A STUDY OF BEHAVIOR OF CONFINED CONCRETE WITH RECTANGULAR AND COMBINED HOOPS

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SUMMARY

This paper summarizes the conclusions drawn from experimental observation. The strength and deformation behaviour of confined concrete are analysed based upon results of 181 concrete units test conducted. Two kinds of analytical models for stress-strain relationship are proposed, the analytical expression considering influence various parameters including spacing and type of hoops and volume ratio of lateral reinforcement are established.

Close spacing of hoops conduces to improve the behaviour on descendant branch and delay the buckling of longitudinal reinforcement. The ability of concrete deformation depends early or late on the occurrence of the buckling of the longitudinal reinforcement.

INTRODUCTION

Many investigators indicated different viewpoints on the confining effect between circular and rectangular hoops. However, it is a disputed point, whether the confinement by rectangular hoops is effective for increasing compressive strength and deformation for confined concrete.

The tests were conducted at a controlled rate of 181 concrete units, each 400 cm square by 60 cm high containing seven different configurations of the transverse hoops (see.Fig.1), and hoops with 6, 8, 10 cm in diameter, and spacing with 5, 10, 15, 20 cm, the volume ratio of transverse reinforcement were mainly in the range 0.3 % to 3.7 %, the ratios of longititudinal reinforcement were in the range 0.3 % to 4.91%, the yield strength of steel was in the range 2350 kg/cm^2 to 3700 kg/cm^2, the cubic strength of concrete was 178 kg/cm^2 and 258 kg/cm^2.

The stress-strain curves obtained from concrete prisms loaded in uniaxil at a stress rate to reach to maximum stress in 2 or 3 minutes at a strain rate in descending branch in 0.02 to 0.04 μm/m/sec.

It is the major object of the test to study influence of various factors considering the spacing and the type of hoops, the diameters of hoops, longitudinal reinforcement on the shape of stress-strain curves. The test result of the hoops at each loaded stage, the analytical models for stress-strain relationship and the calculation formulas for the strength and deformation of confined concrete were proposed.

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EXPERIMENTAL ANALYSIS

Failure Characteristic

A variety of typical stress-strain curves for confined concrete were shown in Fig.2. The failure process of specimens may be divide into three stages:

The first stage was in the ascending part of the stress-strain curve. The appearance of vertical cracks in the concrete cover was at stress approaching the maximum stress.

The second stage was in the plateau part of the curve at the maximum stress. The concrete crazed gradually, the outer layer concrete was spalled along the direction of slant tension and the loaded section became smaller. The longitudinal steel came in sight at plastic compression state. The test demonstrated that the external force did not drop off at a great rate, because the internal stress in the core grew up at the process of increasing deformation, so it exhibited an plateau. The length of the plateau depended on the type of hoops.

The third stage was in descending branch of curves due to the load falling down. When the stress of hoop is at or approaching yield, the confined force cannot still confine transverse expansion. At weak section, the reinforcement in sight got buckling in a range by transverse expansion. The hoops were then broken one by one. It shows that the specimens were falling into failure stage.

The from of failure was the same as that unconfined concrete with widely spacing hoops, to which slope cracks appeared on accross section. However, the confined concrete with close spacing hoops led to failure due to the section of core weakened by cracking form exterior to interior and spalling off. Comparing the shape of stress-strain curves for confined and unconfined concrete, we can conclude that they are similarly in ascend branch, but the later fall down quickly after reaching the maximum stress, its slope is sharp and smaller than 30 degree.

Effect of Hoops

It will be seen that the arrangement of the hoops is of principal factor to influnce over the strength and deformation of the confined concrete.

1. Ratio of transverse hoops

Before the hoops stress approaching to yield strength, the increase in ultimate strength with content of confining steel was very significant, because the more the ra o of hoop was, the more the strain of hoop was, and the transverse confining pressure was also increment. The difference between the test values of increment on the strength of concrete confined by circular and rectangular hoop was not significant, because the change of strains in hoops was small in ascending branch, the maximum gap between the strains of circular and rectangular hoops did not exceed about 25 % (see Fig.3).

Many investigators assumed that the strain of hoops reached to yield for calculating the maximum stress of confined concrete experimentally, it was observed that in some cases, it did not yield. With grade I steel, the yield strain reached at the volume ratio of hoop in 1.4 % and in 2.4 % for the rectangular hoops (see.Fig.3).

2. Spacing of Hoops

The strain curves of different spacing hoops showed in Fig.4. It is clear that the change of the strain of hoop is not noticeable, before maximum stress of concrete has reached. After approaching the uniaxial strength of concrete, the change increased with the decrease of the hoops spacing. So it is significant to improve the behaviour of descending branch, and necessary to take into account the effect of spacing of hoops on descending branch. Fig.5 showed that the descending slope for descendant branch of concrete with the hoop 8mm in diameter is greater than 6, due to one of the hoop's patches increased in hoop with 8 mm in diameter, its strain is smaller at falling branch than that of 6 mm in diameter.

3. Type of hoops

The type of hoop is more significant than any other factor in influencing energy absorption capacity.

Fig.2. gives the diagrams of the strain-stress relationship for different types of hoops. The volume ratio of hoops was constant for each curve, it is worth of note that the ultimate strength was hardly different, but the corresponding strains were different evidently. The shape at the top of some stress-strain curves appeared a plateau branch. It was due to the lateral pressure that reduced the tendency for internal cracking. Appling combination of rectangular hoop with other ones makes a good remedy for each other.

Fig.2. indicated that the strain of specimen with "2" hoop was about five times that with the rectangular ones without tie and the buckling of longitudinal reinforcement did not occur until the strain of concrete arrived at 0.24 $\mu\varepsilon$ about 1.4 times that of the "4" hoop.

Shape of Stress-Strain Curves

The typical shape of curves are shown in Fig.6 , the curves can be divided into two kinds. One is trilinear type, and another is bilinear curves.

The confined concrete with a combination of rectangular hoops and spiral hoops belongs to trilinear curve which consists of three portions: ascend branch, flat branch and descend branch. The confined concrete with a combination of rectangular hoops belongs to bilinear curve which consists of ascend branch and descend branch.

The ascending part of the curve can be represented by a second-degree parabola , the descending one can be represented by a straight line, the flat one can represented by a horizontal line.

Effect of Longitudinal Reinforcement

The test indicated that the buckling took place for all the longitudinal reinforcement (see,Fig.7) after reaching yield point of steel. They took place at the begining of the decend of loading, the better the stiffness of hoop was, the later the buckling place. Once the buckling of reinforcement took place, the concrete of the core lose the state of triaxing pressure, usually the failure of reinforcement concrete element occured as the bucking of the main steel.

Monotonic Repeated Loading

The stress-strain curve for specimen subjected to monotonic repeated loading showed in Fig.8. It was similar for the skeleton curve and stress-strain curve under monotonic loading. The line for repeated loading were paraller each other, there were close in stiffness. These charactars had no relation with the ratio of transverse reinforcement.

THE CALCULATION OF STRENGTH AND DEFORMATION FOR CONFINED CONCRETE

Strength of Confined Concrete

It is known that the axial compressive strength of confined specimen occours following relationship under condition of triaxial compression:

$$R_o = R_a + k\,\sigma_r \qquad (1)$$

where: R_o axial compressive strength of confined specimen
R_a uniaxial compressive strength of unconfined specimen
σ_r lateral confining pressure

$$\sigma_r = 0.5\,\mu_t\,E_g\,\varepsilon_g \qquad (2)$$

μ_t volume ratio of hoop to concrete core
E_g modulus of elasticity for steel
ε_g strain of hoop

The test demonstrated that whether the strain of hoop reached yield strength will depend on the volume ratio of lateral hoop and character of steel. In the case of the hoops with grade I steel, $s < 20$ cm, the relationship between the strain of hoop and the volume ratio of hoop at ultimate strength for concrete was showed in Fig.3. σ_r equals to R_g at $\mu_t > 0.024$ for combined hoops, and at $\mu_t > 0.0012$ for spiral hoops. The regression equation for ε_g is proposed as following :

$$\varepsilon_g = (0.5 + 65\,\mu_t - 1100\,\mu_t^2) \times 10^{-3} \le \frac{R_{gy}^k}{E_g} \qquad (3)$$

Where: Correlation coefficient $r = 0.81$, standard deviation $S = 0.19 \times 10^{-3}$,

The coefficient K mainly depends on σ_r / R_a (see, Fig.9),the regression equation is:

$$K = 0.65\,(\sigma_r / R_a)^{-0.87} \qquad (K \le 14.0) \qquad (4)$$

The comparison of the value of the measure with that of calculation at ultimate strength of concrete showed in Fig.10. The average value of R_o / R_o^s is 1.01.

Deformation of Confined Concrete

According to the varieth of the hoops types, the shape of stress-strain curve of confined concrete can be divided into two groups (see, Fig.6) : one is with flat branch, another is without flat branch.

1. Ascend Branch

The ascend branch of stress-strain curve is the same as most of the experiments in our country and abroad, it may be expressed by a parabolic equation. Which is:

$$\sigma = R_o \left[2\frac{\varepsilon_c}{\varepsilon_o} - \left(\frac{\varepsilon_c}{\varepsilon_o}\right)^2 \right] \quad (5)$$

The strain ε_o relationship of the maximum strength showed in Fig.11, the expression for ε_o is presented as

$$\varepsilon_o = (3 - 0.07\,s + 0.08\mu_t) \times 10^{-3} \quad (6)$$

It seems that the main factor for increasing ε_o is to close spacing of the hoop. While spacing of hoop varied from 20 cm to 5 cm, an increase is twice the deformation on 20 cm, but for plane ratio of hoop varied from 0.07 to 0.17, an increase is only 25 %.

2. Fa t Branch

The length of flat branch may be written as:

$$\varepsilon_{o1} = (K_1 + 1)\,\varepsilon_o \quad (7)$$

Where: ε_{o1} is the strain at the end of flat branch.
K_1 can be obtained from table-1, it is determined by the types of hoop, $K_1 = 0$ for simple rectangular hoop.

Table 1

number of hoop type	4	1	6	2
K_1	0	2	3	4

3. Descend Branch

The slope of descend branch is given by the following equation:

$$\sigma = R_o \left[1 - \frac{\varepsilon - \varepsilon_{o1}}{(3 - 0.15\,s + 0.2\mu_t)\,R_o} \times 10^4 \right] \quad (8)$$

CONCLUSION

1. The strain of hoop increases with the volume ratio of hoop. Using grade 1 steel, the yield strain of hoop is at 1.2 % for circular spirals and 2.4 % for the rectangular hoop. When the higher grade steels are used, in order to exert the effect of the confinement, the high volume ratio of hoops need to be used.

2. The types of hoop have effection on enhancing energy absorption capacity and delaying buckling of longitudinal reinforcement. At ultimate strength, the corresponding strain with spiral hoops. "2" is about five times that with simply rectangular hoops.

3. The model of stress-strain curves for confined concrete mainly depends on the type of hoop. It can be divided into trilinear curve and bilinear curve.

4. Closing the spacing of hoop can reduce the slope of descend branch and delay the buckling of longitudinal reinforcement, increase the strain of concrete at ultimate strength of concrete.

5. The unixial compressed strength R_o of confined concrete can be calculated by expression (1) - (4).

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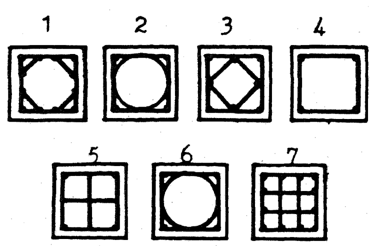

Fig.1 Combined Hoop Typies ("2" spiral Combined Hoop "6" Circular Combined Hoop)

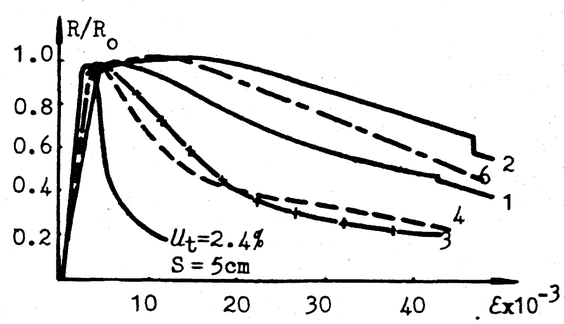

Fig.2 Typical Measured Stress-Strain Curves

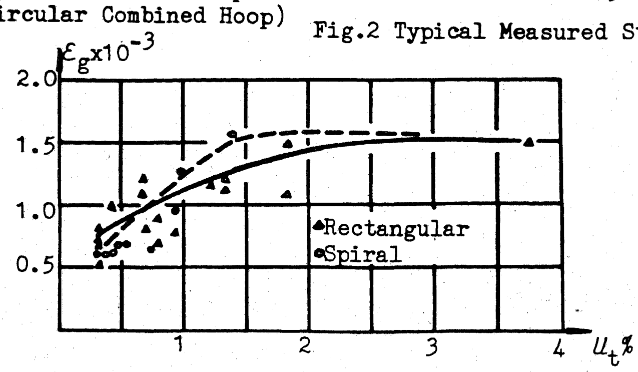

Fig.3 Effect of Hoop Ratio on Hoops Stress at Ultimate Strength of Concrete

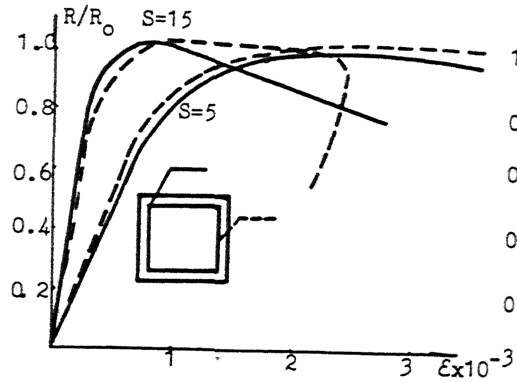

Fig.4 Comparasion of Strain Curves of Different Spacing Hoop

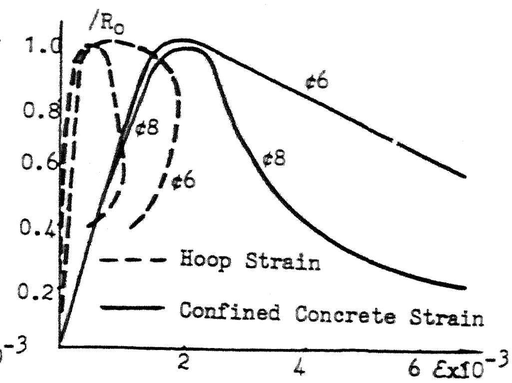

Fig.5 Effect of Hoop Arrangement on Descending Branch

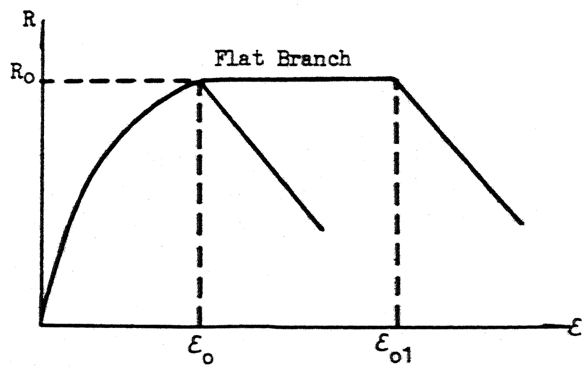

Fig.6 Typial Shape of Stress-Strain Curves

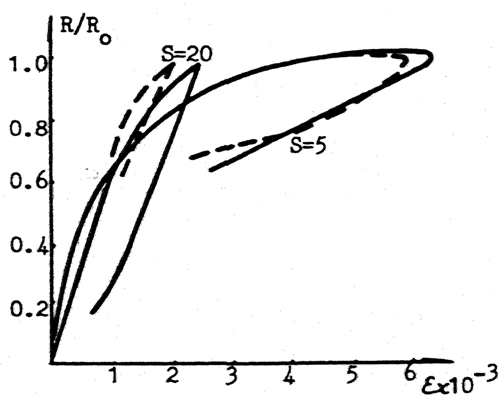

Fig.7 Strain Curve of Longitudinal Buckling Reinforcement

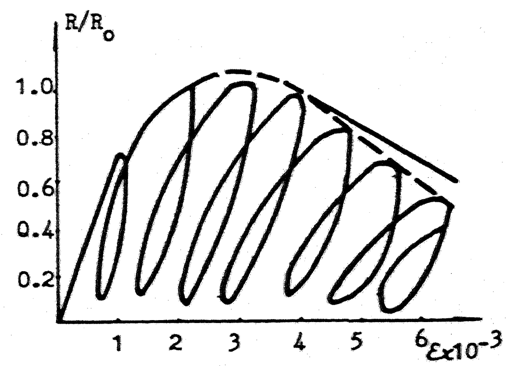

Fig.8 Stress-strain Relationship in Monotonic Repected lood

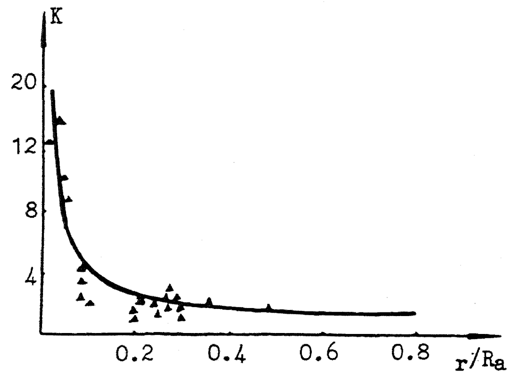

Fig.9 Relationship Between Lateral Increase Coefficent to Stress Ratio

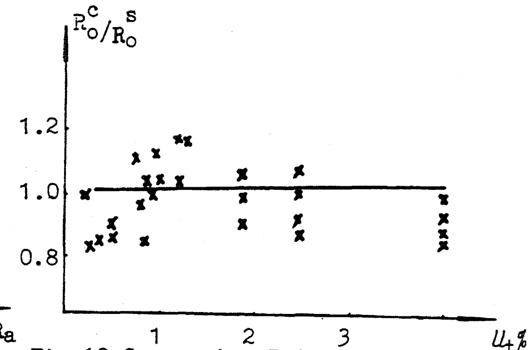

Fig.10 Comparsion Between Experimental and Analytical Strength

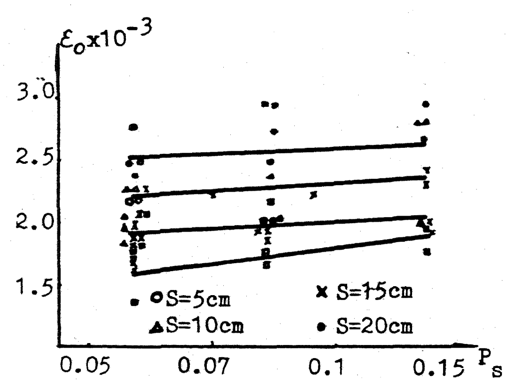

Fig.11 Strain of Confined Concrete at Ultimate Strength

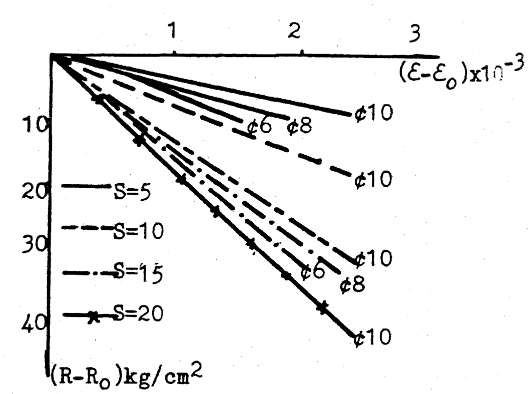

Fig.12 Effect of Hoop Arrangement on Descending Branch