BRIEF NOTE

A SIMULATION OF EARTHQUAKE RESPONSE OF REINFORCED CONCRETE BUILDING FRAMES BY COMPUTER-ACTUATOR ON-LINE SYSTEM

by

Tsuneo OKADA[I] and Matsutaro SEKI[II]

An earthquake response of reinforced concrete one story building frames was simulated by the computer-actuator on-line system (1). A principle of the simulation by the on-line system is to solve a nonlinear differential equation for earthquake response by a digital computer taking into account the real restoring force characteristics obtained by the pseudo-dynamic loading test of the member executed in parallel with the calculation (2).

Analysed Frames and Test Specimens: Four frames of column yielding type having different natural periods were analysed (Table 1 and Fig. 1). The mass of each frame was estimated using the natural period and the initial stiffness of the frame obtained by the cyclic loading test performed previous to the on-line simulation. Test specimens having the shear span of a half of the column height of the frame were used assuming the inflection point of the column was located at the mid-height. The detail of the specimen is shown in Fig. 2.

Loading System: Test setup is shown in Fig. 3. Axial stress of 7.2 percent of the concrete compressive strength was applied by an actuator beginning the test and kept constant during the test. Lateral force was applied by another actuator driven by the command from the computer.

System for Analysis: The flow diagram is shown in Fig. 4. For numerical analysis, the linear acceleration method was used until the response displacement reached at a certain limited value within linear range and then the central difference method (Lumped-impulse method (3)) was used. The acceleration record of the Hachinohe 1968 (NS) was used for the ground motion. The acceleration amplitude was modified so that the ratio of the lateral strength of the frame in terms of the base shear coefficient (k_y) to the peak ground acceleration normalized by the acceleration of gravity (k_g) became constant ($\fallingdotseq 1.13$) for all frames (Table 1). The time interval for numerical integration was 0.01 second and a viscous damping was not considered.

[I]Associate Professor and [II]Research Associate; Institute of Industrial Science, University of Tokyo

Results: Lateral force-displacement relationships of the cyclic loading test (FD-6) is shown in Fig. 5. The lateral force and displacement are transformed to the shear force of the column and the displacement of the frame, respectively. The skeleton curve under monotonic loading could be modeled by a tetra-linear with three breaking points as shown in Fig. 7. Three breaking points occurred at flexural cracking stage, yielding stage of the tensile reinforcements (first yield point) and yielding stage of the middle reinforcements (second yield point). Extension of flexural-shear crack was observed around the first yield point and crush of concrete in compression zone after the second yield point. Strength deterioration occurred during several cycles of cyclic loading with the displacement of twice of the second yield displacement (μ=2) and then the hysteresis loop became almost stable. After the 51-st cycle, the displacement was increased to four times of the second yield displacement (μ=4) and the cyclic load was applied. Concrete outside the core spalled, the compressive reinforcements took buckling and the column collapsed completely at the 54-th cycle.

The hysteresis loops by the on-line test are shown in Fig. 6 Their shapes are similar to that by the cyclic loading test. The maximum response displacements are shown in Table 1 and Fig. 8. The response displacements of the degrading tri-linear system and the origin-oriented system are also shown there. The equivalent tri-linear curve shown in Fig. 7 by a broken line was adopted to simplify the tetra-linear skeleton curve. The tri-linear curve was determined so that the complementary energy at the second yield point became equal to that of the tetra-linear curve. The response displacement spectrum obtained by the on-line test had the similar tendency to those of the degrading tri-linear and the origin-oriented systems, but the values of the maximum displacements were between them. An example of the time history of the response shear force and the displacement is shown in Fig. 9.

References: 1) T. Okada and M. Seki "Non-linear Earthquake Response of Reinforced Concrete Frames by Computer-Actuator On-line System... One story column yielding type... "Pre-print of The 22nd Symposium on Structural Engineering, Tokyo, Japan, 1976.1.
2) K. Takanashi, et al "Non-linear Earthquake Response Analysis of Structures by A Computer-Actuator On-line System... Detail of the System... "Bulletin of ERS, No. 8, 1974.
3) J.M. Biggs "Introduction to Structural Dynamics" McGraw-Hill, 1964.

Table 1 Characteristics of Frames and Ground Acceleration

FRAME ID	INITIAL PERIOD T (SEC)	MASS M $(KG.CM^{-1}.SEC^2)$	PEAK GROUND ACCELERATION $(\ddot{X}_0)max$ (GAL)	$K_g = \frac{(\ddot{X}_0)max}{980}$
FD- 6	—	—	—	—
FD- 7	0.60	155.020	29.67	0.0303
FD- 8	0.40	68.900	66.76	0.0681
FD- 9	0.20	17.224	267.03	0.2725
FD-10	0.15	9.688	474.74	0.4844

Table 2 Response Displacement of Frame

Frame ID	Initial Period T_1 (SEC)	Cracking Stage X_c (CM)	Yield Stage X_{y1} (CM)	Yield Stage X_{y2} (CM)	Maximum Response Displacement: Displacement X_{max} (CM)	Maximum Response Displacement: Rotation Angle $R = \frac{X_{max}}{h_o}$ (h_o=120CM)	Maximum Response Displacement: Ductility Ratio $\mu = \frac{X_{max}}{X_{y2}}$	Max. Response Disp. of D-Tri Model $_cX_{max}$ (CM)	$\frac{X_{max}}{_cX_{max}}$
FD- 6	—	0.09	0.60	1.20	X = 2.4CM (R=0.020) 1-51 cycle X = 4.6CM (R=0.038) 52-54 cycle				
FD- 7	0.6	0.09	0.74	1.40	-1.23	0.010	0.88	-0.81	1.52
FD- 8	0.4	0.10	0.64	1.40	-1.93	0.016	1.38	-0.99	1.95
FD- 9	0.2	0.12	0.82	1.40	2.54	0.021	1.81	1.50	1.69
FD-10	0.15	0.11	0.80	1.40	3.25	0.027	2.32	-2.58	1.26

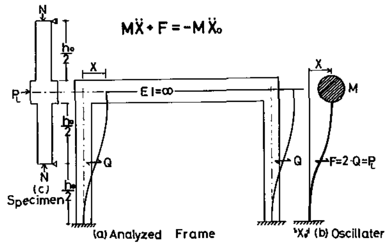

Fig. 1 Analysed Frame and Specimen

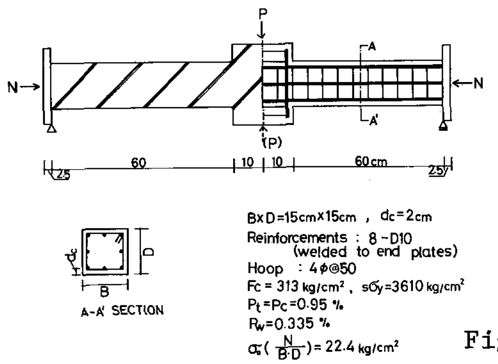

Fig. 2 Detail of Specimen

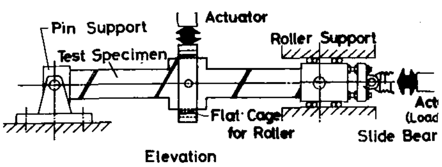

Fig. 3 Test Setup

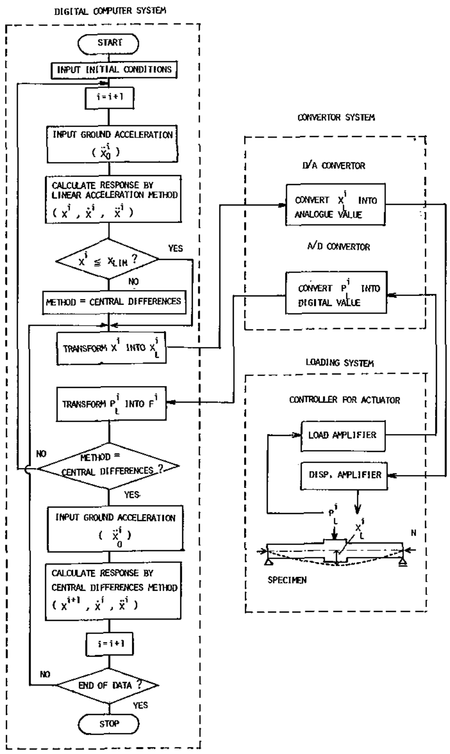

Fig. 4 Flow Diagram of On-line System

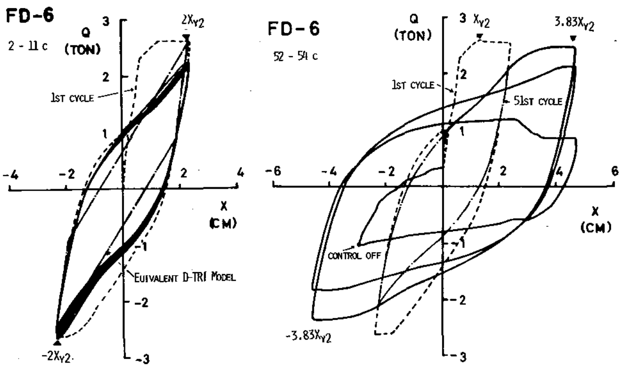

Fig. 5 Shear Force vs. Disp. Relationship by Cyclic Loading Test

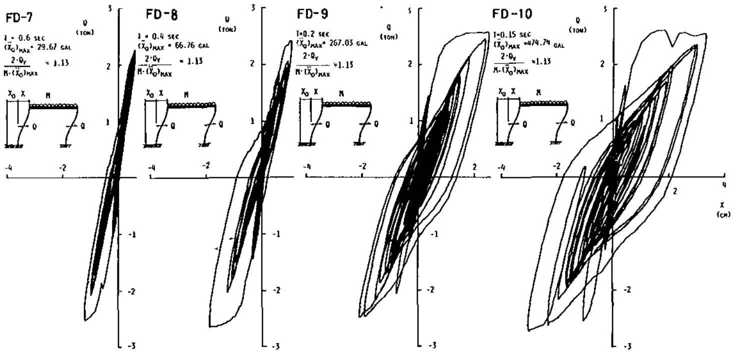

Fig. 6 Response Shear Force vs. Displacement Relationship by On-line Test

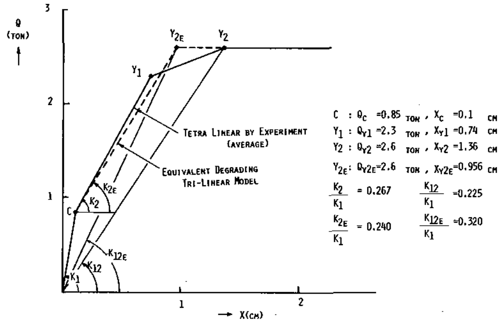

Fig. 7 Average Skelton Curve and Equivalent Tri-linear Curve

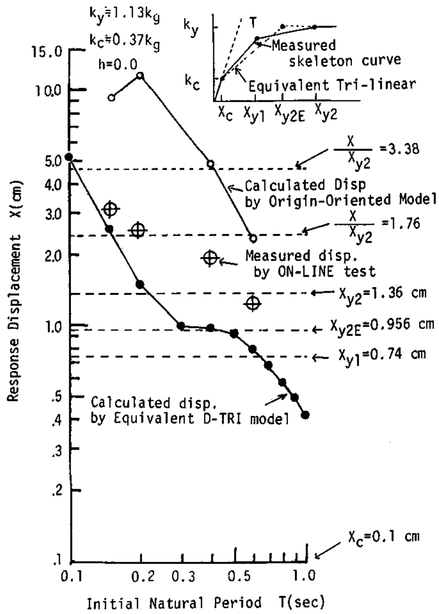

Fig. 8 Response Displacement Spectrum

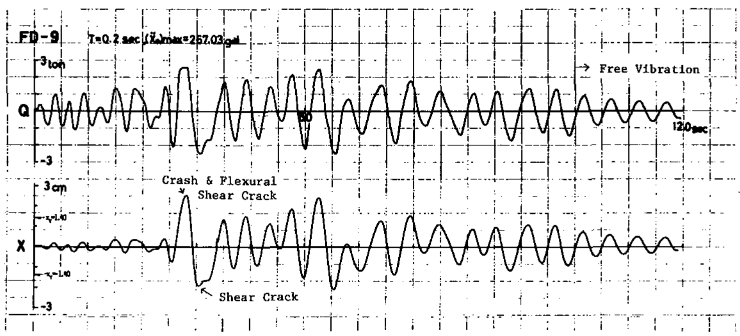

Fig. 9 Response by On-line Test