Seismic Response of Structures with Added Viscoelastic Dampers

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(ABSTRACT)

Several passive energy dissipation devices have been implemented in practice as the seismic protective systems to mitigate structural damage caused by earthquakes. The solid viscoelastic dampers are among such passive energy dissipation systems. To examine the response reducing effectiveness of these dampers, it is necessary that engineers are able to conduct response analysis of structures installed with added dampers accurately and efficiently. The main objective of this work, therefore, is to develop formulations that can be effectively used with various models of the viscoelastic dampers to calculate the seismic response of a structure-damper system.

To incorporate the mechanical effect from VE dampers in the structural dynamic design, it is important to use a proper force-deformation model to correctly describe the frequency dependence of the damper. The fractional derivative model and the general linear model are capable of capturing the frequency dependence of viscoelastic materials accurately. In our research, therefore, we have focused on the development of systematic procedures for calculating the seismic response for these models.

For the fractional derivative model, we use the G1 and L1 algorithms to derive various numerical schemes for solving the fractional differential equations for earthquake motions described by acceleration time histories at discrete time points. For linear systems, we also develop a modal superposition method for this model of the damper. This superposition approach can be implemented to obtain the response time history for seismic input defined by the ground acceleration time history. For random ground motion that is described stochastically by the spectral density function, we derive an expression based on random vibration analysis to compute the mean square response of the system.

It is noted that the numerical computations involved with the fractional derivative model can be complicated and cumbersome. To alleviate computation difficulty, we explore the use of a general linear model with Kelvin chain analog as a physical representation of the damper properties. The parameters in the model are determined through a curve fitting optimization process. To simplify the analytical work, a self-adjoint system of state equations are formulated by introducing auxiliary displacements for the internal elements in the Kelvin chain. This self-adjoint system can then be solved by using the modal superposition method, which can be extended to develop a response spectrum approach to calculate the seismic design response for the structural system for seismic inputs defined by design ground response spectra.

Numerical studies are carried out to demonstrate the applicability of these formulations. Results show that all the proposed approaches provide accurate response values, and the response reduction effects of the viscoelastic dampers can be evaluated to assess their performance using these models and methods. However, the use of a general linear model of the damper is the most efficient. It can capture frequency dependence of the storage and loss moduli as well as the fractional derivative model. The calculation of the response by direct numerical integration of the equations of motion or through the use of the modal superposition approach is significantly simplified, and response spectrum formulation for the calculation of seismic response of design interest can be conveniently formulated.

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