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Seismic control performance for Pounding Tuned Massed Damper based on viscoelastic pounding force analytical method

Qichao Xue [a, c], Jingcai Zhang [a], Jian He [a, *], Chunwei Zhang [b, c], Guangping Zou [a]

[a] College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin, China
[b] Institute for Infrastructure Engineering, Western Sydney University, Sydney, Australia
[c] School of Civil Engineering, Qingdao University of Technology, Qingdao, China

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ABSTRACT

This paper focuses on vibration control performance of Pounding Tuned Massed Damper (PTMD) with viscoelastic pounding layers, which can dissipate energy during collision process. By using of viscoelastic pounding force analytical method, two types of pounding force models for different contact geometries are developed to illustrate interactions among pounding components in PTMD. A shake table test based on a simplified experimental structure is conducted to verify the effectiveness of single PTMD as well as the viscoelastic pounding force model. Furthermore, a parametric study for a 14-storeys steel structure is presented to investigate the performance of PTMD device in multiple degree of freedom (MDOF) system. Results from numerical simulations demonstrated that properties of viscoelastic material and gaps between mass block and the limiters in PTMD are key factors for vibration control performance. By inputting a series of seismic excitations into MDOF system, comparisons between PTMD and traditional TMD reveals that the optimized PTMD has better performance than the traditional TMD in vibration suppression in certain cases.

1. Introduction

Tuned mass damper (TMD) is a traditional but effective vibration control techniques in civil engineering practice, and it was firstly discussed by Chang and Soong [1] in 1980. Since then many researches demonstrated its wide range of applications and remarkable effectiveness. Gu et al. [2] employed TMD to suppress the wind-induced vertical buffeting response of long span bridges. Multiple Tuned Mass Dampers (MTMD) were investigated by Yamaguchi et al. [3] to compare with single TMD in dynamic responses of structures excited on harmonic forces. Yu et al. [4] equipped MTMD to a bridge structure and verified its effectiveness and control mechanism. An adaptive compensation mechanism for suspended pendulum TMDs was proposed and studied by Roffel [5], in which the effectiveness of the proposed system was proved by both experiments and simulations. Rakicevic et al. [6] conducted shake table experiments to verify control effects for TMD with a simplified model coming from a five-storeys steel frame structure.

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* Corresponding author.
E-mail addresses: xueqichao@hrbeu.edu.cn (Q. Xue), hejian@hrbeu.edu.cn (J. He), zhangchunwei@qtech.edu.cn (C. Zhang), zouguangping@hrbeu.edu.cn (G. Zou).

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In spite of these promising applications in engineering practice, shortcomings and deficiencies are still existing in TMD system [7–10]. For instance, the effective frequency range is extremely narrow, and large mass block is necessary for a high-powered damper to maintain satisfying vibration control effect, which may lead to very high costs and space requirements. As one of effective methods to solve these disadvantages, nonlinear vibration absorbers were firstly developed by Gendelman [11] who provided numerical simulation results to prove absorber's effectiveness. Jiang's study [12] indicated that a nonlinear energy sink could absorb steady-state vibration energy from a linear oscillator by localizing the energy away from directly forced subsystem. Gourdon et al. [13] validated the effectiveness of a new linear wise system through numerical approach, and they also used two linear springs implementing on a cubic non-linearity structure and the experimental results verified the theoretical analysis of energy pumping with seismic excitation [14].

Active vibration control ways were widely studied in structural control research area in the last decades [15]. Yazici et al. [16–19] provided some meaningful advices on designing several types of active vibration control devices in seismic-excited structural systems. Guclu et al. [20] investigated performance of active TMD on structure against earthquake. Stewart et al. [21] presented influences from actuator dynamics on active structural control of offshore wind turbines. Pardo-Varela et al. [22] proposed a new type of semi-active piezoelectric friction damper to control seismic responses of large-scale structures. Kou et al. [23] developed a new active structure control device based on equivalent-input-disturbance (EID) approach.

Pounding tuned mass damper (PTMD) was proposed as a combination of traditional TMD and pounding limiters by Song [23]. Zhang, Li and Song's study [24–27] showed that PTMD had great vibration control performance on signal pole, Power Transmission Tower and subsea jumpers. Xue's research [28] indicated that PTMD device shows an excellent performance on single degree of freedom (SDOF) system excited by seismic effects. But there was rarely result showing the controlling performance of building structures with multiple degrees of freedom.

In this paper, viscoelastic pounding force analytical method is firstly introduced based on viscoelastic constitutive model analysis and contact mechanics theories. Then the expressions for two kinds of PTMDs with different contact geometries are deduced separately. After that, a shake table test based on a simplified experimental structure is conducted to verify the effectiveness of single PTMD as well as the viscoelastic pounding force analytical method. Furthermore, a 14-storeies steel structure is taken as an example to investigate the seismic controlling performance of multiple PTMD system. Detailed parametric study and comparisons between PTMD and traditional TMD in Multiple Degree of Freedom (MDOF) system are carried out to reveal vibration control characteristics of PTMD.

2. Schematic of viscoelastic PTMD

Poundings between adjacent structures induced by horizontal seismic action during earthquakes is a common phenomenon which may lead to damages even collapse. However, the interactions between components during collision is a process of energy dissipation and momentum exchange which may induce large pounding forces when collision occurs in a very short time interval. Pounding forces, as an additional effect can be utilized as controlling force to reduce structure vibrations. And the energy dissipation can be enhanced by viscoelastic materials which is squeezed between collision components.

As an improvement of TMD, PTMD consists of two parts: traditional TMD and limiters layered by viscoelastic materials. Fig. 1 illustrates the schematic of a PTMD system. A gap between mass block and viscoelastic layer which is denoted by d_{gap} must be kept to ensure proper functioning. When the relative displacement between mass block and main structure is less than d_{gap}, collisions will not occur. At this time, PTMD act as a traditional TMD. Otherwise, mass block impacts viscoelastic material layers during seismic event. And the pounding force will be regarded as an additional part of controlling effect in collision process, during which mechanical energy can be dissipated.

3. Modeling of pounding force

Precisely to illustrate time histories of pounding forces is precondition for vibration control analysis of PTMD. Many pounding force models have been proposed to figure out problems of interactions between colliding bodies and energy

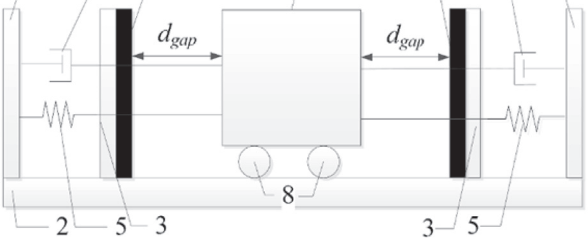

Fig. 1. Schematic of PTMD: 1. Limiter of TMD 2. Bottom board 3. Limiter of pounding device 4. Viscoelastic material 5. Spring 6. Damper 7. Mass block 8. Bearings.