Numerical Simulation Investigation on Seismic Behavior of Fiber Reinforced Concrete Frame Columns

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Abstract. In order to investigate the seismic performance of fiber reinforced concrete frame column under low cyclic loading, the mechanical behavior of PVA fiber reinforced concrete columns under low cyclic loading is simulated by using the fiber model via OpenSees software. Based on the comparison of numerical result and experimental result, parameter analysis of shear span ratio and axial compression ratio of fiber reinforced concrete columns were conducted. The result indicates that the displacement ductility factor increases first and then decreases with the increase of column shear span ratio, and when the shear span ratio is 3, the maximum is reached. The ultimate displacement angle increases with the increase of the shear span ratio. In addition, the displacement ductility factor and the ultimate displacement angle increase with the increase of the axial compression ratio of the column.

Introduction

Reinforced concrete frame structure is widely used around the world. As an important component of the frame structure, the damage of frame column can lead to local failure or even collapse of the frame structure. The results showed that the collapse resistance capacity of the structure mainly related to the plastic deformation capacity, the energy dissipation capacity and the redundancy of the structure [1]. Therefore, it can improve collapse resistance capacity of frame structures by enhancing plastic deformation capacity and energy dissipation capacity of concrete columns.

Due to the low tensile strength of concrete, the brittle fracture of concrete is easy to occur under the action of tensile stress [2]. Adding fiber in concrete can overcome the disadvantages of weak plastic deformation capacity, which is one of the main measures to improve the seismic performance of concrete structure. Many studies have shown that the plastic deformation capacity and energy dissipation capacity of fiber reinforced concrete member had significantly improved [3~5]. Meanwhile, the research on the performance of fiber reinforced concrete columns under high axial compression ratio is relatively limited.

In this paper, the reinforced ECC column specimen with high axial compression ratio under cyclic quasi-static test was modelled and simulated via OpenSees software. And the simulation results were compared with the test results. Then reinforced ECC columns with different parameters such as axial compression ratio and shear span ratio were modelled numerically and analyzed to investigate the influence of these parameters.
Testing Situation

Two ECC column specimens (hereinafter referred to as the R/ECC column) R/ECC1, R/ECC2 with fiber volume content of 1.5% were designed and tested. The cross section size of columns are 150mm×150mm. The shear span ratio is 4.0. The stirrup configuration is less than the requirements of column stirrup configuration according to the code for seismic design of buildings. The specimen has the same configuration of longitudinal steel and greater than the minimum total reinforcement ratio according to the code for seismic design of buildings.

The specimen and the base are made of the same concrete casting. The parameters of specimens such as shear span ratio, longitudinal reinforcement, stirrup configuration and axial compression ratio are shown in Table 1. The detailed dimension and reinforcement of each specimen are shown in Fig. 1. The test setup is shown in Fig. 2, and the loading protocol is shown in Fig. 3.

![Figure 1. Cross section and reinforcement details of specimens.](image1)

![Figure 2. Test setup.](image2)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Shear span ratio</th>
<th>Longitudinal reinforcement</th>
<th>Stirrup</th>
<th>Design axial compression ratio</th>
<th>Experiment axial compression ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/ECC1</td>
<td>4.0</td>
<td>4B10</td>
<td>A6.5@75/150</td>
<td>0.75</td>
<td>0.350</td>
</tr>
<tr>
<td>R/ECC2</td>
<td>4.0</td>
<td>4B10</td>
<td>A6.5@75/150</td>
<td>0.85</td>
<td>0.397</td>
</tr>
</tbody>
</table>
Finite Element Models Based on OpenSees

OpenSees was taken as numerical simulation software to analyze the performance of the specimens.

Material constitutive model. The Ken-Scott-Park uniaxial concrete constitutive model revised by Scott and Park [6] was employed as traditional concrete constitutive model, and was defined by Concrete02 material model in OpenSees [7]. Similarly, the fiber reinforced concrete was also defined by ECC01 material model in OpenSees, which takes tensile effect of concrete and confinement effect of stirrup into consideration. The reinforcing steels were also defined as fibers by using Reinforcing steel constitutive model [7 8], which can account for the deterioration of the strength and stiffness. Because the frame columns considered are with larger axial force and the axial compression ratio, P-Delta transformation was used to coordinate geometric transformation, which takes into consideration P-\(\Delta\) effect.

Finite element analysis model. The fiber section model is developed by using OpenSees. The displacement-based beam-column element was used for frame column components, and each component has five integration points. The column concrete was divided into a certain number of rectangular grids, and each grid was assumed to be a fiber. In order to reflect the confinement effect of stirrup, the concrete of column section were divided into cover concrete and core concrete, and each was defined by the corresponding constitutive parameters of the Concrete02 constitutive model. The element division and section of fiber model was shown in Fig. 4.

Figure 3. Loading protocol.

Figure 4. Sketch of fiber model in OpenSees.
Comparison of Numerical Simulation and Experimental Results

Fig. 5 and Fig. 6 compare the hysteretic and backbone curve of the all specimens under test and numerical simulation respectively. The figures indicate that test and numerical simulation results are identical basically. Compared with traditional concrete column, the deformation capacity of fiber reinforced concrete column is improved significantly. The horizontal load degradation rate decreases and the hysteretic curve is more full when exceeding peak load, and it indicates seismic performance significantly increased. Furthermore, horizontal load degradation rate of specimens increases with the increase of axial compression ratio.

The test and numerical simulation results are very consistent in the early stage of the specimen. Nevertheless, when the specimens go into the elastic-plastic stage gradually, the residual displacement, hysteresis loop area increase and pinching phenomenon becomes obvious due to stiffness degradation and steel slip. Because the fatigue of the specimen and steel slip were not considered in this study, the numerical simulation results are plumper than the experimental results.

![Fig. 5. Test and numerical simulation of hysteretic curve.](image1)

(a) R/ECC1  
(b) R/ECC2

![Fig. 6. Test and numerical simulation of backbone curve.](image2)

(a) R/ECC1  
(b) R/ECC2

Parametric Analysis

Because of the limitation of physical testing, in order to investigate the effect of shear span ratio and axial compression ratio on the seismic performance of frame column more systematically, the influence of parameters such as shear span ratio and axial compression ratio on seismic performance of fiber reinforced concrete frame column was conducted based on verified finite element analysis model and parameters.

**The influence of shear span ratio.** Under given column section size, axial compression ratio,
fiber content and reinforcement, the changes of the ultimate displacement angles and displacement ductility factors with the increase of shear span ratio were shown in Fig. 7. As shown in Fig. 7(a), with the increase of the shear span ratio, the ultimate displacement of columns increase as well. Because the column section size was remained constant, with the increase of shear span ratio, that also means the increase of column length, the ultimate displacement angle did not appear to decrease with the increase of column length. As shown in Fig. 7(b), the displacement ductility factors increase firstly, then decrease and reach the maximum value at the shear span ratio of 3.

![Figure 7. Influence of shear span ratio.](image1)

**The effect of axial compression ratio.** Under given column section size, shear span ratio, fiber content and reinforcement, the changes of the ultimate displacement angles and displacement ductility factors with the increase of axial compression ratio were shown in Fig. 8. The results in Fig. 8 shows with the increase of the axial compression ratio, both the ultimate displacement angle and displacement ductility factor decrease.

![Figure 8. Influence of axial compression ratio.](image2)

**Conclusions**

By using OpenSees software, two tested fiber reinforced concrete column specimens were
simulated numerically under the horizontal cyclic loading. The finite element model was verified by comparing the numerical simulation results with the experimental results. Then parametric analysis of shear span ratio and axial compression ratio on the seismic performance of fiber reinforced concrete columns was conducted. The following conclusions and recommendations can be drawn:

The hysteretic curves and backbone curves of the specimens obtained by numerical simulation are in agreement with the experimental results.

The numerical simulation results show that the shear span ratio has great influence on the displacement ductility coefficient and the ultimate displacement angle of the fiber reinforced concrete columns, which have the same section size, axial compression ratio, fiber content and reinforcement. With the increase of shear span ratio, the displacement ductility coefficient increases at first and then decreases, and reaches the maximum at the shear span ratio of 3. The ultimate displacement angle increases with the increase of shear span ratio.

Under given column section size, shear span ratio, fiber content and reinforcement, both the ultimate displacement angle and displacement ductility factor decrease with the increase of the axial compression ratio.

References


