New elemental damping model for nonlinear dynamic response

Chin-Long Lee*

**Department of Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand, ORCID # 0000-0003-2885-7113*

Abstract. This study proposes a new elemental damping model for incorporating un-modelled energy dissipation in the simulation of seismic response of large-scale structures. It addresses the problems of the existing elemental damping model that result in difficulty in calibrating elemental parameters for desired global structural damping ratio and unintended large coupling effects between modes. The new model maintains the consistency between elemental damping ratio and global structural damping ratio, avoiding unnecessary complex calibration. It also allows the elemental damping ratio to be better correlated with the states of elemental stresses, deformations, damage variables, or any other internal state variables, such that a rational-based update on elemental damping ratio can be used to simulate un-modelled, changing energy dissipation during nonlinear dynamic response. Examples will be used to demonstrate the performance of the new model.

Introduction

Elemental damping models have recently been proposed to address the limitations of Rayleigh damping for incorporating un-modelled energy dissipation in the simulations of seismic response of large-scale structures [1]. In these models, elemental damping coefficient matrices are formulated based on elemental stiffness and mass matrices, and the global damping coefficient matrix is obtained by directly assembling these elemental matrices based on the common nodal degrees of freedom, just like how the global stiffness matrix is obtained from elemental stiffness matrices. This idea is particularly advantageous because it results in a damping coefficient matrix that has the same skyline pattern as the stiffness matrix, so that these models have the same computational efficiency as the Rayleigh model. Unfortunately, the resultant damping coefficient matrix is not proportional, resulting in coupling between modes and the coupling effects could be larger than anticipated. For a decent global damping ratio as low as 2 to 5%, the required elemental damping ratio could also be very large and even larger than 100% [2]. This raises questions on the physical meaning of elemental damping ratio. It is, therefore, warranted to have a new elemental damping model that addresses these problems.

Results and discussions

The new elemental damping model is derived based on the bell-shaped damping model recently proposed [3-6]. It uses a bell-shaped curve as the basis function to generate any user-defined damping ratio curve in the frequency domain, such as a constant, linear, trilinear, or a stepped curve. Although its damping coefficient matrix is fully populated, it can be expanded into a sparse block matrix using the idea of static expansion. The new elemental damping model adopts this sparse block matrix form of the damping matrix on the elemental level, and assemble them to obtain the sparse block matrix form of the global damping coefficient matrix. This big idea maintains a consistent damping ratio on both elemental and global structural level, thereby avoiding complex calibration process. It also allows the elemental damping ratio to be better correlated with the states of elemental stresses, deformations, damage variables, or any other internal state variables, such that a rational-based update on elemental damping ratio can be used to simulate changing un-modelled energy dissipation during nonlinear dynamic response. Examples have demonstrated the excellence performance of the new model.

References

[1] Puthanpurayil A.M., Lavan O., Carr A.J., Dhakal R.P. (2016) Elemental damping formulation: an alternative modelling of inherent damping in nonlinear dynamic analysis, *Bulletin of Earthquake Engineering* **14**: 2405–2434.

[2] Ni Y., Zhang Z., MacRae G.A., Carr A.J., Yeow T. (2019) Development of practical method for incorporation of elemental damping in inelastic dynamic time history analysis, *in: Proceedings of the 2019 Pacific Conference on Earthquake Engineering and Annual NZSEE Conference*, Auckland, New Zealand, 4-6 April, p. **4C.11**.

[3] Lee C.-L. (2020) Proportional viscous damping model for matching damping ratios, *Engineering Structures* **207**:110178.

[4] Lee C.-L. (2020) Sparse proportional viscous damping model for structures with large number of degrees of freedom, *Journal of Sound and Vibration* **478**:115312.

[5] Lee C.-L. (2021) Bell-shaped proportional viscous damping models with adjustable frequency bandwidth, *Computers & Structures* **244**:106423.

[6] Lee C.-L. (2022) Type 4 bell-shaped proportional damping model and energy dissipation for structures with inelastic and softening response, *Computers & Structures* **258**:106663.