V-220 INELASTIC RESPONSE OF R/C FRAMES USING A SUBSTRUCTURED ON-LINE HYBRID TEST METHOD

William TANZO 学生会員 Grad. Student, Kyoto Univ.
Yoshikazu YAMADA 正会員 Prof., Kyoto Univ.
Hirokazu IEMURA 正会員 Assoc. Prof., Kyoto Univ.

Introduction In many large structural systems subjected to strong earthquakes, severe inelastic deformations will likely occur in certain localized regions. For instance, large deformations are usually induced in first-story columns of multistory frames. Most experimental investigations on inelastic behavior of columns are conducted by quasi-static loading tests, in which test specimens are alternately cycled through increasing displacements that are symmetrical in both directions. However, under real earthquake loading, a critical region may undergo extensive nonlinearities biased to one direction. Large plastic deformations are produced in one direction, while the other direction attains relatively lower displacements and with less-frequent excursions. Using displacement histories from shaking-table tests to load cantilevered specimens by actuators, Kawashima et al [1988] reported inelastic response favoring one direction of bridge piers under real earthquake loading and have shown that simulated loading test results are reliable provided that displacement loading histories could be correctly obtained.

In this paper, realistic displacement loading histories are automatically obtained by using substructured on-line hybrid procedure. Test can be done with simple set-up, testing only critical sub-assemblages that are likely to undergo extensive nonlinear behavior. Inelastic response of the total structure are reliably predicted by an analytical procedure utilizing load-deformation characteristics of critical regions measured during an on-line test.

Substructured On-line Hybrid Analysis and Test Procedure Incorporating substructuring concepts, a substructured on-line hybrid test method is developed in which the critical regions are tested experimentally and the rest of the structure are modeled analytically. The equations of motion used in substructured on-line hybrid test are expressed in the following form:

$$\boldsymbol{M}\{\ddot{x}\}_t + \boldsymbol{C}\{\dot{x}\}_t + \tilde{\boldsymbol{K}}\{x\}_t + \{R\}_t = \{P\}_t \tag{1}$$

Load-deformation characteristics are expressed by two terms, $\tilde{\boldsymbol{K}}$ modeling the portions (analytical substructures) whose properties can be reasonably predicted by presently-available mathematical models, while the restoring-force vector $\{R\}$ takes in measured values defining the highly-nonlinear behavior of the experimental substructure(s). Numerically integrating Eq. 1, say using the central difference scheme,

$$\{x\}_{t+\Delta t} = \left[\{P\}_t - \{R\}_t + \left(-\tilde{\boldsymbol{K}} + \frac{2}{\Delta t^2}\boldsymbol{M}\right)\{x\}_t - \left(\frac{1}{\Delta t^2}\boldsymbol{M} - \frac{1}{2\Delta t}\boldsymbol{C}\right)\{x\}_{t-\Delta t}\right] \Big/ \left(\frac{1}{\Delta t^2}\boldsymbol{M} - \frac{1}{2\Delta t}\boldsymbol{C}\right) \tag{2}$$

$\boldsymbol{M}$, $\boldsymbol{C}$ and $\tilde{\boldsymbol{K}}$ are analytically prescribed from estimated properties of the modeled system. Given a specified ground acceleration record, the displacement at the next time step is calculated using Eq. 2 from the knowledge of restoring forces and displacements at the previous steps. Digital value of the calculated displacement at the present step is first converted to a voltage change by a D→A converter. The converted analog signal is sent to the servo-controller, which then regulates the flow of high-pressure hydraulic fluid to the actuators. The actuators, in turn, force the specimen to deflect to the required position. When the desired displacements are achieved, restoring force is measured by the load cells. This information is sent to an A→D converter and fed into the computer, which then calculate the next displacement using Eq. 2.

Nakashima et al [1988] discussed various aspects of substructured on-line hybrid test method.

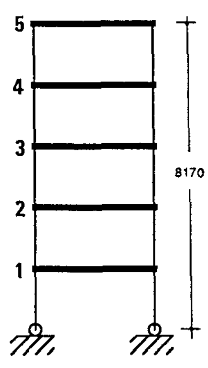
Model, Specimen, and Experimental Set-up Iemura et al [1988] used the substructured on-line test method to study extensive nonlinear behavior of first-story columns in multistory R/C frames. For a 5-story 1-bay frame hinged at its base (Fig. 1a), analytically prescribed values are shown in Table 1. It is subjected to 30 seconds of the NS-component of the 1940 El Centro earthquake scaled to 0.5g.

Test specimen for the identical first-story columns are of 150mm × 200mm section (Fig. 1b) and 1.634m long. Concrete compressive strength is about 480 kg/cm^2. Longitudinal reinforcements consists of four D13 bars with specified yield strength of 3500 kg/cm^2. Transverse reinforcements consists of 5ϕ ties spaced at 40mm for 400mm of the potential plastic hinge region, and continued at 100mm spacing for the remaining length. The cantilevered specimen is securely fixed to the reaction floor and loaded laterally at its tip.

Results and Analysis Response history in Fig. 2 show the first-story columns undergoing large displacements that are highly biased to one direction. Unlike in usual quasi-static cyclic tests in which specimens are reversely cycled through increasing symmetrical positive and negative displacements, a column under earthquake forces may respond nonlinearly biased to one side inducing large plastic deformation on one direction and causing the structure to vibrate mainly about this range. Relatively smaller displacements are attained on the other direction and also with less-frequent excursions. The hysteretic force-displacement curve in Fig. 3 indicated that steel had reached strain-hardening stage on the direction with large and frequent displacements. Displacement response histories of the upper stories are within elastic limits.

Conclusions By substructured on-line hybrid method, critical sub-assemblages and components can be tested economically under realistic load histories considering proper boundary conditions. Test can be done with simple set-up, testing only critical sub-assemblages that are likely to undergo extensive nonlinear behavior. Inelastic behavior of the total structure are reliably predicted by an analytical procedure utilizing load-deformation characteristics of critical regions measured from an on-line test.

References (1) H. Iemura, et al [1988]: "Testing R/C Specimens by a Substructure-based Hybrid Earthquake Loading System," *9WCEE,* IV, 35–40. (2) K. Kawashima, et al [1988]: "Hysteretic Behavior of Reinforced Concrete Bridge Piers by Dynamic Loading Tests and Shaking Table Tests," *9WCEE,* IV, 443–448. (3) M. Nakashima, et al [1988]: "Feasibility of Pseudo Dynamic Test Substructuring Techniques," *9WCEE,* IV, 47–52.



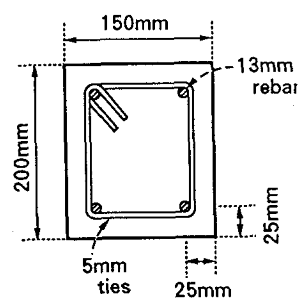


Fig. 1(a) Frame Model.
(b) Test Specimen.

Table 1 Analytically Prescribed Properties of Frame.

	Weights	Damping	Stiffness
1	4.5 t	5%	—
2	3.8 t	5%	.623 t/mm
3	3.8 t	5%	.623 t/mm
4	2.0 t	5%	.374 t/mm
5	2.0 t	5%	.374 t/mm

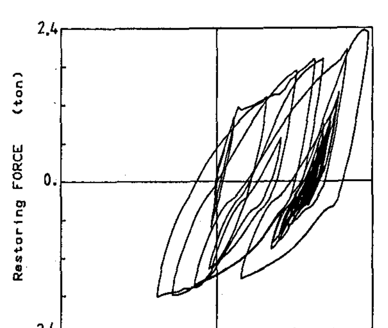


Fig. 2 Load-Deformation Response of 1st Story Columns

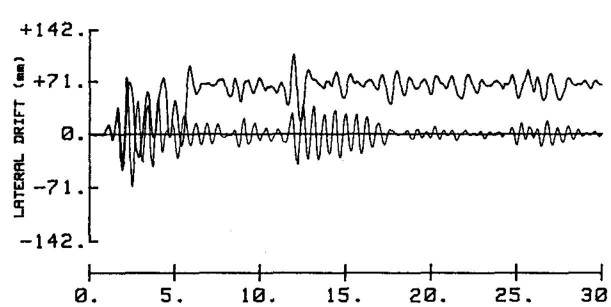


Fig. 3 Displacement Response History of 1st-Story Columns (also indicated: Elastic Response).