Mechanical Systems and Signal Processing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

An optimization study for viscous dampers between adjacent buildings

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ARTICLE INFO

Article history:
Received 14 April 2016
Accepted 2 June 2016

Keywords:
Adjacent building
Structural pounding
Viscous damper
Seismic behavior
Optimization

ABSTRACT

This paper investigates optimum viscous damper capacity and number for prevention of one-sided structural pounding between two adjacent buildings under earthquake motion. The buildings assumed as shear-type structures are modeled by using lumped mass-stiffness technique. Impact forces due to pounding is simulated by nonlinear elastic spring approximation called Hertz model. A parametric study is conducted by varying storey number and stiffness of buildings in addition to the capacity of the viscous dampers. Pounding force and supplemental damping ratio for each case are presented based upon newly defined nondimensional natural frequency parameter ratio. An optimization procedure for determination of viscous damper capacity is developed based on modified supplemental damping ratio equation. Results are compared with each other to clarify the effect of variation in building parameters on pounding forces and viscous damper capacity.

1. Introduction

Buildings in metropolitan cities are usually constructed close to each other due to scarcity of land in densely populated areas like city centers. The seismic gaps stipulated in seismic design codes allow the neighboring buildings and structural parts to make relative translational movements without collision during earthquakes. However, insufficient gap between buildings subjected to ground motions may cause structural pounding leading to significant damages or even collapse as experienced in past earthquakes such as 1985 Mexico City and 1989 Loma Prieta earthquakes [1–4]. Main reason of the earthquake-induced structural pounding is out-of-phase behavior between neighboring buildings due to having different dynamic characteristics. To overcome this problem, there are a number of solutions applied in practice and also proposed in the related literature. The connection of the buildings by linking devices is the most common method used for prevention of pounding. Xu et al. [5] applied fluid viscous damper between adjacent buildings with different number of storeys. The analyses were done in both frequency and time domain to show the efficiency of dampers. Bhaskararao and Jangid [6] implemented friction dampers to reduce seismic responses of adjacent buildings. Raheem [7] used rubber shock absorber to avoid pounding. Yang et al. [8] performed an experimental seismic study of adjacent buildings with fluid dampers. Basili and De Angelis [9] studied the optimal passive control of adjacent structures interconnected by Bouc-Wen model nonlinear hysteretic devices under seismic excitations of a Gaussian zero mean white noise and a filtered white noise. Kim et al. [10]

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http://dx.doi.org/10.1016/j.ymssp.2016.06.001
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analyzed the single degree-of-freedom (SDOF) systems connected by viscoelastic dampers at the seismic joints, under white noise and earthquake ground excitations, in order to observe reduction in earthquake-induced structural responses. They also performed dynamic analyses for 5-storey and 25-storey rigid frames connected to braced-frames. Kandemir-Mazanoglu and Mazanoglu [11] developed a simple optimization procedure for determination of capacity and location of linear viscous dampers between adjacent buildings. They conducted parametric study on both equal and stiff buildings connected with each other by linear viscous damper devices.

In this paper, two adjacent buildings with floors in alignment are analyzed through ground motion, 1999 Duzce earthquake (PGA 239.5 gal), to observe earthquake-induced structural pounding. To the best of author's knowledge, parametric study including location and capacity optimization of viscous dampers to prevent pounding is scarce and/or complex in current literature. In this study, various structural characteristics are taken into account by changing storey numbers and stiffness of buildings. The effects on pounding force are investigated for the cases of varied storey number of equal, stiffer and flexible buildings. Seismic time responses, i.e. displacement and impact forces, are obtained via Newmark-β method. The impact forces between adjacent buildings modeled as nonlinear elastic spring are analyzed for three cases considered. An optimization procedure for prevention of pounding effect by linear and nonlinear viscous dampers is carried out in order to find out optimum location and capacity of dampers. The aim in computation of nonlinear viscous damper capacity is to observe capacity reduction in comparison with that of linear viscous damper. The command of *fmincon* in Matlab Optimization Toolbox is used for optimization of viscous damper capacity and location. The boundary and equality constraints of optimization problem are constituted based on modified formulation of the supplemental damping ratio formulation proposed by FEMA 273/356 [12,13].

2. Formulations

2.1. Viscous dampers

Viscous dampers are velocity-dependent passive energy dissipation devices which do not possess inherent rigidity. Fig. 1 (a) shows schematic of a typical viscous damper. Piston moves with the movement of structure during earthquake motion forcing the viscous fluid inside cylinder to be passed through orifices on piston head. Dissipation of seismic energy is executed by transformation of kinetic energy into heat energy. Displacement response control of these devices is dependent on the stroke of the damper. Inside the stroke limit, viscous damper has no inherent stiffness. The produced damper force F_d, given in Eq. (1), depends on relative velocity between damper ends as follows;

$$F_d = cd(\alpha)\,|\dot{x}|^{\alpha}\,sgn(\dot{x}) \tag{1}$$

where $cd(\alpha)$ is damping coefficient which depends on velocity exponent α, $\dot{x}$ is relative velocity between damper ends, sgn is signum function. Velocity exponent takes value between 0 and 1. This constant value designates the damper type. The device is friction type, linear viscous and nonlinear viscous damper for α=0, α=1 and for 0<α<1, respectively. Fig. 1(b) depicts the force-displacement characteristics of three types of dampers. It is worth noting that damper force of NVD is less than that of LVD for same relative velocity response due to velocity exponent less than one. This feature saves the device from excessive forces when high velocity response occurs. Both linear and nonlinear viscous dampers are addressed in this paper to find out the effects of parametric changes on capacity reduction. Equation of motion of a single degree-of-freedom system with viscous dampers subjected to ground motion is written as in Eq. (2),

$$m\ddot{x}(t)+c\dot{x}(t)+kx(t)+cd(\alpha)\dot{x}(t)=-m\ddot{x}_g(t) \tag{2}$$

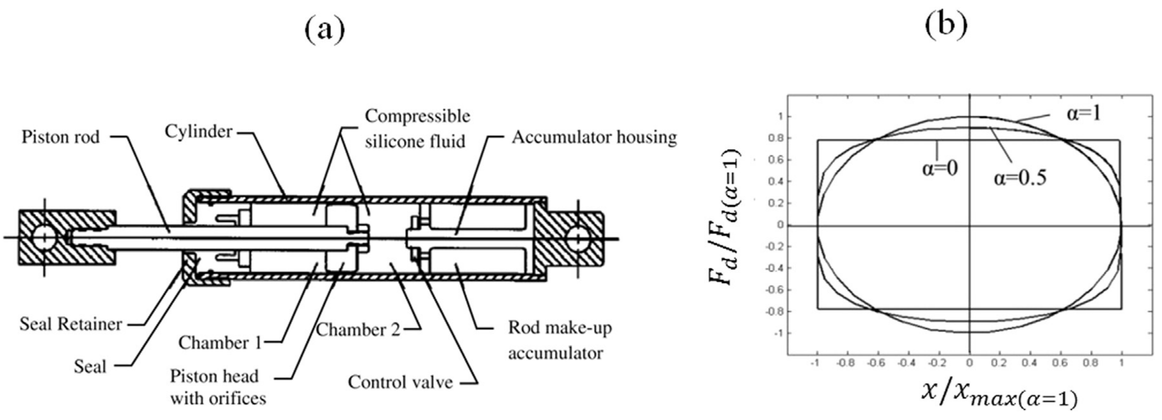

Fig. 1. (a) Schematic view (Symans and Constantinou, [14]) and (b) force-displacement relation of friction, linear and nonlinear viscous damper.