Numerical Analysis of Frames Consisted of L-Shaped Columns under Cyclically Varying Lateral Load

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Abstract: In order to save indoor space, special shaped columns which can be swapped in walls were proposed by researchers and used in buildings in recent years. Parametric analysis of frames consisted of L-shaped column and H-shaped steel beams were proposed in this paper. The L-shaped column is composed of three small sized square concrete filled steel tube columns (mono-column), each mono-column is connected by steel plate. A finite element numerical model was proposed and tested by three experiments. In order to analyze the influence of the parameters such as axial loading ratios, beam-column's linear stiffness ratios, and construction sizes on the seismic behavior of frames, a large number of models were analyzed. The effects of the factors on the behavior were proposed.

Keywords: special shaped column composed of concrete filled steel tube columns(SCFST), concrete filled steel tube columns, seismic performance of frames, finite element analysis.

1. Introduction

With the increase of global population, the shortage of land in the urban become more and more obvious. Special shaped columns including L-shaped, T-shaped and cross shaped which can be swapped in wall, and there is no column can be seen in the room. It’s easy to enlarge indoor space and arrange furniture. There are many kinds of special shaped columns such as concrete special shaped column, SRC special shaped column, steel special shaped column, concrete filled steel tubular special shaped column, special shaped column composed of CFT columns\cite{1-5}. Special shaped column composed of CFT column (SCFST) frames were analyzed in this paper. SCFST column is composed of small sized CFT columns which can be swapped in wall, and the CFT columns(mono-column) are connected by steel plates which is shown in Fig.1. A finite element model was tested by three experiments\cite{5}, the frame construction is shown in Fig.2. Many models with different parameters were calculated to study the influence of axial loading ratios, beam-column's linear stiffness ratios, and construction sizes on the seismic behavior of frames.

2. Model of Frame

2.1.Modeling

The steel tube and steel plates was simulated using SHELL181 element of ANSYS software. The concrete was simulated by SOLID65 element. The stress-strain curves of steel and concrete were defined by eq. 1-eq.2. \cite{6-7} The three translational degrees of freedom of the nodes at the column bottom were restrained. The columns were compressed under constant axial load. The lateral cyclic displacements were applied to the top of the column. The details of specimens are shown in Table 1.
\[\sigma = \begin{cases} E \varepsilon_s & 0 \leq \varepsilon \leq \varepsilon_y \\ \frac{1}{20} \sigma_y + \frac{1}{20} \sigma_y & \varepsilon_y \leq \varepsilon_i \leq \varepsilon_u \\ \frac{1}{20} \sigma_y & \varepsilon_i \geq \varepsilon_u \end{cases}\]

\[\sigma = \begin{cases} f_c \left[ \frac{2s}{s_0} \left( \frac{s}{s_0} \right)^2 \right] & \varepsilon \leq \varepsilon_0 \\ f_c \left[ 1 - 0.15 \left( \frac{s - s_0}{s_{cr} - s_0} \right) \right] & \varepsilon_0 \leq \varepsilon_i \leq \varepsilon_u \end{cases}\]

**TABLE I: Details of specimens**

<table>
<thead>
<tr>
<th>No</th>
<th>Size of column (mm)</th>
<th>Size of beam (mm)</th>
<th>Thickness of connection plate (mm)</th>
<th>Size of rib plate (mm)</th>
<th>k</th>
<th>n</th>
<th>N(_0) (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJ-1</td>
<td>□80×80×4 H150×75×5×7</td>
<td>2200</td>
<td>4</td>
<td>80×30×4</td>
<td>0.184</td>
<td>0.4</td>
<td>500</td>
</tr>
<tr>
<td>SJ-2</td>
<td>□80×80×4 H150×75×5×7</td>
<td>2200</td>
<td>4</td>
<td>80×30×4</td>
<td>0.184</td>
<td>0.2</td>
<td>250</td>
</tr>
<tr>
<td>SJ-3</td>
<td>□80×80×4 H150×75×5×7</td>
<td>1800</td>
<td>4</td>
<td>80×30×4</td>
<td>0.245</td>
<td>0.4</td>
<td>500</td>
</tr>
</tbody>
</table>

The test parameters were axial compression ratio \(n\) and stiffness ratio \(k\) of beam to column. The axial compression ratio \(n\) was calculated by Eq. (3) and Eq. (4). The stiffness ratio \(k\) was calculated by Eq. (5-7). [8]

\[n = \frac{N_0}{N_u}\]  

\[k = \frac{i_c}{i_b}\]  

\[i_c = \frac{E_s I_s + 0.8E_c I_c}{l_c}\]  

\[N_u = 3 \left( f_c A_c + f_s A_s \right)\]  

\[i_b = \frac{E_s I_s}{l_b}\]
2.2. Comparison of the Skeleton Curves between the Model and Test

The comparison of the skeleton curves between the three FEM models and tests are shown in fig. 3. The first specimen's curve matched well. For the second and the third specimens, the ultimate bearing capacity achieved by FEM were a little larger than that by test. The reasons are as follows: 1) the out-plane brace was not strong enough to limit the out-plane displacement, but that of FEM analysis was limited entirely, 2) the contact and slippage between the steel tube and inner concrete was ignored in order to save calculating time. But generally speaking, the FEM analysis matched the experiment well.

![Fig. 3 Comparison between skeleton curves of FEM and TEST](image)

3. Parametric Analysis of Frame

3.1. Parameter Selection

According to the comparison between the test and FEM analysis, the model was tested reasonable. In order to study more parameters of the frame, FEM analysis is an efficient way. There are three parameters were studied in this paper, axial loading ratios, beam-column's linear stiffness ratios, and distance between stiffeners of connecting plats.

3.2. Influence of Axial loading Ratio on the Behavior of Frames

Four specimens with two layers were studied with the axial loading ratio $n$ of 0, 0.2, 0.4 and 0.6. The details of these specimens are shown in Fig. 4. The column is L-shaped SCFST columns, the mono column size is 80×80×4, three mono-columns were connected by steel plates with stiffeners. The distance between each stiffener is 100mm. The size of H-shaped steel beam is H150×75×5×7, so the stiffness ratio is 0.2.

The stress distribution of the specimens under lateral displacement of 20mm are shown in Fig. 4. The maximal stresses are smaller with the increase of axial loading ratio. As for the specimen Z6 with the stiffness ratio of 0.6, the bottom of the column yield before the end of beam.

According to the Load-Displacement curve shown in Fig.5, the plump shaped of the curves shows good energy dissipation capacity of this kind of column-beam frames. It can be seen that with the increase of axial loading ratio, the area surrounded by the curve become smaller, which means the energy dissipation become weaker. The same conclusion can be seen from the skeleton curves shown in Fig.5.
TABLE II: Details of specimens with different axial loading ratios

<table>
<thead>
<tr>
<th>No</th>
<th>Size of columns and beams</th>
<th>Distance between stiffeners d (mm)</th>
<th>Stiffness ratio k</th>
<th>Axial loading ratio n</th>
<th>Axial loading (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z0</td>
<td>Column L80×80×4</td>
<td>100</td>
<td>0.200</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Beam H150×75×5×7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z2</td>
<td>Column L80×80×4</td>
<td>100</td>
<td>0.200</td>
<td>0.2</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Beam H150×75×5×7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z4</td>
<td>Column L80×80×4</td>
<td>100</td>
<td>0.200</td>
<td>0.4</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Beam H150×75×5×7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z6</td>
<td>Column L80×80×4</td>
<td>100</td>
<td>0.200</td>
<td>0.6</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Beam H150×75×5×7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 Stress distribution of specimens with different axial loading ratio \( n \)

(a) \( n = 0 \)  (b) \( n = 0.2 \)  (c) \( n = 0.4 \)  (d) \( n = 0.6 \)

Fig. 5 Load-Displacement curves of specimens with different axial loading ratio \( n \)

3.3. Influence of Beam-Column's Linear Stiffness Ratio on the Behavior of Frames

The beam-column's linear stiffness ratio is an important factor to seismic behavior of frames. In order to design the whole structure composed of SCFST columns, the optimal beam-column's linear stiffness ratio of SCFST column frames need to be studied. It has been know that the size of the mono-column should not be too large, and the optimal width to thickness ratio of the connection plates is 19. So the optimal column size has almost been determined. The change of the beam-column's linear stiffness ratio is according to different span and size of beam. The details of the specimens are shown in Table 3.
TABLE III: Details of specimens with different beam-column's linear stiffness ratios

<table>
<thead>
<tr>
<th>No</th>
<th>Column</th>
<th>Beam</th>
<th>Span</th>
<th>beam-column's linear stiffness ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>XGD-1</td>
<td>L80×80×4</td>
<td>H150×75×5×7</td>
<td>1800</td>
<td>0.245</td>
</tr>
<tr>
<td>XGD-2</td>
<td>L80×80×4</td>
<td>H150×75×5×7</td>
<td>2200</td>
<td>0.200</td>
</tr>
<tr>
<td>XGD-3</td>
<td>L80×80×4</td>
<td>H150×75×5×7</td>
<td>2600</td>
<td>0.169</td>
</tr>
<tr>
<td>XGD-4</td>
<td>L80×80×4</td>
<td>H120×60×6×8</td>
<td>1800</td>
<td>0.150</td>
</tr>
<tr>
<td>XGD-5</td>
<td>L80×80×4</td>
<td>H120×60×6×8</td>
<td>2200</td>
<td>0.123</td>
</tr>
<tr>
<td>XGD-6</td>
<td>L80×80×4</td>
<td>H120×60×6×8</td>
<td>2600</td>
<td>0.104</td>
</tr>
</tbody>
</table>

Fig. 6 shows the skeleton curves of specimens with different span. According to this figure, it can be seen that the ultimate bearing capacity become lower with the increase of span. If the span improved 18%, the ultimate bearing capacity would decrease 5.5%~7%. According to Fig.7, If the height of beam decrease 20%, the ultimate bearing capacity would decrease 19%~20%. It can be seen that the increase of height of beam is an effective way to improve bearing capacity.

3.4. Influence of Distance between Stiffeners on the Behavior of Frames

The mono-columns are connected by connecting plates. In order to avoid the premature buckling of the connecting plates, stiffeners are settled on the connecting plates with appropriate separation distance. The optimal distance between stiffeners of connecting plate is studied. Five frame specimens with the distances of 100mm, 120mm, 140mm, 160mm, and 180mm were calculated, and the skeleton curves are shown in Fig. 8. If the distance increased 25%, the ultimate bearing capacity decreased 3%~4%. So the change of the bearing capacity is very limited with the change of distance between stiffeners.
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