Shear Friction Behavior of Hollow-Precast Concrete Column for Eco-Friendly Construction of Building

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Abstract. Recently, a few studies has been conducted regarding centrifugal formed PC columns to enhance constructability and integrity due to a hollow precast concrete (HPC) column with a hollow part at the center of the column. However, in the case of this Cast-In-Place (CIP) material, and in particular, the contact surface is present between the two materials, forming a composite structure. Accordingly, as HPC column and CIP concrete are subjected to unbalanced compressive forces, the compressive performance is likely to be lowered due to the interfacial shear failure at the interface of the two materials. In this regard, a compression test was performed to figure out the shear friction between CIP and HPC in this paper. As a result, the splitting failure is induced as a lateral stress occurs under unbalanced compression and HPC column is not expected to utilize its bearing strength sufficiently. Accordingly, the splitting failure should be prevented by increasing the thickness (h) of HPC column part through adjustment of the hollow diameter of the HPC column to less than a certain size, or confining the HPC column part with the use of connection rebars.

Introduction

As buildings are becoming higher and larger in construction sites, a reduction in construction period, an improvement of constructability and a decrease in labor costs have emerged as important issues of the construction market. However, the currently used reinforce concrete method (hereafter referred to as RC method) reveals its limitations in reducing labor costs and field expenses as well as construction period due to the need for the absolute term of construction and has many disadvantages in that the construction is affected by external factors such as weather and environmental conditions of the field, temporary materials are needed in the entire process, and thus construction costs increase. However, unlike the conventional method of pouring concrete in the field, a precast concrete method (hereafter referred to as PC method) that assembles the sectional prefabricated column, wall and floor members, which are manufactured in a plant, using lifting equipment in the field makes it possible to reduce labor costs and other expenses owing to a reduction in the absolute term of construction and prevent the construction process from being affected by external factors of the field as the members are delivered after production in the plant. In addition, it can reduce construction costs since there is no need for temporary materials, thereby helping to overcome the shortcomings of the PC method.

However, PC members that are mainly used in the field requires equipment with high lifting capacities, which leads to an increase in transportation costs and has shortcomings posed by a lack of integrity as the prefabricated column members are connected to other members in a cast-in-place (hereafter referred to as CIP) method. In order to compensate for the shortcomings, a few studies [1,2,3] has been conducted regarding centrifugal formed PC columns to enhance constructability and integrity due to a hollow precast concrete (hereafter referred to as HPC) column with a hollow part at the center of the column. However, in the case of this CIP material, and in particular, the contact surface is present between the two materials, forming a composite structure. Accordingly, as HPC column and CIP concrete are subjected to unbalanced compressive forces as shown in Figure 1, the compressive performance is likely to be lowered due to the interfacial shear failure at the interface of the two materials.
In this regard, this study seeks to investigate the effects of unbalanced stresses through interfacial shear failure experiments and analysis on the contact surface between the two materials such as centrifugal formed HPC column and CIP concrete poured in the hollow part.

**Shear Test for Unbalanced Loads**

Different compression forces exist over the HPC column section and cause shear slip between CIP and HPC. In order to figure out the shear friction between CIP and HPC, a compression test was planned.

**Specimen Design**

HPC column specimens used in this study have a cross-sectional dimension of 300mm×300mm with length of 1,000mm. 10mm diameter rebar was used as hoop with spacing of 150mm. 19mm and 13mm diameter rebars were used as main bars. The variables of HPC column include the hollow ratio of HPC column, connection rebar ratio and strength of CIP (Cast-in-placed) concrete, and a total of five specimens were prepared. Table 1 and Figure 2 show the specimen list and dimensions of the specimens, respectively.

<table>
<thead>
<tr>
<th>Specimen name</th>
<th>Hollow Diameter (mm)</th>
<th>Hollow ratio (%)</th>
<th>CIP concrete f_{ck} (MPa)</th>
<th>Cross tie</th>
<th>Bar diameter (mm)</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H50-F21</td>
<td>240</td>
<td>50</td>
<td>21</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H59-F21</td>
<td>260</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H50-F40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H50-F21-C1</td>
<td>240</td>
<td>50</td>
<td>21</td>
<td>10</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>H50-F21-C2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.24</td>
<td></td>
</tr>
</tbody>
</table>

**Loading/Measuring Plan**

For observation of shear deformation at the interface between HPC column and CIP concrete, the lower part of HPC column was supported, and the compressive force was applied only to CIP
concrete. A hydraulic universal testing machine with a capacity of 5000kN was used for loading and a displacement control method with a speed of 0.0067mm/sec was adopted.

**Failure Modes**

Crack patterns found commonly in specimens are that micro-cracks occurred on both sides of upper and lower ends of the column in a vertical direction, and then as loads increased, cracks occurred laterally at the interface in the upper part of column. And the micro-cracks on the sides of the column were gradually expanded to the central part, forming vertical cracks, and ultimately reached the maximum load along with the scaling of the concrete cover. Figure 3 shows the failure modes of the specimens, and it was confirmed that vertical cracks occurred in all sides.

![Failure modes of specimens](image)

**Test Results**

Table 2 shows a summary of the first crack strengths, maximum strengths, maximum stresses for each specimen and support load of CIP concrete. Looking at the changes in bearing strengths according to the changes of hollow diameters, the first crack strengths of the reference specimen H50-F21 and H59-F21 specimen with a larger hollow diameter were 470kN and 300kN, and their maximum strengths were 654kN and 681kN, respectively. However, the maximum stresses obtained by dividing the maximum load by CIP area were 14.53MPa and 12.82MPa, respectively. The reason for the pattern in which the maximum bearing strength slightly increased despite an increase in the area of CIP concrete with a lower strength compared to HPC is because the bearing strength is determined by the splitting failure of HPC. That is, the horizontal deformation increased by the compressive deformation of CIP concrete leads to an increase in flexural stress on the vertical axis of HPC, causing the splitting failure.
Table 2. Test results

<table>
<thead>
<tr>
<th>Specimen name</th>
<th>Initial cracking load (kN)</th>
<th>Ultimate load (kN)</th>
<th>Ultimate stress (MPa)</th>
<th>Resisting load by CIP $f_{ck} \times (\pi d^2/4)$ (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H50-F21</td>
<td>470</td>
<td>654</td>
<td>14.53</td>
<td>949.536</td>
</tr>
<tr>
<td>H59-F21</td>
<td>300</td>
<td>681</td>
<td>12.82</td>
<td>1114.386</td>
</tr>
<tr>
<td>H50-F40</td>
<td>612</td>
<td>680</td>
<td>15.11</td>
<td>1808.64</td>
</tr>
<tr>
<td>H50-F21-C1</td>
<td>580</td>
<td>826</td>
<td>18.36</td>
<td>949.53</td>
</tr>
<tr>
<td>H50-F21-C2</td>
<td>550</td>
<td>994</td>
<td>21.87</td>
<td>949.53</td>
</tr>
</tbody>
</table>

The initial crack strength and maximum strength of H50-F40 specimen with a greater strength of CIP concrete were 612kN and 680kN, showing higher values compared to the reference specimen, and the maximum stress was 15.11MPa, which was also higher than that of the reference specimen. In comparison to the increase in strength of CIP concrete, the improvement of the bearing strength is insignificant, which is because the bearing strength is determined by the splitting failure of HPC as mentioned previously.

The first crack strengths of H50-F21-C1 specimen reinforced with six connection rebars and H50-F21-C2 specimen reinforced with 10 rebars were 580kN and 550kN, respectively. Their maximum strengths were 826kN and 984kN, and maximum stresses were 18.36MPa and 21.87MPa, respectively. Thus, the first crack strengths, maximum strengths and maximum stresses were all higher than those of the reference specimen, which is due to the reason that the increased lateral confinement effect of HPC resulting from an increase in the amount of connection rebars leads to a delay of the splitting failure period of HPC. From the Table 2, only H50-F21-C2 ($\rho_c=0.24\%$) specimen reinforced with 10 connection rebars exhibited the strength greater than the resisting load by CIP. This suggests that more than 10 connection rebars are required to prevent the splitting failure of HPC until CIP concrete reaches its maximum strength. In other words, when the axial force is applied to the CIP concrete part of HPC composite column, the splitting failure is induced as a lateral stress occurs, and the splitting failure in turn prevents HPC column from utilizing its bearing strength sufficiently. Therefore, it is necessary to prevent the splitting failure at the column thickness through the estimation of thickness of HPC column part according to the hollow ratio and connection rebar detailing, and to design HPC column to withstand the strength which is greater than the support strength of CIP concrete.

Summary

This study investigated the effects of unbalanced stresses through interfacial shear failure experiments and analysis on the contact surface between the two materials such as centrifugal formed HPC column and CIP concrete poured in the hollow part. The conclusions obtained from the findings of this study are as follows.

When the axial force is applied to the CIP concrete part of HPC composite column, the splitting failure is induced as a lateral stress occurs. If the splitting failure occurs, HPC column is not expected to utilize its bearing strength sufficiently. Accordingly, the splitting failure should be prevented by increasing the thickness ($h$) of HPC column part through adjustment of the hollow diameter of the HPC column to less than a certain size, or confining the HPC column part with the use of connection rebars.

If the HPC column is used in a special moment frame, the connection rebar needs to be calculated in accordance with the confinement details of the column required by the current seismic design criteria. And with respect to the amount of connection rebars to prevent the splitting failure of HPC,
additional studies need to be conducted regarding the HPC thickness according to the hollow size and concrete strength.

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References

