STRENGTH DEGRADATION OF REINFORCED CONCRETE COLUMNS SUBJECTED TO MULTI-CYCLE REVERSALS OF LATERAL LOAD AT GIVEN AMPLITUDES OF POST-YIELDING DEFORMATION

by

T.Shimazu[I] and M.Hirai[II]

SYNOPSIS

This paper surveys a number of static tests done in Japan on the strength degradation of reinforced concrete columns subjected to multi-cycle reversals of lateral load at various given amplitudes of post-yielding deformation with a couple of dynamic tests done at given amplitudes. The number of cycles of some of the static tests and dynamic tests reaches one hundred at one amplitude. The relations among the strength degradation of columns, the number of cycles, the type of lateral loading, the ratio of hoops, the shear span ratio, the level of axial stresses, the magnitudes of amplitudes and the level of shear stresses are discussed.

INTRODUCTION

The recent remarkable developement in the dynamic analysis of building frames has made it possible to compute the responces for any restoring force characteristics of building frames by using the earthquake motions recorded. The characteristics of restoring force of reinforced concrete columns composing frames are, however, much more complicated than those usually used in dynamic analysis. It has been shown in many experimental studies so far done, that the loop shape of force deflection curves varies considerably with the number of cycles, often losing the stability, in the post-yielding range. The first three of the tests reported below were motivated mainly by the Tokachioki earthquake which had attacked the northern Japan in 1968 and damaged a great number of reinforced concrete columns.

DESCRIPTION AND DISCUSSION

In the Bibliography of this paper are shown the titles of 13 papers dealing with the strength degradation of reinforced concrete columns subjected to multi-cycle reversals of lateral load at given amplitudes of post-yielding deformation. In Table 1 are summarized the size of section of

I
Associate Professor, The University of Hiroshima, Japan
II
Graduate Student, Dept. of Architecture, The University of Hiroshima, Japan

specimens, strength of materials, type of lateral loading, ratios of longitudinal steels and hoops, magnitudes of amplitude, etc., reported in those papers. The specimens were chosen for some of the tests. There are two types of lateral loading, A type of central loading and B type of anti-symmetrical loading, as shown in Fig.1. Each range of variables is as follows; size of sections of specimens 10cm x 12cm - 42cm x 42cm, strength of concrete at test 0.203 - 0.444 t/cm2 yield strength of longitudinal steel 3.00 - 4.60 t/cm2, ratio of gross longitudinal steel area to sectional area 0.9 - 3.8 % (9ϕ - D29 used), ratio of hoops 0.11 - 1.28 % (3ϕ - D10), shear span ratio 1.0 - 11, level of constant axial load 0 - 0.476, and amplitude(deflection ratio to shear span) 0.375 - 4 x 10^{-2}. The strength degradation (ratio of the load at the Nth cycle to that at the first cycle) is shown in Fig.1 for each specimen. The number of cycles of several specimens reaches one hundred, while that of cycles of specimens showing rapid degradation is less than 10. It is seen that there are specimens becoming stable after 10 cycles and, on the contrary, those suddenly becoming instable at the 70th or 90th cycle. The 4 and 9 tests are those of dynamic loading.

The strength degradation at the 10th cycle is plotted in Fig.2 for all the specimens with horizontal axis being ratio of hoops of each specimen. There is a tendency that strength degradation decreases with the increase of ratio of hoops in each test, but the range varies widely with tests. In general, the strength degradation is less for the tests of A type of lateral loading(1,2,4,6,9) than for those of B type(5,7,8, 10,11,12) except 3 and 13, both having a small ratio of longitudinal steel. It should be noted that reinforced concrete columns of actual buildings can be assumed to undergo lateral loads similar to B type by earthquake motions. It is clear from the comparison of 8 and $\overline{8}$ in Fig.2 that strength degradation is more remarkable for the specimens having the greater value of amplitude δ/a. The equation shown in Fig.2 is assumed a boundary line for the scatter at the 30th cycle.

In Fig.3 are shown maximum shear stress levels obtained by dividing maximum shear at a given amplitude with $B\cdot 7d/8\cdot {}_c\sigma_B$ for all the specimens. Most tests contains the specimens becoming instable within 10 cycles in the range that $\tau/{}_c\sigma_B$ value is arround and more than 0.1. A specimen having the greater degradation of the 1 test failed in bond. The values of $\tau/{}_c\sigma_B$ are the greatest for the specimens of the 7 and 10 tests due to the smallest shear span ratio, and the smallest for those of the 4 and 9 tests due to the greatest shear span ratio. It is obvious that much more tests should be done in the range of the greater value of $\tau/{}_c\sigma_B$.

CONCLUSION

1. It was found that there are many factors affecting the stability of reinforced concrete columns for multi-cycle

reversals of lateral loads and that to judge based on small number of tests is dangerous.

2. Strength degradation is greater for anti-symmetrical lateral loading which is assumed to be induced by earthquake motions than for one-central lateral loading.

3. Further dynamic test researches are needed on specimens having the greater values of $\tau/c\sigma_B$.

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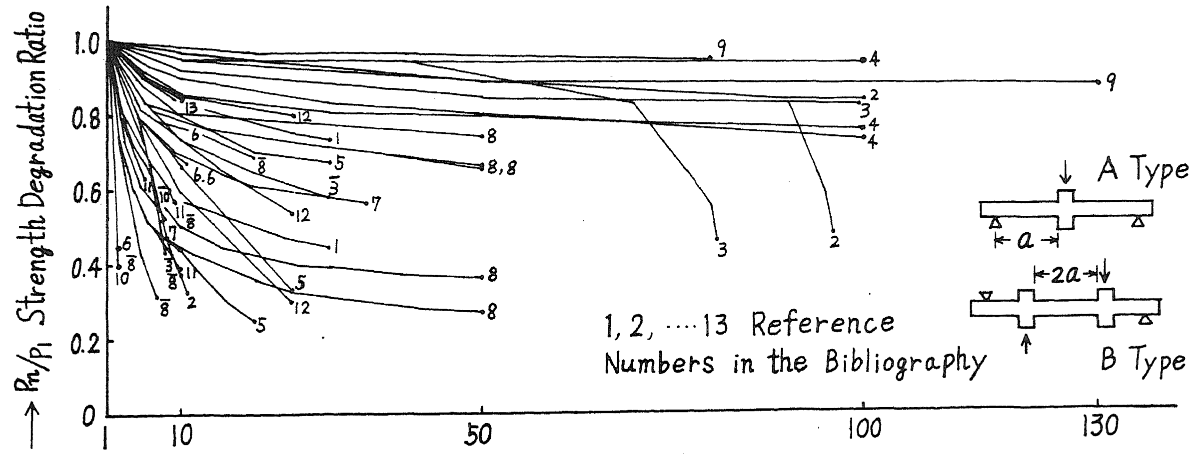
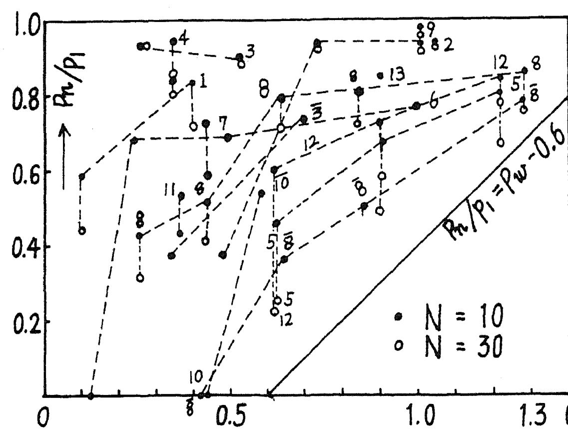


Fig.1 ⟶ N Number of Cycles



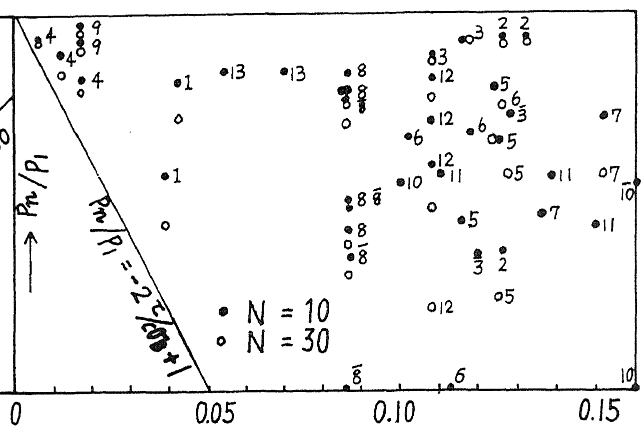


Fig.2 ⟶ Pw Hoops Ratio % Fig.3 ⟶ $\tau/{}_c\sigma_B$ Shear Stress Level

Table 1

	Type	B cm	D cm	${}_c\sigma_B$ t/cm²	${}_s\sigma_Y$ t/cm²	Pg %		Pw %	a/D	$N/{}_c\sigma_B BD$	δ/a 10^{-2}
1	A	20	30	.332	4.06	1.75	D19	.11, 4φ | .40 6φ	6	0	1
2	A	20	20	.203	3.99	1.90	D13	.49 | .74 | 1.05 5.5φ	2.5	.197	1
3.$\overline{3}$	B	20	20	.336	3.89	1.07	D10	.26 | .52 | $\overline{.35}$ | $\overline{.70}$ 4φ	2	.297 | $\overline{.476}$	1
4	A	10	12	.25 | .16	3.60	3.00	D10	.35 3φ	11	0	1 | 2.3 | 4
5	B	35	35	.360	3.50	2.78	D19	.61 | .91 | 1.22 9φ	2.14	.333	1
6	A	15	15	.222	3.00	2.25	9φ	.13 | .25 | .50 | 1.00 3φ	2	.180	2.32
7	B	20	20	.335	3.21	2.09	13φ	.44 6φ	1	.333	.375 | .469
8.$\overline{8}$	B	20	20	.211	3.92	1.42	D10	.26 | .43 | .64 2φ | .86 | 1.28 4φ	1.5	0	1.67 | $\overline{3.33}$
9	A	30	30	.444	3.60	2.26	D25	1.01 D10	5	0	1.43 | 2.85
10 $\overline{10}$	B	20	20	.37 | .29	3.21	2.09	13φ	.44 | $\overline{.59}$ 6φ	1	.167 | $\overline{.333}$	$\overline{.375}$ | .469
11	B	15	20	.33 | .35	4.60	3.80	D19	.37 6φ	1,2,3	.167	1
12	B	35	35	.360	3.50	2.78	D19	.60 | .90 | 1.20 9φ	2.14	.333	1
13	B	42	42	.330	3.92	0.90	D29	1.0 9φ	1.75	.167	1

1.2 ···· 13 = Reference Number. Type = Loading Type shown in Fig. 1. B(D) = width (depth) of Section. ${}_c\sigma_B$ (${}_s\sigma_Y$) = Strength of Concrete (Steel). Pg (Pw) = Reinforcement Ratio of Longitudinal Steels (Hoops). a/D = Shear Span Ratio. $N/{}_c\sigma_B BD$ = Stress Level of Axial Load. δ/a = Amplitude (Deflection Ratio to Shear Span).