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**Technical Note**

# Experimental study on seismic behavior of high strength reinforced concrete frame columns with high axial compression ratios

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## 1. Introduction

In practical designs, the column's sections of large-scale firepower plants are controlled by the limitative values of axial compressive ratios, so the sectional dimension often is larger. It not only increases the deadweight of structure but also takes up houseroom, so it influences the use of structures. High strength concrete (HSC) applied to the framed bent structure of large-scale firepower plants can decrease column section, lighten weight and enhance bearing capacity (Bechtoula 2009, Lu 2009, Zhang 2003). What about the deformation property of HSC columns with high axial compression ratios will be validated by further experimental investigation.

## 2. The experimental design

This test adopts cantilevered loading columns, its computational slenderness ratios (Frédéric 2000, Zhang 2006) are 8 and 10, respectively. The strength grade of concrete took C60; transverse reinforcements took I grade reinforcing steel bars; longitudinal reinforcements took II grade

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Table 1 Specimen dimension and bar arrangement table

| Speci-mens | b×h ($mm^2$) | Slender-ness ratios | Designed axial compres-sion ratios | Column height / mm | Axial compression load / kN | Capacity (National, 2001) | | Transverse reinforcements | | | Longitudinal reinforcements | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Shear horizon-tal loads / *k*N | Bend horizon-tal loads / *k*N | Configura-tions of transverse reinforce-ments | Stirrup diame-ters and spaces | Volume transverse reinforce-ment ratios /% | Actual longitudinal reinforce-ments /$mm^2$ | Actual longitudinal reinforce-ment ratios / % |
| HC4 | 140×280 | 8 | 0.7 | 1120 | 611.1 | 195.4 | 67.5 | S-2 | ϕ8@100 | 2.33 | 339 | 1.98 |
| HC5 | 140×280 | 8 | 0.8 | 1120 | 698.5 | 195.4 | 69.2 | S-2 | ϕ8@100 | 2.33 | 339 | 1.98 |
| HC6 | 140×280 | 8 | 0.9 | 1120 | 786.0 | 195.4 | 78.0 | S-2 | ϕ8@100 | 2.33 | 339 | 1.98 |
| HC7 | 140×280 | 10 | 0.8 | 1400 | 698.5 | 176.9 | 49.7 | S-1 | ϕ8@80 | 1.94 | 226 | 1.32 |
| HC8 | 140×280 | 10 | 0.8 | 1400 | 698.5 | 223.2 | 55.4 | S-2 | ϕ8@80 | 2.92 | 339 | 1.98 |
| HC9 | 140×280 | 10 | 0.8 | 1400 | 698.5 | 223.2 | 55.4 | S-3 | ϕ8@80 | 3.19 | 339 | 1.98 |

reinforcing steel bars; the transverse reinforcements, whose space is 50 mm, were crowded in the 200 mm range of column top to prevent local collapse. The columns test were all designed as strong shear but poor bend, and the sectional dimensions and rebar's configuration reinforcement of specimens see Table 1 (Zhang 2003).

## 3. The testing procedure and loading system

### *3.1 The loading equipment*

The test was carried in pseudostatic loading systems in the structural laboratory in Xi'an University of Architecture & Technology. Loading adopted cantilevered columns, and the specimen top is a ball-pivot which ensured column cap occurring angle displacement in whole testing process. The bottom of specimens was fixed (Zhang 2003).

### *3.2 The measured contents and methods*

The measured contents and methods are as follows: the curve $V$–$\Delta_1$; the strain variational rules of longitudinal reinforcement bars and stirrups; concrete strain; the data of every measuring point are collected by data collected system in the fluid servo loading systems, the quasi-kinetic strain measured system DH3815 and the static strain measured system DH3816.

## 4. Main testing results and analysises

### *4.1 Failure process and mode*

The cracking loads of columns HC4, HC5 and HC6 were 50 kN, 55 kN and 65 kN, respectively. All the cracking loads of columns HC7, HC8 and HC9 were 40 kN. That is to say the cracking loads increase with the increasing of axial compression ratios.

With the repeating loads proceeding, there appeared the spalling phenomenon at right-and-left root range of columns HC4, HC5 and HC6. Some concrete at the bottoms of columns HC8 and HC9 spalled quite severely; the other spalled severely weakly, some even showed up all reinforcing steel bars at the bottom of columns (Zhang 2003). Because the testing columns were all designed as strong shear but poor bend, the failure modes of columns HC4~HC6 took place bending failure finally (Zhang 2003). From testing breakoff phenomenon it can be seen that the failure of columns HC7, HC8 and HC9 belonged to bending failure (Zhang 2003). The mode of transverse reinforcement of column HC7 is plain rectangular transverse reinforcements and its volumetric transverse reinforcement ratio is fewer, its ductility is poorer than that of column HC9 and it took place abrupt brittle failure (Zhang 2003).

## *4.2 Testing results*

### *4.2.1 Load-displacement hysteretic and backbone curves*

The load-displacement hysteretic and backbone curves of testing columns gained at this test have following characteristics:

(1) The descending branch of backbone curves is steep and the bearing capacity of specimens loses largely and the powerwasting capacity is poorer in high axial compression ratios (Lu 2000).

(2) As the composite transverse reinforcements with some volume transverse reinforcement ratios adopted, the test also indicated that: the plastic zone after the yielding of reinforcing steel bars developed in a quite long zone if the axial compression loads were not very larger and it still had some plastic zones even though the axial compression loads were larger. Therefore, the deformation capacity of specimens improved obviously (Lu 2000).

(3) From the load-displacement hysteretic curves in different axial compression ratios it can be distinctly seen that the axial compression ratios had more influences on the ductility of specimens (Zhang 2003). With the axial compression ratios increasing, the hysteretic curves of specimens became plump. From the hysteretic curves it can be seen that crisscross composite transverse reinforcements at high axial compression ratios can still meet the requires of earthquake-resistant behaviors.

With the long reinforcement ratios and transverse reinforcement ratios increased, the hysteretic curves of each column became plumper; the cumulative hysteretic dissipation of energy became larger; the absorbed earthquake energy and the ductility also increase accordingly. But from hysteretic curves and failure modes it can be seen that the ductility of column HC7 were more poorer than that of columns HC8 and HC9 and the other two transverse reinforcement modes at high axial compression ratios can still meet the requires of earthquake-resistant behaviors (Zhang 2003).

### *4.2.2 Ductility of specimens*

This time is mainly to study the influences of axial compression ratios, the modes and ratios of transverse reinforcement on the ductility of frame columns (Lu 2007, Zhang 2006).

**The influence of axial compression ratios on ductility** Whether HSC or ordinary strength concrete (OSC) frame columns, the ductility decreased gradually with the axial compression ratios increasing. The ductility of OSC columns decreased linearly with the axial compression ratios increasing. Their ductility is basically linear relationship with the axial compression ratios (Zhang 2006). But from the relationship between the axial compression ratios of HSC columns HC4, HC5, and HC6 it can be seen that the ductility decreased with the axial compression ratios increasing and the decreasing amplitude of ductility is larger with the axial compression ratios increasing.

**The influence of the mode and ratios of transverse reinforcements on ductility** From the above analysis it can be known: the ductility of HSC frame columns gradually increased with the volume transverse reinforcement ratios increasing; the ductility of well composite transverse reinforcements is better than that of and the crisscross composite transverse reinforcements. This is to say the ductility of HSC frame columns has the relations with not only volume transverse reinforcement ratios but also transverse reinforcement modes, which composite transverse reinforcements had better be used.

## 5. Conclusions

(1) These testing columns all took place bending failures finally. The concrete of column's surface with high axial compression ratios and low transverse reinforcement ratios spalled more seriously than that of column's surface with low axial compression ratios and high transverse reinforcement ratios.
(2) The hysteretic curves of specimens became plumper and the cumulative hysteretic dissipation of energy became larger and the absorbed earthquake energy increased as well as the ductility also increase accordingly.
(3) Whether HSC or OSC frame columns, the ductility decreased gradually with the axial compression ratios increasing.
(4) The ductility of HSC frame columns gradually increased with the volume transverse reinforcement ratios increasing; the ductility of frame columns with well composite transverse reinforcements is better than that of the frame columns with the crisscross composite transverse reinforcements.

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