Feasibility of Using of Steel Tube for Reinforcement Detail Simplifying of RC Coupling Beam

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Abstract

In this paper investigates feasibility of using of steel tube-filled concrete for reinforcement detail simplifying of RC coupling beam. In this new connection system, the steel tube is completely interrupted in the connection zone. In addition, to investigate the feasibility of using of steel tube for reinforcement detail simplifying of coupling beam, experiments were conducted for three coupling beam. The first specimen was made in accordance with the code of ACI 318(11). The other specimens were made with alternative detail using steel tube-filled concrete. The test results show the failure mode and hysteretic loop.

Keywords: Coupling Beam, Simplifying of RC coupling, steel tube-filled concrete

1 Introduction

Earthquakes are very dangerous. They exemplify the true power of nature and cannot be avoided. On 12th September 2016, a strong earthquake of Mw 5.4 hit Gyeongju in Republic of Korea at 20:33 local time. So, Republic of Korea is no longer safety zone from the earthquake. Thus, even regions considered safe seismically over the short term should still insure an adequate seismic design. Coupling beam have been widely used in high-rise buildings for the last decades arising from their advanced mechanical and seismic behaviors such as high strength and stiffness, good ductility and convenience for construction [1].

In addition, reinforced concrete (RC) walls are widely applied in medium-rise RC building systems in order to resist effectively seismic effects due to their good stiffness properties and lateral resisting capacity. The concrete coupling beam has some common shortcomings, including heavy self-weight, low bearing capacity, insufficient ductility, limited energy dissipation capacity and difficult post-earthquake reconstruction [2, 3].

As viable substitutes for reinforced concrete coupling beams, the use of steel coupling beams and composite coupling beams have also been investigated by several researchers [4-6]. As an alternative to diagonally reinforced concrete coupling beams, the use of steel coupling beams has also been investigated by Park et al [7].

This paper proposes a feasibility of using of Steel tube for reinforcement detail simplifying of RC coupling beam connection to provide capability replace of the diagonal reinforcement coupling beam connections.
2 Experimental Programs

Table 1 and Figure 1 show the test variables and specimen details. These three specimens have identical dimensions and longitudinal reinforcement details [8, 9]. First specimen, C1 was designed in accordance with the seismic design requirements of the ACI 318-11. Other specimens, C2 and C3 were used to reinforcement method diagonally reinforcement (steel tube). Steel tube size was 55x55x5t. Figure 2(a) shows the compressive stress of concrete used for each of the three specimens.

The compressive tests were conducted on the specimens in accordance with the method defined in ASTM C39 to determine the compressive strength. The compressive strength of the concrete for specimens is about 34MPa, as shown Fig. 2(a).

The yield and ultimate strengths of the D5 steel, D10 steel and steel tube was 285 MPa, 500 MPa and 264 MPa respectively. In addition, Tensile strengths of D5 steel, D10 steel and cold-formed steel channel was 363 MPa, 576 MPa and 361 MPa respectively, as shown in Fig. 2(b).

<table>
<thead>
<tr>
<th>Specimen name</th>
<th>Reinforcement method</th>
<th>Material</th>
<th>Longitudinal reinforcement</th>
<th>Stirrup</th>
<th>Diagonal reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>ACI318-11</td>
<td>Concrete</td>
<td>D6-12</td>
<td>D6@50</td>
<td>D10-8</td>
</tr>
<tr>
<td>C2</td>
<td>Diagonally reinforcement</td>
<td>Concrete</td>
<td>D6-12</td>
<td>D6@100</td>
<td>Steel tube (55x55x5t)</td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1 Details of test specimens (uint; mm)
The test-setup was shown in Figure 3. The coupling beam was arranged vertically, and the bottom stub was fixed to the steel frame with bolts. Loading was imposed horizontally by a hydraulic actuator with a capacity of 1,000kN on the steel frame connected to the top stub to simulate the behavior of coupling beams under lateral loads. The data acquisition system consists of 36 to 50 internal controls and recording channels. Instrumentation was provided to measure the load, displacement, and strain at critical locations. A cyclic loading used in the vertical direction of beams wall divided clearly into two phases as shown in Fig. 4. For each drift loading amplitude, two same-drift consecutive cycles were applied to evaluate strength and stiffness degradations.
3 Experimental Result

Figure 7 show the cracking and failure mode of specimens. In specimen C1 initial cracking occurred at the bottom beam during the first negative loading cycle (-50kN). At about 0.5% drift ratio, diagonal cracking occurred in the center. At about drift 4% ratio, maximum strength was expressed. Final failure mode localized spalling and crushing of the concrete along the top and bottom beam of the RC coupling beam in the embedment region was observed in final stage of the tests, as shown in Fig 5(a). In specimen C2 initial cracking occurred at the bottom beam during the first negative loading cycle (-50kN). At about 0.5% drift ratio, diagonal cracking occurred in the top beam. At about 2% drift ratio, multiple shear cracking occurred in the center. Final failure mode localized spalling and crushing of the concrete along the center beam of embedment region was observed in final stage of the tests, as shown in Fig 5(b). In specimens C3 initial cracking occurred at the center beam during the first positive loading cycle (+50kN). At about 0.5% drift ratio, diagonal cracking occurred in the center beam. And 3.0 drift ratio, thereafter severe spalling of concrete in compression occurred at the beam ends. Experiment results showed that C1 specimen appeared the less destruction than C2 and C3

![Image of specimens C1, C2, and C3]

Fig. 5 Failure mode

Table. 2 Summarizes the maximum strength

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$V_u$(kN)</th>
<th>Average maximum strength</th>
<th>$\theta_d$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>(+) 331.94</td>
<td>328.09</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>(-) 324.24</td>
<td></td>
<td>4.5</td>
</tr>
<tr>
<td>C2</td>
<td>(+) 313.21</td>
<td>296.30</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>(-) 279.38</td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td>C3</td>
<td>(+) 295.54</td>
<td>293.37</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>(-) 291.19</td>
<td></td>
<td>2.0</td>
</tr>
</tbody>
</table>

Note : $V_u$(kN)=measured maximum load, $\theta_d$(%)=maximum drift ratio
specimens. This is because the bond area of coupling beam using channel is smaller than coupling beam using bundled bars so there is more slipping at interface with concrete and steel.

Table 2 summarizes the maximum strength ($V_u$), maximum drift ratio ($\theta_u$). The hysteretic loop presented in Fig. 6. The hysteretic loop is an important result to check the seismic behavior of coupling beam elements and usually reflects some main points such as ultimate resistance capacity, peak-to-peak stiffness and energy dissipation capacity. In specimen C1 maximum strength ($V_u$) is to 331.94kN and maximum drift ratio ($\theta_u$) is to 4.0% in the positive loading direction. In addition, maximum strength ($V_u$) is to 324.24kN and maximum drift ratio ($\theta_u$) is to 4.5% in the negative loading direction. In specimen C2 maximum strength is to 313.24kN and maximum drift ratio ($\theta_u$) is to 3.0% in the positive loading direction. In addition, maximum strength ($V_u$) is to 279.38kN and maximum drift ratio ($\theta_u$) is to 3.0% in the negative loading direction. In specimen C3 maximum strength ($V_u$) is to 295.54kN and maximum drift ratio ($\theta_u$) is to 2.0% in the positive loading direction.

![Hysteresis loops for specimens C1, C2, and C3](image)

In addition, maximum strength ($V_u$) is to 291.19kN and maximum drift ratio ($\theta_u$) is to 2.0% in the negative loading direction. C1, C2 and C3 specimens could be subjected to average maximum strength of 328.09kN, 296.30kN and 293.37kN, respectively. In specimens C1 was 1.11 and 1.12 times larger than those of specimens...
C2 and C3. It shows that coupling beam made in accordance with the code of ACI-318 had higher maximum strengths than made with alternative detail using tube steel-filled concrete. Because of the bond area of coupling beam using tube steel is smaller than coupling beam using bundled bars so there is more slipping at interface with concrete and steel. The test results support that tube steel-filled concrete was not effective coupling beams with steel.

4. Conclusion

Based on the experimental results, failure mode shows that C1 specimen appeared the less destruction than C2 and C3 specimens. In addition C1, C2 and C3 specimens could be subjected to average maximum strength of 328.09kN, 296.30kN and 293.37kN, respectively. In specimens C1 was 1.11 and 1.12 times larger than those of specimens C2 and C3. Because of the bond area of coupling beam using tube steel is smaller than coupling beam using bundled bars so there is more slipping at interface with concrete and steel.

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