CONFINEMENT EFFECTS OF WEB REINFORCEMENTS ON REINFORCED CONCRETE COLUMNS

by

Takayuki SHIMAZU [I] and Masafumi HIRAI [II]

SYNOPSIS

The axial stress-strain relationships were first established, taking into consideration the confinement effects of such variables on web reinforcements as amount ratio, diameter, spacing and shape enclosed, (circular or square) based on a number of small specimens test results for concentric axial loading done in Japan. Secondly, the outline of tests done on reinforced concrete square columns with several web reinforcement amounts, subjected to eccentric axial loading were presented with the moment-curvature relationships of the test results being examined by using the axial stress-strain relationships established above and with the strain distribution of a hoop bar provided.

INTRODUCTION

The importance of hoops in improving the eathquake resistance capabilities of columns has been very evident both from the damages of columns of buildings due to many great earthquakes and from the results of a number of tests on columns, subjected to lateral loads. The quantative understanding has, however, not yet been obtained on the confinement effects of hoops on reinforced concrete columns. In this paper are presented the results of two parts of the investigation taken as a first step to get this understanding.

AXIAL STRESS STRAIN RELATIONSHIPS

The results of the tests as shown in Bibliography were examined. In Table 1 is shown the ranges of variables in each test. In this paper web reinforcement ratio (hoop ratio) is defined as the ratio of a hoop volume to concrete volumes enclosed by a hoop, that is,

$$P_W = \pi\phi^2{}_W / (D \cdot S) = \pi(\phi_W / D)^2 \cdot (D / S) \qquad (1)$$

where ϕ_W = hoop bar diameter, D = distance between both sides of a hoop and S = interval of hoops. This P_W can be transformed into as shown above. In Fig. 1 is plotted the ratios of maximum stress of specimens to that of specimens without hoops, with the abscissa being P_W. In Fig. 2 is also plotted the ratios of strain at maximum stress of specimens. It is found from these figures that the strain at maximum stress increase more remarkably with web reinforcement ratios regardless of circular, or square sections than the maximum stress.

I Assoc. Prof., University of Hiroshima, Dr. of Eng.

II Technical Officer, University of Hiroshima

Many researches have so far been made on the effects of lateral pressure on concrete strength and the following expression has been presented by Richart et. al.

$$\sigma_0 = c\sigma B + 4.1 \text{ fs.} \tag{2}$$

where σ_0 = maximum stress $c\sigma B$ = maximum stress of unconfined concrete, fs = lateral pressure. This can be transformed into, as below for the case of hoop confinements as shown in Fig. 5, if the confinement effects are assumed uniformly distributed both along circumference of section and along length.

$$\sigma_0 / c\sigma B = 1 + 2.05\ P_W \cdot s\sigma y / c\sigma B \tag{3}$$

where $s\sigma y$ = yield strength of hoop bar. Uniform distribution will be, however, valid if the section is circular and hoops are very densely arranged, that is, hoop bar diameter is very small in the range of ordinary ratio of web reinforcement. The confinement effects are, in general, assumed smaller than that calculated based on the equation (3).

In Fig. 4 are plotted the values K_1 of $(\sigma_0 / c\sigma B - 1) / (2.05\ P_W \cdot s\sigma y / c\sigma B)$ calculated for each specimen with the abscissa being $(\phi_W / D)\,2$ which is in inverse proportion to D / S as shown in the equation (1). There is a scatter but the following equations can be obtained on the average.

$$K_1 = \begin{cases} 1 - 100\,(\phi_W / D)\,2 & \text{for circular section} \\ 0.5 - 50\,(\phi_W / D)\,2 & \text{for square section} \end{cases} \tag{4}$$

In Fig. 5 are similarly plotted the values K_2 of $(\epsilon_0 / c\epsilon B - 1) / (2.05\ P_W \cdot s\sigma y / c\sigma B)$ calculated for each specimen where ϵ_0 $(c\epsilon B)$ = strain at maximum stress (of unconfined concrete). There is a larger scatter but the following equations can be obtained to some extent conservatively.

$$K_2 = \begin{cases} 2 - 200\,(\phi_W / D)\,2 & \text{for circular section} \\ 1 - 100\,(\phi_W / D)\,2 & \text{for square section} \end{cases} \tag{5}$$

These equations results in the following relation for both sections.

$$2\,(\sigma_0 / c\sigma B - 1) = \epsilon_0 / c\epsilon B - 1 \tag{6}$$

That strength effects of square section is one half of that of circular section as seen above, can be explained by the assumption that concrete consists of many particles as shown in Fig. 6. For square section, confinement effects can be expected only to four corners of section that means, vertically two dimensional effects while the effects are vertically three dimensional for circular section as shown in Fig. 6.

TEST OF ECCENTRIC LOADING

Eccentric loading test of square section columns has been conducted in order to examine axial stress-strain relationship mentioned in the preceding section, for the members subjected to eccentric loading and also to get strain distribution in a frame of hoop bar under eccentric loading. The details and properties of specimens are shown in Fig. 7 and Table 1 respectively. Double spiral hoops were mainly used as web reinforcement in connections to other kinds of tests. The material strength of longitudianl bar, hoop and concrete were about 4.6 t/cm^2 ($s\sigma y$), 4.5 t/cm^2 ($s\sigma B$) and 0.30 t/cm^2 ($c\sigma B$) respectively. Compression loading with eccentricity of one-sixth were applied with several times unloading-reloading, up to ultimate (Fig. 9). Deflection and strains were measured. (Fig. 7). From these tests the following were summarized: 1) Load-deflection curve (envelope) can be approximately estimated by using the axial stress strain relationship mentioned in the preceding section and assuming polynominal expression between zero point and the point of maximum stress (Fig. 8 and 13). 2) It is found that a truss consisting of both hoop bar frame and the assumed compression members drawn between the centroid of compression force and four corners of the frame, is, particularly in the range of large deflection, formed, not only for concentric but also eccentric loading, by comparing the axial strains at four sides in hoop frame (Fig. 10–11)

CONCLUSIONS

The main conclusions of these studies are as follows: 1) Broadly general expressions were proposed on axial stress-strain relationship taking into considerations confinement effects of hoops. It is however necessary to investigate various effects, due to welding of hoop anchor or longitudinal bars or size of members, in order to establish more precise expressions. 2) Further researches are much needed to clarify the confinement effects of hoops in the behaviour of members subjected to combined loads such as axial loading of various eccentricities or bending under constant axial load or both bending and shear under axial load.

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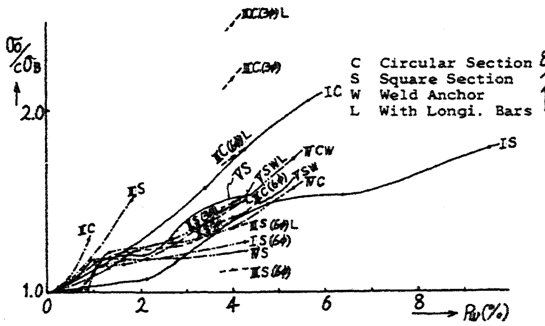


Fig. 1 Maximum Stress Ratio - Hoop Reinforcement Ratio

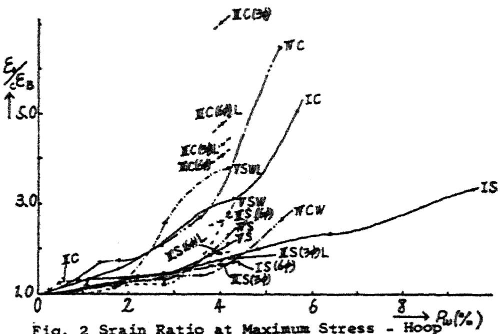


Fig. 2 Srain Ratio at Maximum Stress - Hoop Reinforcement Ratio

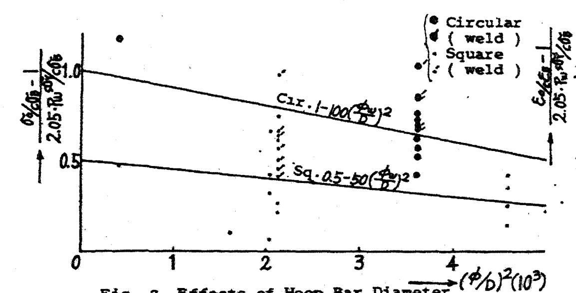


Fig. 3 Effects of Hoop Bar Diameter on Maximum Stress

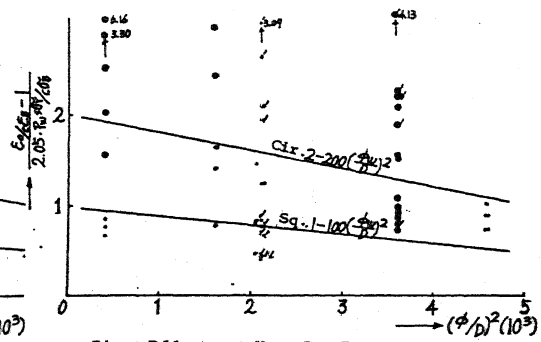
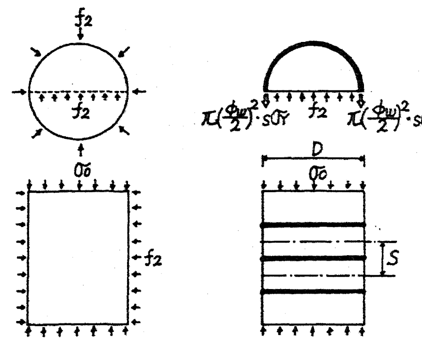
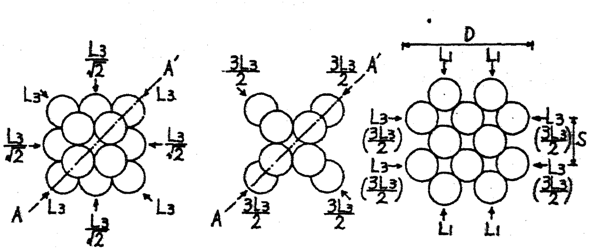


Fig.4 Effects of Hoop Bar Diameter on Strain at Maximum Stress



(a) Under Lateral Pressure (b) Hooped Column

Fig. 5 Effects of Lateral Pressure or Hoops



(Circular Section) (Square Section) (A - A' Section)

Fig. 6 Resistance Mechanism of Particles Model

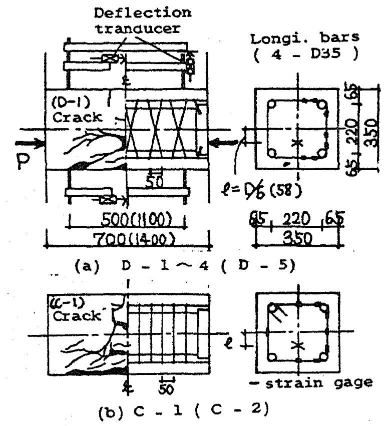


Fig. 7 Reinforcement Arrangements, Loading and Measuring Methods and Crack Patterns

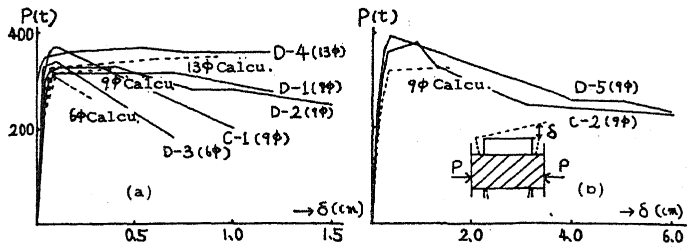


Fig 8 Load - Deflection Curves (Envelope)

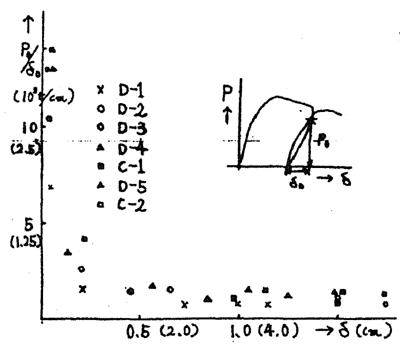


Fig. 9 Slope at Unloading

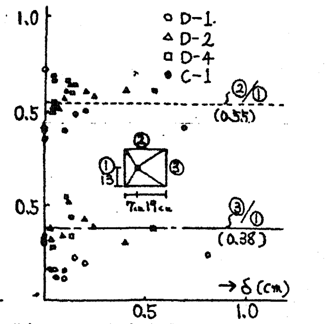


Fig. 10 Axial Strain Ratios of Other Two Sides to Compression Side in Hoop

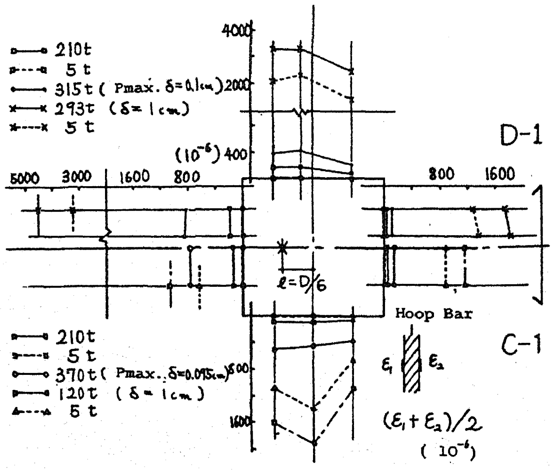


Fig. 11 Axial Strain Distribution in Hoop illustrated

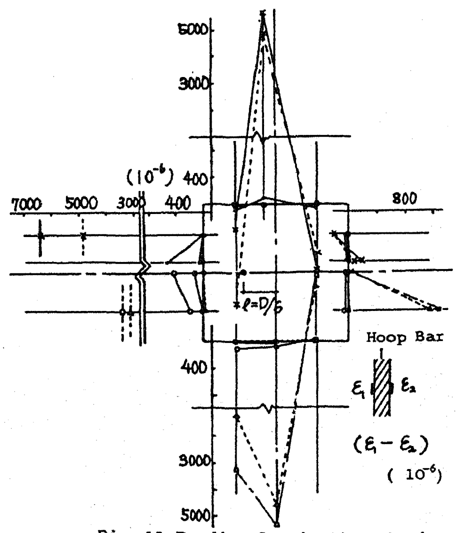


Fig. 12 Bending Strain Distribution in Hoop illustrated

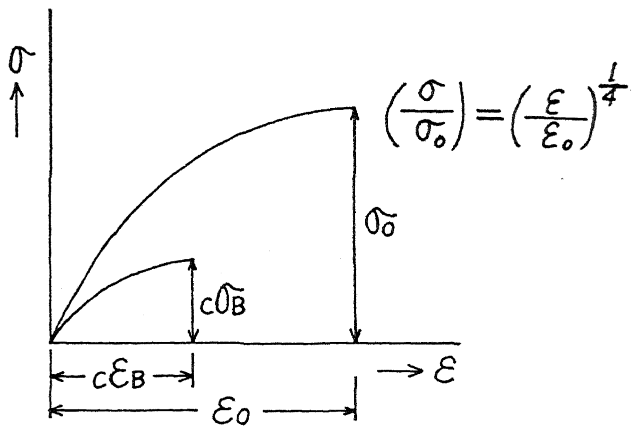


Fig. 13 Stress - Strain Curves

Table 1 Ranges of Variables in Each Test

	Specimen size	Hoop(ϕ_w)	p_w(%)	$_s\sigma_Y$(kg/cm²)	$_c\sigma_B$(kg/cm²)	Remark
I	15cm C x30cm 13.3cm S×30cm	9φ 9φ 6φ	1.7 ~ 5.65 0.96 ~ 9.56 0.85 ~ 4.25	3230 〃 2800	204 280 286	
II	15cm C x30cm 15cm S x30cm	3φ	0.225 ~ 0.9 1.82	3000	280 250	With longi. bars(8-6φ)
III	the same as above	3φ, 6φ 3φ, 6φ	4.0	2090 2880	180 201	With longi. bars(8-6φ) (half)
IV	10cm C x20cm 13cm S x30cm	6φ	1.33 ~ 5.31 0.92 ~ 4.15	2800	407 355 230	Weld Anch. for Hoops
V	13cm S x30cm	6φ	0.64 ~ 4.15 0.59 ~ 2.76 0.64 ~ 4.15	〃	269 286 264	Weld anch. Weld anch. with 4-9φ

1) C = Circular Section S= Square Section
2) Cover is all very thin

Table 2 Kinds of Specimens and Test Results

Spec.	Leng. (mm)	Hoop				First Crack		Maximum		※ Def. 1cm (4cm)	
		※ p_s (%)	Dia.	Ang. to Lo.	Weld	P_1 (t)	Def. (10^{-2}cm)	P_{max}(t)	Def. (10^{-2}cm)	P_2 (t)	P_2/P_{max}
D-1	700	1.71	9φ	Abo. 77°	weld	180	3.3	315	10.0	293	0.93
D-2	〃	1.71	〃	〃	no	315	6.0	330	14.0	278	0.84
D-3	〃	0.87	6φ	〃	weld	300	2.0	340	10.0	140	0.41
D-4	〃	3.39	13φ	〃	〃	330	1.8	370	54.3	360	0.97
D-5	1400	1.71	9φ	〃	〃	240	13.4	390	37.5	(240)	0.62
C-1	700		〃	90°	no	315	4.8	370	9.5	210	0.57
C-2	1400		〃	〃	〃	240	12.9	375	86.0	(226)	0.60

p_s: a hoop volume divided by concrete enclosed by a hoop

DISCUSSION

R.Y. Soni (India)

1. Many authors do not consider increase of strength of concrete due to confinement in columns, whereas in pure compression, there is an increase in strength. In fact the codes allow for increase of strength in confined columns for vertical loads. What is your observation on this point?

2. The ultimate strain in concrete in columns subjected to bending and axial force is a function of not only volume of web reinforcement but also dependent on the size of aggregates the depth of neutral axis, the aspect ratio of column dimensions and the spacing of longitudinal reinforcement. How these factors likely to be accounted for ?

Author's Closure

With regard to the question of Mr. Soni, we wish to state that it seems to the authors that the reason why many other authors consider only the effects on ductility due to confinement is that the effect on strength is smaller than that of ductility and is greatly influenced by reinforcing methods, such as the welding of web reinforcements. However the authors recommend that the strength increase due to confinement should be thoroughly evaluated because it directly influence the strength and ductility of the columns subjected to both axial force and bending.

2. The authors agree that the ultimate strain is influenced by not only volume of web reinforcement but also many other factors which essentially have relations with both material and geometrical properties of columns. However we conclude that the most important factor in improving the strain capacity is the volume and, in next, the spacing of web reinforcements although the effects of these other factors should be made clear quantatively.