SUBSTRUCTURED COMPUTER-ACTUATOR HYBRID LOADING TESTS FOR INELASTIC EARTHQUAKE RESPONSE OF STRUCTURES

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INTRODUCTION By incorporating substructuring concepts into on-line hybrid test technique, a substructured on-line hybrid test method is developed in which only the critical regions are tested experimentally, while the other regions of the structure are modeled analytically. In this paper, development and implementation of a substructured on-line hybrid loading system are briefly summarized. Some problem areas and difficulties are pointed out for further considerations in improving the system.

DEVELOPMENT AND PRESENT IMPLEMENTATION In the initial stage of development, a multistory shear frame structural model with hinge supports was used to study and verify the feasibility of substructured hybrid loading test method [Iemura et al, 1988]. Two main impediments towards general applicability of substructured on-line hybrid test methods were identified: (1) numerical stability and accuracy problems when applied to MDOF structures; and (2) lack of general loading system capable of subjecting a specimen under axial, lateral and bending loads.

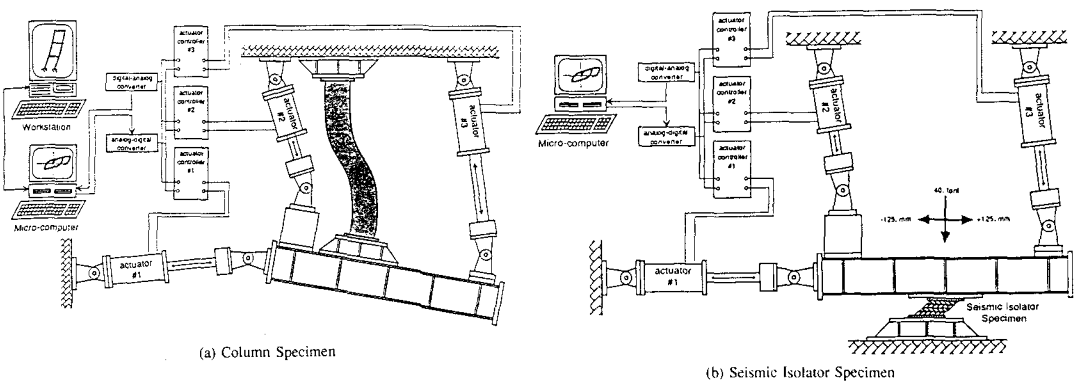

Fig. 1 General in-plane loading system for axial, shear, and bending loads

For an *inelastic structure*, the equations of motion may be expressed as follows:

$$[M]\{\ddot{x}\}_t + [C]\{\dot{x}\}_t + \{R_f\}_t = \{P\}_t \tag{1}$$

in which, the restoring-force vector $\{R_f\}$ comes from both analytical models and measured restoring forces from the loaded specimen. A class of so-called mixed integration methods originally developed for finite element analysis of structure-fluid interaction has been found to be suitable for substructured hybrid tests [Nakashima, et al, 1990; Dermitzakis and Mahin, 1985].

The other major problem is the lack of a loading system capable of subjecting a specimen under axial, shear, and bending loads. Major efforts have been done in developing and implementing the hardware and software system to achieve this objective. The developed loading system has been used to test diverse specimens (Fig. 1) such as RC columns [Yamada et al, 1990], steel box-section columns [Yamada et al, 1992], and high-damping rubber seismic isolation bearings [Iemura et al, 1991].

All three actuators are displacement controlled. In reality, explicit control of all three degrees of freedom (axial, lateral, and rotational) is hard to achieve especially for axially stiff elements. In the implemented control algorithm, the axial d.o.f. is controlled in order to achieve a certain target axial load within a certain specified error range (Fig. 2). Higher accuracy in axial control may be achieved (5% in Fig. 2b compared with 10% in Fig. 2a), but longer loading time is needed. This should be carefully used when loaded specimen is sensitive to relaxation problem.

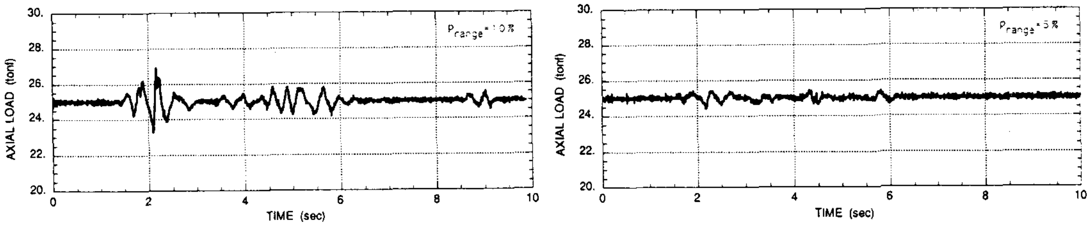

Fig. 2 Control of axial load variation using (a) 10% and (b) 5% allowable error

FUTURE DIRECTIONS The major work done in this research is to develop the basic hardware and software control of a 3-DOF general in-plane loading system. A lot of possibilities exists for further development. In one direction, more effort can be taken towards implementation of more inelastic hysteretic models and structural elements to better characterize the analytical substructures. The developed dynamic analysis program is implemented in such a manner that new structural elements, new hysteretic models, and new numerical time integration methods may be simply added.

In another direction, a 6-DOF loading system may be implemented with the addition of three actuators. With such system, very important structural research areas involving out-of-plane behavior such as torsional problems in structural components may be tested. The control software may be extended to impose three displacements and three rotations by expressing the geometrical relationships in space coordinates. Likewise, the dynamic analysis algorithm may be extended to include space frame problems.

CONCLUSIONS Major efforts have been done towards the development and implementation of a substructured hybrid loading test system with general applicability. The developed loading system can subject a specimen under combined axial, shear and bending loads. In this way, critical sub-assemblages and components can be tested economically under realistic load conditions considering proper boundary conditions. Using substructured hybrid test method, inelastic earthquake response of the total structure can be reliably predicted.

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