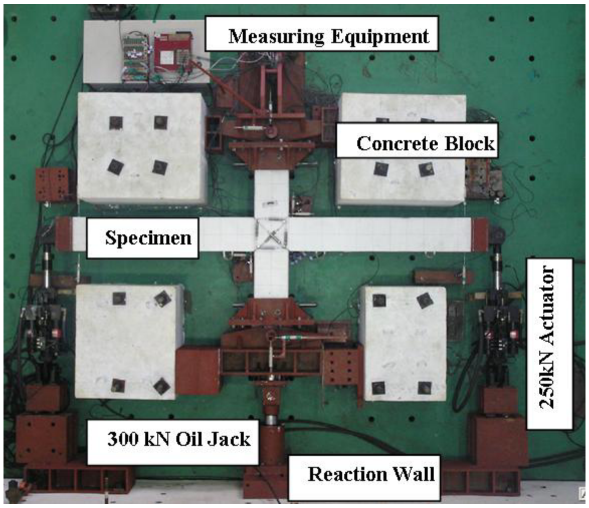

Figure 5. Details of interior joint test

Test Results

Cracks and Failure Patterns

As the load increased, crack and failure patterns of all specimens developed as follows: flexural cracks of the PC beam at a drift angle of 0.2%, horizontal cracks on face of cast-in-place concrete at drift angles of 0.2%~0.25%, flexural cracks on column at drift angles of 0.35%~0.5%, shear cracks at the joint at drift angles of 0.75%~1%, vertical cracks on column at drift angles of 1.5%~2.0%, and shear failure at the joint at a drift angle of 4.25%. Crack patterns of all specimens after failure are shown in Figure 6. For the interior connection specimens, all specimens showed similar development of cracks and failure patterns. In general, after longitudinal reinforcements of the PC beam yielded, cracks were transferred to the connection, and then the interior specimens failed in shear at the connection.

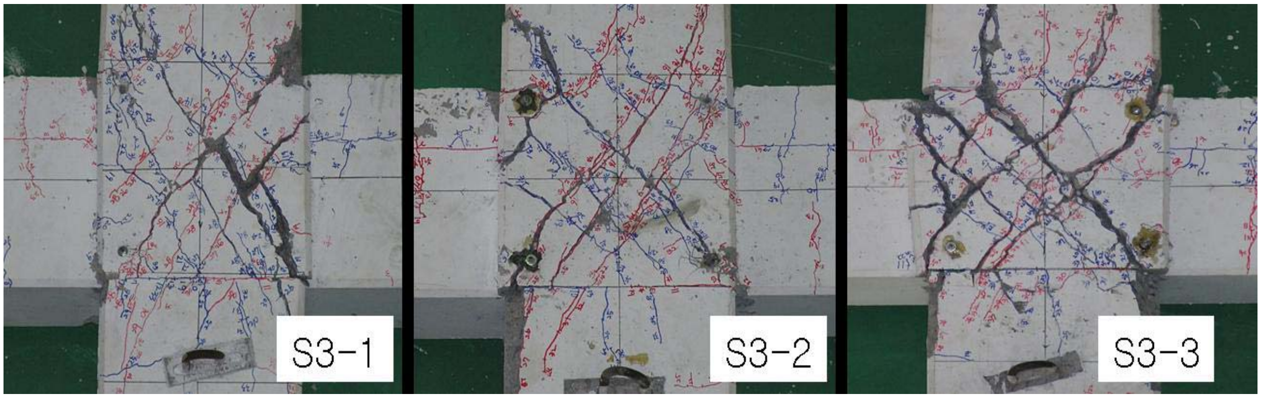

Figure 6. Failure patterns

Hysteresis Behaviors and Strengths

The moment-drift angle curves of the interior connection specimens, S3-1, S3-2, and S3-3, are shown in Figure 7~9. Yield moment, yield drift angle, maximum moment, maximum drift angle, ultimate drift angle, and ductility ratio of the interior connection specimens are shown in

Figure 7~9. Yield drift angle and maximum drift angle were decided based on yield moment and maximum moment, respectively. Yield moment was decided from maximum moment among the same drift angle as when the bottom reinforcements first yielded at a certain drift angle. For the negative load cycle, when the yield strain was unclear, the negative maximum moment was chosen from the same load cycle that the positive maximum moment was decided. Stiffness at each load cycle was decided by the slope of a line that connects from origin to maximum point at the corresponding load cycle.

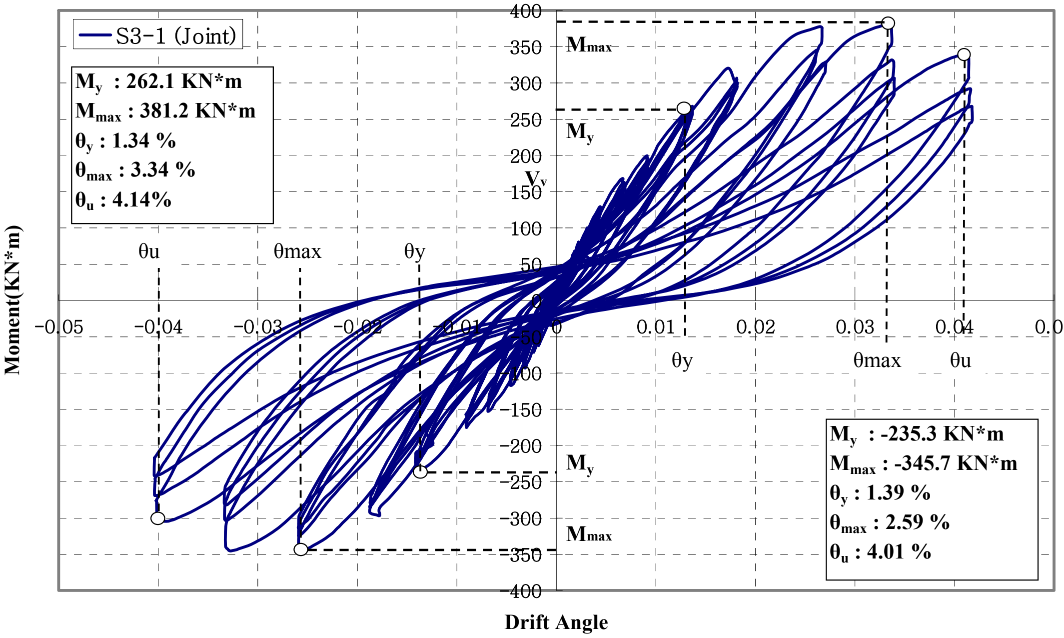

Figure 7. Moment-drift angle curve: S3-1 specimen

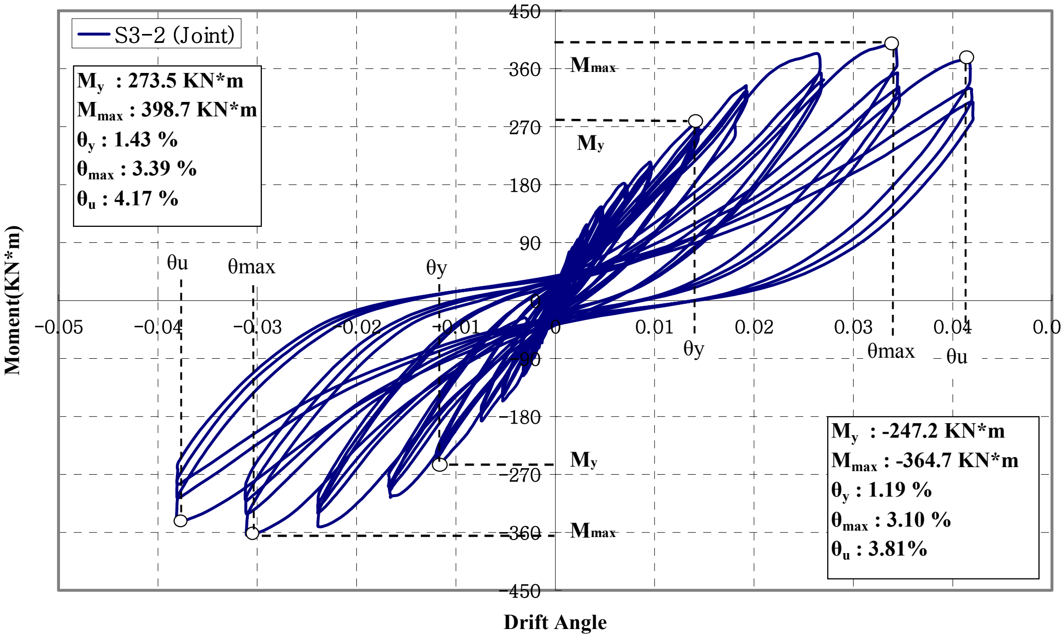

Figure 8. Moment-drift angle curve: S3-2 specimen

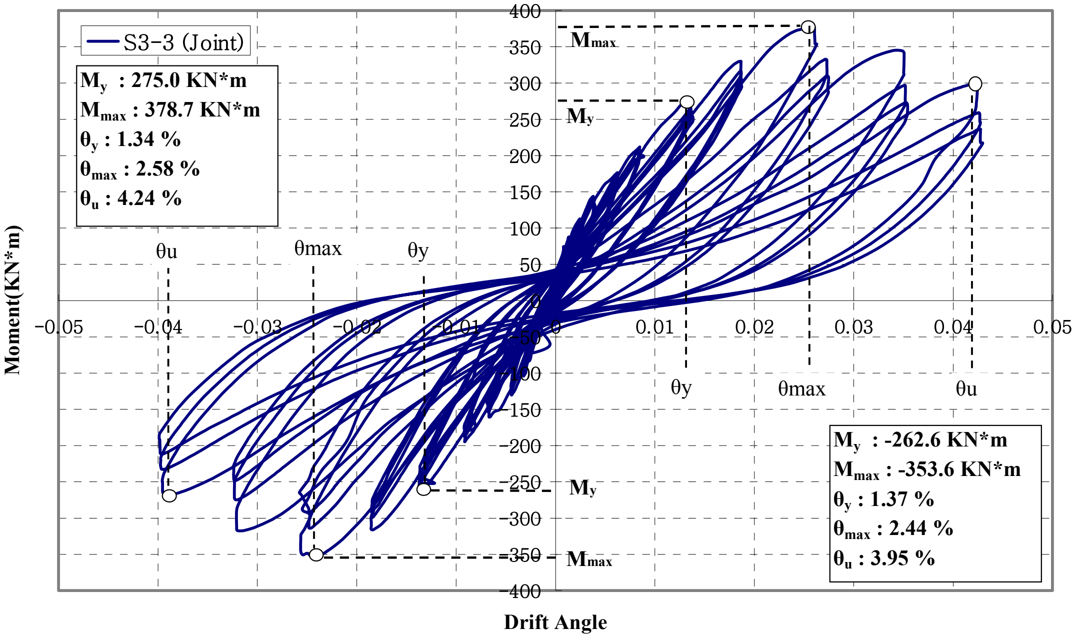

Figure 9. Moment-drift angle curve: S3-3 specimen

As shown in the Figure, maximum strength of the specimens occurs near positive and negative 3% drift angle, and then the strength decreased gradually up to drift angle of 4%. There is little difference between the behaviors of S3-1 and S3-2 specimen which have four strands. The major parameters of the specimens, which were the presence or absence of the transverse reinforcements, had little effect on the hysteresis behaviors of the specimens. This shows that the connection with U-shaped strands confine the concrete in the joints as well as the general beam-column connection with transverse reinforcements usually do. Also, the four strands, which have equal strength of the bottom reinforcements of the beam, are strong enough to transfer the load to the joints.

The maximum strength of S3-3 was similar to that of S3-1, but S3-3 showed strength and stiffness degradation after the maximum strength was reached. Also, compared to S3-1 and S3-2, S3-3 showed slip within the joint with increasing drifts. This is because one extra tendon of S3-3 increases the flexural stiffness more than the shear strength at the connection when compared to the stiffness and strength of S3-1. Therefore, S3-3 starts shear fracture at a lower drift angle than S3-1 and leads to faster strength degradation of S3-3.

Conclusions

Based on the performance results of the experiments on the splice between bottom reinforcements and strands and the interior semi PC beam-column connection with U-shaped strands the following conclusions were reached.

(1) The failure occurred in the following order: flexural cracks on the beam, horizontal cracks on the face of cast-in-place concrete, flexural cracks on the column, shear cracks at the joint, and vertical cracks on the column. Flexural yield of the beam was reached first, and then shear failure at the joint followed

(2) The positive and negative load-displacement curves showed symmetric behavior, and it was evaluated that sufficient lap splice length was secured, since slippage between bottom reinforcements and strands did not occur.

(3) When U-shaped strands were used as connectors for the semi PC system, it was observed that the system was able to transfer load from the beam to the connection, until drift angle of 4% was reached. Therefore, it was evaluated that the structural system is applicable for moderate seismic areas.

Acknowledgments

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