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Joint Design of Precast Concrete Moment Frame using Hollow Precast Concrete Column

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Abstract*—In order to develop a proper design procedure of the joints composed with hollow precast concrete (HPC) column and precast concrete (PC) beams, experimental results performed previously were analyzed in this paper. From the analysis of the experimental results about exterior and interior PC joints using HPC, it was found that design of strong moment connection at the joints is possible. For the design of the beam-column joints using HPC column, a design procedure was established in accordance with the design standard and examined by comparing with the test results. As a result, it was confirmed that the strength of HPC joint using the design process is adequately predicted by following the suggested design procedure.

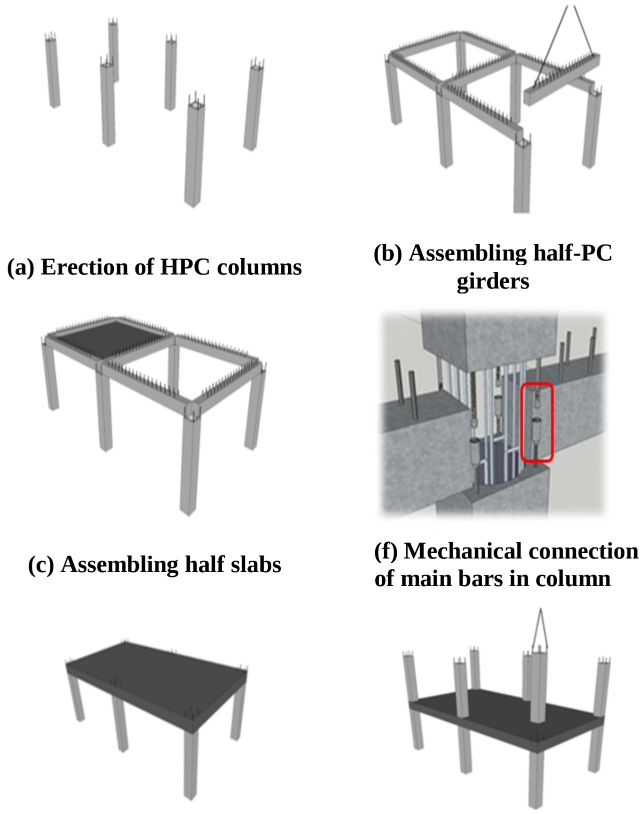
***Index Terms*— Hollow precast concrete (HPC) column, precast concrete (PC) beam, beam-column joints, Strong moment connections, Design procedure.**

I. INTRODUCTION

Precast concrete (PC) system offers a benefit of minimizing the amount of work in site compared with the conventional reinforced concrete (RC) system. However, it has been generally known that the joints in the PC moment frame system are easy to be vulnerable when the lateral force is acting on since the joint is difficult to be strong to resist a large moment as a rigid one [1]-[4]. A failure of joints can cause significant damage in building so that the failure at joint and column must be avoided. To solve this problem, a composite PC column made in combination of hollow precast concrete (HPC) and cast-in-place (CIP) concrete has been developed [5]-[7]. From a series of experiments, it was found that the PC beam-column joint with HPC is able to be designed to have a moment connection [8]-[11]. In this manner, this study aims to construct a design procedure of the PC joints composed with HPC column.

II. MOMENT FRAME SYSTEM USING HPC

The HPC column-PC beam system has the advantages of both the RC system and the PC system. Hollowed PC columns manufactured by centrifugal casting and half-PC beams are assembled in site. The connection of the rebar utilizes head-splice sleeves to enhance the performance and workability of the column-column connections. In addition, when the lower re-bar of the beam is fixed, it is fixed in the hollow portion of the lower column without being fixed to the inside of the joint, so that the arrangement in the joint can be simplified and the anchoring capacity of the bars can be exerted. Fig. 1 shows the construction process of frame system composed of HPC column and Half-PC beam. After assembling the members, the hollow parts of the HPC columns are filled with cast-in-place concrete at the same time as the casting of the slabs, structurally unifying the joints.



(a) Erection of HPC columns
(b) Assembling half-PC girders
(c) Assembling half slabs
(f) Mechanical connection of main bars in column
(d) Concrete casting
(e) Erection of HPC columns of upper floor

Fig. 1Construction process of PC frame system with HPC columns

For the connection of main bars in column, head splice sleeve (HSS) connects is used. The bar of upper column has head which is going to be inserted in the sleeve. The head is fixed by high strength mortar in the sleeve so that there is no need for an additional tube to inject epoxy mortar as shown in Fig.2 Furthermore, the anchorage length of the bar can be reduced according to the enhanced bond strength by the embedded head, and thus, the section can be optimized. Regarding the structural performance of the HSS, a series of experiments [12], [13] have been performed to evaluate the bond behavior of HSS, and verified that the HSS achieves sufficient tensile performance.

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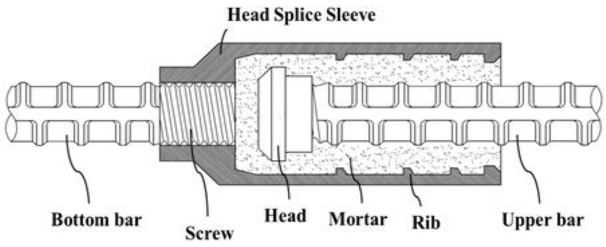

Fig. 2Shape and detail of head-splice sleeve (HSS)

III. DESIGN OF BEAM-COLUMN JOINT USING HPC COLUMN

A. Joint Design Procedure Using HPC column

In the moment frame to resist horizontal loads, the design concept at joint is used to be based on strong column-weak beam. This induces failure of beams by concentrating only on the section of the plastic hinge when the frame is under severe loading conditions. This minimizes the failure of the columns and provides to increase the ductility of the entire structure through the flexural failure of beams. The design process of the PC frame joint using HPC column in this study is as shown in Fig. 3. It is base on the failure process that the failure of the joint occurs after the yield of beam forming a plastic hinge. The design procedure is as follows;

1) STEP 1: The lateral load ( ) acting on the beam-column joint and the information about the target member are input. These include the dimensions of beams, columns, joint section, the strength of materials, the spacing of bars etc.

2) STEP 2-1: The flexural and shear strengths of the HPC columns are calculated corresponding to the previous study [7], [14]-[16] by using the effective concrete strength considering the ratio of the PC member in the confined concrete and the area of the filled concrete in the hollow.

3) STEP 2-2: The design shear strength of the joint can be calculated using Eq. (1) as presented in ACI-ASCE Committee 352.

$$V_{j,ACI} = 0.083\gamma\sqrt{f_{ck}}\,b_j \qquad (1)$$

where, is nominal shear strength of joint concrete panel ( ), is type of joint and seismic zone coefficient, is effective width of joint(m), is depth of column to be joined(m), $_j$ is concrete strength (MPa).

The design shear strength of the joint can be estimated using Eq. (2) in Korean code (2012).

$$V_{j,KCI} = \gamma\sqrt{f_{ck}} \qquad (2)$$

where, is effective cross-sectional area in the joint parallel to the face of the rebar that causes shear at the joint.

The shear force when the joint reaches the design shear strength can be estimated as Eq. (3).

$$V_{nb} = \frac{V_j V}{V_j} \qquad (3)$$

Where, is design shear strength of joint ( ), V is the shear strength of adjacent beams when yielding ( ), V_j is the joint shear force when the adjacent beam yields ( ).

4) STEP 2-3: The design shear strength of the beams can be estimated using Eq. (4) in KBC 0507, and the maximum bending strength can be obtained by nonlinear cross-section analysis.

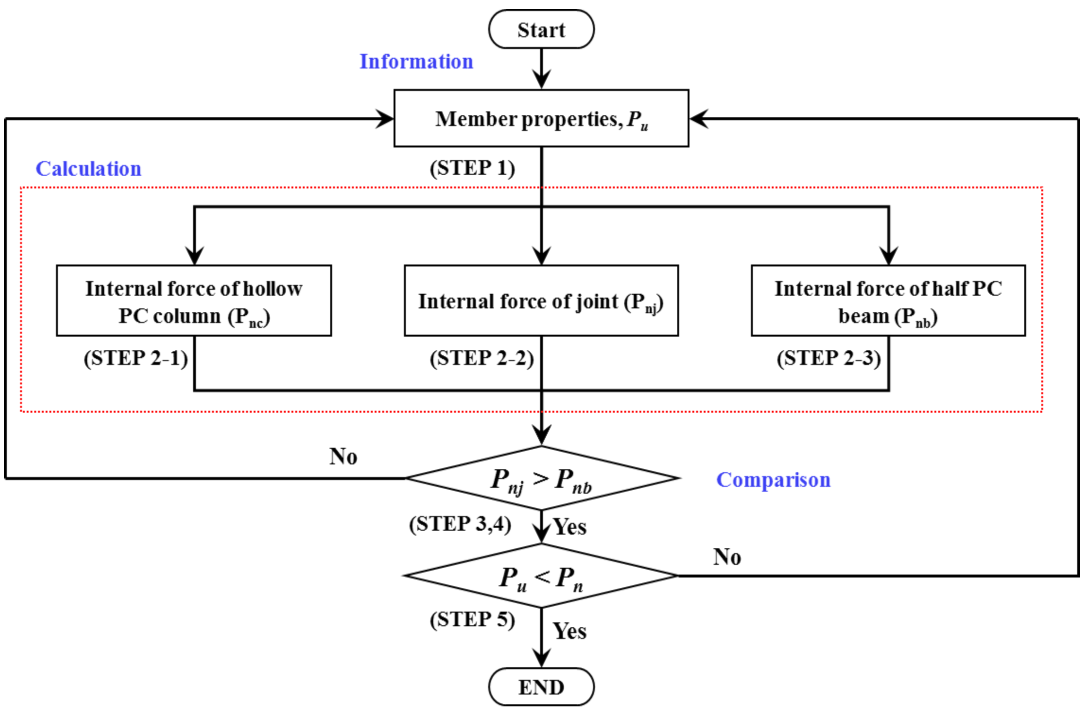

Fig 3Design procedure of the joint using HPC column

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$V_n = V_c +$ (4)

where, $V_s = A_v f_y d$, . is the cross-sectional area of the shear reinforcement in the spacing *s*, is yield strength of re-bar(MPa), *d* is compression zone depth(mm), *s* is space of stirrup, $V_c = \lambda\sqrt{f_{ck}}b_w d$, is light-weight concrete factor, $_j$is concrete strength (MPa), $_i$ is beam width (mm).

5) STEP 3: The load carrying capacity of the joint is obtained by the equilibrium condition of the forces acting on the joints. The lateral load acting on the column top as shown in Fig. 4 is the same as the shear force acting on the column. By converting V to lateral load as in Eq. (5), the lateral load at the time the joint reaches the design shear strength can be estimated.

$P_{nj} = \frac{V_{\cdot}}{}$ (5)

where, F is lateral load when the joint reaches the design shear endurance (k), is the beam length between the vertical supports (mm), is the net column height(mm).

The lateral load when the beam reaches the ultimate moment can be estimated as Eq. (6).

$$P_{nb} = \frac{(V_{bp}+V_{bn})l}{h} = \frac{(M_{bp}+M_{b}}{h(l-h_c}$$ (6)

where, V and M are the shear force and moment developed by yielding of the beam bottom bars(k, $kN\cdot$), V and M are the shear force and moment developed by yielding of the beam top bars(k, $kN\cdot$), respectively, is the beam length between the vertical supports(mm), is the net column height(mm), is the column depth(mm).

6) STEP 4: The lateral load (F) when the beam reaches the ultimate moment and the lateral load (F) when the joint reaches the design shear strength are compared. When F is lower than F, the characteristic of the member is modified and iteratively calculated.

7) STEP 5: The lateral load when the beam reaches the ultimate moment is assumed to be the load carrying capacity ( ) of the beam-column joint. Modify the characteristics of the member until the calculated value becomes higher than the required lateral force ( ) and calculate it repeatedly.

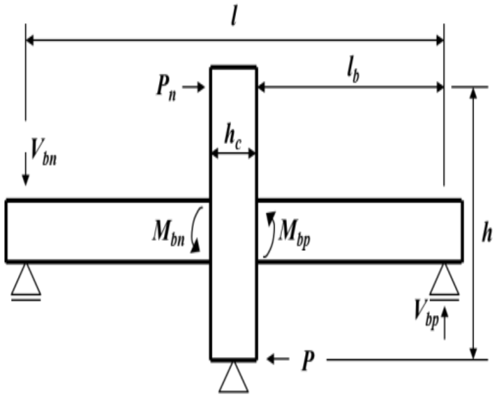

Fig 4 Interior beam-column joint

Table 1Specimen list of Shin et al.(2017) and Noh.(2017)

Specimen		Shin et al.(2017)-Exterior joint			Noh(2017)-Interior joint		
		HPC1	HPC2	HPC3	HPC1	HPC2	HPC3
Beam	Dimensions ($b \times h$) ($mm \times mm$)	250 × 150					
	Precast concrete strength (MPa)	44.4			35.9		
	CIP concrete strength (Mpa)	30.7			21.8		
	Top bars	3-D13			4-D13		
	Bottom re-bars	3-D13	3-D13	2+3-D13	4-D13		
	Stirrup (type of re-bars)	D6@80			D6@50		
Column	Dimensions ($b \times h$) ($mm \times mm$)	300 × 300					
	Precast concrete strength (MPa)	40.1	32.7	45.1	44.1	43.7	45.1
	CIP concrete strength (Mpa)	30.7			21.8		
	Bars	8-D19					
	Stirrup (type of re-bars)	D10@150			D10@150		

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Table 2 Comparison with the calculated strength and test result

Researchers	Specimen	$P_m(kN)^*$	$P_{nb}(kN)^{**}$	$P_{nj}(kN)^{***}$		P_m / P_{nb}
				ACI	KCI	
Shin at el.(2017) Exterior joint	HPC-1	+22.79	+20.73	39.60	47.80	1.10
		-28.38	-21.34			1.33
	HPC-2	+25.17	+20.73			1.21
		-25.75	-21.34			1.21
	HPC-3	+33.05	+30.16			1.10
		-31.37	-21.92			1.43
Noh (2017) Interior joint	HPC-1	57.43	51.23	56.90	61.00	1.12
	HPC-2	56.87	51.23			1.11
	HPC-3	58.99	51.23			1.15

*P_m is the ultimate force obtained from the test.
**P_{nb} is calculated form Eq.(6).
***P_{nj} are calculated form Eq.(5).

B. Design Result by the Proposed Design Procedure

The designs about the specimens by Shin et al. (2017) and Noh (2017) were performed by using the proposed procedure. For each specimen, the axes of the beam and column intersect at right angles, and the re-bar of beam passes through the joint. In addition, it was shown that the specimen was designed assuming that the tensile steel bar of the beam yields at the joint, which is a PC beam column joint designed with a strong column weak beam. The calculated values were compared with the lateral load capacities ( ) obtained from the experiments. The width and depth of half PC beam are 150mm and 250mm, respectively and the depth includes 50mm tapered concrete. The dimension of HPC columns are 300mm x 300mm and the diameter of hollow part is 200mm. Table 1 summarizes the data collected for each specimen.

Table 2 represents the comparison result of the calculated values obtained by the design process with the experimental values of the existing studies. In the Noh (2017) study, slip phenomenon occurred in the experiment, and the positive load was higher than the negative eccentricity. In this study, absolute value of averages was used for comparison. As a result of calculating the value obtained through the design process, the actual experimental value was 1.10 ~ 1.43 times higher than the calculation strength, and the average value was 1.20 higher than the calculation strength. From this, the joints can be properly designed and satisfied with the structural requirements.

IV. CONCLUSION

The design process of the PC beam-column joint using HPC column was established according to the design standard and the load capacity of the specimen was predicted for the lateral force. Based on the design process, a comparative analysis showed that the results of a joint study using HPC, which utilizes the existing research methods, showed average 1.20, satisfying the structural requirement performance. Through this, it is considered that the design process appropriately predicted the bearing capacity of HPC beam column and the ultimate lateral load of beams.

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