I-487 SUBSTRUCTURING TECHNIQUE FOR HYBRID LOADING SYSTEM OF EARTHQUAKE RESPONSE

William TANZO --- graduate student, Kyoto University
Yoshikazu YAMADA --- professor, Kyoto University
Hirokazu IEMURA --- associate professor, Kyoto University
Kazuyuki IZUNO --- research associate, Kyoto University

Introduction   Earthquake response of single degree-of-freedom (SDOF) models have been realistically simulated by HYLSER (Hybrid Loading System of Earthquake Response) system [Iemura et al, 1980; 1984; 1986]. Detailed investigation of the hysteretic behavior of SDOF models by such hybrid analytical-experimental method gives better results than those possible under pure analytical studies or quasi-static cyclic loading tests.

A far larger class of structures, however, cannot be modeled as SDOF systems. In cases of severe inelastic deformations limited to certain localized regions in a large structural system, considerable costs could be saved by testing only those portions where present state of development does not allow inelastic behavior to be modeled mathematically. This paper deals with a substructuring technique that could be used to extend the utility of the HYLSER system without entailing any additional hardware need.

Substructure-Based Hybrid Earthquake Loading System   Using the proposed substructure-based on-line hybrid loading system, seismic behavior of a member being studied is simulated by imposing on a cantilever model the local deformation level that a member sustains as part of a complete structural system under earthquake forces. These local deformations, transformed from generalized displacements corresponding to the test specimen, results from a step-by-step inelastic seismic structural analysis. Restoring forces developed on the loaded specimen are measured and transformed into generalized forces. These generalized experimental restoring forces are then assembled to those of the analytical members, whose properties are defined by mathematical constitutive laws.

At each time step, equations of motion are set up and reduced to a form similar to static force-displacement relationship.

$$\left[A \right] \left\{ \Delta \right\}^{t+\delta t} = \left\{ B \right\}$$

The **A**-coefficient matrix contains constants related to both mass and damping matrices; while the **B**-vector is updated incrementally for changes in applied earthquake loads, analytical stiffness matrix, and experimental restoring-force vector. Displacements at the next time step are explicitly determined based entirely on displacement vectors of the previous two steps. From there, step-by-step solution proceeds recursively to get the next displacement vector.

As an investigative tool for studying general seismic behavior of frame structures, deformation (axial, lateral, rotational) histories need not be imposed in the exact manner outlined above. Great simplification is achieved by pinpointing the inflection on the frame member where a critical section is to be studied. Presumably, if the inflection point does not shift appreciably during dynamic motion, inelastic property of a frame member in focus could be modeled by forcing the tip displacements of an analytical cantilever sub-element and an experimental cantilever sub-element to deform so that these equal the lateral deformation of the simulated frame member at the inflection point. Based on this implementation,

$$\left[A\right]=\frac{1}{(\delta t)^2}\mathbf{M}+\frac{1}{2\delta t}\mathbf{C}$$

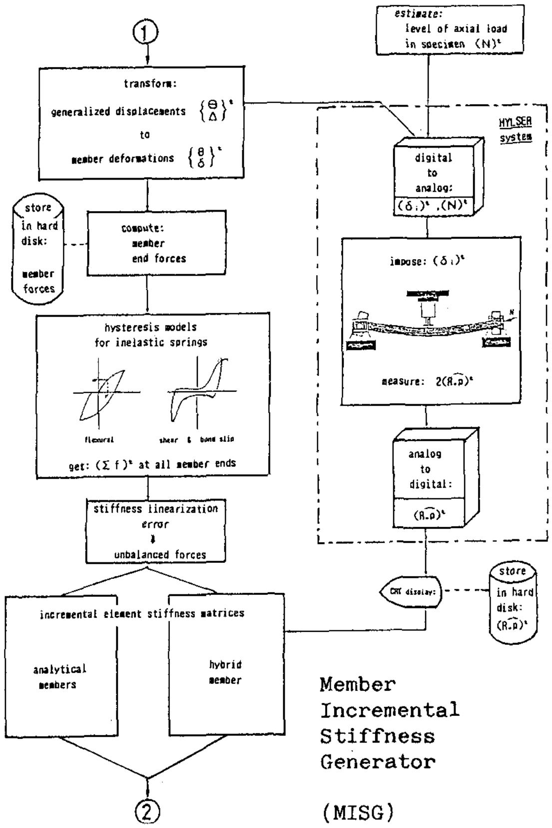
$$\left\{B\right\}=\mathbf{M}\,a_g{}^t-\left\{\Phi_\Delta^*\right\}^t-\left[\overline{\mathbf{K}}_\Delta^*-\frac{2}{(\delta t)^2}\mathbf{M}\right]\left\{\Delta\right\}^t-\left[\frac{1}{(\delta t)^2}\mathbf{M}-\frac{1}{2\delta t}\mathbf{C}\right]\left\{\Delta\right\}^{t-\delta t}$$

$$\left[\overline{\mathbf{K}}_\Delta^*\right]=\left[\overline{\mathbf{K}}_{\Delta\Delta}\right]-\left[\overline{\mathbf{K}}_{\Delta\theta}\right]\left[\overline{\mathbf{K}}_{\theta\theta}\right]^{-1}\left[\overline{\mathbf{K}}_{\theta\Delta}\right]$$

$$\left\{\Phi_\Delta^*\right\}=\left\{\Phi_\Delta\right\}-\left[\overline{\mathbf{K}}_{\Delta\theta}\right]\left[\overline{\mathbf{K}}_{\theta\theta}\right]^{-1}\left\{\Phi_\theta\right\}$$

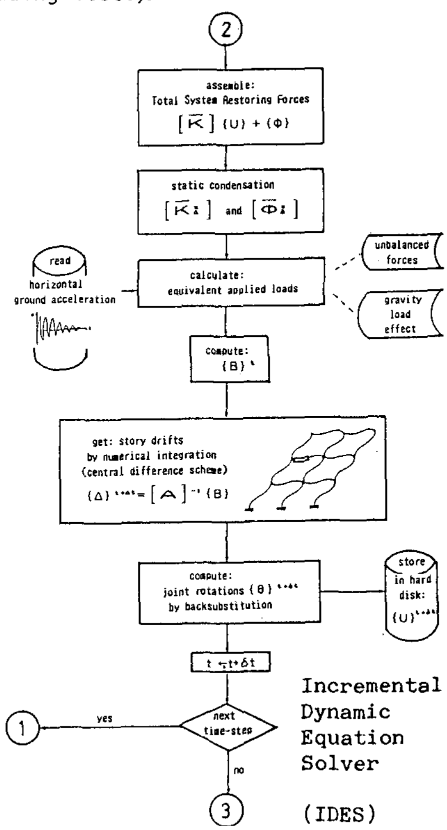
Flow diagrams describing the two main routines of a substructure-based on-line experimental system (Sub-HYLSER) are charted in the accompanying figures.

Concluding Remarks　　The same SDOF-able HYLSER system is used to determine the earthquake response of a critical member as part of a MDOF structural frame, by implementing a so-called hybrid substructuring technique. The experimental program devised could test isolated-beam specimens under a better-defined realistic loading criteria (compared with quasi-static cyclic loading tests).



Member
Incremental
Stiffness
Generator

(MISG)



Incremental
Dynamic
Equation
Solver

(IDES)

Refs. [1] H. Iemura:　7th WCEE, Turkey, 1980.
[2] H. Iemura:　8th WCEE, San Francisco, 1984.
[3] D. Ristić, Y. Yamada, H. Iemura:　research report no. 86-ST-01, Kyoto Univ.
[4] D. Ristić, Y. Yamada, H. Iemura:　8th ECEE, Portugal, 1986.