Analytical Simulation of Axial Behavior of RCFT Wall

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Abstract. Rectangular concrete-filled tubes (RCFTs) have been widely used as columns of building and bridge piers due to several advantages such as their strength-to-size efficiency and facilitation of rapid construction. Recently, some researchers have tried to use RCFT as a wall system in a building. RCFT wall have a high aspect ratio while the aspect ratio of the RCFT column is usually one. Thus, the behavior of the RCFT wall is clearly different from that of RCFT column and it needs to be investigated. In this study, the axial behavior of the RCFT wall was investigated through analytical simulation, and the effects of the aspect ratio, internal stud, and through rebar on axial behavior of the RCFT wall were examined. From the results, it was found that axial load capacity is decreased with increasing aspect ratio due to local buckling of the steel tube, and this local buckling can be efficiently prevented by using internal through rebar.

Introduction

Rectangular concrete-filled tube (RCFT) is a composite member that consists of rectangular steel tube and concrete infill. RCFTs have several advantages. The steel tube serves as both reinforcing and formwork eliminating the need for both, and provides large tensile and compressive capacities. The concrete infill restrains buckling of the steel tube, which increases the strength, stiffness, and deformability of the section. Furthermore, composite structural systems offer sustainability advantages and embodied carbon can be reduced by substituting cement with supplementary cementitious materials (SCMs) in concrete. To take these advantages, RCFTs have been widely used as building columns and bridge piers.

Fig. 1. Structures with RCFT component

Figure 1 shows the typical building structures with RCFT components. Axial and lateral load are mainly resisted by RCFT column and shear wall, respectively and it provides the efficient structure system. Numerous studies on RCFT column have been conducted and many applications have been reported. On the other hand, the behavior of the RCFT wall is not sufficiently understood yet and it needs to be investigated. The major loading of RCFT wall is lateral load. However, RCFT wall is subjected combined axial-lateral loading. Thus, axial behavior must be fully investigated first. In this study, axial behavior of RCFT wall was investigated by using analytical simulation, and the effects of...
the aspect ratio, internal stud, and through rebar on axial behavior of the RCFT wall were examined. From the results, it was found that axial load capacity is decreased with increasing the aspect ratio due to local buckling of the steel tube, and this local buckling can be efficiently prevented by using internal through rebar.

Analytical model & verification

Analytical model overview. Structural analysis program ABAQUS [1] was used to investigate the behavior of composite wall system in this study. Figure 2 shows the typical finite element analysis model used in this study. 8-node continuum element and 4-node shell element were used to model the concrete infill and steel tube, respectively. GAP element1 was used to simulate the interface between steel tube and concrete infill, including modeling contact behavior of the interface and separation of the steel and concrete surfaces while restricting penetration of one node into an adjacent one. Under compression, the pressure transferred across the gap provides confinement to the concrete thus permitting explicit modeling of the confining effect of the tube. In addition, the combination of the compressive stress normal to the interaction surface with a coefficient of friction at the interface provides shear stresses that are orthogonal to the contact direction. The coefficient of friction was adopted as 0.47 based on the experimental study conducted by Baltay & Gjelsvik [2]. To simulate the RCFT wall under axial load, bottom of concrete infill and steel tube were restrained in direction 3 (See Fig. 2). Top and bottom of the steel tube were restrained in direction 1 and 2 to prevent premature local buckling in boundary and loading region. Then, the uniform displacement was applied on the top of the RCFT wall to simulate the axial load. The uni-axial stress-strain curve for concrete used in this study is shown in Fig. 3(a), where the linear elastic stress in compression is assumed up to a stress of 0.5\(f'_{c}\). For concrete in tension, the tensile stress is assumed to increase linearly with tensile strain until the concrete cracks. After the concrete cracks, the tensile stresses decrease linearly to zero. The value of strain at zero stress is usually taken as 10 times the strain at maximum tensile stress as shown in Fig. 3(a).

In this study, a concrete damaged plasticity model1 was used to simulate the inelastic behavior of the concrete. This is a model which is specifically concerns the stress triaxiality dependent plastic hardening. For steel, the tri-linear stress-strain relationship was used where an isotropic hardening plasticity rule was applied. Young’s modulus \(E_s\) was approximated as 200,000MPa; Poisson’s ratio \(\nu_s\) was set to be 0.3; and the ultimate strain of the steel \(\varepsilon_{su}\) was approximated as 0.1 as shown in Fig. 3(b).

Verification. To verify the finite element model used in this study, a series of test for stub square CFT column conducted by Yoo [3] was simulated and the analysis results were compared with those of test. Table 1 shows the properties of test specimens. In table 1, \(t\) is the thickness of the steel tube, \(l\) is the longer width of the RCFT, \(w\) is the short width of the RCFT, \(l/w\) is aspect ratio of RCFT, and \(L\) is the height of the RCFT, and \(f_y\) is the yield stress of the steel tube. For all models, \(f'_c\) was 46MPa. Comparisons of finite element analysis results with test are shown in Fig. 4. It can be seen that proposed finite element model provides good predictions of axial load-strain relationship of the test materials.
specimens as shown in Fig. 4. The maximum and average discrepancy of ultimate strength between finite element analysis and test were 8% and 4%, respectively, and finite element model used in this study was successfully verified.

### Table 1. Properties of verification models.

<table>
<thead>
<tr>
<th>Model</th>
<th>$t$ (mm)</th>
<th>$l$ (mm)</th>
<th>$l/w$</th>
<th>$L$ (mm)</th>
<th>$f_y$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH125-3.2</td>
<td>3.2</td>
<td>125</td>
<td>1.00</td>
<td>312.5</td>
<td>351.82</td>
</tr>
<tr>
<td>SH125-4.5</td>
<td>4.5</td>
<td>125</td>
<td>1.00</td>
<td>312.5</td>
<td>337.12</td>
</tr>
<tr>
<td>SH125-6.0</td>
<td>6.0</td>
<td>125</td>
<td>1.00</td>
<td>312.5</td>
<td>418.46</td>
</tr>
<tr>
<td>SH150-4.5</td>
<td>4.5</td>
<td>150</td>
<td>1.00</td>
<td>375.0</td>
<td>326.34</td>
</tr>
</tbody>
</table>

![Fig. 4. Comparison with test results:](image)

(a) SH125_3.2; (b) SH125_4.5; (c) SH125_6.0; (d) SH150_4.5.

### Parametric study

**Effect of aspect ratio.** Finite element models listed in Table 2 were analyzed and the results are shown in Fig. 5. Main parameter is the aspect ratio of the RCFT wall system and $l/w$ is varied from 0.96 to 6. For all analysis models, $f_y$ and $f_c'$ are 344.5 and 41.3MPa, respectively.

### Table 2. Properties of models for parametric study.

<table>
<thead>
<tr>
<th>Model</th>
<th>$t$ (mm)</th>
<th>$l$ (mm)</th>
<th>$w$ (mm)</th>
<th>$l/w$</th>
<th>$L$ (mm)</th>
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<tr>
<td>A1</td>
<td>6.35</td>
<td>238.2</td>
<td>247.8</td>
<td>0.96</td>
<td>609.6</td>
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<tr>
<td>A2.2</td>
<td>6.35</td>
<td>385.9</td>
<td>177</td>
<td>2.18</td>
<td>609.6</td>
</tr>
<tr>
<td>A3.2</td>
<td>6.35</td>
<td>509.8</td>
<td>159.3</td>
<td>3.20</td>
<td>609.6</td>
</tr>
<tr>
<td>A6</td>
<td>6.35</td>
<td>849.6</td>
<td>141.6</td>
<td>6.00</td>
<td>609.6</td>
</tr>
</tbody>
</table>

![Fig. 5. Axial load vs. axial strain for various aspect ratio.](image)

![Fig. 6. Local buckling shape of A3.2 and A6 models.](image)

In Fig. 5, $x$ and $y$ axis represent the axial strain and dimensionless axial load ratio $P/P_o$, respectively, where $P_o$ is the maximum axial load capacity specified in AISC specification and given by $0.85f_c' A_c + f_y A_s$ where $A_c$ and $A_s$ are area of the concrete and steel section, respectively [4]. Figure 5 clearly shows that axial load capacity of RCFT is decreased with increasing the aspect ratio. For analysis models having aspect ratio 0.96 and 2.2 (A1 and 2.2), dimensionless axial load ratio $P/P_o$ was 1.09 and local buckling was not observed before maximum axial load capacity was achieved. However, axial load capacity was governed by local buckling for the analysis models having aspect ratio of 3.2 and 6 (A3.2 and 6), and $P_o$ was not achieved. Figure 6 shows the local buckling shapes for
A3.2 and 6 models. Local buckling was observed in loading region and center of the tube for A3.2 and 6 models, respectively. Again, the axial load capacity reduced by the local buckling of the tube when aspect ratio of the RCFT wall is large. Thus, it is important to control the buckling of the steel tube to obtain the maximum axial load capacity without any loss of the strength.

**Effect of internal stud & through rebar.** It is important to prevent the local buckling of the tube to increase the axial load capacity. To increase the local buckling resistance, two different alternative RCFT wall systems were considered as shown in Fig. 7 in this study.

![Fig. 7. Alternative RCFT wall system: (a) RCFT wall with internal stud; (b) RCFT wall with through rebar.](image)

![Fig. 8. Examples of pattern of stud or through rebar(For A3.2 model): (a) 3.6x4 pattern; (b) 3.6x4 zigzag pattern](image)

![Fig. 9 Effect of internal stud: (a) Axial load-stain relationship; (b) Deformed shape of A3.2(3.6x4, stud, zigzag).](image)

![Fig. 10 Effect of internal through rebar: (a) A3.2 model; (b) A6 model.](image)

Figure 7(a) and (b) show the RCFT wall system with internal stud and through rebar, respectively. In this study, the stud and through rebar were modeled as pin connection and truss element, respectively. Several patterns of stud or through rebar were examined to investigate their effects on the axial load capacity of the RCFT wall and typical examples of the patterns used in this study are shown in Fig. 8. Figure 9 shows the effect of internal stud on the axial load capacity of the RCFT wall. Axial load capacity of the RCFT wall was increased by introducing internal stud. However, severe degradation of the axial strength was observed after the maximum axial load as shown in Fig 9(a). This is because the internal stud cannot prevent dilation of the concrete efficiently as shown in Fig.
9(b). The concrete infill was pulled out together with steel tube when the local buckling of the tube occurred. On the other hand, analysis results show that internal through rebar is very efficient to prevent local buckling of the steel tube as shown in Fig. 10. Figure 10(a) and (b) show the analysis results for A3.2 and 6 models, respectively. It can be found that internal through rebar increase not only axial load capacity but also ductility of the system. Strength degradation was considerably reduced by introducing internal reinforcing bar. Tensile stress that is developed in internal through rebar prevented the dilation of the concrete infill and local buckling is not likely occurred in the analysis. Also, ductility of the RCFT wall is increased with decreasing spacing of the internal through rebar. Figure 11 shows the change of deformed shape of the RCFT wall when the internal through rebar is used. It can be seen that the local buckling of the tube prevent by introducing of the internal through rebar.

![Diagram](image)

**Fig. 11 Change of deformed shape by introducing internal through rebar.**

**Summary and conclusions**

In this study, the behavior of RCFT wall system was investigated by using analytical simulation. From the results, it can be found that the axial load capacity of the RCFT wall significantly affected by local buckling of the tube when the wall has large aspect ratio. The internal through rebar is very efficient to prevent the local buckling by preventing dilation of the concrete infill. Furthermore, internal through rebar is helpful to increases the ductility of the system.

**References**


