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Shaking table tests of reinforced concrete small scaled model structures

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ABSTRACT: In order to establish a testing technique using extremely small scaled model structures to investigate the seismic behavior of reinforced concrete structures, shaking table tests of 1/15 scaled model structures used micro concrete and scaled deformed re-bars were conducted. The fabrication and the response characteristics of the model structures are discribed.

1 INTRODUCTION

Recently, a size of specimens for structural tests tends to become larger and larger. A large scaled model test makes possible to obtain data similar to real structures. However, since it requires large size testing facilities and large amount of research funds, it makes difficult to execute parametric tests. In order to establish a testing technique using extremely small scaled model structures to investigate the seismic behavior of reinforced concrete structures, trials to fabricate 1/15 scaled reinforced concrete structures and to conduct shaking table tests were made.

2 OUTLINE OF TESTS

2.1 MODEL STRUCTURES

The test structures are 1/15 scaled eleven-storied models with two dwelling units at each story as shown in Fig. 1. The number of specimens is two with the test parameter of the shape of the plan as shown in Fig. 2.

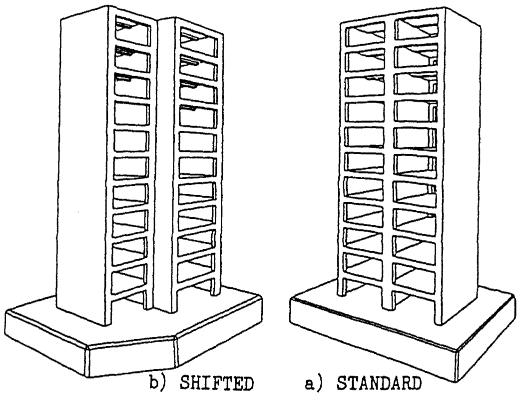


Fig. 1 General Views of Model Structures

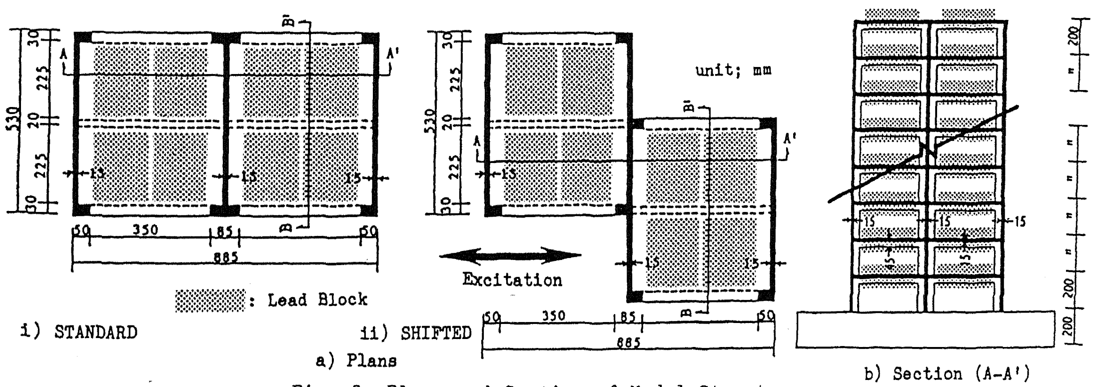


Fig. 2 Plans and Section of Model Structures

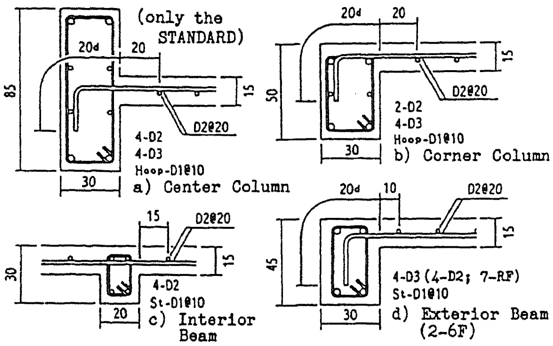


Fig. 3 Dimensions of Columns and Beams

Non-shifted type specimen is named as 'STANDARD', and the other is 'SHIFTED'. Dimensions of columns and beams are shown in Fig. 3. Vertical re-bars in columns and transverse walls are continuous from the basement to the top.

The mass of the model structures was increased by adding lead blocks at each floor as shown in Fig. 2.

The model structures were designed so that a yield hinge mechanism of strong columns-weak beams could be developed. In the case of the STANDARD, the estimated base shear coefficient at the ultimate stage is 0.275, when concrete and reinforcement in slabs and transverse walls within a range regulated in the Code [Ref.] are assumed effective to the stiffness and ultimate strength. When those within slabs and the wall are fully effective, the coefficient is 0.42.

2.2 LAW OF SIMILARITY

Law of similarity is shown in Table 1. The normal stress of columns that is 9.08kgf/cm^2 at the first story is, however, a half of the target in the similarity law due to the space limitation. As the natural periods of the model structures were actually $1/\sqrt{2}$ times of the target, the shaking table tests were performed under a compressed time scale of $1/\sqrt{30}$. The scaling factor of shear force coefficients was 2.0. The ratio of shear force coefficient to input acceleration, however, was 1.0 because the actual scaling factor of input acceleration was twice of the target.

Table 1 Law of Similarity

	Target	Actual
Length	1/15	1/15
Stress	1	1[*1]
Strain	1	1
Time	$1/\sqrt{15}$	$1/(\sqrt{15}\times\sqrt{2})$
Weight[*2]	$1/15^2$	$1/(15^2\times2)$
Deformation	1/15	1/15
Deflection Angle	1	1
Acceleration	1	2
Force of Inertia	$1/15^2$	$1/15^2$
Shear Force Coef.	1	2
Fundamental Period	$1/\sqrt{15}$	$1/(\sqrt{15}\times\sqrt{2})$

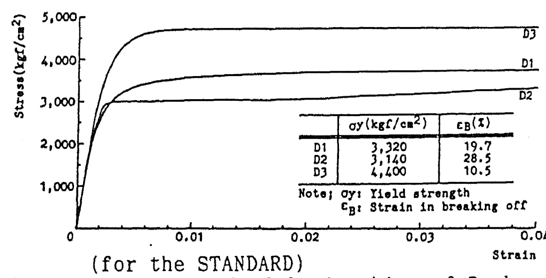
Note; [*1] Actual axial stress is 1/2 of the target value.
[*2] Total weight including additional lead blocks

2.3 MATERIAL

Deformed re-bars and micro concrete was used in the model structures. Deformed bars, D1, D2 and D3; D denotes nominal diameter and the unit of the numbers is mm, were specially rolled for the tests.

1. Deformed re-bars

The deformed bars were produced by rolling a wire through a pair of grooved metal rolls. The process to roll was cold drawing. The bars were annealed before being deformed, and only D2 bars were annealed after being deformed, too. Configuration of the bars was proportional to that defined in the Japanese Industrial Standard. Stress-strain relationships and the average tensile strength are shown in Fig. 4.



(for the STANDARD)

Fig. 4 Stress-Strain Relationships of Re-bars

2. Micro concrete

Dsign specified strength is 150kgf/cm^2 and Air-Entraining water reducing agent is used. Compressive test results of concrete are shown in Table 2. The particle size distribution of coarse aggregate was within the allowable range defined in Japanese Architectural Standard Specification.

Concrete, which was cast vertically at every story, was very carefully cured by wet blanket, and no shrinkage cracks were, therefore, found.

2.4 TEST PROGRAM AND MEASURING

The model structures were subjected to the east-west component of the earthquake record obtained at the Hachinohe Harbor in Aomori Prefecture, Japan during the Tokachi-Oki Earthquake in 1968, scaled to the peak acceleration of 40gals, 200gals, 400gals, 600gals and 800gals. Each test is referred

Table 2 Compressive Tests of Concrete

Story	STANDARD		SHIFTED	
	Slump (cm)	Strength* (kgf/cm^2)	Slump (cm)	Strength* (kgf/cm^2)
Base	14.5	232.8	——	——
1	25.5	370.4	22.0	392.3
2	20.0	348.5	20.0	309.7
3	9.0	369.7	20.0	298.0
4	13.0	353.3	22.0	272.1
5	5.5	417.1	23.0	302.7
6	20.0	408.1	22.0	363.7
7	19.5	352.7	23.0	231.0
8	16.0	377.4	22.0	294.3
9	20.5	409.4	23.0	305.1
10	20.5	339.8	22.0	313.4
11	19.5	351.2	21.5	339.2

Note; * Average of three cylinders

to as 'G40', 'G200', 'G400', 'G600' and 'G800', respectively. Time scale was reduced to $1/\sqrt{30}$ of the original record to conform with the similarity law. Finally, the model structures were also subjected to excitation with peak acceleration of 800gals and reduced time scale of $2/\sqrt{30}$ to observe ultimate behaviors of the structures; G800-2. The input accelerogram is shown in Fig. 5.

Absolute accelerations, relative displacement to the basement were measured at each floor level in the direction of excitation. Strain gages were installed to reinforcing bars at 28 locations in the STANDARD and at 31 locations in the SHIFTED.

The measured data were recorded continuously throughout the tests on a magnetic tape with a sampling rate of 1/200sec..

3 TEST RESULTS

Final crack patterns and hysteresis loops at the first story are shown in Figs. 6 and 7, respectively. The maximum responses are shown in Table 3.

3.1 Damage Procedure

G40; Although small cracks were observed in the case of the STANDARD, the response ranges of both specimens were almost within elastic ranges.

G200; As was the case of the STANDARD, a few cracks were observed.

G400; Although the input acceleration level was about 70% of the target in the case of the SHIFTED, several cracks were observed.

G800; As was the case of the STANDARD, the response range was similar to that of G600.

G800-2; Flexural cracks were developed at the ends of almost all beams and bottom

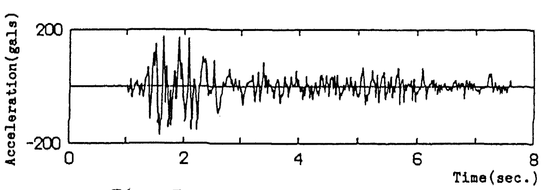
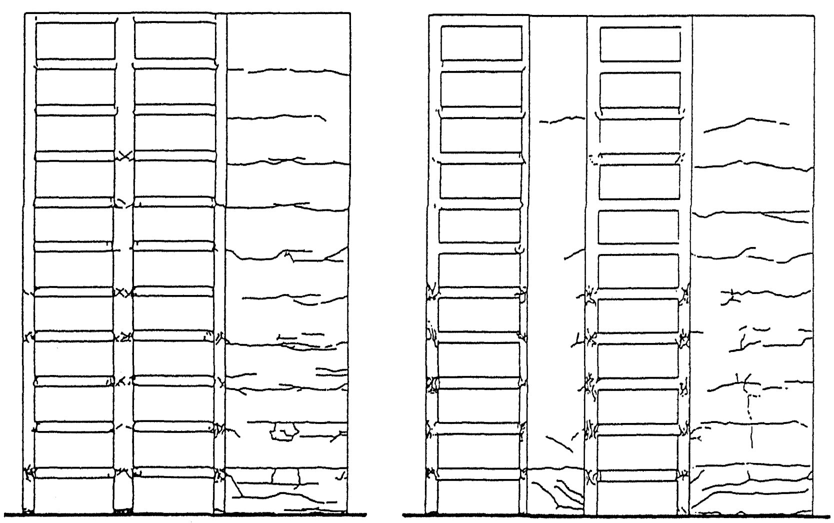


Fig. 5 Input Accelerogram

Table 3 Maximum Responses

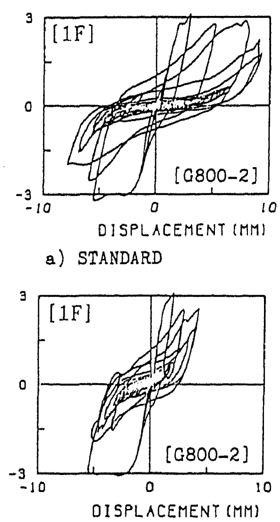
Step	Input Accel. (gal)	Base Shear Coefficient	Drift Angle at 1st Story (x10^{-3} rad.)
G40	39 [33]	0.13 [0.08]	0.51 [0.24]
G200	213 [160]	0.50 [0.32]	2.37 [1.10]
G400	408 [289]	0.84 [0.64]	7.18 [3.54]
G600	560 [593]	0.89 [0.69]	8.39 [4.16]
G800	796 [827]	0.83 [0.64]	8.24 [4.58]
G800-2	922 [839]	1.10 [0.96]	46.3 [27.4]

Note; Values for the SHIFTED are in brackets.



a) STANDARD b) SHIFTED

Fig. 6 Final Crack Patterns



a) STANDARD

b) SHIFTED

Fig. 7 Hysteresis Loops

reinforcing bars in beams were broken off at intermediate stories. At lower stories, cracks due to punching shear were also observed at the intersection of the transverse wall and interior beams. Severe damages were observed in columns at the bottom of the first story; i.e., concrete crushed and reinforcing bars buckled in the case of the SHIFTED, and were broken off in the case of the STANDARD which transverse walls could sustain axial force and avoid collapse.

3.2 Acceleration Response Spectrum

Relationships of changes of fundamental period and the maximum response acceleration on response acceleration spectra of command acceleration, which is similar to those observed at the first floor during the tests, are shown in Fig. 8. The ordinate gives a magnification factor of the response acceleration, and the abscissa gives period. Circles in this figure indicate the predominant period during early 2.5sec. (5.0sec. in G800-2) of testing that response relative displacement became maximum approximately. The period was from the ratio of Fourier spectra of response acceleration at the top floor to those at the first floor.

It is very interested that the magnification factors of response acceleration of testing were nearly equal to the elastic response acceleration corresponding to response fundamental period in the region of the maximum response displacement.

3.3 Story Shear Coefficient and Distribution of Shear Force

Distributions of maximum shear coefficient ratios to maximum base shear coefficient are

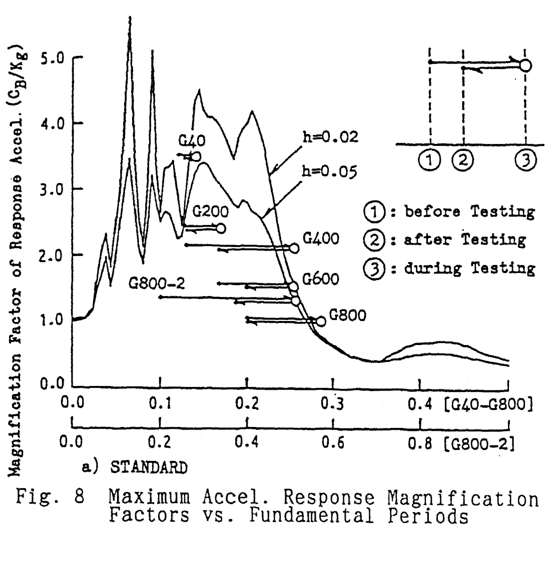


Fig. 8 Maximum Accel. Response Magnification Factors vs. Fundamental Periods

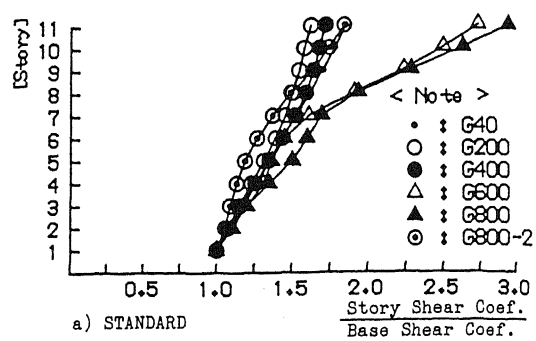


Fig. 9 Distribution of Story Shear Coefs. (each story shear is the maximum)

shown in Fig. 9. At elastic stage; G40 run, distribution of the ratios is very close to the inverted triangular force distribution. At upper stories, the ratios decrease at slightly damaged stage; G200 and G400 runs, and increase at moderately damaged stage; G600 and G800 runs. The distribution at lower stories is, however, similar to the inverted triangular force distribution through all runs.

4 CONCLUDING REMARKS

Shaking table tests of 1/15 scaled model structures used micro concrete and scaled eformed re-bars are effective enough to simulate the earthquake response.

Response characteristics of model structure depended upon changes of fundamental period due to stiffness deterioration. The maximum response amplitude could be assumed from response acceleration spectrum of input acceleration.

The distribution of story shear force coefficients is similar to the inverted triangular force distribution at elastic stage. The inverted triangular force distribution, however, underestimates the distribution of story shear force coefficients at upper stories in plastic stage.

5 ACKNOWLEDGMENTS

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