BEHAVIOR OF REINFORCED CONCRETE COLUMNS AND FRAMES STRENGTHENED BY ADDING PRECAST CONCRETE WALLS

Yoichi Higashi I), Masamichi Ohkubo II) and Kou Fujimata III)

SYNOPSIS

Inelastic behavior of reinforced concrete columns strengthened by adding side-walls and adding precast concrete panels were investigated by the tests using specimens of about one fourth of full scale. The method of welding wall reinformements to existing reinforcements and the method of using special steel anchor-pieces were tried as jointing walls to existing members.

The increasing ratios of ultimate strength after strengthening to calculated strength before strengthening were about 2 in the columns with adding side-walls, and were about 4 in the frames with precast concrete panels. Stiffness and strength after strengthening were analyzed on the basis of idealized load transfer mechanisms in strengthening with precast concrete panels.

INTRODUCTION

A number of research results on reinforced concrete structures and many precepts obtained from past earthquakes are available not only for establishing seismic design method, but also for evaluating seismic capacity of existing structures. For the existing structures, which are evaluated not to be safe against severe earthquake, the strengthening would be required.

Following two policies would be basicly considered for strengthening the existing reinforced concrete structures;

1) increasing the ultimate strength of the structure,
2) increasing the ductility of the structure due to the plastic deformation absorbing earthquake energy.

In this paper, some methods increasing the ultimate strength of the existing structure were adopted. Namely, side-walls were added to each side of existing column and precast concrete panels were set in the inside of existing frame, and the effects of them were investigated by tests under lateral loading reversals. These strengthening methods were conceived from the test results in which the ultimate strength of monolithic columns with side walls was considerably large as compared with the columns without side wall.

TEST PROGRAMS AND TEST SPECIMENS

Following two test series were programed.

A) SERIES-CW: The tests of columns, strengthened by side-walls.

(a) Type AC In this type, concrete was cast after covered concrete of existing members was taken off and wall reinforcements were welded to the reinforcements of existing members, as shown in Fig. 1.
(b) Type PW In this type, precast panels of reinforced concrete were used as side walls, and wall reinforcements were also welded as shown in Fig. 2. The joints between adding walls and existing members were filled

I) Professor of Tokyo Metropolitan University, Dr. Eng.
II) Assistant of Tokyo Metropolitan University, Dr. Eng.
III) Graduate student of Tokyo Metropolitan University.

up with expanding mortar.

(c) Type PA In this type, precast panels were used as shown in Fig. 3, and they were jointed using special steel anchor-pieces shown in Fig. 5. The joints were filled up with expanding mortar. The workability on strengthening is simplified as compared with Type AC and Type PW.

B) SERIES-PCW: The tests of frames with precast panels.

Four precast panels jointed in each other and the beams were set in the inside of existing one span frame, as shown in Fig. 4. Precast panels and their jointing methods were same as Type PA.

The outline of test specimens, 12 in SERIES-CW and 3 in SERIES-PCW, were summarized in Table 1. One of SERIES-PCW is monolithic shear wall with same dimension as precast walls for comparisons.

The cross section of existing column were all 15 cm square, and they had comparatively lower reinforcement ratios for flexure and shearing. However, beams were considerably large as compared with columns for the reasons of testing procedure.

Fig. 6 shows the testing facility for SERIES-CW. Anti-symmetric moments were loaded cyclicly using two pairs of oil jacks under constant axial forces, corresponding 20 kg/cm^2 compressive stress.

TEST RESULTS

Fig. 7, 8 and 9 show some examples of the relationships between loads and displacements, and Fig. 10, 11 and 12 show their crack patterns at the state of maximum load. Fig. 13 and Fig. 14 show the envelope curves of relationships between loads and displacements in each specimen. Initial stiffness and maximum load obtained from each test and ratios of them to calculated values before strengthening are summarized in Table 3.

Test results are summarized as follows.

1) In columns with side-walls strengthened by the method of Type AC and Type PW, in which wall reinforcements were welded to existing reinforcements, adding side-walls and existing column behaved almost monolithicly. Therefore, increasings of stiffness and ultimate strength were remarkable. Final failure mode in these types was the flexural crushing of concrete in adding side walls, as shown in Fig. 10.

2) In Type PA, in which precast side-walls were jointed by special steel anchor-pieces, adding side-walls and column did not behaved monolithicly. Therefore, increasings of stiffness and ultimate strength were not sufficient. In this type, the failure in joints between side-walls and columns due to dowel actions of steel anchor-pieces occurred as shown in Fig. 11, in case of the specimens with eccentiric walls, but such failure did not occurred in case of specimens adding side-walls to column center.

3) In frames with precast panels, SERIES-PCW, increasing of stiffness was not remarkable for the incomplete joints between precast walls and frame, but increasing of ultimate strength was remarkable due to the truss action in individual precast panels as mentioned later analysis. Final failure mode in this type was the crushing of corner concrete in precast concrete panels, but the ductilities were sufficient due to the effect of steel angles around precast panels.

STIFFNESS AND STRENGTH AFTER STRENGTHENING

Stiffness and ultimate strength after strengthening were analyzed on the basis of following assumptions. The ratios of calculated values to experimental values are shown in Table-3. Calculated values approximated comparatively to test results.

1) In Type AC and Type PW, in which wall reinforcements were welded to existing reinforcements, stiffness and ultimate strength were analyzed on the assumption that adding side-walls behaved monolithicly with existing column.

2) In Type PA, in which special steel anchor-pieces were used, idealized load transfer mechanisms shown in Fig. 15 were considered. Fig. 15-a shows bending-shear model with one column and two side-walls which are jointed parallel in each other. Fig. 15-b shows the model in which the effects of dowel action of steel anchor-pieces are considered. Fig. 15-c shows moment diagram resulted from Fig. 15-b. Stiffness and ultimate strength were analyzed combining above models.

3) In frames of SERIES-PCW, precast walls were replaced to idealized truss model shown in Fig. 16.

CONCLUSIONS

1) Columns with side-walls strengthened by welding wall reinforcements to existing reinforcements almost behaved as monolithic column with side-walls. In this strengthening method, the effects of increasing on stiffness and ultimate strength are considerably expected.

2) In columns with side-walls using precast panels of reinforced concrete and steel anchor-pieces, stiffness and ultimate strength do not increase sufficiently for the incomplete joints between side-walls and column, though the workability of strengthening is comparatively simplified.

3) In frames strengthened by precast panels, stiffness do not increase remarkably, but ultimate strength increases by the truss actions of precast panels.

ACKNOWLEDGEMENTS

The tests on the strengthening methods of existing reinforced concrete structures described in this paper, were carried out as a part of the projects of the 5th Committee for School Buildings of the Architectural Institute of Japan sponsored by the Ministry of Education.

REFERENCES

1) Architectural Institute of Japan, "The evaluation method of the earthquake resistant properties and the strengthening method of reinforced concrete school buildings", 1975.

2) Y. Higashi and S. Kokusyo, "The Strengthening Methods of Existing Reinforced Concrete Buildings", Proceeding of the REVIEW MEETING U.S.-Japan Cooperatives Research Program in Earthquake Engineering with Emphasis on THE SAFETY OF SCHOOL BUILDINGS, Aug., 1975, Honolulu, Hawaii.

3) K. Fujimata and others, "Experimental Studies on the Strengthening Methods of Existing Reinforced Concrete Structures, Part 1 ~ 3", Synopsis of Paper and Reports at Annual Meeting of A.I.J., 1975.

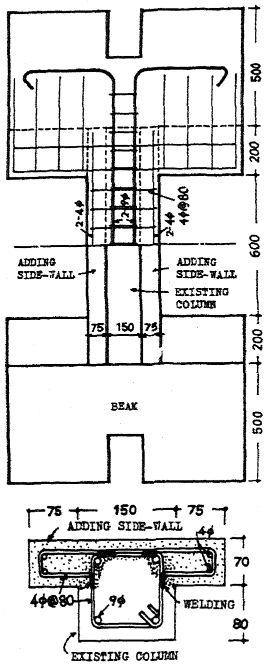


Fig.1 SPECIMEN OF SERIES-CW, TYPE AC-A1

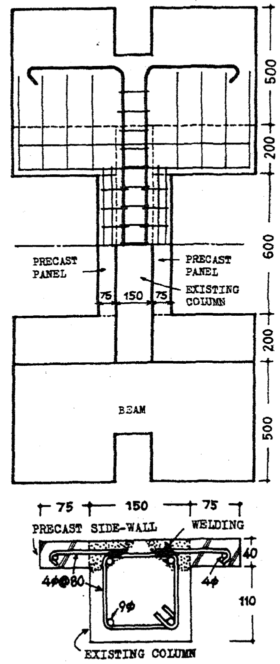


Fig.2 SPECIMEN OF SERIES-CW, TYPE PW-A2

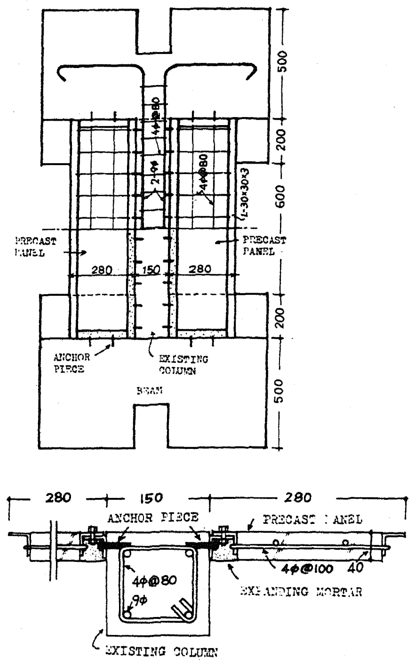


Fig.3 SPECIMEN OF SERIES-CW, TYPE PA-4H1

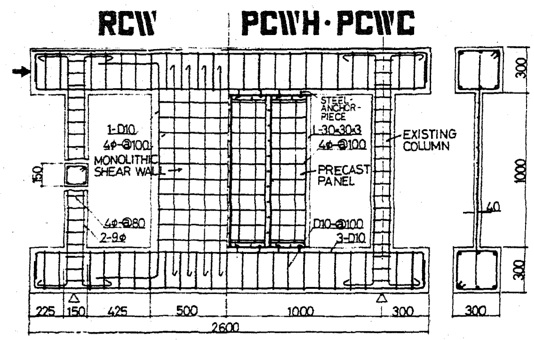
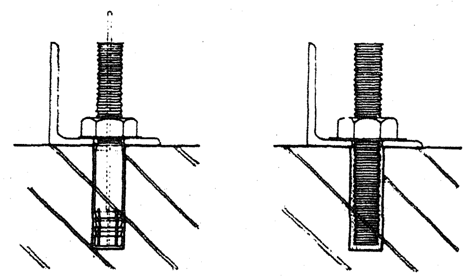


Fig.4 SPECIMEN OF SERIES-PCW



a) MECHANICAL ANCHOR b) CHEMICAL ANCHOR

Fig.5 STEEL ANCHOR-PIECES

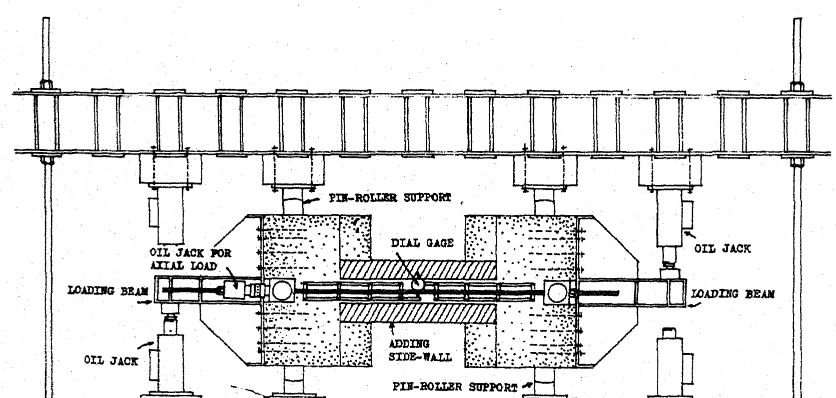


Fig.6 TEST FACILITY FOR SERIES-CW

Qcalc. shows the calculated strength before strengthening.

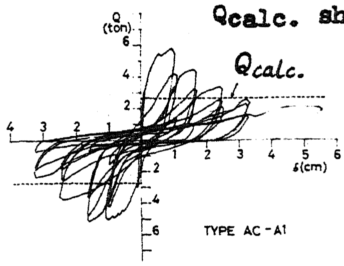


Fig.7 Q - δ CURVE OF TYPE AC-A1

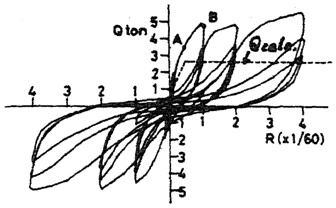


Fig.8 Q - δ CURVE OF TYPE PA-4H1

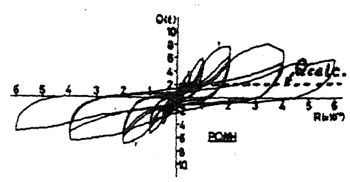


Fig.9 Q - δ CURVE OF SERIES-PCW, PCWH

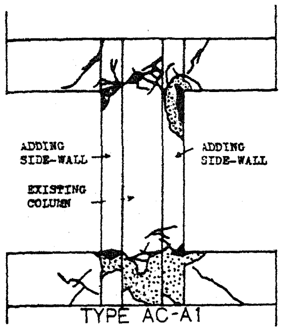


Fig.10 CRACK PATTERN

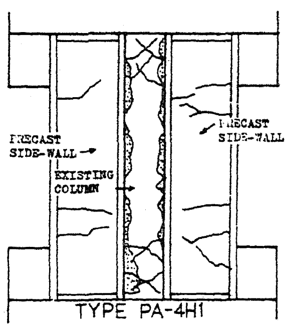


Fig.11 CRACK PATTERN

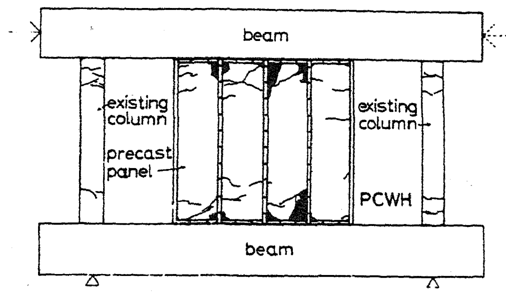


Fig.12 CRACK PATTERN OF PCWH, SERIES-PCW

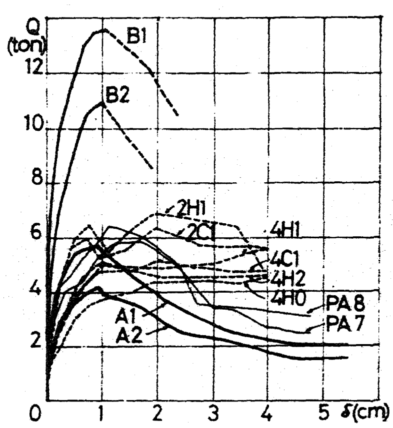


Fig.13 ENVELOPES OF Q- δ CURVES, SERIES-CW

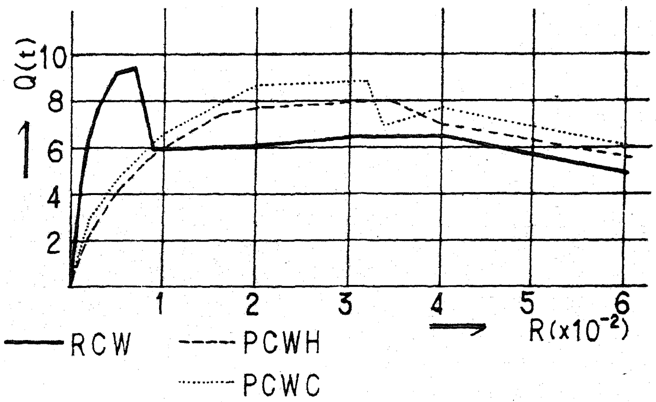
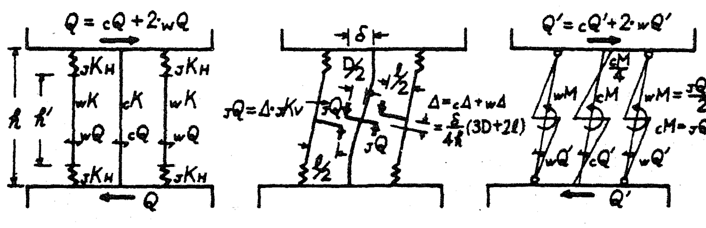


Fig.14 ENVELOPES OF Q- δ CURVES, SERIES-PCW



(a) (b) (c)

Fig.15 IDEALIZED LOAD TRANSFER MODEL OF SERIES-CW, TYPE PA

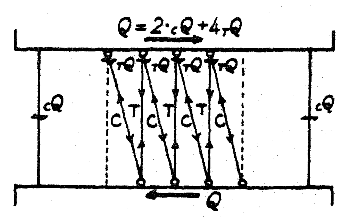


Fig.16 IDEALIZED TRUSS MODEL OF SERIES-PCW

Table 1 TEST SPECIMENS

SPECIMENS			h_o/D	WIDTH OF WALL	THICKNESS OF WALL	p_t(%)	p_w(%)	p_{sh}(%)
SERIES	TYPE	SYMBOL						
CW	AC	A1	4	0.5D *	7(cm)	0.57	0.21	0.45
		B1	2	1.0D	7	0.85	0.56	1.20
	PW	A2	4	0.5D	4	0.57	0.21	0.39
		B2	2	1.0D	4	0.85	0.56	1.05
	PA	4H0	4	1.7D	4	0.57	0.21	0.31
		4H1	4	1.7D	4	0.57	0.21	0.31
		4C1	4	1.7D	4	0.57	0.21	0.31
		4H2	4	1.7D	4	0.57	0.21	0.31
		2H1	2	1.7D	4	0.57	0.21	0.31
		2C1	2	1.7D	4	0.57	0.21	0.31
		PA7	4	1.7D	4	0.57	0.21	0.31
		PA8	4	1.7D	4	0.57	0.21	0.31
PCW		RCW	6.67	6.67D	4	0.57	0.21	0.31
		PCWH	6.67	6.67D	4	0.57	0.21	0.31
		PCWC	6.67	6.67D	4	0.57	0.21	0.31

* D shows the depth of existing column, b x D = 15 x 15 cm.

Table 2 PROPERTIES OF MATERIALS

STRENGTH OF MATERIAL (kg/cm^2)		AC	PW	PA,PCW
COMPRESSIVE STRENGTH OF CONCRETE	EXISTING COLUMNS	227.8	227.8	244.3
	WALLS	302.5	233.0	244.3
YIELD STRENGTH OF REINFORCEMENT	LONGITUDINAL BARS	3865	3865	3755
	HOOPS, BARS OF WALLS	2289	2289	3615

Table 3 TEST RESULTS

TYPE	SYMBOL	TEST RESULTS STIFFNESS K_{test} (ton/cm)	TEST RESULTS STRENGTH Q_{max} (ton)	BEFORE STRENGTHENING $\left(\frac{K_{test}}{K_{calc}}\right)$	BEFORE STRENGTHENING $\left(\frac{Q_{max}}{Q_{calc}}\right)$	AFTER STRENGTHENING $\left(\frac{K_{calc}}{K_{test}}\right)$	AFTER STRENGTHENING $\left(\frac{Q_{calc}}{Q_{max}}\right)$
AC	A1	62.5	5.8	4.3	2.2	0.74	0.90
	B1	163.1	13.6	3.6	2.4	1.01	0.98
PW	A2	20.8	4.2	1.4	1.6	1.38	1.12
	B2	83.3	11.0	1.9	2.0	1.08	0.85
PA	4H0	13.3	4.6	1.3	1.8	1.39	0.96
	4H1	18.3	5.5	1.8	2.1	1.10	0.80
	4C1	20.1	5.2	2.0	2.0	0.96	0.80
	4H2	24.9	5.1	2.5	1.9	1.00	1.23
	2H1	45.9	6.9	1.5	1.4	1.45	0.99
	2C1	38.5	6.4	1.1	1.3	1.70	1.02
	PA7	57.1	5.8	2.3	2.3	0.62	0.75
	PA8	62.9	6.4	2.5	2.5	0.56	0.68
PCW	RCW	133.3	9.7	10.3	4.8	0.81	0.97
	PCWH	10.8	8.2	0.83	4.1	0.67	1.17
	PCWC	14.5	8.9	1.1	4.4	0.89	1.26