DUCTILITY OF R/C COLUMNS WITH VARIOUS TYPES OF TIES AND STIRRUP RATIOS

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SUMMARY

By testing 14 R/C columns with different types of overlapping stirrups under cyclic reversed loading, the influence of the stirrup type to the ductility of R/C column is discussed. A modification factor α of characteristic value of stirrup ratio(λ_K), which shows the confinement effect of the different overlapping stirrups, is suggested. In order to calculate the ductility of R/C column, an empirical formula with variables $\alpha\lambda_K$ and the coefficient of nominal depth of compression zone of concrete ξ is recommended. In this paper, both the curvature distribution along the member and the plastic hinge length under cyclic loading are studied, and an empirical formula for plastic hinge length is also suggested.

OUTLINE OF THE TEST

14 specimens with shear-span ratio 4.3 are tested. All specimens are 2 m in length and 20 x 20 cm^2 in cross-section. The cubic strength of 14 specimens are varied in the range of 200-300 kg/cm^2. As seen in Fig. 1, 12 main longitudinal reinforcements 10mm in diameter are placed at the edge of the stirrups. While spiral stirrups are added, 8 among 12 bars are placed along circumference of the spiral in equal distance as shown in Fig. 1. The yield strength of the main longitudinal bars is 4405 kg/cm^2. The overlapping stirrups consist of the rectangular stirrup, with additional the network stirrups, spiral stirrups, or opened or closed octagonal stirrup. The diameter of stirrup is 4mm and the yield strength is 4500 kg/cm^2. The volumetric ratios of stirrup are 0.475 - 1.367%.

The sketch of loading equipments and the measuring gauges are shown in Fig. 2. The axial forces, exerted at the ends of the specimen are constant during the test. The cyclic reversed loading is exerted alternatively by two jacks placed at the mid-span of the column. The displacement, the rotation, the rotational distribution along the member and the relative slippage of reinforcement in the joint area of the member are measured.

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MODIFICATION FACTOR α OF CHARACTERISTIC VALUE OF STIRRUP RATIO

The measured stress-strain curves of the concrete prisms with overlapping stirrup are compared with those of the prisms with rectangular stirrups as shown in Fig. 3. Both of them have the same characteristic value of stirrup ratios and the spacing of stirrup. It is shown that the strength and ultimate strain of the concrete prisms with the overlapping stirrups are larger than those of the prisms with the rectangular stirrup. Especially, the descending branchs of the stress-strain curves are more flate than those with rectangular stirrups. It is obvious that the confinement effect of overlapping stirrup is better than that of the rectangular stirrup, so increases the ductility of concrete.

The effective types of the stirrup to increase the ductility of R/C Column are proved by this experiment as well as in elsewhere [1]. [2]. As seen in Fig. 4, while the characteristic value of stirrup ratio λ_K and the coefficient of norminal depth of compression zone of concrete ξ are same, the displacement ductilities of R/C columns with overlapping stirrups are larger than that of R/C column with rectangular stirrup. With the larger characteristic value of stirrup ratio, ductility increases more greatly. The ductility ratio of the member is obtained by using the ultimate displacement which is difined as the displacement corresponding to the load 10% decreasing from the maximum load.

To express the influence of various types of stirrup to the ductility of R/C column, a modification factor α is used. This factor is difined as the ratio of λ_K^r for the rectangular stirrup to λ_K^o for the overlapping stirrup with the same ξ under the same ductility ratio. If value α is larger than 1, the type of stirrup is effective. In the other words, with less stirrup ratio of the overlapping stirrup may obtain the same ductility ratio, but with higher rectangular stirrup ratio. It is shown in Fig. 4, that the values of the overlapping stirrup α vary from 2.8-3.2, and the average value is 3.00. The average value of spiral stirrup is 2.05. The confinement effect of overlapping stirrup as well as spiral stirrup are better than that of rectangular stirrup. When ξ is 0.3, the ductility ratio of R/C column with overlapping stirrup is 1.6 times that of column with the rectangular stirrup and the spiral is 1.4 times.

The influence of unsupported length of stirrup to the confinement effect of the stirrup is apparent.

An empirical formula for calculating the modification factor of characteristic value of stirrup ratio is given:

$$\alpha = \left(\frac{h_1}{h'} \cdot \frac{b_1}{b'}\right)^{\gamma} \left(1 + \frac{\mu_f}{\mu_t}\right) \quad \ldots\ldots \quad (1)$$

where b_1, h_1, are the projection length of the rectangular or the spiral stirrup along the width and depth of the section respectively, b', h' are the unsupported length corresponding to b_1, h_1 respectively, μ_t is the valumetric ratio of stirrup and γ is a constant. From results of Ref.[1][2] and this experiment, the average value of γ is 0.38. The calculated values α by formula (1) are listed in Tab. 1, and they are shown in good agreement with the experimental results. The relationship between the modificed characteristic value of stirrup ratio $\alpha\lambda_K$, and the ductility ratio of displacement β_{fu} of the member is shown in Fig. 5.

DUCTILITY OF R/C COLUMN WITH OVERLAPPING STIRRUPS

Fig. 6 and Fig. 7 show the measured curvature ϕy under yield load and ϕm under ultimate load with the relation to ξ. Due to the confinement of the overlapping stirrups, the ultimate strain of concrete increase largely. Thus, the measured ultimate curvature is larger than that of column with the rectangular stirrup. When the longitudinal steel starts to yield the confinement effect of stirrup is not so effective that the influence of the types of stirrups to the yield curvature of column is not obvious.

The relationships between the curvature ductility ratios of column and $\alpha\lambda_K$ which represents the modified characteristic value of stirrup ratio, and the coefficient of the nominal depth of compression zone ξ are shown in Fig. 8. As the results of Ref. [1],[2] and this test, an empirical formula for the curvature ductility ratio is suggested:

$$\beta_{\phi m} = \frac{1000\sqrt{0.1+2\alpha\lambda_K}}{85(1.85+8.3\xi)\xi^{0.85}} \qquad \ldots\ldots (2)$$

In formula (2) the ultimate deformations are used as the deformation corresponding to the maximum load while it starts to reduce. It is shown that the confinement effect of the overlapping stirrups becomes more effective for ductility of column. So, it is reasonable to use the ultimate deformation as the deformation value corresponding to the load reducing 10% from the maximum load. The curvature ductility ratio $\beta_{\phi u}$ is suggested as the following empirical formula:

$$\beta_{\phi u} = \frac{26\sqrt{0.04+2\alpha\lambda_K}+1}{(1.85+8.3\xi)\xi^{0.85}} \qquad \ldots\ldots (3)$$

The measured and calculated curvature ductility ratio are illustrated in Fig. 9.

The measured displacement ductility of the members are illustrated in Fig. 10, 11. β_{fm} and β_{fu} are the displacement ductility of the member corresponding to use maximum load while it starts to reduce and to the load 10% reduced from the maximum load respectively.

Two empirical formulas for the displacement ductility of the member are suggested:

$$\beta_{fm} = \frac{3.21\sqrt{0.1+2\alpha\lambda_K}}{(1.85+8.3\xi)\xi^{0.85}} + 0.7 \qquad \ldots\ldots (4)$$

$$\beta_{fu} = \frac{7.95\sqrt{0.04+2\alpha\lambda_K}+0.31}{(1.85+8.3\xi)\xi^{0.85}} + 0.7 \qquad \ldots\ldots (5)$$

It is shown from Fig. 8, 9, 10, 11 that under the same coefficient ξ both the curvature and displacement ductilities of R/C column are increased with the increasing modified characteristic value of stirrup ratio. The increase of ductility ratio, however, becomes slowly when $\alpha\lambda_K$ is over certain value, so the effect of stirrup ratio for increasing the ductility is obviously only in a certain range. When the bars of the critical section of the column start to buckle, the bearing strength of the column reduces rapidly and the member may be collapsed soon, so it is important to close the space of stirrups as well as using the effective types of stirrups for improving the ductility and the ability of resisting shear strength of R/C column.

CURVATURE DISTRIBUTION AND PLASTIC HINGE LENGTH

The curvature distribution which is obtained from measured rotation along the member is shown in Fig. 12. It is seen that with the increase of the curvature at midspan section the curvature along the member also increases. But after yielding the longitudinal bars, the increase of curvature in a small region near the midspan is much faster than that of other sections, especially, when the ratio of axial load to compressive strength is small. As the results of test, the length of yield Lp of the longitudinal reinforcement versus the curvature at the midspan section is shown in Fig. 13. It can be seen that the length of yield Lp becomes larger not only with the increase of the coefficient ξ , but also with that the increase of the curvature at the midspan section. The yield length of the longitudinal bars may be calculated as following:

$$\frac{L_p}{h_o} = 1+1.67\xi - \frac{13}{\varnothing_o/\varnothing_y+8} \qquad \ldots\ldots (6)$$

when

$$\frac{\varnothing_o}{\varnothing_y} > 10-14\xi$$

where h_o the effective depth of the cross section

$\varnothing_y$ the curvature at midspan section

After the longitudinal bars yielded, idealized curvature distribution along length of the member is shown in Fig. 14. l_p is difined as the equivalent effective length of plastic hinge.

When the load is 10% reducing from the maximum load, both measured Lp and lp are shown in Fig. 15. Lp is obviously larger than lp. It is convenient to use the equivalent effective length of the plastic hinge in the nonlinear analysis of the structures, but the length of closing space of stirrup should't be less than the length of Lp. According to the results from the test, when the load 10% reducing from the maximum load, the average value of the yield length is about 1.1 h_o and the average value of the equivalent effective length of plastic hinge is about 0.47 h_o . Both of them are increased with the increase of the ratio of axial load to compressive strength.

CONCLUSIONS

(1) The overlapping stirrups which consist of the rectangular stirrup with additional types of stirrups such as network stirrup, spiral and so on significantly increase the ductility of R/C column, especially with the additional network stirrup.

(2) The coefficient α can express the affect of various types of stirrup to the ductility of R/C column. If the rectangular stirrup is used α equals 1, α for overlapping or spiral stirrup equals 3 or 2 respectively.

(3) Empirical formula for calculating the ductility of R/C

column, with the modified characteristic value of stirrup ratio $\alpha\lambda_K$ and the coefficient of nominal depth of compression zone of concrete ξ give the results in good agreement with the experiment.

(4) The length of yield of R/C column is increased with the increase of the curvature of the critical section. After the longitudinal bars yielded, the length of yield increases very rapidly, but it become slowly after reaching the maximum load.

REFERENCE

1. Shen Ju-min, Weng Yi-jun and Feng Shi-ping, Behaviour of R.C Compression-Flexure Members under Cyclic Loading, China Civil Enginnering Journal, Vol. 15, No. 2, 1982.

2. Shen Ju-min, Liu Zhu-qing and Weng Yi-jun, The Experimental Investigation of the Seismic Resistance Behaviour of Reinforced Concrete Hollow Core Column, Journal of Building Structures, No. 5, 1982.

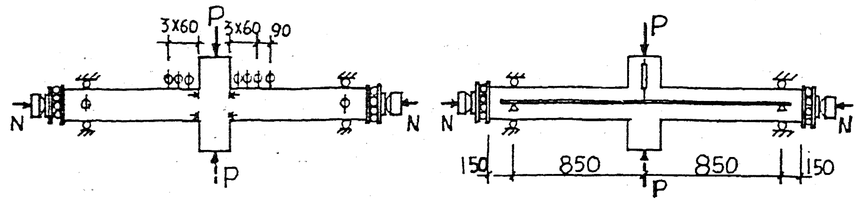


Fig. 2

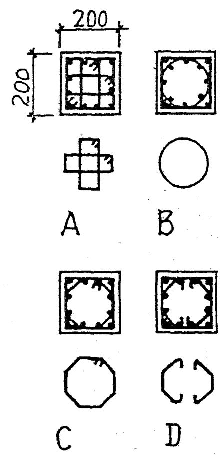


Fig. 1

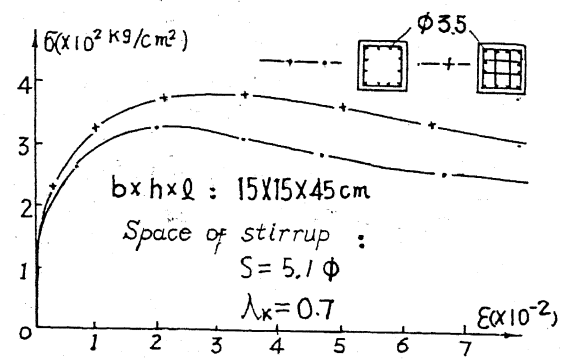


Fig. 3

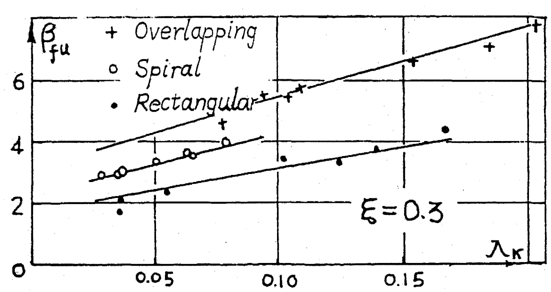


Fig. 4

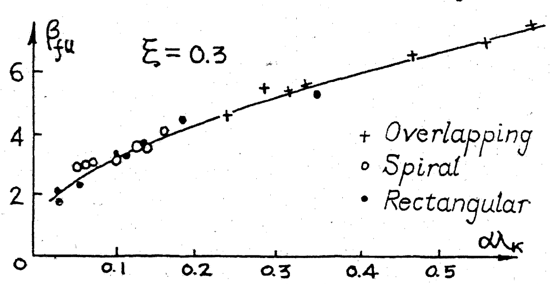


Fig. 5

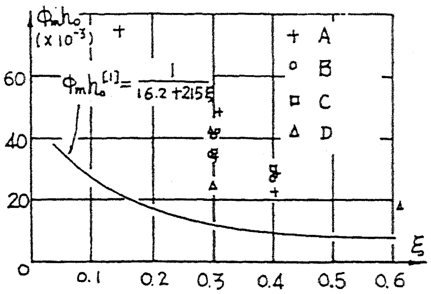


Fig.7

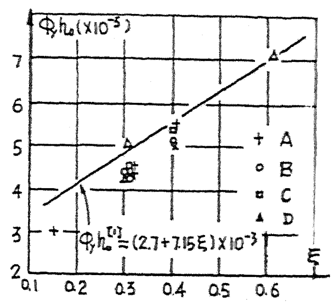


Fig. 6

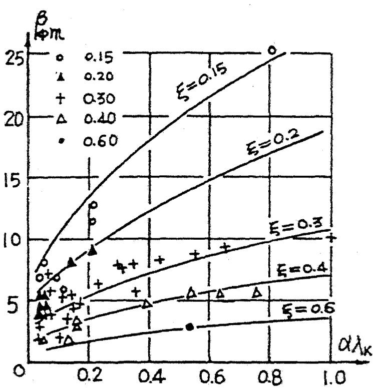


Fig. 8

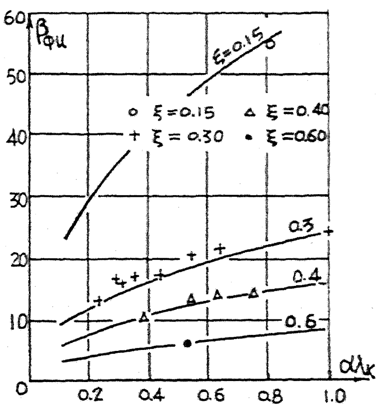


Fig.9

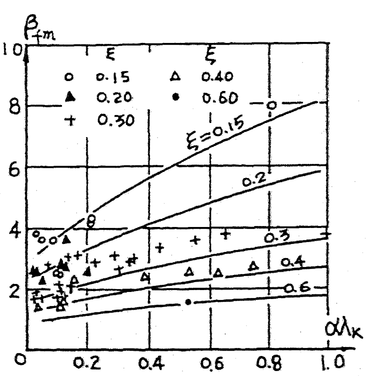


Fig.10

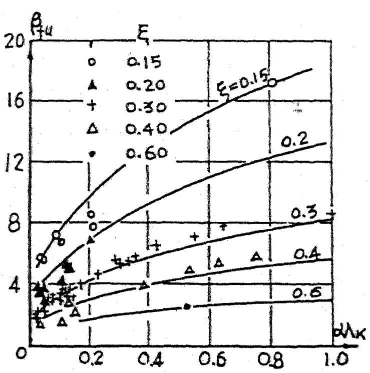
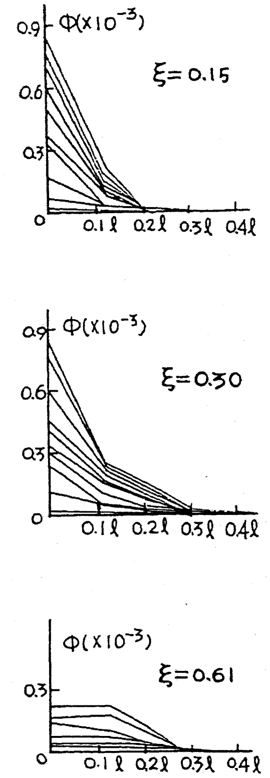


Fig. 11



Curvature distribution along the member

Fig.12

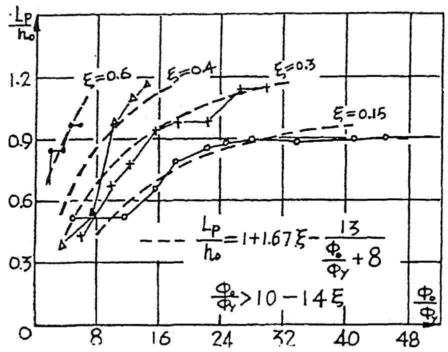


Fig.13

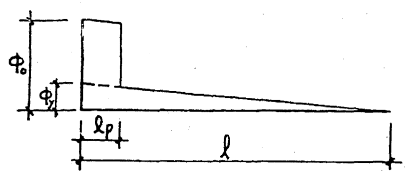


Fig.14

Modification factor α Table . 1

Col. $\bar{\alpha}$	1.00	2.07	3.23	3.17	2.97	2.84
Exp $\bar{\alpha}$	1.00	2.05	3.00			

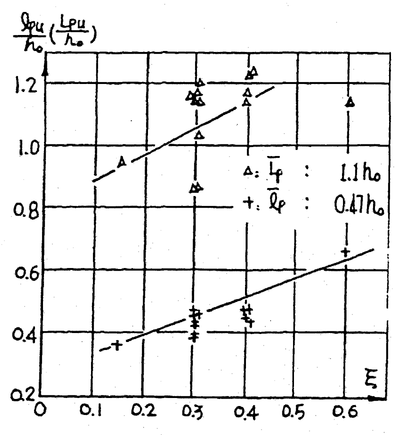


Fig.15