PSEUDO-DYNAMIC RESPONSE ANALYSIS BY COMPUTER-ACTUATOR HYBRID SYSTEM AND IT'S APPLICATION TO ASEISMIC DESIGN OF STEEL STRUCTURES

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INTRODUCTION

The response analysis of a building structure to earthquake ground motions can be achieved by solving the equation of motion of the structural system. Very often it is required for aseismic design that the response behavior beyond the elastic limit is examined. There, non-linear numerical models such as bi-linear, tri-linear, Ramberg-Osgood type functions etc. have been widely used to represent the non-linear restoring force characteristics of structures. However, the appropriateness of such numerical models is not always approved. The most suitable model should be determined to describe the real behavior of each structure. But it is indeed a difficult problem to know the real behavior where the deterioration in the stiffness and strength takes place because of the yielding of materials, loss of stability and fracture at structural members and connections.

On this standpoint, this paper describes two phases of non-linear response analysis. In the first phase the analysis aims at the acquisition of real response behavior of structures to earthquake ground motions. Experimentally it is achieved by vibration tests and shaking table tests on structural models. However, some restriction must be imposed on these tests due to the performance of testing machine such a shaking table capacity. A structural model tested must be made usually in a considerable reduced scale. In such a model some details and/or even the material must be changed or simplified by the reason of difficulty in manufacturing. So the model becomes different from the prototype in some senses.

In order to obtain the inelastic response behavior of full scale or semi-full scale structural models, a response analysis system, called IIS Computer-Actuator (On-line) Hybrid System, was developed by the earthquake engineering research group.
(ERS) in Institute of Industrial Science, University of Tokyo (Takanashi, K. et al. 1978). The system comprises a mini-computer and computer-controlled actuators (hydraulic jacks). In the integral manipulation of the equation of motion by the mini-computer, the restoring force value is supplied from the measurement in the structural model test loaded by the actuator. Already, several analyses have been completed by using the system. The inelastic response behavior of some structural models is discussed later.

The second phase of analysis is to compose a numerical model describing a restoring force characteristics in the inelastic range. The numerical model is desired to be as simple as possible from the viewpoint of structural design. In the following articles some numerical models are presented, which are compared with the corresponding response results obtained by the above mentioned hybrid system.

EARTHQUAKE RESPONSE ANALYSIS

IIS Computer-Actuator (On-line) Hybrid System

An earthquake response analysis system, IIS Computer-Actuator (On-line) Hybrid System, is a hybrid system where response calculations are carried out on the basis of real restoring force characteristics. The basic idea of the hybrid system is illustrated in Figure 1, comparing with the "pure" computer analysis. The fundamental flow of the procedure in the hybrid system can be expressed by the right dashed-line boxed diagram. There, the integration of the equation of motion is done by the computer, but the restoring forces for the manipulation are provided by the load test on a full scale or a reduced scale structural model. The restoring forces are measured during the load test, while the actuators are controlled by the computer to impose the exactly same response displacements on the structural model as calculated in the integral manipulation.

The "pure" computer analysis widely used in the aseismic design is expressed by the left dashed-line boxed diagram in Figure 1. There, a pre-determined numerical restoring force model must be provided beforehand. Bi-linear, tri-linear, Ramberg-Osgood type function and more complicated models are often assumed in the inelastic response analysis. Therefore, it can be stated that such assumptions of restoring force characteristics in the "pure" computer analysis are replaced by the load test in the hybrid system.

The response values of the k-th floor in a multi-story building frame can be obtained by integrating the equation of motion

\[ M_k \ddot{X}_k^i + F_k^i = -M_k \ddot{Y}_i \]

for the acceleration of a certain ground motion \( \ddot{Y}_i \), where \( M_k \), \( X_k^i \) and \( F_k^i \) are the mass, the displacement at the floor level and