EXPERIMENTAL STUDY ON REINFORCED CONCRETE COLUMNS WITH DOUBLE SPIRAL WEB REINFORCEMENTS

by

Hajime UMEMURA I), Takayuki SHIMAZU II), Shinichi TADEHARA III),
Teruhiko KONISHI IV), Yuhei ABE V)

SYNOPSIS

This paper presents the experimental studies carried out on reinforced concrete columns with double-spiral web-reinforcements wound and welded on logitudinal bars by the machine which has been developed, aiming at the prefabrication of reinforcement bars assemblages as well as the improvement of columns as regards to earthquake resistance capacities. About thirty specimens have been tested, subjected to alternating repeated anti-symmetric loads with constant axial load. The variables considered in this investigation are shear span ratio, axial load level, the amount and diameter of web reinforcement, the angle between web and longitudinal reinforcements and the with or without welding between both the reinforcements. It has been found from the tests that double spiral web reinforcements are much more effective for reinforced concrete columns than conventional web reinforcements.

INTRODUCTION

One of the most important factors in the Structural design of tall buildings in such countries having large seismic loads as Japan, is how to obtain sufficient shear strength for the columns with small shear span ratio. The objective of this paper is to review recent reseach(4) carried out at University of Hiroshima, on reinforced concrete columns, made from the reinforcement bars assemblages fabricated by the machined as shown in Fig. 1(2) and to use these results to provide a means of determining seismic design for columns with double spiral web reinforcements.

I) Prof. University of Tokyo, Dr. of Eng.
II) Assoc. Prof. University of Hiroshima, Dr. of Eng.
III) Assistant, Hiroshima Institute of Technology
IV) Senior Chief Engineer, Japan Public Corporation of Housing
V) Chief Engineer, Japan Public Corporation of Housing

TEST PROGRAM

The tests specimens, as shown in Fig. 2, are one-third full scale of the columns which are subjected to anti-symmetrical lateral loading with or without constant axial load as shown in Fig. 4. The variable elements of the specimens are shown in Table 1. Structural deformed bars SD35 (D25, ${}_{s}\sigma_{r}$ = 3.82 t/cm^2 and D29, ${}_{s}\sigma_{r}$ = 3.75 t/cm^2) were used as logitudinal reinforcements in columns and steel wire (5ø, 9ø) and structural round bars SR24 (9ø) were used as double spiral hoops (web reinforcements) and conventional hoops respectively. The stress strain curves for these hoop materials are shown in Fog. 3. The ordinary mixed concrete consisted of portland cement, river sands and usual size aggregates were used and their compressive strength of cylinder are shown in Table 1. Specimens were subjected to more than ten times alternating lateral loads up to ultimate to study their hysteretic loop characteristics. The relative displacements due to the rotation between both up and down gauge houlders were measured as shown in Fig. 4. The strains for both reinforcements and concrete were also measured by using wire strain gauges.

TEST RESULTS

The results of tests are shown in Table 2 and illustrated in Fig. 5-6. Based on the results of 26 tests, the following trends were observed:

(1) The maximum load of double spiral hoop specimens without axial load is about 30% higher, regardless of the shear span ratio and web reinforcement ratio, than that of conventional hoop specimens with the same ratio of web reinforcement. It is about 24% and 15% higher for the specimens with axial load of 36.7 kg/cm^2 and 73.3 kg/cm^2 respectively (Table 2, 8) col.).

(2) The maximum load is not influenced by the diameter of web reinforcement or the angle between web and longitudinal reinforcements (Table 2, 8) col. No. 3 - 10 specimens).

(3) The loop of load-deflection is nearly the same in positive and negative loadings for double spiral hoop specimens while it is smaller in negative loadings for conventional hoop specimens (Figs. 5-6).

(4) The resisting load does not decrease so much even in the range of large deflection for the double spiral hoop specimens with the web reinforcement ratios of 1.2% and 1.8%.

(5) The maximum load of the specimens with web reinforcement ratio of 1.8% is nearly the same with that of specimens of 1.2% but the resisting load at large deflections does not decrease even under high axial stresses of 73.3 kg/cm^2 (Table 2, 6) col.).

(6) The resisting load at small deflection is small for the specimens without welding, compared with that of specimens with welding but they are nearly the same at large deflection.

(7) The difference of loops between double spiral hoop and conventional hoop is larger for the shear span ratio of 1.5 partly due to the fact that the double spiral hoop specimens reached their bending capacities.

General examinations were made into the test results, on the crack strength, and maximum strength.

(8) There is little difference between double spiral hoop specimens and conventional hoop specimens regarding stress levels of bending crack, bending shear crack or middle inclined crack from which loads deflections increase more remarkably than before (Table 2 and Fig. 7). Diagonal line crack or shear compression loads are, however, higher for double spiral hoop specimens. Bending shear crack level can be approximately calculated by Arakawa formula$^{I)}$.

(9) Web reinforcement share, τw, in ultimate shear strength of double spiral hoop specimens can be estimated by

$$\tau w = 0.5 \cdot pw \cdot s\sigma y \qquad (pw \cdot s\sigma y \leqq 80 \text{ kg/cm}^2) \qquad (1)$$

in which pw is web reinforcement ratio and $s\sigma y$ is effective yielding strength for steel wire not having a definite yield point ($0.85 \cdot s\sigma B$) while concrete share τuc is calculated by Ōno-Arakawa formula$^{II)}$ (Fig. 8). The above equation is also supported by the results of embedded strain gauges for steel wire.

I) $\tau_c = \sqrt{\tau_0(\tau_0 + \sigma_0)}, \qquad \tau_0 = kc\ (500 + Fc)\dfrac{0.085}{M/Qd + 1.7}$

II) $\tau_{uc} = (0.90 + \sigma_0/250) \cdot ku \cdot kp \dfrac{0.115}{M/Qd + 0.115}(180 + Fc)$

kc,ku,kp: Coefficients dependent on d,d, and pt, respectively.

CONCLUSIONS

The results from these tests of the specimens with small shear span ratio are summarized as follows:

(1) The maximum load of the specimens with double spiral hoop is much higher than that of conventional hoop specimens and the loop of load deflection curves is much more stabilized even at large deflections.

(2) The web reinforcements share in ultimate shear strength for double spiral hoop specimens can be calculated by assuming the half of reinforcements reaching the effective yielding strength ($0.85 s\sigma B$).

(3) Further researches are needed to establish design formula of taking into considerations the loop stabilities at large deflections.

ACKNOWLEDGEMENTS

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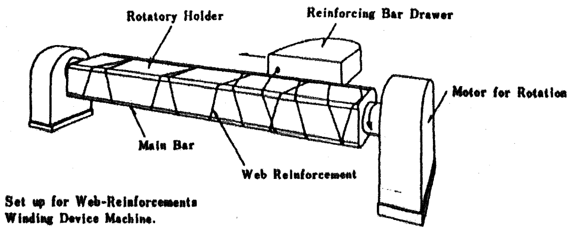

Fig. 1 Set up for Web-Reinforcements Winding Device Machine.

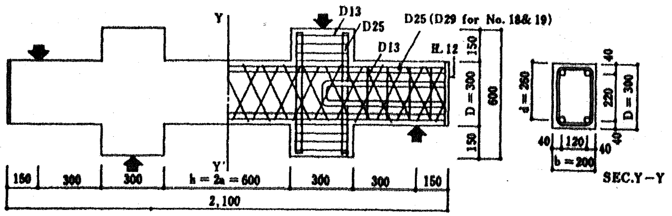

Fig. 2 Test Specimen

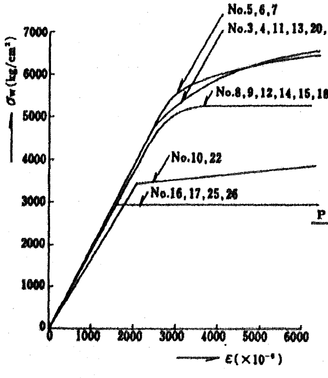

Fig. 3 Stress-Strain Curves of Web-Reinforcements

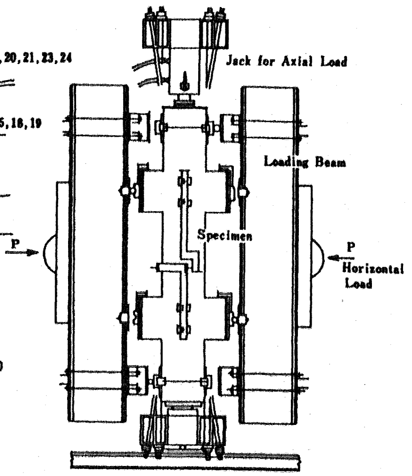

Fig. 4 Test Set-up

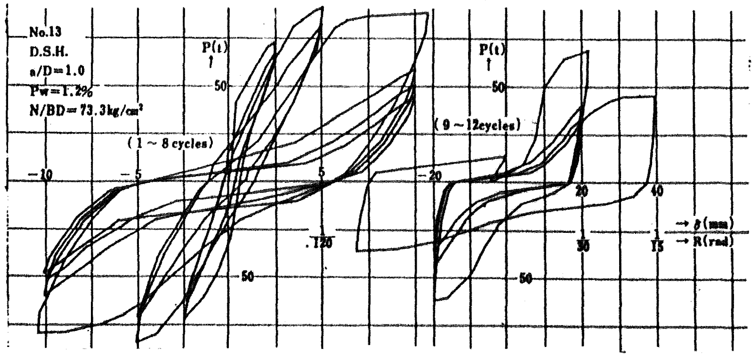

Fig. 5 Load-Deflection Curves (No.13)

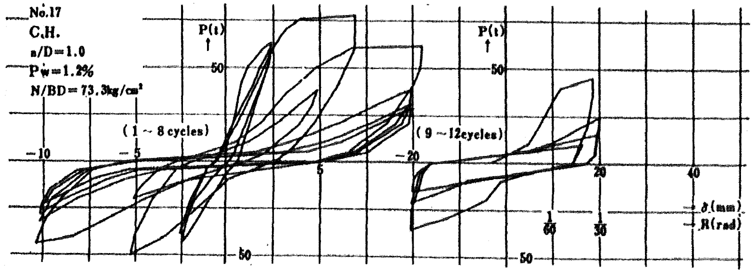

Fig. 6 Load-Deflection Curves (No.17)

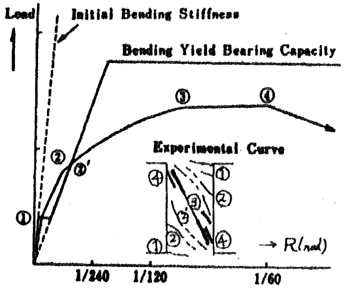

Fig. 7 Load - Deflection (Envelope) Curve and Crack Pattern

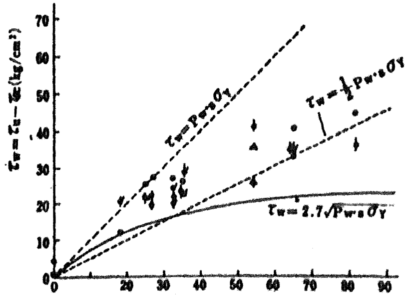

Fig. 8 Web Reinforcement's Share in Ultimate Shear Strength

TABLE 1——PROPERTIES OF SPECIMENS

Symbol of Specimens No.	h/2D.	Main Bar	Web Reinforcement					8)	9)
		2) Pt (%)	3) Pw (%)	4) ϕ (mm)	5) θ (deg.)	6) Weld.	7) $_s\sigma_y$ (kg/cm²)	$c\sigma_B$ (kg/cm²)	σ_0 (kg/cm²)
1	1.0	1.69	0.	——	——	——	——	203	0.
2	1.0	1.69	0.	——	——	——	——	203	73.3
3	1.0	1.69	0.6	9	65	Weld	5630	220	0.
4	1.0	1.69	0.6	9	65	Weld	5630	218	73.3
5	1.0	1.69	0.6	6	63	Weld	5504	203	0.
6	1.0	1.69	0.6	6	63	Weld	5504	203	36.7
7	1.0	1.69	0.6	6	63	Weld	5504	203	73.3
8	1.0	1.69	0.55	9	45	Weld	4490	173	0.
9	1.0	1.69	0.55	9	45	Weld	4490	173	73.3
10	1.0	1.69	0.6	9	90	No Weld	3057	203	73.3
11	1.0	1.69	1.2	9	65	Weld	5630	220	0.
12	1.0	1.69	1.2	9	65	Weld	4490	173	36.7
13	1.0	1.69	1.2	9	65	Weld	5630	218	73.3
14	1.0	1.69	1.2	9	65	No Weld	4490	173	0.
15	1.0	1.69	1.2	9	65	No Weld	4490	173	73.3
16	1.0	1.69	1.2	9	90	No Weld	2943	220	0.
17	1.0	1.69	1.2	9	90	No Weld	2943	218	73.3
18	1.0	2.14	1.8	9	65	Weld	4490	173	0.
19	1.0	2.14	1.8	9	65	Weld	4490	173	73.3
20	1.5	1.69	0.6	9	65	Weld	5630	203	0.
21	1.5	1.69	0.6	9	65	Weld	5630	211	73.3
22	1.5	1.69	0.6	9	90	No Weld	3057	231	73.3
23	1.5	1.69	1.2	9	65	Weld	5630	203	0.
24	1.5	1.69	1.2	9	65	Weld	5630	211	73.3
25	1.5	1.69	1.2	9	90	No Weld	2943	203	0.
26	1.5	1.69	1.2	9	90	No Weld	2943	211	73.3

Note —— 1) Shear Span Ratio, h : Clear Length of Column, D : Depth of Column.

2) Tension Reinforcement Ratio, Pt = at/bD, at : Tension Reinforcement Area,

b : Width of Column.

3) Web Reinforcement Ratio, $P_w = \frac{\Sigma a_w}{bx}\sin\theta$, aw : Web Reinforcement Area,

x : Pitch, θ : Angle of Web Reinforcement against Main Bar. 4) Diameter.

5) → 3). 6) Spot Welding between Web Reinforcements and Main Bars

7) Yield Point or Effective Yield Point (0.85 $s\sigma_B$)

8) Cylinder Strength. 9) Average Stress of Axial Load Applied.

TABLE 2——RESULTS OF TESTS

Specimen No.	1) $P_{B.C.}$ (ton)	2) $P_{B.S.C.}$ (ton)	3) $\tau_{B.S.C.}$ (kg/cm²)	4) $P_{M.I.C.}$ (ton)	5) $\tau_{M.I.C.}$ (kg/cm²)	6) $P_{max.}$ (ton)	7) $\tau_{max.}$ (kg/cm²)	8) $\frac{P_{max.}}{C.H.P_{max.}}$	9) $\frac{P_{max.}}{Ca.P_{B.Y.}}$	10) $\delta_{P.max.}$ (cm)	11) Failure Mode
1	17.8	17.8	13.0	17.8	13.0	39.1	28.6	—	0.46	0.50	S.C.
2	——	44.9	32.9	35.0	25.6	44.9	32.9	—	0.32	0.25	S.C.
3	20.0	30.0	22.0	41.8	30.6	70.8	51.9	1.30	0.82	1.06	S.C.
4	40.0	46.5	34.1	50.0	36.6	67.3	49.3	1.12	0.57	0.50	S.L.B.
5	17.2	20.0	14.7	30.0	22.0	70.8	51.9	1.30	0.83	0.50	S.C.
6	29.5	40.0	29.3	56.0	41.0	70.0	51.4	1.22	0.62	0.50	S.C.
7	30.0	50.0	36.6	30.0	22.0	70.0	51.4	1.16	0.50	0.20	S.C.
8	14.0	18.0	13.2	20.0	14.7	65.7	48.1	1.32	0.77	0.52	S.C.
9	28.5	65.0	50.0	47.6	36.6	69.5	50.9	1.27	0.56	0.25	S.C.
10	45.0	45.0	33.0	28.5	20.9	60.0	44.0	1.00	0.43	0.25	S.C.
11	20.0	20.0	14.7	15.3	11.2	89.5	65.6	1.28	1.03	0.97	S.C.
12	28.0	50.0	36.6	57.0	41.8	92.7	67.9	1.26	0.89	1.03	S.C.
13	74.0	74.0	54.2	63.5	46.5	91.5	67.0	1.14	0.70	0.50	S.C.
14	20.0	30.0	22.0	42.0	30.8	77.8	57.0	1.12	0.91	2.04	S.C.
15	40.0	48.3	35.4	48.3	35.4	75.0	55.0	0.97	0.61	1.14	S.C.
16	25.0	18.0	13.2	30.0	22.0	70.0	51.3	1.00	0.82	0.50	S.C.
17	62.8	49.0	35.9	60.0	44.0	77.2	56.6	1.00	0.59	0.50	S.L.B.
18	20.0	30.0	22.0	40.0	29.3	92.4	67.7	—	0.87	0.85	S.C.
19	30.0	50.0	36.6	58.0	42.5	91.3	66.9	—	0.64	1.00	S.C.
20	15.0	15.0	11.0	30.0	22.0	55.0	40.3	1.32	0.95	1.50	S.C.
21	36.0	42.0	30.8	42.0	30.8	57.0	41.8	1.08	0.66	1.50	S.L.B.
22	27.5	50.0	36.6	40.0	29.7	53.0	38.8	1.00	0.61	0.75	S.C.
23	15.0	30.0	22.0	30.0	22.0	68.8	50.4	1.30	1.19	3.08	B.
24	46.0	50.0	36.6	50.0	36.6	76.8	56.3	1.14	0.89	1.50	S.C.L.B.
25	14.0	22.5	16.5	37.5	27.5	53.0	38.8	1.00	0.91	1.50	S.C.
26	26.6	48.8	35.8	56.0	41.0	68.0	49.8	1.00	0.79	1.50	S.L.B.

Note —— 1) Bending Crack Load (Initially Observed).

2) Bending Shear Crack Load. 3) Average Shear Stress at 2).

4) Middle Inclined Crack Load. 5) Average Shear Stress at 4).

6) Maximum Load. 7) Average Shear Stress at 6).

8) Ratio to Max. Load of Conventional Hoop's Specimen with the Same Web Reinforcement Ratio.

9) Ratio to Bending Yield Load Calculated.

10) Deflection at Max. Load. 11) S : Shear Failure Type, S.C. : Shear Compression Failure Type,

B : Bending Failure Type, L.B. : Lateral Buckling.

DISCUSSION

B.R. Seth (India)

The conclusion of 50% of web reinforcement contributing to ultimate shear strength should be based on more rational way. The quantity contributing to ultimate shear strength will depend on the ratio of web reinforcement used. The proportion shall be high for low ratios and low for higher ratios for web steel. More thorough investigations are recommended.

Author's Closure

With regard to the question of Mr. Seth, we wish to state that the authors agree that the web reinforcement contributing to ultimate shear strength is not proportional to the ratio of web steel used. However, the web reinforcement ratios used are usually relatively high for the shear-failure-type columns with the small ratio of shear span, for which double spiral web reinforcements have been found to be used most effectively. In this range of high ratios, the conclusion of 50% will be valid. It is also natural that non-linear expression, such as the 1.5 times as much as the values obtained by the non-linear curve shown in the Fig. 8 of the paper, should be established for the wider range of web reinforcement ratios.