

Experimental Study of Column-Foundation Joint Using Semi-Precast System Subjected to Axial and Lateral Cyclic Loading

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Abstract—Semi-precast column consists of the combination of cast-in-place concrete and segmental precast concrete. In semi-precast concrete column, difference in compressive strength exists between the cast-in-place and precast concrete. The aim of this research is to investigate the behavior of column-foundation joint of semi-precast concrete column under axial and lateral cyclic loading. The behavior of column-foundation joint of semi-precast concrete column has been evaluated by using ACI T1.1.2005. The result shows that the column complies with acceptance criteria of ACI T1.1-05 at point c. Thereby semi- precast column can be used only at the moderate moment resisting frame system (SRPMM) of precast concrete structure, with maximum value of R (modifications response factor) is 6 (ACI T1.1-05).

Keywords-column-foundation, cyclic loading, semi-precast.

I. INTRODUCTION

Semi-precast column system is a system which has been developed to support sustainable green construction. Column is one of the elements developed in a semi-precast column system. Material of column is made of mortar, which has hollowed square cross section. The dimension of the hollow precast column is of 29x29x14 cm, the configuration of the system is shown on Fig. 1. The column consists of material of which the reinforcement is placed inside and the concrete is cast-in-place, has an f_c' of 21 MPa (Figure1d). In buildings, the bottom ends of column are permitted to yield. Experimental research of connection between column and foundation to resist earthquake load is then conducted. The purposes of this research are (1) to know the ability of the column under the earthquake load based on ACI T1.1-05; (2) to find out the stiffness and the ductility of column; (3) to find out the crack and the failure pattern of the column.

Imran et al. [1] have done experimental research of connection between column and foundation using precast concrete system using still sleeves method. A full scale of column and foundation connection which subjected to cyclic lateral loading has been tested. This research has two specimens. All specimens have dimension of 300 x 300 mm cross section and 1625 mm high with f_c' of 25 MPa and 4D25 of flexural reinforcement with f_y of 400 MPa. The steel ratio

of the first and the second specimen is of 2.18% and 3.3% respectively. The ratio of the sleeves to the gross area of the cross section of column is of 6.95% and 10.42% respectively. The clear distance between sleeves of the first and the second specimens is of 131.1 mm and 38.5 mm respectively. The specimen details and the testing setup of the test can be seen in Fig. 2. The test results indicate that the requirement of special moment resisting frame system can be completed by two specimens.

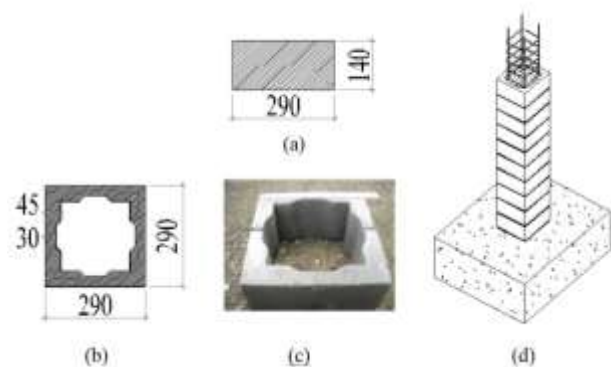


Fig. 1. Material hollow precast column: (a). Elevated view, (b). Top view, (c). 3D view, (d). Specimen of Column

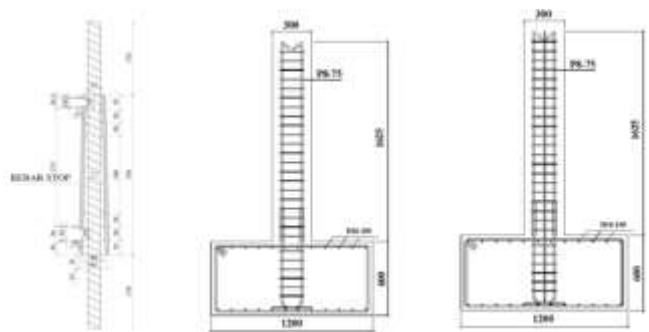


Fig. 2. Specimens of Column [1]

Lee et al [2] had conducted research with the title of cyclic loading test for exterior beam-column joints of CEFT columns. This research was based on the paper of concrete-filled steel tube column encased with thin precast concrete by Park.et.al [3]. A cyclic loading test was performed to investigate the seismic performance of exterior beam-column

joints of concrete-encased-and-filled steel tubular (CEFT) columns. Two specimens with steel beams and two specimens with precast concrete (PC) beams were tested under cyclic loading. The dimensions of the column cross section were 670 × 670 mm, which was a two-thirds-scale model of the prototype column as shown in Fig. 3. The test parameters for the steel beam and the PC beam were the beam depth (488 and 588 mm) and the flexural rebar ratio (1.1% and 1.5%), respectively. In the steel beam-CEFT column joints, continuity plates were used, while in the PC beam-CEFT column joints, couplers were used for the rebar connection. The steel beam-column connections failed due to early fracture of the continuity plate, and the PC beam-column connections failed due to rebar buckling and concrete spalling after beam yielding. The strength of the steel beam-column connections was evaluated using an existing design method, and the seismic performance of the PC beam-column connections was evaluated. On the basis of the test results, design considerations for beam-CEFT column joints were recommended.

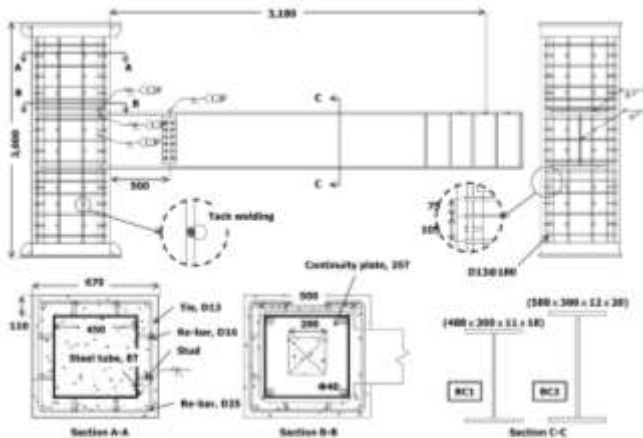


Fig. 3. Detail specimen beam-column

Kim et.al [4] had conducted the research about the title of cyclic loading test for concrete-filled hollow precast concrete columns produced by using a new fabrication method. In this research, a new fabrication method is proposed for concrete-filled hollow precast concrete columns (HPCC) as shown in Fig. 4. In the proposed method, corrugated steel plates were used for the internal mold of the hollow core section to improve production efficiency and structural safety. To evaluate the constructability and structural performance, mock-up tests and cyclic loading tests were performed for four HPCC specimens and a conventional RC specimen. The test results showed that the overall behavior of the HPCC specimens was similar to that of the monolithic RC specimen, and the structural performances such as the maximum load, the initial stiffness, the displacement ductility, and the energy dissipation were comparable to or even higher than those of the RC specimen. The ultimate strength of the HPCC specimens agreed with the prediction by the current design code which indicated that the proposed composite columns of precast concrete and cast-in-place concrete showed the full composite strength.

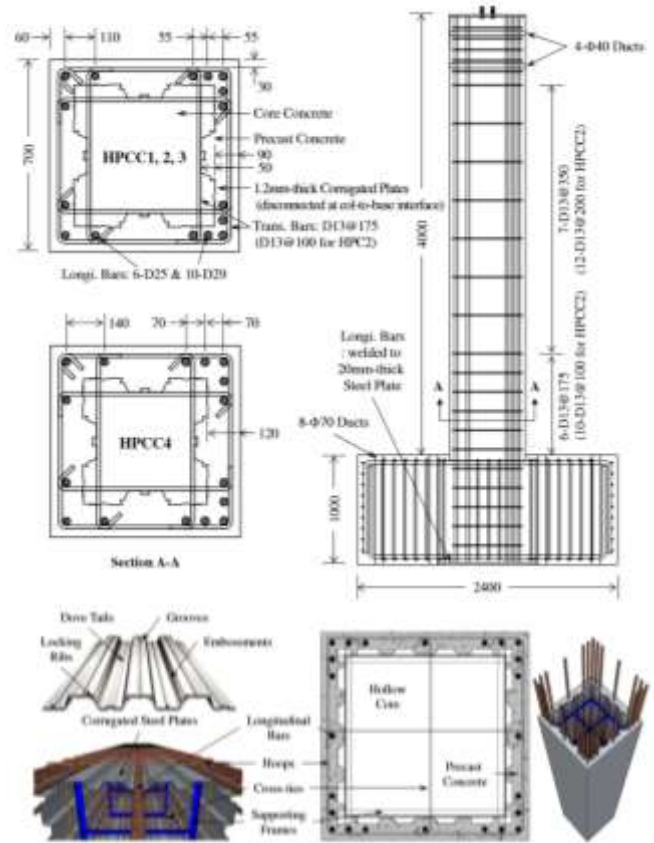


Fig. 4. Detail of specimen column-foundation

II. METHODOLOGY

In this research, the specimen of column which has flexural reinforcement of 8P12 and shear reinforcement of P8-65 mm has been made. The specimen was axially loaded by 126.3 kN and variable lateral cyclic load until failure. Specimens were modeled to represent a half of column height. The columns have square section with the dimension and high of 290x290 mm and 1800 mm respectively. The foundation has dimension of 1200x1200 mm and 350 mm thick with average of f_c' of 25 MPa. The detail of each specimen and reinforcement can be seen in Table I and Fig. 5.

TABLE I. DATA OF SPECIMENS

Specimens	Reinforcements	
	Shear	Flexural
KS	P8-95	8D12

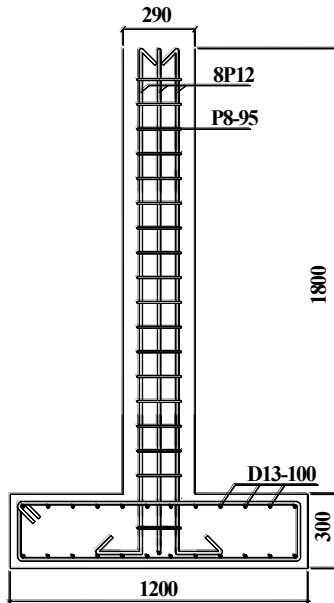


Fig. 5. Reinforcement of Specimen

III. EXPERIMENTAL TESTING

The specimens were tested after 28 days. Test setup of specimens can be seen in Fig. 6.

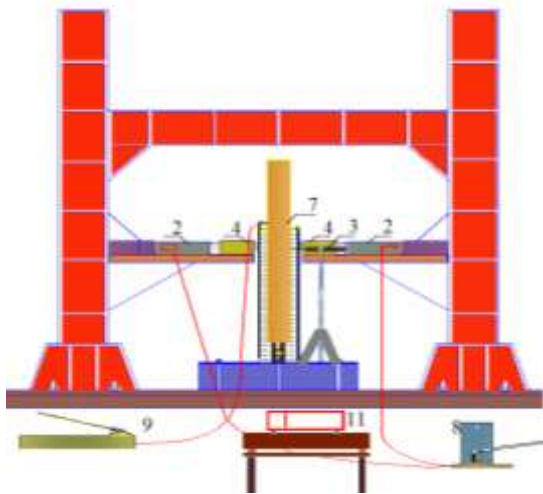


Fig. 6. Testing Setup

IV. LOAD VS DISPLACEMENT

Hysteretic curve representing lateral load vs displacement at negative and positive directions of each cycle can be investigated from experiment testing, as shown in Fig. 7. From the hysteretic curves parameters like lateral load capacity, stiffness, ductility, drift ratio and relative dissipation at each column specimen can be determined. Using the acceptance criteria of ACI T1.1-05 the performance of the columns can be analyzed and the acceptability to resist earthquake load can also be determined.

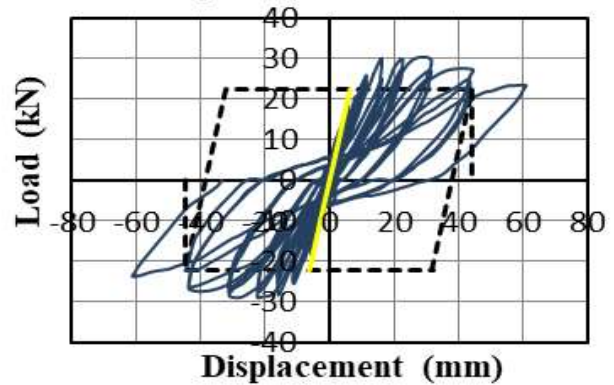


Fig.7. Hysteretic Curves of Specimen KS

V. LATERAL LOAD CAPACITY

Lateral load capacity of three group specimens from experimental testing can be compared to calculate shear capacity based on SNI 03-2847 2012 which shear strain values were recorded from strain gauge and yield value of shear reinforcement ($V_{n1} = V_c + V_{fs}$). The comparison is shown in Table II. Based on experimental results it can be compared to SNI 03-2847 2012. Value of shear capacity that calculated on basis of SNI 03-2847 2012 (V_{n1}) is different than experiment (V_{exp}). The result basis of SNI 03-2847 2012 (V_{n1}) of specimen has different value to experimental research of 111.46%. Result on basis of SNI 03-2847 2012 (V_{n2}) of specimen has different value to experimental research of 301.32%. As the plastic hinge occurred, the shear reinforcement was not yield ($f_s < f_y$).

TABLE II. COMPARISON BETWEEN EXPERIMENTAL RESULT AND ANALYSIS

Specimens	Lateral Forces (kN)				
	V_{kexp} kN	V_{n1} kN	Different (%)	V_{n2} kN	Different (%)
(2)	(3)	(4)	(5) = (4/3)	(6)	(7) = (6/3)
KS-2	29.50	31.53	111.46	88.51	301.32

VI. ACCEPTANCE CRITERIA

The hysteretic curve can be compared to acceptance criteria based on ACI T1.1-05, and the results are:

1. The average of Lateral load capacity at the drift ratio of 2%, resulted from experimental test of specimen KS is 29.23 kN. The column can be used in semi-precast bataton system if the value of shear force is less than the lateral load capacity of specimens which have been tested.

2. The column with configuration of reinforcement as shown on KS-2 has an average of maximum lateral load capacities of, 29.37 kN.
3. The maximum cyclic load level was indicated at the drift ratio of 2.5%. According to ACI 316 criteria these specimens comply with:
 - a. The peak load in two directions, given to all column specimens is greater than $0,75.E_{max}$.
 - b. Relative dissipation is the ratio between hysteretic loop (A_h) of the third cycle at the displacement of 44,27 mm (drift ratio of 2.9%) and the area of $(E1+E2)(\theta1'+\theta2')$ which have marked by dash line in Fig. 7 not less than 1/8. The relative dissipation at each specimen can be seen in Table III.

TABLE III. RELATIVE DISSIPATIONS

Benda uji	Drift	A_h (kNmm)	E1 (kN)	E2 (kN)	$\theta1'$ (mm)	$\theta2'$ (mm)	B
KS-2	0,029	885,38	22,30	22,20	38,00	-38,8	0,259

Stiffness at the drift ratio -0.35% to 0.35% of each specimen can be seen in Table IV and is greater than 0.05 of initial stiffness.

TABLE IV. COMPARISON OF STIFFNESS VALUE

Specimens	Stiffness (-0.35% - 035%)
	(kN/mm)
KS-2A	0.224

The acceptance criteria based on ACI T1.1-05 can be fulfilled by specimen KS-2 at the drift ratio of 2.5%. Based on Imran et al. [1], the column complies with the acceptance criteria of ACI T1.1-05 at point c) above. Thereby column bataton can be used only at the moderate moment resisting frame system (SRPMM) of precast concrete structure, with the maximum value of R (modifications response factor) of 6 (See ACI T1.1-05) [5].

VII. CRACK AND FAILURE PATTERN

Based on the visual investigation of cracks of each specimen, the failure of the column can be classified as flexural failure, which has been dominated by horizontal cracks in both directions. Initial crack has occurred in the horizontal directions, which has indicated the flexural cracking. Incremental step of the loading has caused the cracks open wider, longer and the spalling has occurred at the end of two directions of the bottom column. The spalling at the end of the bottom columns occurred in the

concrete cover only. The behavior of cracks and spalls can be seen in Fig. 8.

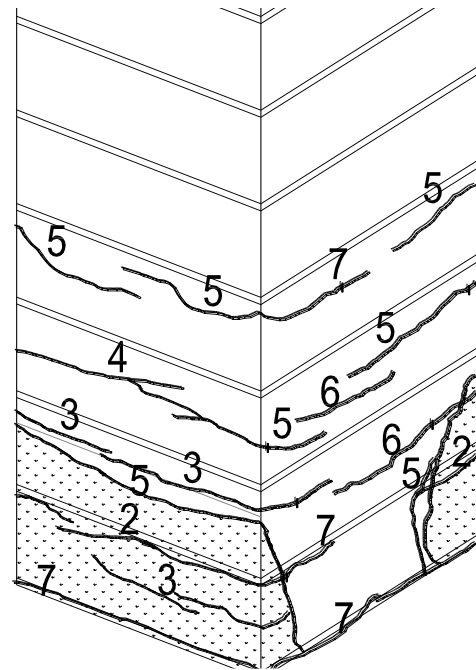


Fig. 8. Cracks and Spalls of Specimen KS-2

VIII. CONCLUSION

The conclusion on this research is the following: The column shear force is based on the drift ratio of 2%, resulted from experimental test of specimen KS-2 is 29.23 kN. The column can be used in semi- precast bataton system if the values of shear force are less than the lateral load capacity shown above. Based on Imran et al. [1] the column complies with the acceptance criteria of ACI T1.1-05 at point c). Thereby column bataton can be used only at the moderate moment resisting frame system (SRPMM) of precast concrete structure, with the maximum value of R (modifications response factor) of 6 (See ACI T1.1-05) [5].

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