# Experimental and analytical studies on the confinement effect of transverse reinforcement in concrete columns under cycle loading

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**ABSTRACT :**

Four RC frame column specimens without cover were tested under constant axial compressive and cycling lateral loading. The seismic behaviors under different loading path and axial load ratios are discussed. The hoop strains of lateral reinforcements in different heights of columns under cycling loading were gained by means of 8 or more strain gauges attached along the hoops. And also the distribution characteristics of transverse reinforcement strain were obtained. And the transverse reinforcement strain stage of development were discussed.

**KEYWORDS:** concrete column, transverse reinforcement, ductility, confinement action, axial load ratio

## 1. INTRODUCTION

In displacement-based seismic design, the ductility of a RC column is an important design parameter. The calculation of yielding displacement may be easier, however, calculation of ultimate displacement may be difficult because the ultimate strain of concrete affects section ductility directly, and the displacement ductility of the column depends directly on its section ductility. Futhermore, the ultimate strain of concrete is affected by the lateral confinement. So, a lot of researchers concentrated their research on the stress-strain relationship of confined concrete[1] and also suggested several effective calculated models for axial compression concrete[2-5]. But few researchers consider the effect of transverse reinforcement on columns under eccentrically compression loading.

This experiment investigation aimed at the distribution of stress and strain of concrete columns section under cycle loads. The axial load ratio, loading path and location of transverse reinforcement effect on section confined force are analyzed. The relationship between strain changes of transverse reinforcement and concrete crush are also obtained. And the experiment results will be the base of transverse reinforcement confining model for concrete columns.

## 2. TEST DESIGN

### *2.1. Specimen design*

In order to ensure the veracity and validity of transverse reinforcement strain measurement, two measures were used: At first there is no concrete cover, the outside of transverse reinforcement is exposed to air; second, in the potential plastic hinge region, the transverse reinforcement was instead by steel rings made by seamless steel tube. The two measures can make strain gauge installation much easier and insure the quality of installation.

There are total 4 specimens with different circular section, diameter D=336mm, designed concrete strength is C30. The net length of columns H=1800mm(including top enhanced region), the top enhanced region size 400mm×400mm×500mm. Each specimen has a 2000mm×700mm×430mm.base.

There are 8 HRB335 longitudinal reinforce bars($\Phi = 14$mm). In the plastic hinge region, the steel ring size is D336×7, width b=8mm. There are total 7 steel rings disturbing in 480mm length from top of base. In other region, the transverse reinforcement is HRB335 bar( $\Phi = 8$ mm, spacing 80mm).

The specimen model is shown as figure 1 and the strain gauges arrangement is shown as figure 2. In figure 2, CG means transverse reinforcement gauges, ZG means vertical reinforcement gauges, a~h represent transverse reinforcement gauges location on the steel rings. It's special that there is 16 transverse reinforcement gauges on the steel ring of RC-4.

**Table 1.Material Properties of Specimens**

| No. | $f_c$ (MPa) | $f_y$ (MPa) | $f_{yv}$ （MPa） | $f'_{yv}$ （MPa） | $\rho_s$ （%） | $\rho_{sv}$ （%） |
|---|---|---|---|---|---|---|
| RC-1～4 | 21.4 | 361.6 | 318.3 | 273.1 | 1.38 | 0.854 |

*** $f_c$ : concrete strength; $f_y$ : longitude bar yielding strength; $f_{yv}$ : transverse reinforcement yielding strength; $f'_{yv}$ : steel ring yielding strength; $\rho_s$ : longitude bar area ratio; $\rho_{sv}$ : transverse reinforcement volume ratio**

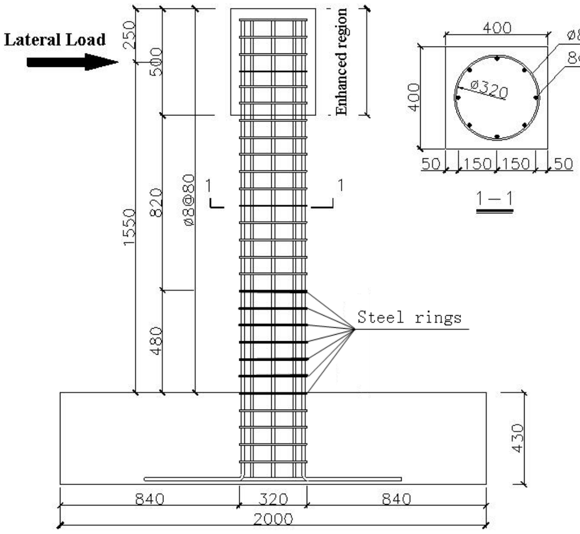



Fig. 1 Specimen design

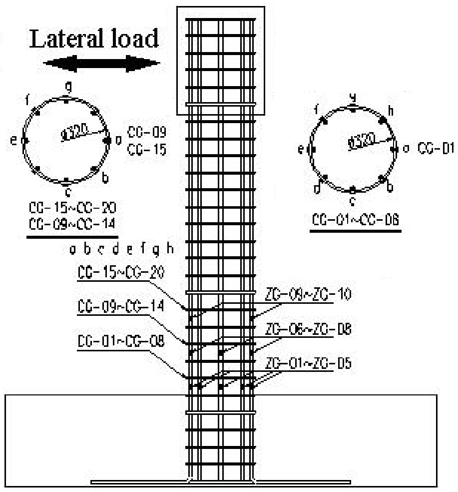



Fig. 2. Gauges arrangement

## *2.2. Test Setup And Loading Sequence*

The experiment is tested in structural laboratory of Hunan University. A schematic drawing of the test setup is shown in Fig. 3. The specimen was mounted vertically with the bottom of the RC foundation rested by two steel beams. The end of the column was loaded by a hydraulic jack and controlled to provide a constant axial force varying from 450 to 900 kN (i.e., from 0.4 $f_c A_g$ to 0.8 $f_c A_g$ ). The column was subjected to reversed cyclic loading by an actuator horizontally mounted to a reaction wall. The actuator have a capacity of 600 kN and was capable of moving the column 150 mm in both positive and negative directions. The design load ratio of RC-1 and RC-2 is 0.4, RC-3 and RC-4 is 0.8. All data is auto-recorded by MTS system.

The specimens were tested under displacement control. There were two kinds load path: For RC -1 and RC-3, the displacement was increased by 5 mm (i.e., column drift of 0.32%) for every three cycles, the displacement cycles were repeated to measure the strength degradation. For RC-2 and RC-4, first step displacement is 60mm, and each step decreased 5mm.

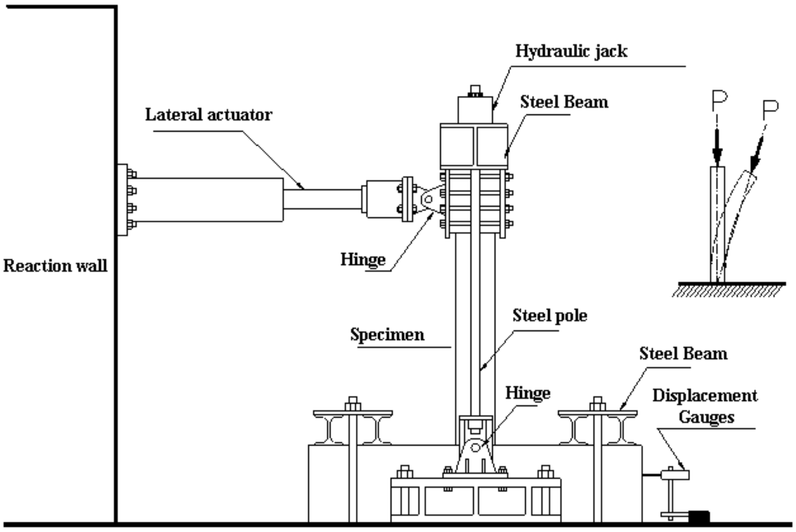



Fig. 3. Test setup

## 3.TEST RESULTS

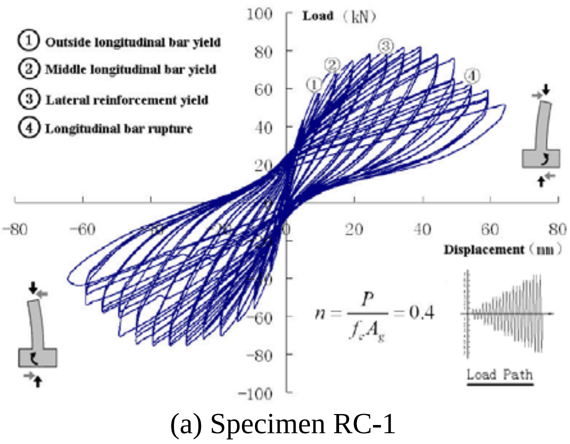
### *3.1.General Observations*

For the reason of without concrete cover, there is no crack outside tensile region, but we can observe that transverse reinforcement separated from concrete in the tensile region. Compression region concrete was crushed after transverse reinforcement yielded. The failure mode is flexure for all specimens.

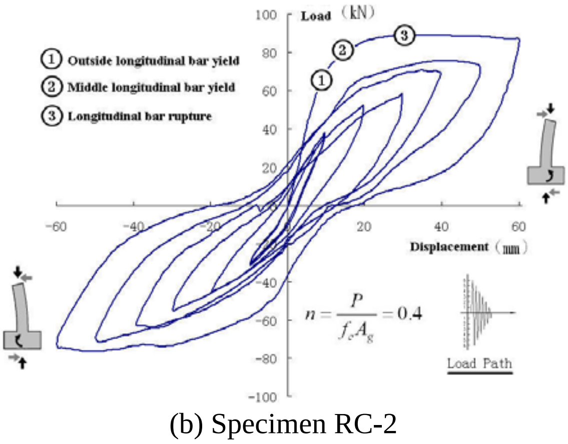
### *3.2 Hysteretic Loops*

The hysteretic loops of the load-displacement relationships for RC-1~RC-4 are shown in Fig. 4 respectively. The yielding of longitudinal steel bars, yielding of transverse reinforcement and rupture of longitudinal steel bars of each column also are indicated in Fig. 4.

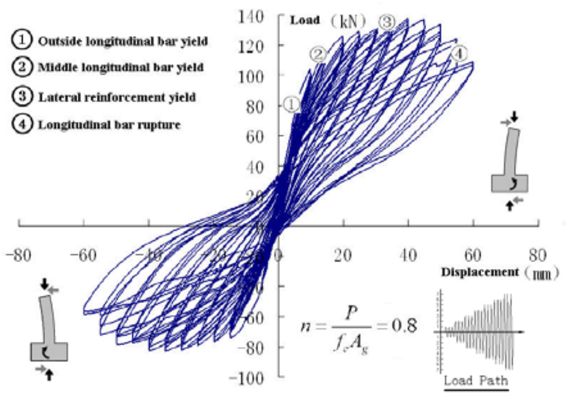
It can be seen from Fig. 4 that the hysteretic loops of RC-1 and RC-3 pinches, transverse reinforcement yielding after longitudinal steel bars yielding. And the longitudinal bars ruptured at last, and then the horizontal carrying ability degraded rapidly. For the reason of load steps decreased, RC-2 and RC-4 hysteretic loops more plump than others.

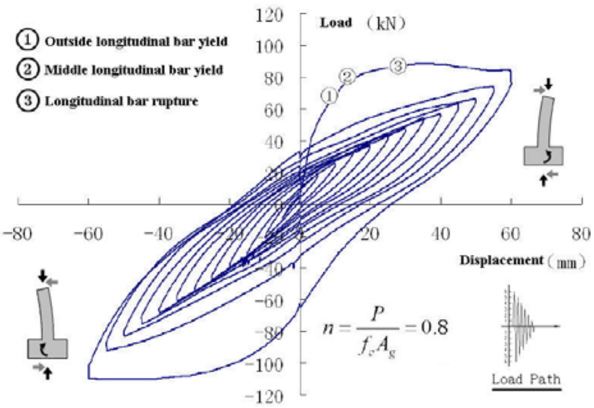



(a) Specimen RC-1




(b) Specimen RC-2



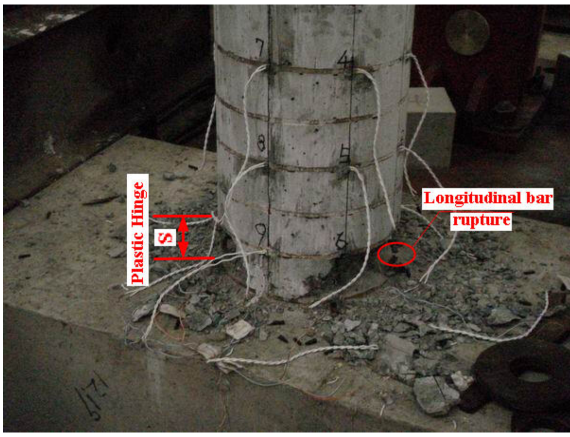




(c) Specimen RC-3 (d) Specimen RC-4

Fig. 4 Hysteretic Loops of Load-Displacement Relationships of Specimens

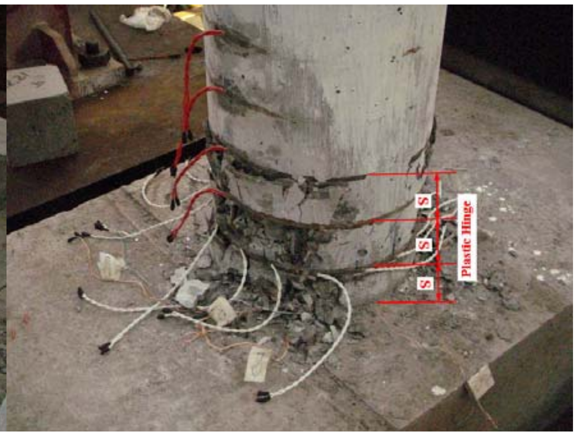
### *3.3 Damage and Plastic hinges*

In Fig. 5, the plastic hinge formed in the lowest transverse reinforcement spacing, and RC-1 specimen concrete crushed much more badly than RC-2; RC-3 specimen concrete crushed in lowest two spacing and RC-4 crushed in lowest three spacing.





(a) Specimen RC-1 (b) Specimen RC-2


(c) Specimen RC-3 (d) Specimen RC-4

FIG. 5. Failure Modes and plastic hinge region of specimens

Compared the concrete crush length, it can be conduct that the load ratio and load path affect the crush region and plastic hinge obviously. With the same load path, high load ration affect higher plastic hinge; in the other way, load step increased conduct small crush region than load step decreased with same load ratio. Some researcher[6-7] and design code[8] suggest that involved load ratio in plastic length calculation.

### *3.4 Transverse reinforcement strain test result*

The transverse reinforcement strain test is the most important part in this experiment. The transverse reinforcement strain distribution can be seen from Fig. 6 (a) and (b). The Fig. 6(c) show that lateral strain increment distribution of RC-4. The Fig. 6(d) show that lateral strain distribution along the columns height direction.

It can be seen from Figs.6, that transverse reinforcement strain distribution have following character:

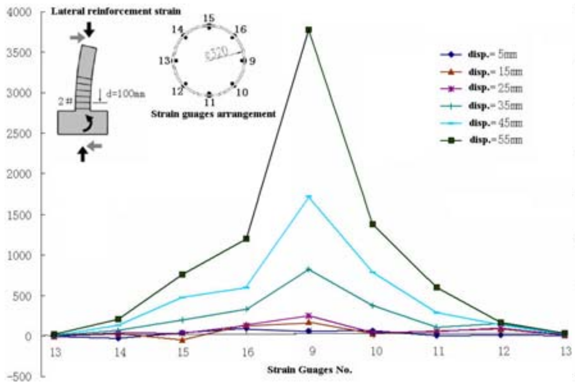
1. The lateral strain distribute asymmetric. Before the concrete crushed, the lateral strain is tensile strain both in tensile and compression region. It indicate that transverse reinforcement confined concrete in the whole section.

2. After compression region concrete crushed, the lateral strain will not decrease until concrete spalling.

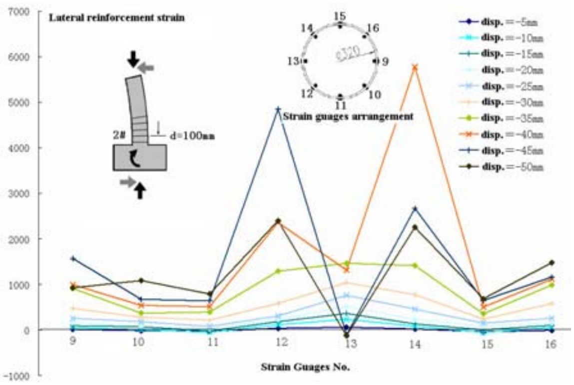
3. Before transverse reinforcement yielded, lateral strain increase slowly. Once the transverse reinforcement yielded, the lateral strain increases rapidly. It indicate that transverse reinforcement lost confined capability after yielding, the lateral strain of section out of transverse reinforcement control.

4. Compared with reversed cyclic loading, the transverse reinforcement strain much less than the monotonous loading procedures in the same load level. It indicated that the cumulated strain by reversed cyclic loading affect confining force.

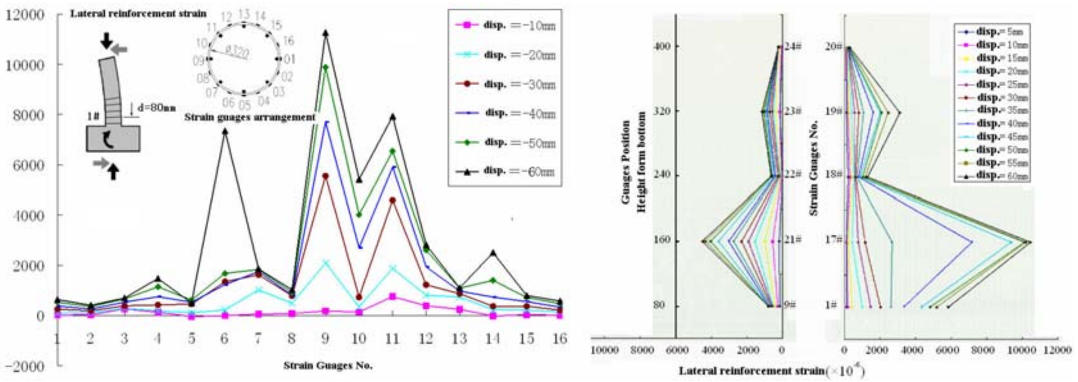
5. In the plastic hinge region, the lateral strain is not correlative with section location. Peak lateral strain appeared at the 2nd or 3rd spacing of transverse reinforcement. At the bottom of columns, the lateral strain usually is small because of base confinement[9].




(a) specimen RC-2




(b) specimen RC-3



(c) Increment distribution of specimen RC-4 (d) Distribution along height of specimen RC-3

FIG. 6. Lateral strain distribution of specimens

## 4.CONCLUSIONS

Based on the experiment analysis of 4 specimens under cycle loading, the effect of different axial load ratio and loading path on columns seismic capability is compared. It is found that axial load ratio and loading path affect plastic hinge length obviously. Plastic hinge length increased as axial load ratio increased. Before concrete crushed, transverse reinforcement can provide confining stress both in tensile and compressive section. Strains of transverse reinforcement increase rapidly after it yields, and lateral load arrives peak value at this stage.

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