CORRELATION STUDY ON SHAKING TABLE TESTS AND PSEUDO-DYNAMIC TESTS BY R.C. MODELS

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SUMMARY

Correlation between the shaking table tests and the pseudo-dynamic tests for reinforced concrete half scale models was studied. For input excitation on the shaking table tests, the recorded accelerogram at Tohoku University during the Miyagi-ken-oki earthquake of 1978 was applied. On the pseudo-dynamic tests, the input excitation was determined by the obtained accelerogram on the table during the shaking table test. As a result, a good agreement among the experimental and analytical results can be observed. It is pointed out that the restoring force characteristics with the effects of strain rate and stress relaxation should be evaluated accurately.

INTRODUCTION

A correlation study on the responses of the shaking table tests and the pseudo-dynamic tests was carried out with about half-scale reinforced concrete models as one of the tests supporting the full-scale seven story reinforced concrete building under "the U.S.-Japan Cooperative Research Program Utilizing Large Scale Testing Facilities"1) 2).

In this paper, the dynamic tests by shaking table and the pseudo-dynamic tests on the computer-actuator online system, and the correlation of them are described. The results obtained from two different experimental procedure and analytical results are compared.

TEST MODELS AND INPUT MOTION

Outline of Models - Four reinforced concrete specimens of two-story half-scale models, two each for shaking table tests and for pseudo-dynamic tests, were prepared. These four specimens had identical material properties and dimensions. Figure 1 shows the plan and section of a test specimen. As seen in Fig. 1, the dimensions are 3m x 1m in plan, 3.9m in total height. Concrete is a normal weight with a design strength of 240kg/cm^2. High early strength cement and deformed bars, SD30, having a nominal yielding stress of 3.0kg/cm^2 were used. The calculated fundamental natural period of the test model was 0.18sec.

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Input motion - For input excitation for the shaking table test, the recorded N-S component at the first floor of Tohoku University obtained during the Miyagi-ken-oki earthquake of June 12, 1978 was applied. According to similitude law, the time axis was scaled by one-half, and the amplitudes was doubled. Figure 2 shows time traces of waveforms both recorded at Tohoku University and used for the command signal to the shaking table. For the pseudo-dynamic tests, the exciting ground motions for the online computer program was determined by the recorded accelerogram on the shaking table.

OUTLINE OF EXPERIMENTS

The schematic flow of the testing procedure for the correlation study is shown in Fig.3. The loading sequence for the correlation study is shown in Table 1. In this table, two series of pseudo-dynamic loading tests (Pl and P2) correspond to the first series of shaking table tests (Dl). View of specimens No. 1 and No.2 under the tests is shown in Photo 1.

Shaking Table - The shaking table is an elastic-hydraulic servo controlled type, which is driven in one horizontal direction with a maximum stroke of ±10cm. The operational frequency range is zero to 50Hz and the maximum load is 20 tons.

Loading - The specimen was loaded by two actuators, with a maximum load of ±100ton, a maximum stroke of ±500mm and a maximum velocity of 2mm/sec. The actuator were fixed to the reaction wall and load was applied at the center of each floor level. For input excitation, acceleration recorded on the shaking table in Dl series was used. A step-by-step integration in equation of motion for the computer-actuator online system was calculated by the central difference method. The time interval for integration was 0.005 sec. The damping coefficient was zero in Pl test and 0.03 in P2 test.

Instrumentation - In order to investigate the dynamic behavior of test model under earthquake motion, the following items were measured; the relative displacements, the absolute displacements with servo and differential type transducers, the absolute accelerations with U-gage type accelerometers. The test data were recorded by data recorders and monitored by electric-magnetic oscillograph recorders.

For pseudo-dynamic test inductance type transducers were used to measure the horizontal displacements. These measured displacements were used for actuator control. The transducers were attached vertically to the steel reference-frame. A steel wire, extending horizontally from each floor level, passed around a pulley before connecting with the transducers. The locations of measurements for strain and etc. were same as in the dynamic test.

EXPERIMENTAL RESULTS

Shaking Table Test - Figures 4(a) and (b) show the accelerograms at each floor level of the test model under earthquake motions DR10 and of DR20. Time histories of relative floor displacements are shown in Figs. 5(a) and (b) Figures 6(a) and (b) show the shear force vs. story deflection at the first story. The maximum story drift angles of the first story were 1/228 and 1/51, respectively. Figure 13 shows the final crack patterns of test model. Referring to the values of Table 2, the dynamic behaviors for the shaking table test are as follows; The natural period of the specimen, which was determined from a steady state vibration, was 0.23 sec. prior to the DR10 test. After the DR20 test, it became 0.71 sec. The former is 1.3 times and the latter is 3.9 times larger than the calculated period. Damping coefficients of 3.9% and 6.0% were obtained from resonance curves during the two series of steady state vibration tests, respectively.

Pseudo-Dynamic Test - Figures 7(a) and (b) show the load history at each floor of the P1 series (h = 0%) under the earthquake motions of DR10 and DR20. The recorded relative displacements are shown in Figs. 8(a) and (b). Figures 9(a) and (b) show shear force vs. story deflection at the first story. The maximum story drift angles at the first story were 1/202 and 1/32, respectively. Figures 14 shows the final crack patterns of test model.

Similarly, Figs. 10, 11, 12(a) and (b) show the histories of loading, relative displacements at each floor and shear force vs. story deflection at the first story, respectively, for the P2 series (h = 3%) under earthquake motions of DR10 and DR20. The maximum story drift angles at the first story were 1/250 and 1/32, respectively. Figures 15 shows the final crack patterns of test model.

Referring to the values of Table 2, the correlations between the two pseudo-dynamic tests with damping coefficients of zero and 0.03 are as follows; i) The maximum displacement of the two tests are nearly equal to each other in the test DR10. In the test DR20, the maximum displacements in the one direction, with h = 0.00 or h = 0.03, were nearly equal, but in the other direction, the displacement obtained from the test with a damping coefficient of 3% was larger than that from the test with no damping, ii) The maximum first story shear forces were nearly equal with each other in these two pseudo-dynamic test, iii) From the spectral ratios of displacment between records measured at the base and the top of the test model, the fundamental periods were 0.36 sec. in DR10 and 0.46 - 0.47 sec. in DR20. The former is 2 times and the latter is 2.6 times larger than the calculated period, and iv) Differences in response on the computer-actuator online system, due to the damping coefficients of zero or 3%, were small. The relative displacements at each floor obtained from the P1 and P2 series agreed fairly well with each other.

COMPARISON AMONG EXPERIMENTAL RESULTS

Comparing the values in Table 2, the results are as follows; i) The maximum displacement and peak-to-peak displacement of the three tests (D1, P1 and P2 series) were nearly equal in case of the DR10 test, ii) In the DR20 test, the maximum relative displacement obtained from two pseudo-dynamic tests (P1 and P2 series) were 1.4 to 1.7 times as much as that obtained in the shaking table test (D1 series). The maximum peak-to-peak displacements were 1.2 to 1.4 times larger than those from the shaking table test, iii) In the

DR10 and DR20 tests, the maximum first story shear force in the D1 series were generally larger than those in the P1 and P2 series. The ratio was 1.2 to 1.5 in the DR10 test and was 0.95 to 1.1 in the DR20 test, iv) In the DR10 test, the fundamental period in D1 series was smaller than those in the P1 and P2 series. In both tests, the difference was about ten percent, but in the DR20 test, the differences were small, and v) The final crack patterns in cases of D1, P1 and P2 series were similar with one another.

Fig. 16 shows the variation of average stiffness estimated during each cycle of shear force vs. story deflection in the DR10 and DR20 tests. In the DR10 test, the initial stiffness of the D1 series at the first story was larger than those in the P1 and P2 series, the ratio was 1.2 to 1.8. The initial stiffness at the second story was nearly equal to each other. In the DR20 test, the differences of the initial stiffness at the first story were lower than in the case of DR10.

COMPARISON BETWEEN ANALYTICAL AND EXPERIMENTAL RESULTS

The dynamic response analyses in both the elastic and inelastic ranges were done by use of a lumped mass model with and without the effects of strain rate and stress relaxation[3]. The modified D-Tri-linear model in which stiffness and strength are determined from the measured test data and the Maxwell Visco-elastic model was applied for the hysteresis rule. Figure 17 shows the phenomenon of stress relaxation in a specimen under pseudo-dynamic testing. Figures 18(a)∼(d) show results for the DR20 series, obtained from the experimental data and from the analytical model considering strain rate and stress relaxation effects. The results are as follows; i) In both the DR10 and DR20 series, the response wave and the shear force vs. story deflection obtained from the analytical model in P1 and P2 series are in good agreement with the results obtained from the pseudo-dynamic tests, but do not agree with the results of the D1 and D2 series, ii) When stiffness and strength of the model were taken from the results obtained from the D1 and D2 series, the predicted response is in good agreement with that of the D1 and D2 series, and iii) In the DR20 series, the response wave and shear force vs. story deflection obtained from analyses considering the effects of strain rate and stress relaxation are in good agreement with the corresponding experimental results (compare Fig. 18(a) with (c) and (b) with (d)).

CONCLUSIONS

The results obtained from the two different experimental procedures and analytical results were compared. The correlations among these results were investigated. The results are summarized as follows;

i) In the reinforced concrete test model, the influence on response of hysteresis damping is greater than that of viscous damping.

ii) The influence of stiffness and strength on response is fairly critical.

iii) Comparison of the test with the analytical predictions indicates that a good agreement between experimental and analytical results can be observed if the measured stiffness and strength of test specimens is used and consideration is given to the effects of strain rate and stress relaxation.

iv) As a result, it is pointed out that the restoring force characteristics with the effects mentioned above should be evaluated accurately.

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Table 1 Loading Sequence

Specimen	Run Number	Maximum Acc.	Note
NO. 1	DR 10	212 (gal)	
	DR 20	555	
NO. 2	DR 10	212	h= 0 (%)
	DR 20	555	
NO. 3	DR 10	212	h= 3 (%)
	DR 20	555	
NO. 4	DR 20	175	
	DR 21	807	

Remark : The former loading is intend to investigate elastic behavior of the speciemen , and the latter , inelastic behavior.

Table 2 Experimental Results

		Displacement (mm)				Maximum Shear Force	Natural Period	Damping
		Maximum		Peak-to-Peak				
		2F	RF	2F	RF	(ton)	(sec)	(%)
DR10 212gal	STT	+8.2 -7.5	+12.3 -11.5	15.7	23.8	+4.7 -4.8	0.33	3.9
	PDT-1 h=0%	+9.3 -8.1	+12.3 -11.8	17.4	24.1	+3.8 -3.6	0.36	2.9
	PDT-2 h=3%	+7.5 -10.4	+9.7 -14.1	17.9	23.8	+3.1 -3.2	0.36	2.4
DR20 555gal	STT	+36.5 -29.0	+48.5 -50.1	65.5	98.6	+8.0 -7.0	0.46	6.0
	PDT-1 h=0%	+58.4 -30.1	+82.7 -43.1	78.2	109.2	+7.6 -7.3	0.47	
	PDT-2 h=3%	+58.3 -41.8	+81.1 -57.3	99.6	137.2	+7.8 -7.2	0.46	8.4

STT : Shaking Table Test PDT : Pseudo - Dynamic Test

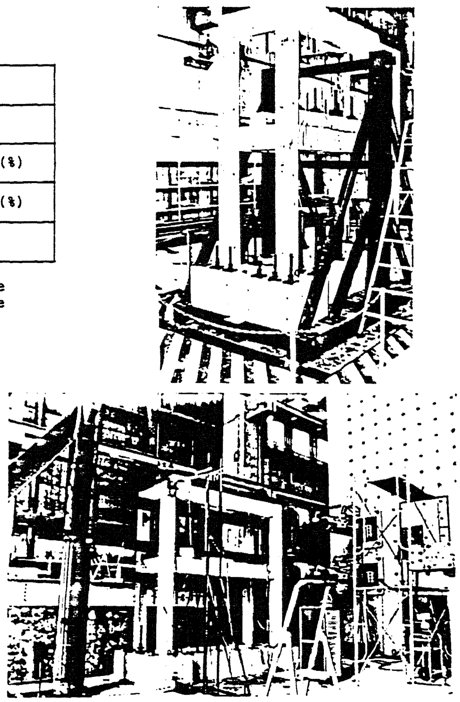

Photo 1 View of Specimens

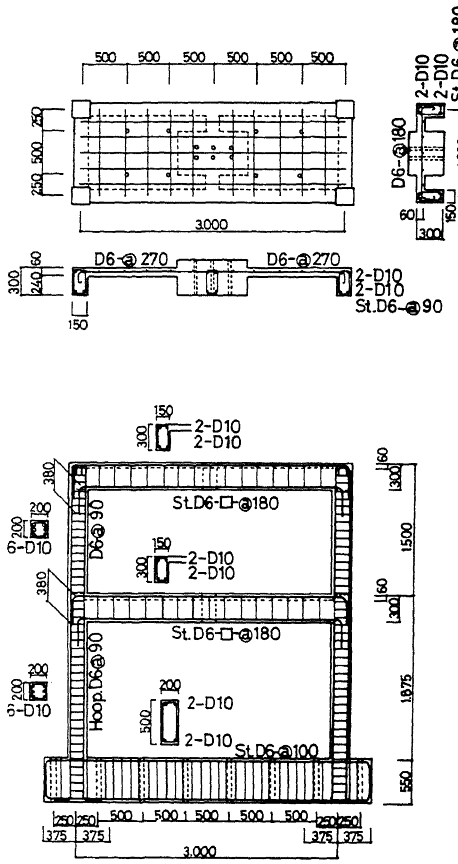

Fig. 1 Plan and Section of Test Specimen

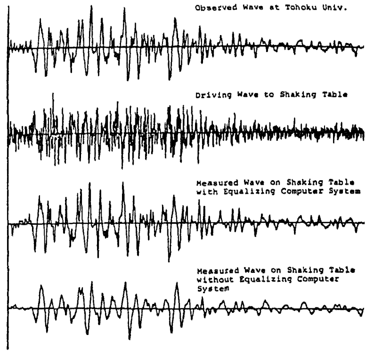

Fig.2 Recorded and Used Accelerograms

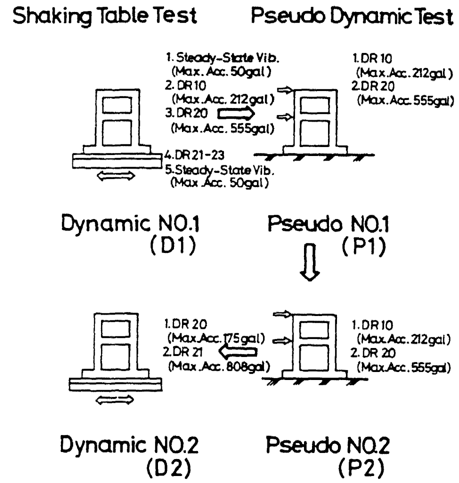

Fig.3 Schematic Flow of Testing Procedure

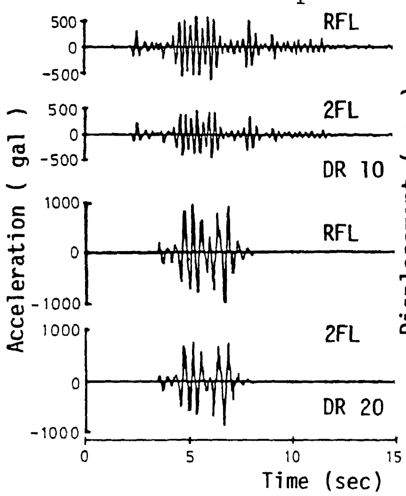

Fig.4 Accelerograms

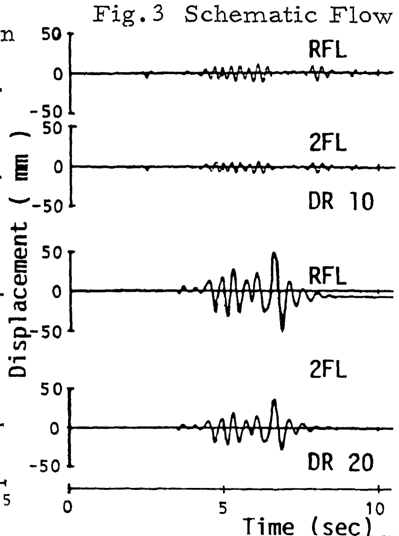

Fig.5 Time Histories of Relative Displacements

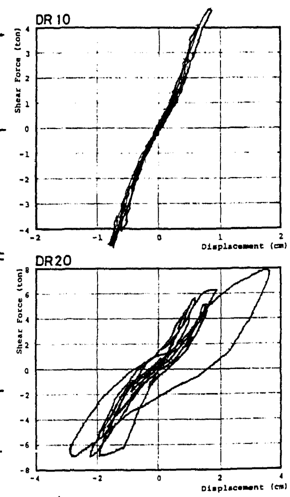

Fig.6 Shear Force vs. Story Deflection

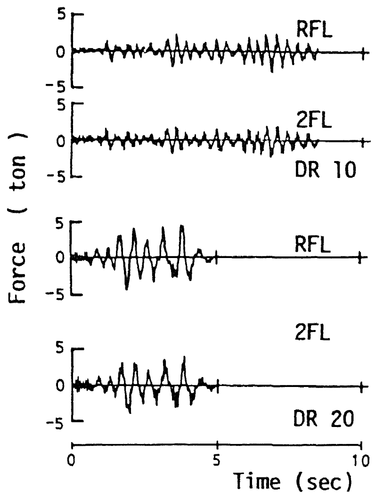

Fig.7 History of Loading

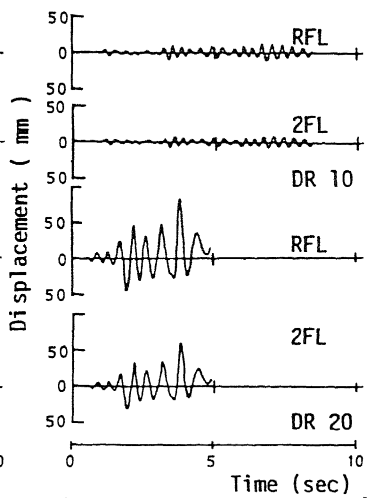

Fig.8 Time Histories of Relative Displacements

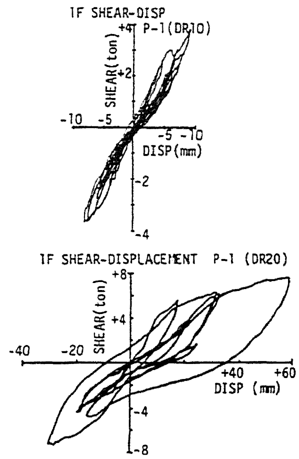

Fig.9 Shear Force vs. Story Deflection

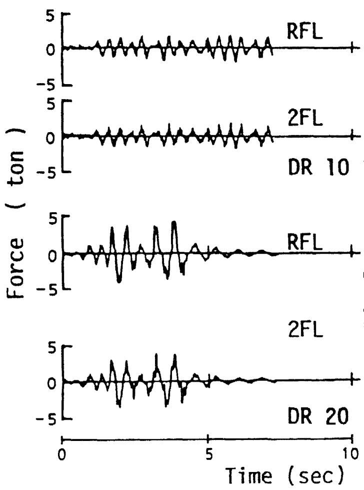

Fig.10 History of Loading

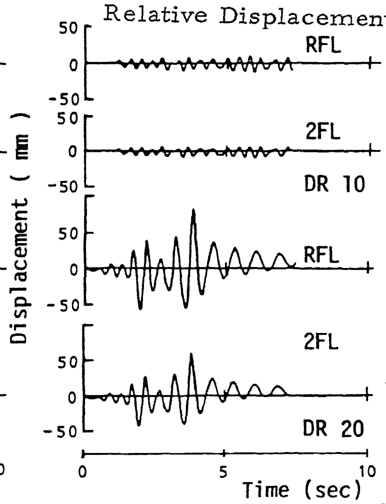

Fig.11 Time Histories of Relative Displacements

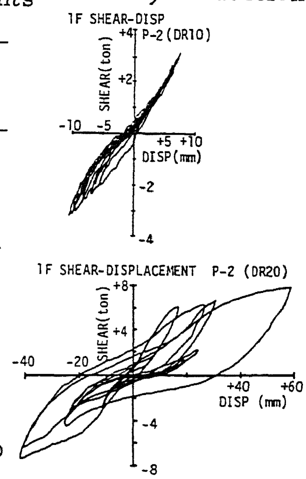

Fig.12 Shear Force vs. Story Deflection

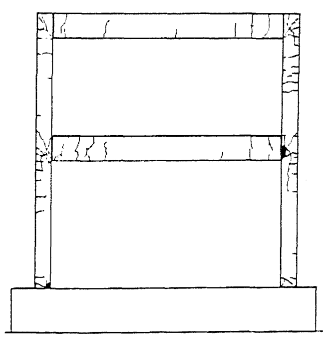

Fig.13 Final Crack Patterns

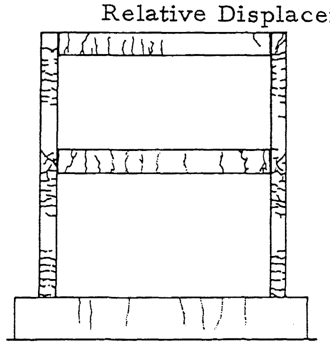

Fig.14 Final Crack Patterns

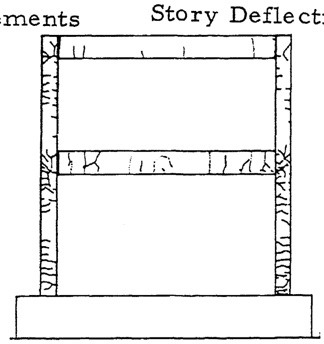

Fig.15 Final Crack Patterns