[2121] 鉄筋コンクリート柱のせん断終局強度に及ぼすせん断補強量及び軸力の影響に関する実験研究

EFFECT OF THE AMOUNT OF SHEAR REINFORCEMENT AND AXIAL FORCE ON THE ULTIMATE SHEAR STRENGTH OF RC COLUMNS

Tetsumitsu EIGAWA*, Seiji KOKUSHO**,
Yasuhiro MATSUZAKI*** and Katsumi KOBAYASHI****

1. INTRODUCTION

Recently, deformed high strength steel bar (ULBON) has been used in engineering field widely as shear reinforcement of reinforced concrete beams and columns, especially in high-rise reinforced concrete buildings. This kind of steel can be shaped in circular, rectangular and square spiral automatically by cold work according to design requirement. (See Photo.1).

In order to utilize further this high strength steel for structural design effectively, series of RC beams with combination of high strength concrete had been tested (1). The relation between the ultimate shear strength τu and the product of Pw and $w\sigma y$ (Pw: shear reinforcement ratio, $w\sigma y$: yield strength of shear reinforcement) is given in Fig.1. As shown in the figure, in the range of high $Pw \cdot w\sigma y$ the shear reinforcement did not yield and the failure mode was shear compression of concrete. It is expected that the shear compression failure mode will occur easily in case that the compressive axial force is applied. Therefore the objective of this experimental study reported here is to investigate the effects of the amount of shear reinforcement and axial force on the ultimate shear strength of RC columns with the high strength shear reinforcement.

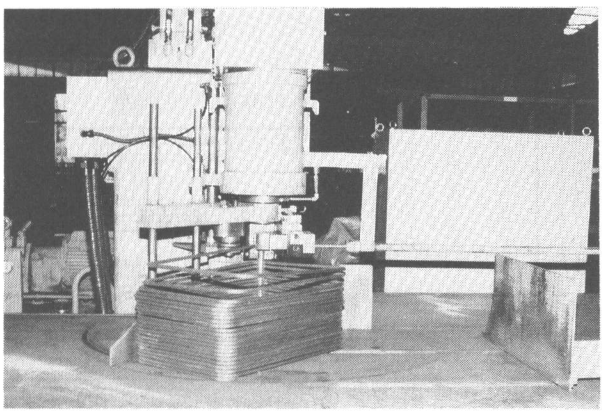


Photo.1 Manufacturing of ULBON spiral

* Prestressing Steel Div., Neturen Co.,Ltd.
** Research Laboratory of Engineering Materials, Tokyo Inst. of Tech.
*** Department of Architecture, Tokyo Science University
**** Department of Architecture, Fukui University

2. OUTLINE OF EXPERIMENT

2.1 SPECIMENS AND MATERIALS

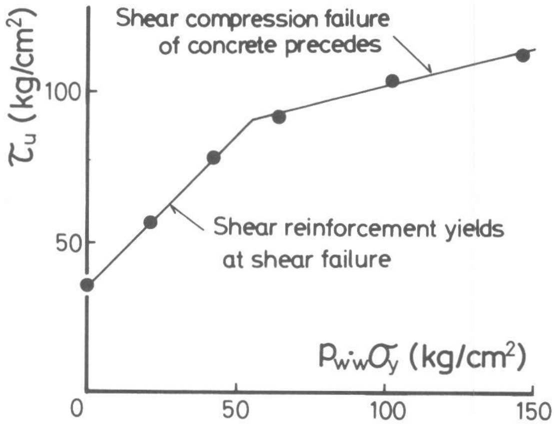


Fig.1 Test results of RC beams

The details of the specimens are given in Fig.2. All the specimens had same cross section (b x D = 15cm x 27cm), and same shear span to depth ratio (1.5). The interval of rectangular spiral shear reinforcement was fixed to be 7.36cm. It was considered desirable to let the columns fail in shear. For this purpose, longitudinal reinforcements with high yield strength of 8,790 kg/cm^{2}had been arranged. Five longitudinal deformed bars of 13mm in dia. were placed in two layers on both compressive and tensile sides of the column. The variables were compressive axial stress σ_o (N/bD, N: applied axial force) and the value of $P_w \cdot {}_w\sigma_y$. Compressive strength of concrete cylinder (ϕ10cm x 20cm) and yield strength of shear reinforcement at 0.2% offset were shown in Table 1.

2.2 TEST PROCEDURE

Figure 3 shows the loading apparatus and Fig.4 shows the measuring system. The axial force (N) was applied by oil jack with pin-joints on both ends and was kept constant during the test. The horizontal force (P) was

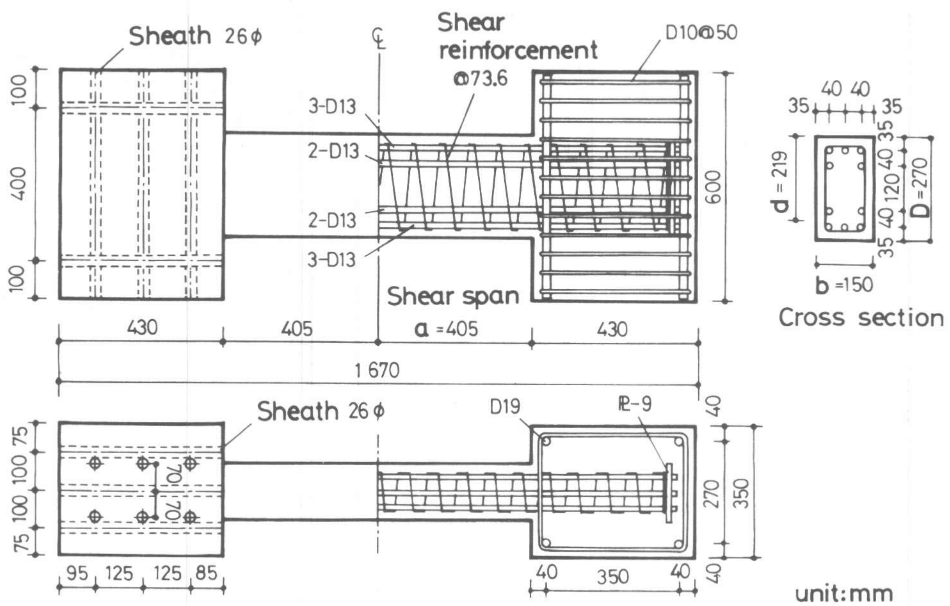


Fig.2 Details of specimens

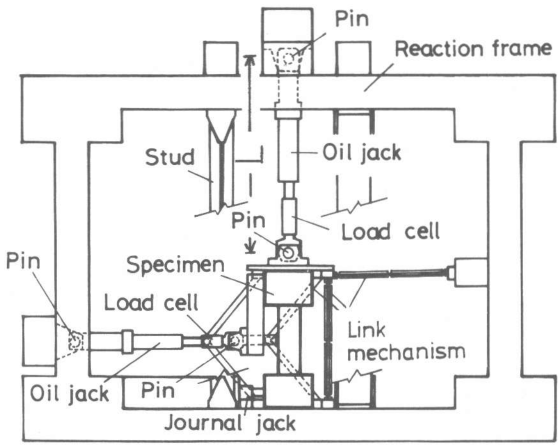
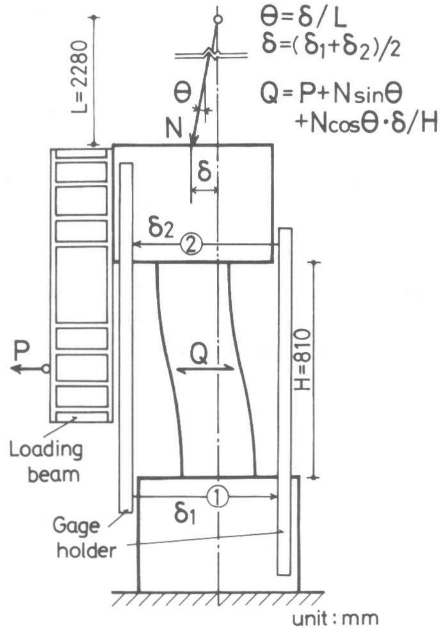


Fig.3 Loading apparatus

introduced monotonically also by oil jack until the column was destroyed. The link mechanism was set in three phases orthogonal to each other in order to restrain the relative rotation of the upper and lower stubs. The relative horizontal displacement δ was estimated as average of δ_1 and δ_2 as indicated in Fig.4. Shear force Q was counted as the sum of the applied horizontal force P, the horizontal component of applied axial force ($N \sin\theta$), and the equivalent horizontal force ($N \cos\theta \cdot \delta / H$) calculated based on the assumption that the additional bending moment caused by the axial load was linearly distributed along the axis of the column.



L: length between the pin joints (See Fig.3)
H: height of column
θ: inclination angle of applied axial force with axis of column

Fig.4 Measuring system

3. TEST RESULTS

3.1 RELATIONSHIP BETWEEN τ_u AND $P_w \cdot {}_w\sigma_y$

The list of test results are shown in Table 1 and the relation between the ultimate shear strength τ_u and $P_w \cdot {}_w\sigma_y$ are shown in Fig.5. In the figure, the specimens in which the yielding of shear reinforcement were observed at the stage of shear failure and the specimens without shear reinforcement are indicated by open marks. While the specimens in which the yielding of shear reinforcement was not confirmed at the stage of shear failure are indicated by solid marks. The region of $P_w \cdot {}_w\sigma_y$ tended to be narrow in which the shear reinforcement yielded, as the compressive axial stress σ_o increased, while the region of $P_w \cdot {}_w\sigma_y$ tended to be wide in which the shear compression failure occurred. In the region where the shear reinforcement developed to yield, the ultimate shear strength τ_u increased

Table.1 Specimens and test results

Specimen's name	σ_o (kg/cm^2)	Ds (mm)	$_w\sigma_y$ (kg/cm^2)	Pw $_w\sigma_y$ (kg/cm^2)	$_C\sigma_B$ (kg/cm^2)	Qu exp (ton)	τ_u exp (kg/cm^2)
C00-0	3			0	353	9.2	32.0
C00-32N	3	3.2	6370	9.3	331	9.5	33.1
C00-40N	3	4.0	6230	14.2	331	11.9	41.3
C00-32H	3	3.2	13100	19.1	331	13.9	48.4
C00-40H	3	4.0	13000	29.6	331	15.8	54.8
C00-50H	3	5.0	14000	49.8	353	18.2	63.4
C00-60H	3	6.0	14200	72.7	353	19.5	67.9
C00-74H	3	7.4	14500	105.0	353	21.4	74.4
C02-0	72			0	367	13.7	47.7
C02-32N	72	3.2	6370	9.3	352	14.3	49.9
C02-40N	72	4.0	6230	14.2	352	16.2	56.4
C02-32H	72	3.2	13100	19.1	352	15.9	55.4
C02-40H	72	4.0	13000	29.6	352	17.2	59.8
C02-50H	72	5.0	14000	49.8	367	18.7	65.2
C02-60H	72	6.0	14200	72.7	367	19.2	66.8
C02-74H	72	7.4	14500	105.0	367	20.8	72.2
C04-0	144			0	346	18.0	62.6
C04-32N	144	3.2	6370	9.3	366	15.8	55.1
C04-40N	144	4.0	6230	14.2	366	16.5	57.4
C04-32H	144	3.2	13100	19.1	366	17.8	61.9
C04-40H	144	4.0	13000	29.6	366	17.5	60.9
C04-50H	144	5.0	14000	49.8	346	18.2	63.3
C04-60H	144	6.0	14200	72.7	346	18.8	65.4
C04-74H	144	7.4	14500	105.0	346	19.4	67.5
C06-0	216			0	358	17.2	59.7
C06-32N	216	3.2	6370	9.3	295	17.2	59.7
C06-40N	216	4.0	6230	14.2	295	17.7	61.6
C06-32H	216	3.2	13100	19.1	295	17.0	59.3
C06-40H	216	4.0	13000	29.6	295	16.3	56.8
C06-50H	216	5.0	14000	49.8	358	20.9	72.6
C06-60H	216	6.0	14200	72.7	358	19.6	68.3
C06-74H	216	7.4	14500	105.0	358	21.1	73.4

Notes:

In specimen's name, the first letter "C" means column, the next two numerals represent axial force ratio ($\sigma_o/_C\sigma_B$) and the next two numerals after a hyphen represent the diameter of shear reinforcement ("0" represents no shear reinforcement). The last letter means type of shear reinforcement ("N" means normal strength steel bar, "H" means high tension steel bar).

σ_o : Compressive axial stress (N/bD, N: Applied axial force)
Ds : Diameter of the shear reinforcement
$_w\sigma_y$: Yield strength of shear reinforcement (0.2% offset)
Pw•$_w\sigma_y$: Product of shear reinforcement ratio (Pw) and $_w\sigma_y$
$_C\sigma_B$: Compressive strength of concrete cylinder (ϕ10cm x 20cm)
Qu exp: Maximum shear force in experiment
τ_u exp: Shear stress at maximum shear force (Qu exp/bj, j=19.2cm)

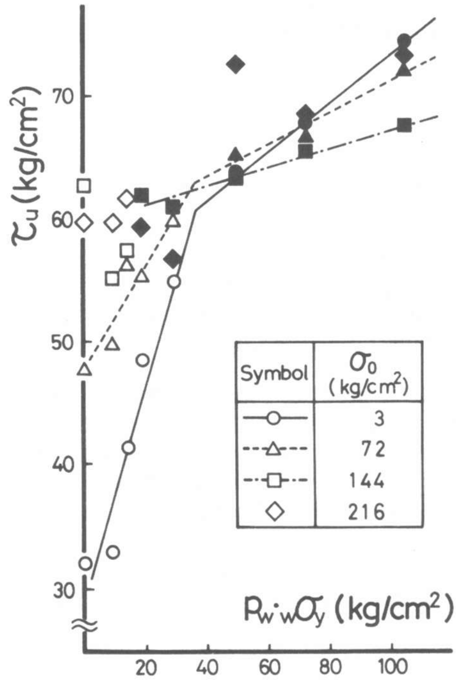


Fig.5 τ_u - $P_w \cdot {}_w\sigma_y$ relation

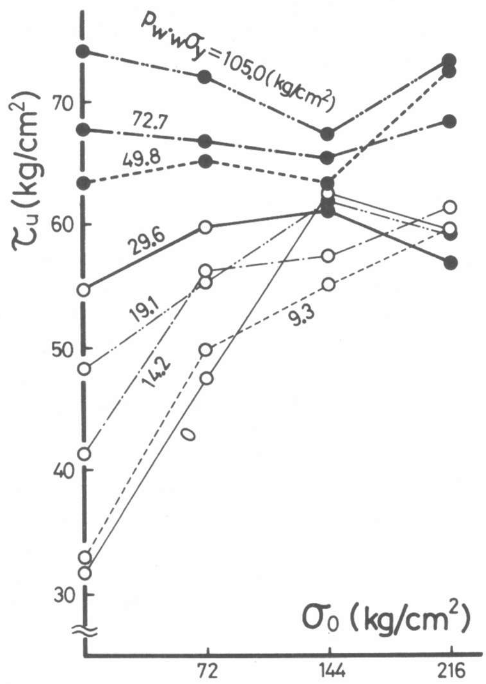


Fig.6 τ_u - σ_o relation

with increasing of the compressive axial stress σ_o. For the specimens of shear compression failure mode in which shear reinforcement did not reach to yield, τ_u tended to decrease with increasing of σ_o, and the slope of increasing of τ_u due to the increase of $P_w \cdot {}_w\sigma_y$ became gentle in the region that σ_o was less than 144 kg/cm^2. For the group of σ_o = 216 kg/cm^2, the test results were scattered because it was difficult to catch accurate data due to the high axial compressive force.

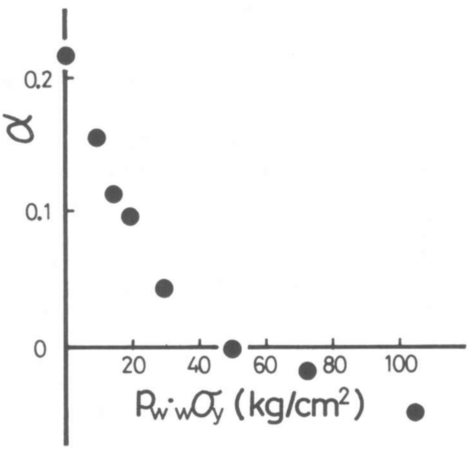


Fig.7 α - $P_w \cdot {}_w\sigma_y$ relation

3.2 RELATIONSHIP BETWEEN τ_u AND σ_o

The relation between the ultimate shear strength τ_u and the compressive axial stress σ_o is shown in Fig.6. In the region that σ_o was less than 144 kg/cm^2, the increment of τ_u due to the increase of σ_o tended to decrease with increase of $P_w \cdot {}_w\sigma_y$. In the figure, the coefficient α was obtained by the least square method as the increment ratio of τ_u to the increase of σ_o in the region that σ_o was less than 144 kg/cm^2. The relation between α and $P_w \cdot {}_w\sigma_y$ is shown in Fig.7. The ultimate shear strength of column with compressive axial force can be evaluated as the sum of τ_u of column without axial force and the contribution of compressive axial force $\alpha \cdot \sigma_o$. The provision bases on the proposal revised Arakawa's equation α is 0.1

constantly (2). In this experiment, it is shown that α is variable with the value of $Pw \cdot w\sigma y$, and the value of $Pw \cdot w\sigma y$ for which α is estimated to be 0.1, is near 20 kg/cm^2.

4.CONCLUSIONS

(1) In the range of low $Pw \cdot w\sigma y$, shear reinforcement develops to yield at the stage of shear failure, while in the range of high $Pw \cdot w\sigma y$, shear compression failure of concrete precedes the yielding of shear reinforcement. However, it is also observed that the range of $Pw \cdot w\sigma y$ becomes narrow in which shear reinforcement develop to yield at the stage of shear failure as the compressive axial force increases.

(2) In case that shear reinforcement develop to yield, the ultimate shear strength increases with increasing of the compressive axial force. On the contrary, in case that the shear reinforcement does not develop to yield, shear compression failure occurs, and the ultimate shear strength of column tends to decrease as the compressive axial force increases.

(3) In case of the presence of compressive axial force, the ultimate shear strength is strongly affected by the value of $Pw \cdot w\sigma y$ as well as the amount of σo

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