IMPROVED NUMERICAL INTEGRATION PROCEDURE FOR APPLICATION TO SEISMIC HYBRID SIMULATION

Maedeh ZAKERSALEHI
PhD Candidate, Tarbiat Modares University, Tehran, Iran
m.zakersalehi@modares.ac.ir

Abbas Ali TASNIMI
Professor, Tarbiat Modares University, Tehran, Iran
tasnimi@modares.ac.ir

Mehdi AHMADIZADEH
Assistant Professor, Sharif University of Technology, Tehran, Iran
ahmadizadeh@sharif.edu

Leila HAJNAJAFI
PhD Candidate, Amirkabir University of Technology, Tehran, Iran
lila_najafi@aut.ac.ir

Keywords: Seismic Hybrid Simulation, Numerical Integration, Accuracy, Error Index

Hybrid simulation method is a relatively new test method for evaluating seismic performance of new and complex structural components experimentally in large scale. In this method the structure is divided into several experimental and numerical substructures in which only parts of structure with unknown or complicated behavior are tested experimentally. The most important advantage of this test method is that its results are comparable with shake table tests while its expenses are considerably lower.

In hybrid simulation, the response of the structure is obtained by numerically solving the equation of motion of the whole system. For solving the equation of motion, explicit integration methods have been widely used in hybrid simulation because their implementation is very easy. However, their stability criteria are very restrictive especially for multi degree of freedom systems which limit their application to simple systems. In implicit integration methods better stability and accuracy is achieved and larger time steps can be used, but application of these integration methods for hybrid simulation is not as easy as pure numerical simulations because iteration on experimental substructure is not practical. Furthermore it is required to determine the tangent stiffness matrix in each integration time step that its online estimation for experimental substructure is difficult.

In this paper an integration procedure is proposed to use a stable and accurate implicit integration method for hybrid simulation without the need for iteration on experimental substructures or estimating the experimental tangent stiffness matrix. In the proposed method which is named VTS Method (Variable Time Step Method) by adjusting the time step length (Δt), implicit integration methods are employed for hybrid simulation as easy as explicit methods. In each step of this method, after imposing the command displacements to the experimental substructures and measuring restoring forces, Δt is determined in such a way that not only the equation of motion is satisfied but also a proper kinematic relations between displacement, velocity and acceleration upon an implicit method is maintained. The algorithm of the proposed method is illustrated in Figure 1:

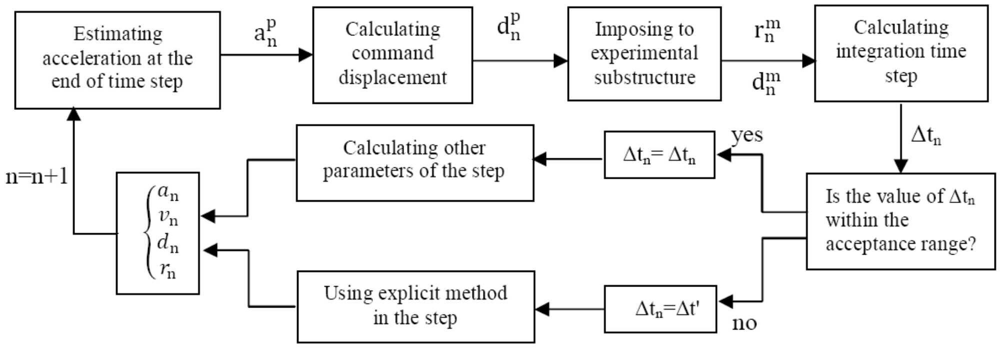

Figure 1. Algorithm of the VTS method for hybrid simulation

Performance of the VTS method has been examined through the simulation of a wide range of structures and the results showed the proper accuracy, stability and convergence of this method. Figure 2 presents an example of the time history response of a SDF nonlinear system under Tabas earthquake for a pure numerical simulation. In this figure the response of the system is plotted for both VTS method and Newmark implicit method. The figure shows that the results of VTS integration method are in great compatibility with the results of Newmark implicit method which shows the effectiveness of the proposed method for hybrid simulation.

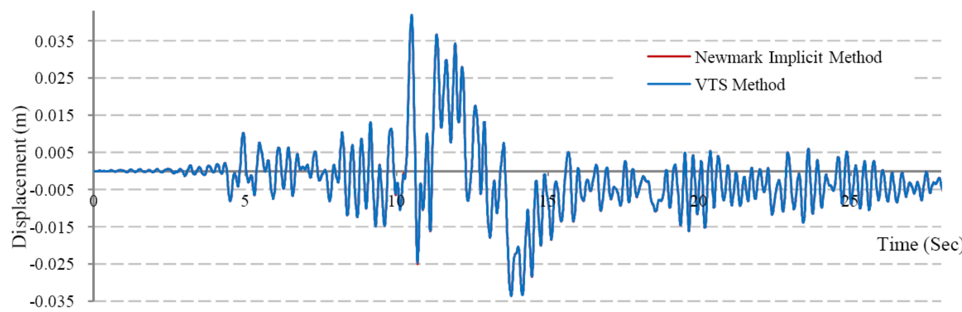

Figure 2. Response of the SDF nonlinear system under Tabas earthquake

Furthermore, the results of the VTS method have been compared with mostly used integration methods for hybrid simulation and advantages and disadvantages have been discussed.

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