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Procedia Engineering 14 (2011) 2489–2497

Procedia Engineering

www.elsevier.com/locate/procedia

The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction

Optimal Allocation of Non-Linear Viscous Dampers for Three-Dimensional Building Structures

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Abstract

A new approach has been proposed by the authors and applied to allocate linear viscous dampers optimally for two- and three-dimensional building structures recently. This approach is extended to search for the optimal allocation of non-linear viscous dampers in this paper. The same initial damper placement is used for conducting the analysis. However, instead of carrying out the linear time-history seismic analysis, the non-linear time-history seismic analysis is performed first to obtain the inter-story drift ratio. Then, check the inter-story drift ratio for the locations where dampers were added and move the damper in the location with the minimal inter-story drift ratio to the location with the maximal inter-story drift ratio. Finally, repeat this process until the prescribed stop criterion is met. The non-linear viscous dampers with two exponents, including 0.3 and 0.5, and two seismic records, including the El Centro earthquake and Chi-Chi earthquake, are used in this paper. Three examples, including two 10-story and one 20-story three-dimensional unsymmetrical building structures, are used to demonstrate the efficiency and accuracy of the proposed approach. The results are compared with those obtained using the simplified sequential search algorithm (SSSA) and are also compared with the optimal placement of linear viscous dampers obtained using the proposed approach. It is found that the proposed approach requires much fewer analyses than the SSSA while their accuracy is comparable. The efficiency of the proposed approach for allocating non-linear viscous dampers is also comparable to or better than for allocating linear viscous dampers.

Keywords: Damper, Optimal allocation, SSSA, Non-linear viscous damper, Inter-story drift ratio.

1. INTRODUCTION

Placing dampers properly and effectively on structures has been a research focus for two decades since dampers got started to be applied popularly in earthquake-resistant design of buildings. Many papers related to this subject have been published since early 1980s. Then, more and more researchers got involved in this topic and presented papers in related journals. So far, several methods have been

doi:10.1016/j.proeng.2011.07.313

proposed for allocating linear viscous dampers. Among them, the SSSA is probably the simplest one. Garcia and Soong (2001, 2002) developed and proposed the SSSA on the basis of engineering knowledge and judgment to find the optimal allocation of supplemental dampers. Each time a damper is added to the position with maximal structural response so as to suppress it after carrying out a dynamic analysis; the procedure is repeated until all dampers are added. The more the number of dampers to be added in the building structures, the more the number of dynamic analysis to be performed. To reduce the number of dynamic analysis, a simple approach for relocating dampers with the idea similar to the SSSA is proposed in this paper.

2. ESTIMATION OF THE DAMPING CONSTANT OF ADDED DAMPERS

Given a damping ratio, the method for calculating the corresponding damping constant of viscous dampers in common design practice is based on the equivalent energy method. The equivalent damping ratio ξ_d due to the action of the supplemental nonlinear viscous dampers can be calculated approximately from the fundamental modal energy and given by:

$$\xi_d = \frac{\sum_{j=1}^{j=n_d} \lambda C_j \phi_{rj}^{1+\alpha} \cos^{1+\alpha}\theta_j}{2\pi A^{1-\alpha} \left(\frac{2\pi}{T}\right)^{2-\alpha} \sum_{i=1}^{i=n} m_i \phi_i^2} \tag{1}$$

where T is the fundamental period of the structure, ϕ_i is the first mode displacement at floor i, ϕ_{rj} is the first mode relative displacement between the ends of damper in the horizontal direction, C_j is the damping constant for damper j, θ_j is the inclined angle of damper j, m_i is the mass of floor i, A is the roof displacement when the modal displacement ϕ_j is normalized to one unit at the roof, n is the number of floor, n_d is the number of damper, α is the damping exponent between 0 and 1, and λ is a parameter which can be calculated by

$$\lambda = 2^{2+\alpha} \frac{\Gamma^2(1+\alpha/2)}{\Gamma(1+\alpha)} \tag{2}$$

in which Γ is the gamma function. The values of λ are tabulated in FEMA 273 based on Eq. (2).
Assume all the damping constants of supplemental dampers are the same and their inclined angles are also the same, i.e., $C_j = c$, $\theta_j = \theta$. Re-arrange Eq. (1) and the damping constant of each supplemental damper can be expressed as:

$$c = \frac{2\pi \xi_d A^{1-\alpha} \left(\frac{2\pi}{T}\right)^{2-\alpha} \sum_{i=1}^{i=n} m_i \phi_i^2}{\lambda \sum_{j=1}^{j=n_d} \phi_{rj}^{1+\alpha} \cos^{1+\alpha}\theta_j} \tag{3}$$

Given a damping ratio ξ_d, Eq. (3) allows one to calculate the damping coefficient of each added damper. Note that only the translational component is considered when calculating the modal kinetic energy in Eq. (1) and Eq. (3), which is the case for symmetrical three-dimensional building structures. However, the torsion effect in unsymmetrical three-dimensional building structures may be significant, which cannot be considered in Eq. (3). To resolve this problem, one needs to consider the associated energies due to the torsional component. If the number of dampers is chosen as twice the number of floors, i.e., $n_d = 2n$. Also, the added dampers are assumed to be placed uniformly along each story of two selected bays. Then, Eq. (3) is modified as: