DUCTILITY IMPROVEMENT OF CONCRETE STRUCTURAL MEMBERS BY USING LATERALLY CONFINED CONCRETE WITH HIGH STRENGTH HOOP REINFORCEMENT

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SUMMARY

To verify the full possibility of curvature ductility improvement in concrete flexural member by the use of confined concrete, monotonous and repeated high-over loading tests were carried out on the post-tensioned prestressed concrete beams and the ordinary reinforced concrete columns with the high yield strength confining reinforcement. Test results were compared with those obtained from corresponding specimens confined by ordinary yield strength hoop reinforcement. From the monotonous loading tests, significant curvature ductility improvement were obtained in the beams and columns confined by the high yield strength hoop reinforcement. Also, very stable moment-curvature hysteretic curves were observed in the repeated high-over loading tests.

INTRODUCTION

The primary importance in the aseismic design of framed structure is to provide the curvature ductility sufficient to absorb the earthquake energy at the critical section of each constituent member. There are several methods for increasing the curvature ductility in reinforced and prestressed concrete flexural members. The lateral confining of concrete seems to be one of most effective and most practical methods for this purpose, because the compressive deformation capability of concrete can be considerably improved by lateral confining.

Past many experimental studies (Ref. 1 ~ 5) on laterally confined concrete had been carried out by using relatively low yield strength hoop reinforcement of 4,000 kgf/cm^2 or less, and the yielding of confining reinforcement had taken place at an early stage of loading, for instance, when the axial strain of concrete becomes 0.3 to 0.4 %. The yielding of hoop reinforcement generally reduces the improving efficiency of compressive deformation capability in concrete, because of the considerable decrease in lateral confining stiffness by yielding. The author emphasized from the previous studies on the confined concrete with various strengths of hoop reinforcement from 1,640 to 14,250 kgf/cm^2 that the use of confining reinforcement having 8,000 kgf/cm^2 or more in yield strength is necessary for full improvement of compressive deformation capability of concrete by elastic lateral confining. In this study, to verify the full possibility of curvature ductility improvement in concrete flexural member by the use of confined concrete, monotonous and repeated high-over loading tests were carried out on the post-tensioned prestressed concrete beams and the ordinary reinforced concrete columns with the high yield strength confining reinforcement. Test results obtained were mainly discussed on the ability of curvature ductility improvement in comparison with those confined by ordinary yield strength hoop reinforcement.

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COMPRESSION BEHAVIOR OF CONCRETE CONFINED BY HIGH YIELD STRENGTH HOOP REINFORCEMENT

Prior to describe the beam and column test results, typical loading test results on the laterally confined concrete obtained from the author's previous studies (Ref. 6 ~ 9) are summarized briefly in this section.

Tests were carried out on 28 - ϕ15 x 30 cm concrete cylinders confined by circular spiral reinforcement and 36 - 19.4 x 19.4 x 40 cm square columns by square one. As the confining hoop reinforcement, the steels having 1,640 to 14,250 kgf/cm^2 in yield strength and having 5 to 9.2 mm in diameter were used. The volumetric ratios of spiral reinforcement varied from 0.4 to 3.13 %, which correspond to the pitches from 32 to 2.5 cm. The compressive strength of plain concrete was 300 kgf/cm^2, excepting that it varied from 300 to 600 kgf/cm^2 in some test series for obtaining the effect of concrete strength upon the confining efficiency.

Typical stress-strain curves and corresponding confining stress for concrete are shown in Fig. 1. The confining stress is calculated from the measured strain of spiral reinforcement by the formula $\sigma_L = 2A_s f_s/(s \cdot D)$, where A_s denotes the sectional area of spiral reinforcement, f_s the tensile stress in spiral reinforcement, s the pitch of spiral reinforcement and D the diameter of cylinder specimen or width of square column specimen, respectively. It can be seen in Fig. 1 that the yielding of spiral hoops takes place at the concrete strain of 0.4 % in case of the ordinary yield strength spiral reinforcement and after that the strain softening can be obviously observed. On the contrary, in the case of high yield strength spiral reinforcement linear increase in hoop strain is obtained with a little or without any decrease in compressive stress over remarkably large compressive strain in concrete. These facts well suggest that the lateral hoop reinforcement should confine the concrete without any release by yielding for purposing the full improvement of compressive deformation capability in concrete.

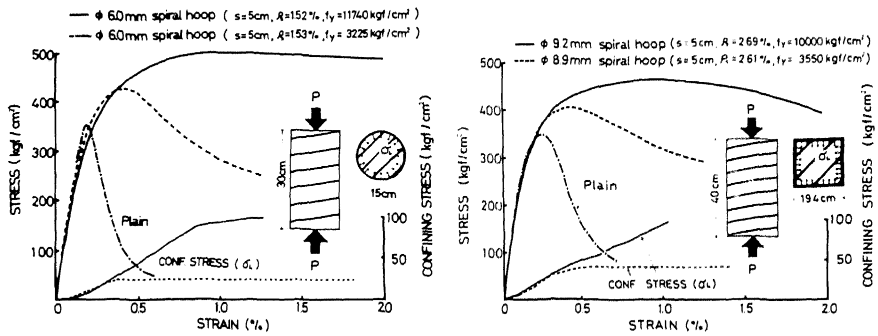

Fig. 1 Typical measured stress-strain curves and corresponding confining stress obtained from axial loading tests

To evaluate quantitatively the compressive deformation capability improvement in concrete by lateral confining, the axial compressive strain at which the average stress in measured stress-strain curve becomes maximum was calculated. Such strain is defined as the available limit of compressive strain in this study. The values obtained are shown in Fig. 2. From Fig. 2 it can be seen that the available limit of compressive strain obtained from the specimens with high yield spiral hoop reinforcement become more than 2 times those obtained from ordinary yield strength ones in the cylinder specimens and almost 1.5 times in the square column specimens, when the amount of spiral hoop reinforcement is sufficient. Especially, it is notable that the lateral confining by square spiral hoop reinforcement becomes significantly effective for improving the compressive deformation capability in concrete when using the high yield strength steel.

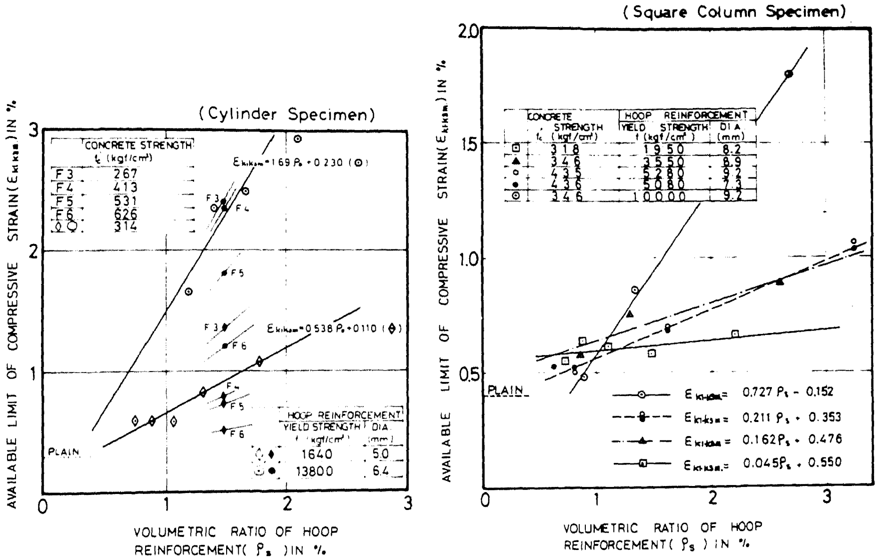

Fig. 2 Available limit of compressive strain of concrete obtained from monotonous concentric loading tests

As a reference, typical stress-strain curves under cyclic high-over axial loads obtained from the cylinder specimen with the high yield strength spiral hoop reinforcement is shown in Fig. 3 with comparative that with the ordinary

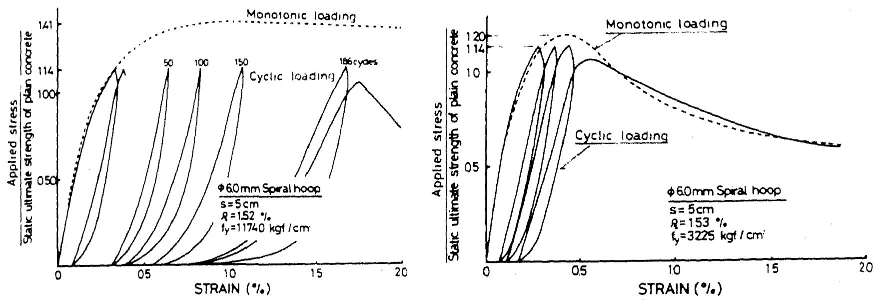

Fig. 3 Typical stress-strain curves for cylinder specimens under cyclic high intensity axial loadings

yield strength one. The stable stress-strain hysteretic curves are observed in the former in comparison with those in the latter.

Also, the stress-strain relationship of confined concrete with various yield strength of hoop reinforcement was idearized by the author basing on the measured stress-strain curves. Details are omitted in this report (see Ref. 9).

IMPROVING THE CURVATURE DUCTILITY IN PRESTRESSED CONCRETE BEAMS BY HIGH YIELD STRENGTH LATERAL CONFINING REINFORCEMENT

The prestressed concrete beam shows relatively smaller curvature ductility in comparison with the ordinary reinforced concrete one, and thus the improving of its' curvature ductility is necessary for successful use in the seismic area. To verify the possibility of flexural ductility improvement by the use of high yield strength lateral confining reinforcement, monotonous loading tests were carried out on three post-tensioned bonded beams laterally confined by high yield strength rectangular spiral reinforcement and corresponding three beams confined by ordinary yield strength one. The beams are 16 x 21 cm in rectangular cross sectional dimension with 14 x 19 cm in confined concrete core dimension shown in Fig. 4. As the confining reinforcement, ϕ6 mm round bar with 11,740 kgf/cm^2 in yield strength was used in the former beam specimens and that of 3,600 kgf/cm^2 in the latter ones. Three different pitches of 2.5, 5.0 and 7.5 cm in confining reinforcement are prepared in corresponding to the volumetric ratio of 2.81, 1.40 and 0.94 %, respectively. The mix proportion of concrete was 1 : 2.17 : 2.65 by weight with the water cement ratio of 45 %. The compressive strength of concrete at the age of beam tests (at 5 weeks) was 354 kgf/cm^2 in average. After casting the concrete, the beams were wet-cured until the test age. At the age of two weeks, the prestressing force of 19.4 tons in nominal was transmitted in each beam by ϕ 21 mm straight prestressing steel bar in the eccentricity of 3.5 cm.

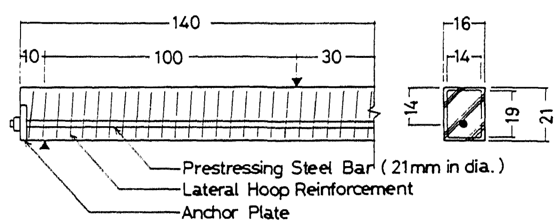

Fig. 4 Scheme of test specimen and loading condition (unit : cm)

In addition, two beams confined by ϕ6 mm confining reinforcement of 2.5 cm in pitch were prepared in the same manner for repeated high-over loading tests, where one is confined by high yield strength rectangular spiral reinforcement and remaining by ordinary yield strength one.

The loading tests were carried out under the loading condition shown in Fig. 4, and compressive and tensile fiber strains at midspan section were measured by the electric displacement transducer in the guage length of 50 cm, from which the flexural curvature was calculated.

Moment-curvature relations obtained from the monotonous loading tests are shown in Fig. 5 and Fig. 6, respectively. From these figures, it can be seen the the degree of ductility improvement becomes larger as the increase of volumetric ratio of lateral confining reinforcement. Especially, in case of the specimen with the confining reinforcement of high yield strength with the pitch of 25 mm, (Specimen BH25M), excessively large post peak deformation was

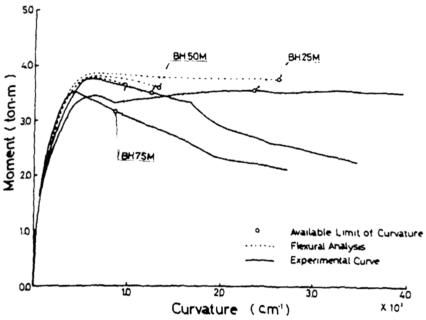

Fig. 5 Measured and calculated moment-curvature curves for beams with the confining reinforcement of high yield strength

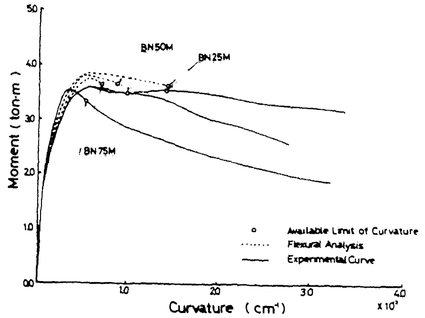

Fig. 6 Measured and calculated moment-curvature curves for beams with the confining reinforcement of ordinary yield strength

observed without any obvious decrease of load carrying capacity. Such a considerably ductile curvature deformation seems to be owing to the improvement in compressive deformation capability of concrete by using the lateral reinforcement of high yield strength.

For the quantitative comparison of degree of curvature ductility improvement, the curvature at which the compressive fiber strain of confined core concrete reaches at the available limit of strain in the stress-strain curve described in previous section is indicated on the measured curves in Fig. 5 and Fig. 6 . In this study, such a curvature is names as the available limit. In Table 1, the available limits of curvature obtained are summarized with the values at the yield load.

Table 1 Available limit of curvature and ductility ratio

Beam No.	Confining reinforcement		Curvature at yielding		Available limit of curvature		$Ø_a/Ø_y$	$Ø_{ac}/Ø_{yc}$
	pitch cm	f_y* kgf/cm²	$Ø_y$(observed) $\times10^{-3}cm^{-1}$	$Ø_{yc}$(calculated) $\times10^{-3}cm^{-1}$	$Ø_a$(observed) $\times10^{-3}cm^{-1}$	$Ø_{ac}$(calculated) $\times10^{-3}cm^{-1}$		
BH25M	2.5	11700	0.58	0.695	2.32	2.63	4.00	3.78
BH50M	5	11700	0.56	0.540	1.20	1.33	2.14	2.46
BH75M	7.5	11700	0.43	0.476	0.83	0.97	1.93	2.04
BN25M	2.5	3060	0.58	0.565	1.42	1.47	2.45	2.60
BN50M	5	3060	0.58	0.476	1.03	0.91	1.78	1.91
BN75M	7.5	3060	0.37	0.494	0.55	0.73	1.49	1.48

* 0.2% off-set stress

As a reference, the moment-curvature relationships calculated by using the idearized stress-strain curve of confined concrete (Ref. 9) are plotted in Fig. 5 and Fig. 6 by broken lines with the indication of available limit of curvature. Good agreement are obtained between experimental and calculated results.

Fig. 7 and Fig. 8 show the midspan deflection hysteretic curves obtained from repeated high-over loading tests on additional beams. Test results showed that even under the repeated high-over load, the deflection ductility can be considerably improved by using the closely spaced lateral confining reinforcement. Especially, it can be emphasized from the comparison between the hysteretic curves in Fig. 7 and Fig. 8 that the improving of the flexural ductility becomes excessively large in case of the confining reinforcement of high yield strength, which provides the extremely stable hysteretic load-deflection characteristics in a plastic range without any decrease of load carrying capacity.

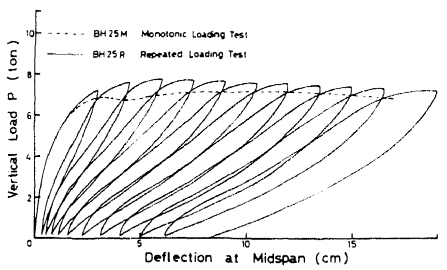

Fig. 7 Load-deflection hysteretic curve on the beam with the confining reinforcement of high yield strength

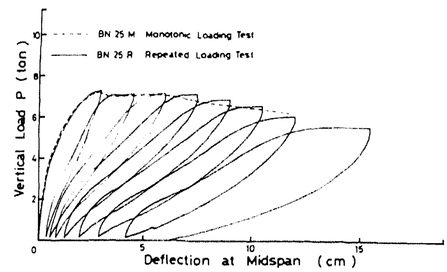

Fig. 8 Load deflection hysteretic curve on the beam with the confining reinforcement of ordinary yield strength

IMPROVING THE FLEXURAL DUCTILITY OF REINFORCED CONCRETE COLUMN BY HIGH YIELD STRENGTH LATERAL CONFINING REINFORCEMENT

The improving of ductility in columns is also quite important to secure the ductility of frame itself because the rupture of the column immediatly leads to the collapse of total frame as a structure. From such consideration, the possibility of improving the flexural ductility of columns by using high yield strength spirals were also investigated in this study.

The specimens used are 20 x 20 cm in full sectional dimension with the core of 18 x 18 cm and are confined by ϕ6 mm square spiral hoops with 11,240 kgf/cm^2 and 3,165 kgf/cm^2 in yield strength. The pitches were 3 cm and 6 cm, which correspond to the volumetric ratios of 1.68 % and 0.84 %, respectively. In Fig. 9, the schematic figure of specimen is shown. The target compressive strength of concrete was 200 kgf/cm^2. The tests were carried out by means of applying the flexural load under the action of various magnitudes of constant axial load.

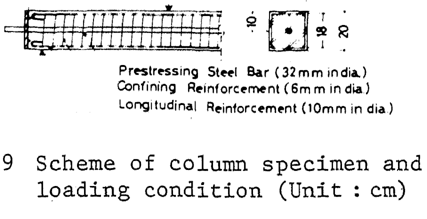

Fig. 9 Scheme of column specimen and loading condition (Unit : cm)

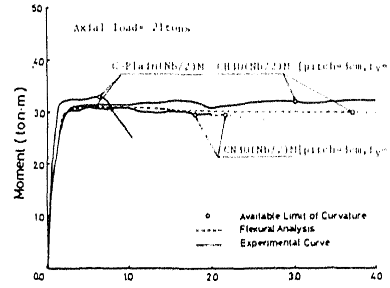

Fig.10 Measured and calculated moment-curvature curves for columns with various strength hoop reinforcement

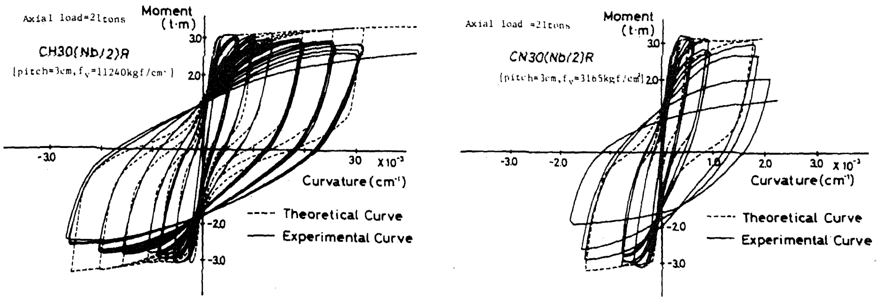

Fig. 11 Measured and calculated moment-curvature hysteretic curves for columns with various yield strength hoop reinforcement

The typical moement-curvature relationships as well as the typical hysteretic moment curvature curves obtained are shown in Fig. 10 and Fig. 11. Also the test results are plotted on the calculated moment- and the curvature-axial load interaction curves in Fig. 12. As can be seen in these figures, the rotational capacity of the column can be also significantly improved by using the high yield strength hoop reinforcement even under considerably high axial load.

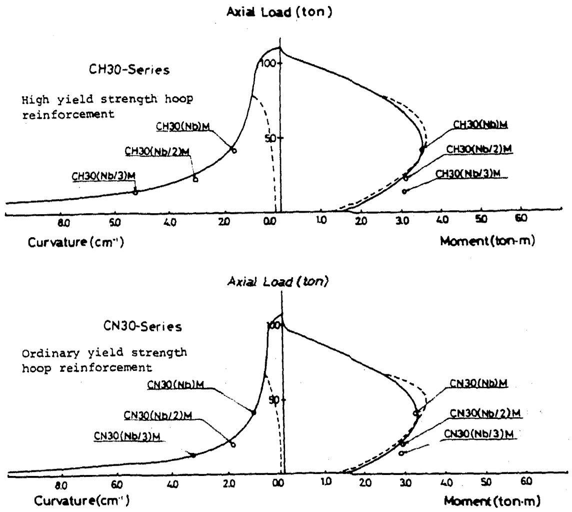

Fig. 12 Calculated moment- and curvature-axial load interaction curves for columns specimens

CONCLUSIONS

From the test results, following conclusions can be derived.

1) Lateral confinement of concrete by high yield strength lateral reinforcement can remarkably enhance the compressive ductility of concrete subjected to uniaxial load in comparison with that by ordinary strength lateral reinforcement. Such confinement is also very effective for preventing the early fatigue failure of concrete under high intensity repeated load.

2) The flexural ductility of prestressed concrete beams, which is generally supposed to be undesirably small compared with ordinary reinforced concrete beams, can be considerably improved by using the confined concrete with high yield strength lateral reinforcement not only under monotonous load but also under repeated high-over load.

3) Also, in case of ordinary reinforced concrete column subjected to combined axial load and flexural moment the use of such confined concrete enables to increase significantly the curvature ductility.

4) As the test results obtained in this study concern, it can be recommended that the steel having the yield strength more than 10,000 kgf/cm^2 is desirable to use as a lateral confining reinforcement for full improvement of flexural ductility in the prestressed concrete and the ordinary reinforced concrete flexural members.

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