Abstract
The objective of this study is to investigate the structural behavior of beam-to-column connection of CFT (Concrete Filled Tube) when air cavity exists under the diaphragm of CFT members. CFT can be expected the confined effect between steel tube and infilled concrete if only the concrete is filled perfectly without air cavity. The rectangular hollow section members are used for steel tubing of CFT member in this study. The short column tests and the beam-to-column connection test with air cavity are carried out. The ratio of air cavity with respect to the infilled concrete area is also discussed about the strength and the deformation of connection by using of CFT. It is seen that the influence of air cavity about CFT is not severe within admissible range.

1. Introduction
CFT (Concrete Filled Tube) columns have better structural performance compared with hollow tubular columns. The confined effect of CFT is well known from the test results. The width-to-thickness ratio of hollow tubular members is restricted respectively to use it for structural elements. The encasement of concrete can prevent steel parts from occurring local buckling in case of CFT. Infilled concrete can take a share in large axial forces of columns in case of high rise buildings.

But it must be careful that air cavity occurs in the tube when concrete is not perfectly filled. There were some short column test about CFT with air cavity by another researchers, but the test of beam-to-column connection is seldom in the case of the CFT connection with air cavity. The objective of this study is to investigate the behavior of short columns and the structural behavior of beam-to-column connection of CFT when air cavity occurs under the diaphragm. The rectangular hollow section members are used for steel tube of CFT member. The parameters of the test for this study are the ratio of axial force and the ratio of air cavity with respect to the infilled area of concrete. The
influences of those parameters are investigated from the test results. The ratio of air cavity with respected to the infilled area of concrete is also discussed about the strength and the deformation of connection by using of CFT.

2. Short Column Test with Air Cavity

2.1 Material properties of tubes and H-shaped section steel

Two types of rectangular tube and one type of H-shaped section steel were used for specimens which are for short column test and beam-to-column connection test. The results of tension test are shown in Table 1. It was ascertained that their material properties satisfied Korean Standards (KS) as SS400 class steel.

2.2 Specimens with air cavity

Six short columns with air cavity were tested to investigate the influence of strength and deformation. \(\square-250\times250\times6\) is used for rectangular hollow section members. The configuration of specimens is shown in Figure 1. They have penetration type diaphragms with thickness 9mm and circular hole to fill concrete continuously. The ratio of air cavity varies from 0% to 75%, and it means the ratio of air cavity area with respected to the infilled area of concrete. The location of air cavity and the circular holes to fill concrete are shown in Figure 2. Soft styrene with 5mm thickness was used for artificial air cavity. The infilled concrete with 24 MPa compressive strength was used.

2.3 Short column test results

Figure 3 shows the short column test setup. Test machine with 9800kN capacity was used. Maximum loads of short columns are shown in Table 2. Specimen RF-20 and specimen RF-20M are different in the diameter of circular hole. The ratios of strength in case of air cavity with respected to that without air cavity also shown in this table.

Figure 4 shows the load-displacement relationships of short columns. CFT short columns have better structural performance compared with hollow tubular columns such as specimen RH-0 as shown in this figure. It can be seen from Figure 4 that the maximum strengths of all specimens are higher than the superposition strength of tube and concrete. The difference of initial stiffness can not be found even though in case of the ratio of air cavity of 50%. The initial stiffness changes in case of the ratio of air cavity of 75% compared with another cases.

Table 1 : The results of tension test

<table>
<thead>
<tr>
<th></th>
<th>Yield strength (MPa)</th>
<th>Maximum strength (MPa)</th>
<th>Yield ratio</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\square-250\times250\times6)</td>
<td>403</td>
<td>484</td>
<td>0.83</td>
<td>33</td>
</tr>
<tr>
<td>(\square-500\times500\times12)</td>
<td>288</td>
<td>459</td>
<td>0.63</td>
<td>42</td>
</tr>
<tr>
<td>(H-582\times300\times12\times17)</td>
<td>296</td>
<td>427</td>
<td>0.69</td>
<td>46</td>
</tr>
</tbody>
</table>
Table 2: The results of short column test with air cavity

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Tube (mm)</th>
<th>Diameter of hole</th>
<th>Ratio of air cavity (%)</th>
<th>Maximum load (kN)</th>
<th>Case of air cavity/Case of no air cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH-0</td>
<td>□-250×250×6</td>
<td>128</td>
<td>0</td>
<td>1089</td>
<td>-</td>
</tr>
<tr>
<td>RF-0</td>
<td></td>
<td>128</td>
<td>0</td>
<td>3736</td>
<td>1.00</td>
</tr>
<tr>
<td>RF-20</td>
<td></td>
<td>20</td>
<td>20</td>
<td>3559</td>
<td>0.95</td>
</tr>
<tr>
<td>RF-20M</td>
<td>100</td>
<td>20</td>
<td>20</td>
<td>3550</td>
<td>0.95</td>
</tr>
<tr>
<td>RF-50</td>
<td>128</td>
<td>50</td>
<td>75</td>
<td>3197</td>
<td>0.86</td>
</tr>
<tr>
<td>RF-75</td>
<td></td>
<td></td>
<td></td>
<td>3003</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Figure 1: Configuration of specimens

Figure 2: Location of air cavity

Figure 3: Short column test setup
The regression curves about air cavity of CFT was suggested as follows in Ref. 5.

\[
\left(\frac{cN}{cN_0}\right)^n + \left(\frac{\alpha}{100}\right)^n = 1
\]

where,

- \( cN = N_{\text{max}} - A \cdot \sigma_y \)
- \( cN_0 = A \cdot \sigma_B \)
- \( N_{\text{max}} \) : Maximum strength from test
- \( A \) : Section area of steel tube
- \( \alpha \) : Ratio of stress of steel
- \( \sigma_y \) : Yield stress of steel
- \( \sigma_B \) : Compressive strength of concrete
- \( \alpha \) : The ratio of air cavity (%)

Test results are compared with Eq.(1) in Figure 5. The strengths of each specimen are presented in nondimension with their axial forces in this figure.

3. Beam-to-Column Connection test

3.1 Specimen with air cavity

Five subassemblage specimens were tested to investigate the structural behavior. Their geometrical configurations are shown in Figure 6. The story height is 3600mm and span length is 5600mm. The steel section of column was fabricated by partial-penetration welding at every corner seam. Cross section of columns are 500mm square and shear span length is 1509mm. Distance from loading point of the beam to the column face is 2550mm. The beam-to-column connections were reinforced by two horizontal diaphragms with circular hole.

The parameters of specimen are the ratio of axial force, the ratio of air cavity. The specimens of BSM-00 and BSM-02 in Table 3 do not have air cavity. The specimens of BSM-02-10, BSM-02-20 and BSM-02-30 in Table 3 have 10%, 20% and 30% air cavity respectively. Soft styrene with 5mm thickness was also used for artificial air cavity as like as short columns. All the specimens except BSM-00 were tested in the condition of axial force ratio of 0.2.

3.2 The Results of Beam-to-Column Connection Test

Three sets of loading system were used for test. Monotonic loading applied to each specimen assuming lateral loading condition. The configuration of beam-to-column connection specimen is shown in Figure 6. Dial gauges and wire strain gauges were used to measure displacements and strains.
Figure 4: Load-Displacement relationships of rectangular CFT short columns

Figure 5: Relationships between CFT strength and air cavity
Table 3: The results of beam-to-column connection test

<table>
<thead>
<tr>
<th>Specimen identification</th>
<th>Tube H-shaped section steel</th>
<th>Ratio of air cavity (%)</th>
<th>Ratio of axial force</th>
<th>Maximum story shear force (kN)</th>
<th>Maximum story drift (rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM-00</td>
<td>□-500×500×12 H-582×300×12×17</td>
<td>0</td>
<td>0.0</td>
<td>900</td>
<td>0.51</td>
</tr>
<tr>
<td>BSM-02</td>
<td>□-500×500×12 H-582×300×12×17</td>
<td>0</td>
<td>0.2</td>
<td>737</td>
<td>0.20</td>
</tr>
<tr>
<td>BSM-02-10</td>
<td>□-500×500×12 H-582×300×12×17</td>
<td>10</td>
<td>0.2</td>
<td>778</td>
<td>0.18</td>
</tr>
<tr>
<td>BSM-02-20</td>
<td>□-500×500×12 H-582×300×12×17</td>
<td>20</td>
<td>0.2</td>
<td>738</td>
<td>0.13</td>
</tr>
<tr>
<td>BSM-02-30</td>
<td>□-500×500×12 H-582×300×12×17</td>
<td>30</td>
<td>0.2</td>
<td>734</td>
<td>0.14</td>
</tr>
</tbody>
</table>

The results of beam-to-column connection test are listed in Table 3. The relationships of story shear force and story drift of each specimen are shown in Figure 7 and Figure 8. \( Q_{pb} \) and \( Q_{yb} \) mean equivalent plastic shear force and equivalent yielding shear force of beam respectively. \( Q_{cp} \) and \( Q_{yc} \) mean equivalent plastic shear force and equivalent yielding shear force of CFT column respectively. The structural behavior of BSM-00 specimen, which do not have air cavity and do not loaded axially, is shown in Figure 7(a). Maximum strength occurred in the point of welding crack of the flange of H-shaped beam. Local buckling happened in case of BSM-02 specimen but the behavior continued until the fracture of flange. The loading test was stopped in case of BSM-02-10 specimen when the flange fractured. The specimens of BSM-02-20 and BSM-02-30 showed very unstable behavior after the fracture of flange.
Figure 7: Story shear force–Story drift of BSM specimen

(a) BSM-00

(b) BSM-02

(c) BSM-02-10

(d) BSM-02-20

(e) BSM-02-30
It is seen in Figure 7 and Figure 8 that the connection strengths of all specimens are higher than the equivalent plastic shear force of H-shaped section beam although the crack of welding part or the fracture of flange occurred in all specimens. $N/N_y$ in Figure 8 means the ratio of axial force. The deformation capacity of specimens with air cavity, that are BSM-02-10, BSM-02-20 and BSM-02-30, is lower than that of BSM-02 specimen, but it is thought that the tendency is not so severe. The difference of the quantity of air cavity is not seen from this test results. Almost same structural behaviors of specimens with air cavity were shown in the strength and the deformation as like as Figure 7. The influence of air cavity is not clear within the ratio of air cavity of 30% compared with the test result of BSM-02 specimen.

4. Conclusions

The air cavity of CFT was investigated through the short column test and beam-to-column connection subassemblages test. Concluding remarks could be obtained as follows;

(1) The difference of initial stiffness can not be found even though in case of the ratio of air cavity 50% from short column test results.

(2) The strength of CFT columns depends on the ratio of air cavity, but the strengths of all specimens are higher than the superposition strength of tube and concrete.
(3) The influence of air cavity is not clear from the beam-to-column connection subassemblages test within the ratio of air cavity 30%.

(4) However the welding part of flange was fractured in all specimens with air cavity in case of axial loading and the deformation capacity of CFT can not be expected from test results.

5. References