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論 文

[2182] SEISMIC BEHAVIOR OF HALF PRECAST BEAM-COLUMN JOINTS

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ABSTRACT

An experimental investigation was conducted to study the seismic performance of half precast beam-column joints. A composite structure was developed for beams, in which the exterior was a U-shaped precast element and the interior was concrete cast in-situ. Four interior beam-column subassemblages were tested under simulated seismic loads. The behavior differences concerning the strength , ductility, stiffness, energy dissipation, and bond deterioration at the beam-column joints are presented.

Tests results indicated that the proposed method of connection showed an adequate structural performance when the subassemblage was subjected to large cyclic inelastic deformations.

1. INTRODUCTION

In the composite systems which combine precast and cast in-situ concrete, the structural continuity necessary for an adequate seismic performance is provided by the cast in-situ concrete. However the major problems have been related with the connections lack of adequate flexural and shear strengths specially in the joint region. Therefore, the anchorage of the beam main bars should be taken into special consideration. In this paper, several methods to anchor the beam main bars are proposed. The system herein presented is composed by U-shaped precast beam used as permanent formwork, and the core part as well as the columns is cast in-situ. The beam stirrups and part of the lower main bars are embedded in the precast elements. The rest of the lower reinforcement and the upper reinforcement are placed into the concrete cast in situ.

2. SPECIMENS

The outline of the test specimens is showed in Fig. 1. The $1/\sqrt{2}$ scale specimens represent the portion of an interior beam-column joint , taken out from the first story of a low story frame by cutting the beams and

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columns at inflection points due to horizontal loads; i.e. the middle height of the columns and the middle span of beams. This study involved the test of one monolithic (RC1), and three precast (PCA1, PCA2, PCB2) specimens. Among them, RC1, PCA1 and PCB2 were designed so that the plastic hinges in the beams should develop prior to the flexural yielding in the columns or shear failure in the beams, columns or joint. On the other hand, Specimen PCA2 was designed as joint shear failure type.

In order to realize a good binding condition between the pre-cast concrete and concrete cast in-situ, the inner surface of the precast members were provided with cotters (50x50x8mm) distributed horizontally and vertically at every 100 mm, as shown in Fig. 2. The specimens characteristics are shown in Table 1 and Fig. 3. Material properties are listed in Table 2.

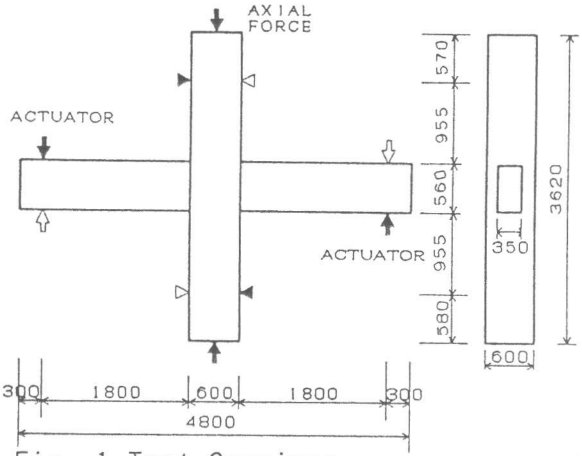


Fig. 1 Test Specimen

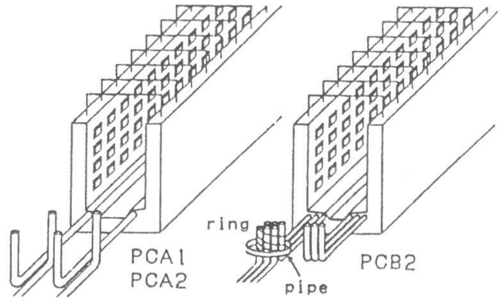
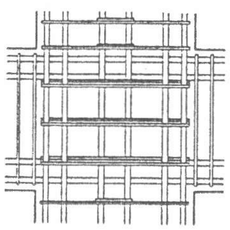
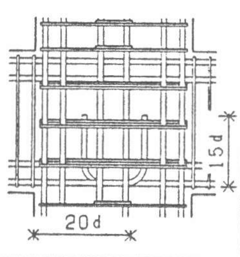
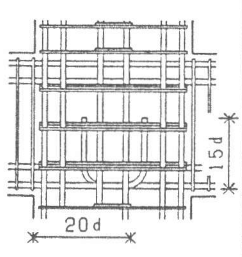
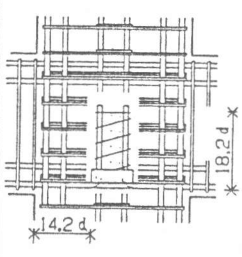


Fig. 2 Details of Precast Beams

Table 1 Details of Specimens

	SPECIMEN	RC1 Cast in-situ Concrete	PCA1 Precast Concrete	PCA2 Precast Concrete	PCB2 Precast Concrete
COL.	Section	60 X 60 cm			
	Main Bars	20-D19 (SD345)		Hoops 4-D10 @100 (SD295A)	
	Reinf. Ratio	Pg=0.71 %		Pw=0.48 %	
BEAM	Section	35 X 56 cm			
	Top Bars	8-D19 (SD345)		8-D19 (SD490)	8-D19 (SD345)
	Bottom Bars	8-D19(SD345)	8-D19 (SD345)	8-D19 (SD490)	6-D16 (SD345) 4-D19 (SD345)
	Reinf. Ratio	Pt=1.28 %	Pt=1.28 %	Pt=1.28 %	Pt=1.39 %
	Stirrups	2-D10 @60 mm (0.7%)	2-D10 @60 mm (0.7%)	2-D13 @60 mm (1.21%)	2-D10 @60 mm (0.7%)
REMARKS		Prototype Beam yielding Type	Two embedded bars bent up. The rest of the lower bars passing straightly in the joint. Anch. length=20d+hook+15d Beam yielding Type	Two embedded bars bent up. The rest of the lower bars passing straightly in the joint. High strength beam bars. Anch. length=20d+hook+15d Joint Shear Type	Six embedded bars bent up, in the center of the col. tied with steel pipe and spiral ring. Anch. length=14d+hook+18d Beam yielding Type
JOINT DETAIL					

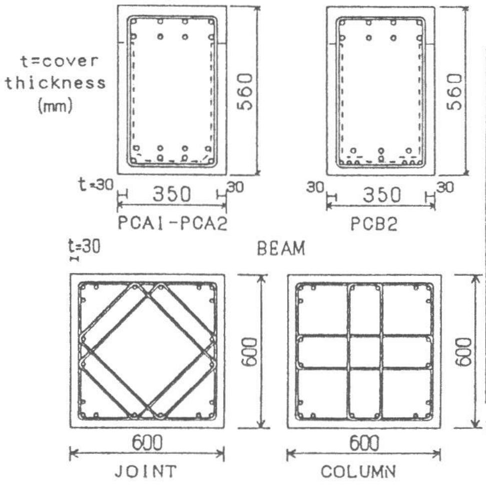


Fig. 3 Sections of Members

Table 2 Material Properties

Specimen		RC1	PCA1	PCA2	PCB2
Column Main Bars		3640 (D19)			
Beam Main Bars		3640 (D19)	3640 (D19)	5140 (D19)	3710 (D16)
Stirrups		3830 (D10)		3550 (D13)	3830 (D10)
Hoops		3830 (D10)			
Concrete Strength Kgf/cm²	In-Situ	286	259	224	249
	Precast	—	330	332	321

Units .Kgf/cm²

3. LOADING SYSTEM AND INSTRUMENTATION

Constant axial force was applied at the top of the column, equivalent to an axial stress of 40 Kgf/cm^2. Two actuators were used to apply opposite forces to simulate the seismic loads at the beam ends. The specimens were subjected to a loading history as follows; one cycle at a drift angle of R=±1/800 and ±1/400, two cycles at R=±1/200, ±1/100, ±1/50, respectively, and finally up to R=1/30 rad. The total deformation, the beam and column deformations were measured by two sets of devices attached to the test specimens as shown in Fig. 4. The curvature of beams, and columns as well as the joint shear distortion were measured by clip gauges. The strain distribution of the beam main bars were also measured.

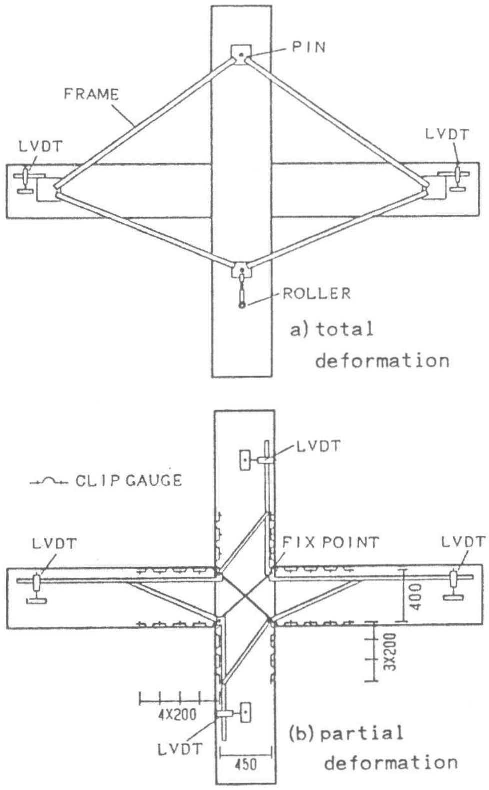


Fig. 4 Measurement Devices

4. TEST RESULTS

4.1 Crack Pattern

The observed crack patterns of two specimens at R=1/50 are showed in Fig. 5. Specimens RC1, PCA1 and PCB2 showed almost the same crack patterns. Major cracking was a result of flexure in beams particularly in the vicinity of the joint. When the main bars yielded at R=1/100, the cracks widened and spread along the beams. Diagonal shear cracks in the joint were observed at approximately R=1/200. Only a limited number of

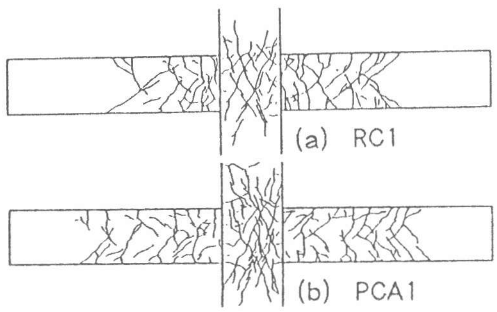


Fig. 5 Crack Patterns at R=1/50

flexural cracks were observed in columns immediately above or bellow the joint. In case of Specimen PCA2, most of the inelastic action was concentrated in the joint and severe diagonal cracks within the joint were noticeable. For the three precast specimens the shell concrete spalled off from the joints at the last stage.

4.2 Hysteresis Relationship

The beam load vs. beam displacement relations of Specimens RC1 and PCB2 are showed in Fig. 6. The beam yielding type Specimens RC1, PCA1, and PCB2 showed similar hysteretic responses, in which the hinges developed at the column faces. Yield was first observed at R=1/100 when the beam main bars reached the yield point at the column face. After the main bars yielded the total subassemblage stiffness were considerably reduced, as a consequence of the cracking of concrete and yield penetration along the beam main bars. Specimen PCA2 reached the joint shear failure before the beam flexural yield at R=1/50. At this stage, pinching behavior and a little strength reduction could be observed as a consequence of the high shear stress developed in the joint. The experimental and analytical results regarding with the ultimate strength are shown in Table 3.

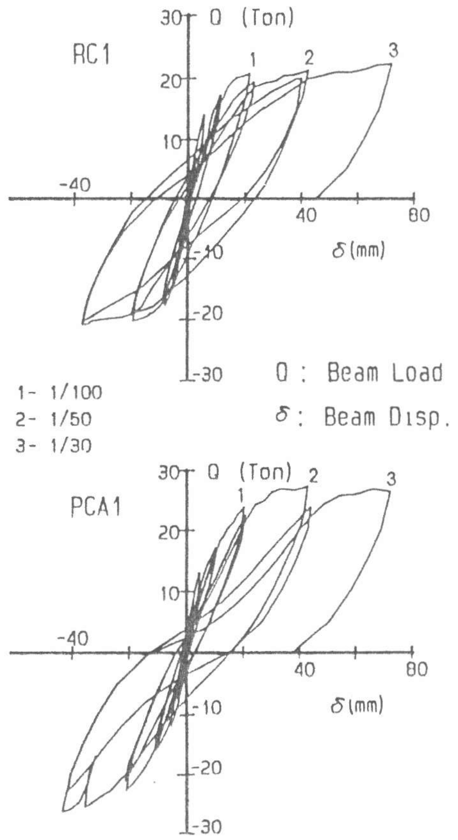


Fig. 6 Beam Load vs. Beam Disp.

Table 3 Test Results

Spc.	Beam Ultimate Strength				Joint Shear Stress		
	R	Qbu exp.	Qbu cal.	exp./cal.	τu exp.	τu cal.	exp./cal.
RC1	1/30	22.5	21.6	1.04	-	-	-
PCA1	1/30	22.8	21.6	1.05	-	-	-
PCA2	1/50	27.3	30.8	0.88	98	102	0.96
PCB2	1/30	23.2	24.5	0.95	-	-	-

$\tau = \frac{Qb\ L - Qcol\ jb}{jc\ jb\ tp}$, $tp = (bc+b_B)/2$

jc=45cm , jb=40cm

Mbu =0.9 at σ_y db , Qbu=Mbu/L

Kamimura's Formula $\tau u = \tau c + \tau s$

$\tau c = Fc(0.78 - 0.0016\ Fc)$, $\tau s = 0.5\ Pw\ \sigma y$

Units : Q (tonf) , τ (kgf/cm²)

4.3 Joint Shear Stress

Joint shear stress-shear distortion relations are shown in Fig. 7. The effective joint area to resist the shear is defined as the column effective depth multiplied by the average of the beam and column widths. For Specimen PCA2, the maximum shear stress reached 98 kgf/cm^2, and failed in shear at 1/50 before the flexural yielding. On the other hand, Specimen PCB2 also exhibited shear failure (85 kgf/cm^2) at the final stage. For the other specimens (RC1, PCA1), the joint distortion was rather small, and did not failed in shear even at the last stage.

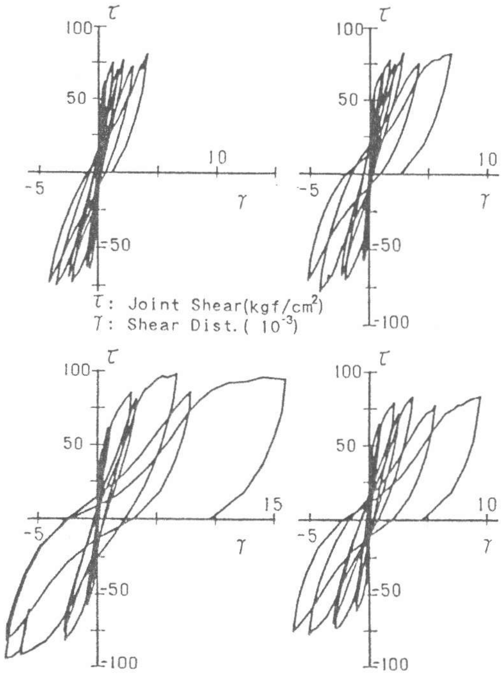


Fig. 7 Joint Shear Stress

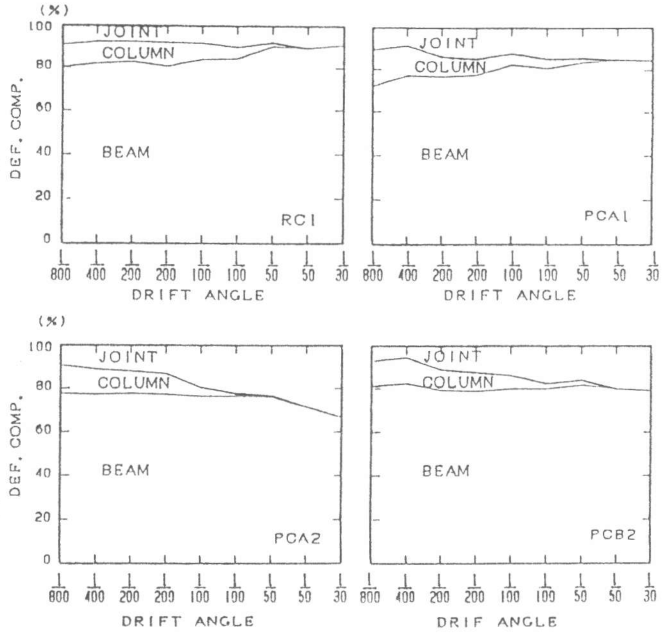


Fig. 8 Deformation Components

4.4 Deformation Components

The contribution of each part of specimens to the total deformation is showed in Fig. 8. The contribution of beam deformation was about 80% of the total deformation for all specimens. For RC1 the joint deformation was limited within 10% of the total deformation, and for PCA1 the joint deformation increased gradually up to 15%, but remained almost constant until R=1/30. In other words, the joint did not fail in these specimens. The ratio of the joint for PCB2 also increased gradually up to 20% and finally failed in shear at the last stage. For PCA2 the joint components increased remarkably with drift angle and exceeded 30% of the total deformation at R=1/30. An abrupt increase of this ratio generally identifies the shear failure mode.

4.5 Strain Distribution

Measured strains along the length of the top and bottom main bars are showed in Fig. 9. The solid lines represent the distribution during the positive loading and the broken in the negative. For all specimens, the measured strains suggest that no local loss of bond occurred within the joint before R=1/100. For later cycles, the top bars at the compression side showed tension strain because of the yield penetration, but no bond deterioration was observed along the bars within the joint. When the lower bent up bars for PCA1 and PCA2 yielded in tension at the column face, the strains in the bent up portion remained in tension, but did not yield until the last stage, indicating a good anchorage. For PCB2 the lower bars showed almost same strain distribution than the others two precast specimens, but the strains in the bent up portion were smaller, showing a good effect of the anchorage. The bent up and straightly placed bars showed similar strain characteristics at the same sections.

5. CONCLUSIONS

Based on the test results, the following conclusions can be drawn:

1) Specimens designed as a beam yielding type, showed ductile behavior. In all cases no strength reduction was observed. Hence, the joint performance was satisfactory under cyclic loading even in the inelastic range.

2) The length of 35 times the bar diameter (35d), used to anchor the bent up bars for Specimens PCA1 and PCA2 proved to be long enough to obtain good anchorage performance. Specimen PCB2 with an anchored length a little shorter than 35d also showed a good anchorage behavior, but failed in shear at the last stage.

3) The different ways of anchorage used for precast beams were proved to be effective. The main bottom bars in precast concrete as well as those located in concrete cast in situ showed almost identical characteristics at the same section. Therefore it is possible to conclude that they have almost monolithic behavior as a whole.

4) Precast beam-column joints with properly detailed reinforcement showed adequate ductility and maintained strength when subjected to inelastic deformation.

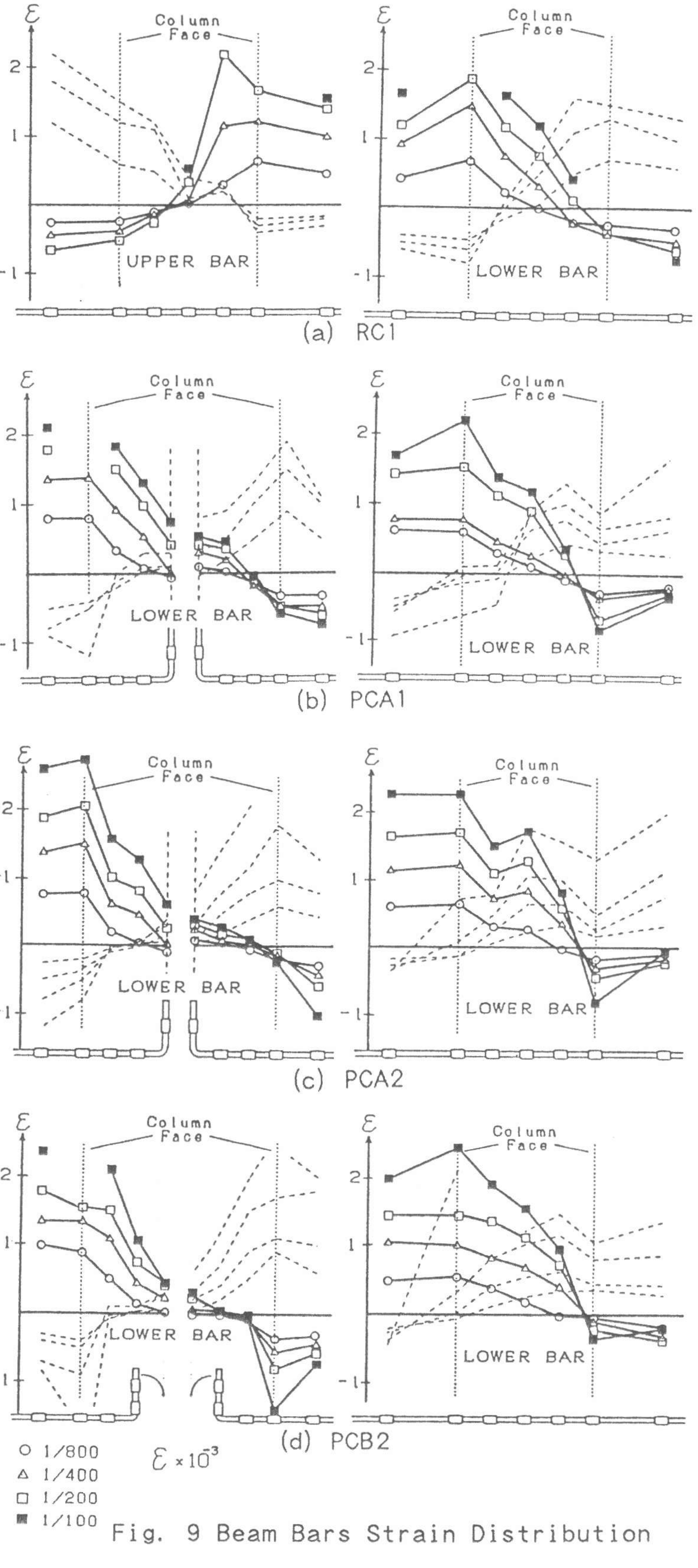


Fig. 9 Beam Bars Strain Distribution