A simple implicit nonlinear dynamic analysis with structural damping in inelastic structural systems

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Introduction

Explicit integration methods, such as central difference method, have been frequently employed to analyze the nonlinear and/or discontinuous behaviors of structural systems due to its computational efficiency. However, when analyzing a large complicated system with high-frequency responses, an extremely small time step is required to guarantee numerical stability because explicit integration methods are conditionally stable. Additionally, since iterations are not conducted to rigorously satisfy the equilibrium equations within explicit integrations, very small time steps are used to obtain an accurate analysis results. Furthermore, when stiffness-proportional damping should be considered in structures, the explicit method will lose its computational efficiency because the equations of motion are no longer decoupled.

The most commonly used implicit methods, such as the Newmark with trapezoidal rule, are unconditionally stable. Even though large time steps can be adopted in the nonlinear dynamic analysis, a great amount of computation results from the factorization of an effective matrix. In order to combine the advantages of both the conventional explicit and implicit integration methods, but with their disadvantages removed, the concept of equivalent nodal secant stiffness and stiffness-proportional damping coefficients are employed to decouple the dynamic equilibrium equations. When analyzing geometrically nonlinear structural systems, a simple method using the corotational coordinate description and the rigid body rule is utilized to rapidly calculate the stiffness-proportional damping nodal forces on the element level. Based on the traditional incremental-iterative solution procedure, the nonlinear dynamic response can be predicted using the Newmark method. The study of several structural examples demonstrates that the simple procedure is robust when used to analyze practical nonlinear dynamic structures and that it exhibits high computational efficiency and stability.

In literatures, several researchers showed that unrealistic damping forces are generated at plastic hinges in which the element stiffness changes abruptly, when Rayleigh-type damping based on the initial stiffness matrix is used in seismic analysis. An important advantage of the simple dynamic analysis is that any kind of FE can be included in the analysis procedure as long as the element internal and damping nodal forces can be exactly evaluated. Since the stiffness-proportional damping nodal forces are evaluated for each element in the simple dynamic analysis, different Rayleigh coefficients can be arbitrary assigned for each element, even changed or waived. Thus, the objective of this study is to present that the simple dynamic analysis is robust and efficient computationally in dealing with the structural damping without unrealistic damping forces when analyzing large structural systems exhibiting inelastic behavior under extreme earthquakes.