Improved model for real-time substructuring testing system

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Abstract

Real-time substructuring (RTS) is a hybrid technique meant for evaluation of dynamic response of large structures. The critical component of the structure is experimentally tested, while the remaining components are modelled numerically. This paper discusses about various issues associated with the simulation of RTS. An improved model based on Simulink module of MATLAB is proposed to create the actual experimental conditions. Detailed model of electro servohydraulic actuator based on fluid power engineering is used to emulate the nonlinear behaviour of the actuator. As the response of the actuator is a function of the specimen, the actuator model involves boundary conditions of the experimental setup. Such detailed model is then simplified to develop a transfer function for the actuator. Feedforward compensator with modified inverse dynamics is employed to compensate for actuator dynamics. Time integration is carried out by using Rosenbrock-W method, to solve the dynamic equations of motion of the numerical substructure. The dynamic response of a linear single degree of freedom (SDOF) system, nonlinear SDOF system and linear multi degree of freedom (MDOF) system to El-Centro earthquake is evaluated by using the proposed RTS model. The evaluated responses are compared with those obtained from the numerical analysis of full structure without substructuring using Operator Splitting Method (OSM). Upon comparison, the proposed model is found to be suitable for evaluation of the dynamic response of a structure.

1. Introduction

Civil engineering structures are generally large and it is difficult and sometimes impossible to perform full scale dynamic testing in a laboratory. Presently, various techniques like shake table test, pseudodynamic test, numerical modelling are being used to evaluate the dynamic response of a structure. Each of these techniques has some limitations. Shake table test is carried out on a scaled down model of a structure. It is difficult to investigate the resistance mechanism or demonstrate the effect of structural control devices at the smaller scales. A structure may fail because of local failure which one may not observe in a scaled down model. Pseudodynamic test is carried out on an extended time scale because of which the method is not able to capture the rate dependent effects like damping. Extrapolation to full scale dynamic behaviour becomes even more difficult when a structure exhibits nonlinear response.

Another method to evaluate the dynamic performance of the structural system is by developing a numerical model, for example, by using finite element method (FEM). With the advancement in technology, new materials of construction and complex structural architecture are being used in practice. It is difficult to accurately model the structure because of its size and complex behaviour. Real-time substructuring (RTS) is relatively new technique which tries to overcome these problems. RTS is based on the concept of structural partitioning. It takes the advantage of the fact that nonlinearity occurs only in the few components of the structure. So only those components of the structure are tested physically and then coupled with the numerical model of the rest of the structure. This technique requires high performance and compatibility of both the testing equipment as well as numerical algorithms in order to obtain reliable responses.

Hakuno et al. [1] were the first to come up with the idea of real-time hybrid experiment. It was not successful because of the limitations of the hardware available at that time. After few decades, Nakashima et al. [2] have successfully implemented RTS technique and were able to capture the dynamic response of the building constructed on two rubber isolation bearings with a viscous damper installed in parallel up to 1 Hz. The dynamics of the actuator in a real-time experiment was first considered by Horiuchi et al. [3,4]. The actuator delay was compensated by predicting the displacement of the actuator after time delay by $n$th order polynomial extrapolation based on current and previous displacements. Nakashima and Masaoka [5] have proposed a method in which the tasks of computing the target displacements and the command signals to the actuator were separated. Both the tasks were performed on a single digital signal processor. The method was shown to produce reasonable results for a 9-storey building (10 DOFs) with

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