Annual Reviews in Control 000 (2017) 1–28

Contents lists available at ScienceDirect

Annual Reviews in Control

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

Review article

Research developments in vibration control of structures using passive tuned mass dampers

Said Elias*, Vasant Matsagar

Department of Civil Engineering, Indian Institute of Technology (IIT) Delhi, Hauz Khas, New Delhi, 110 016, India

ARTICLE INFO

Article history:
Received 23 July 2017
Revised 25 September 2017
Accepted 26 September 2017
Available online xxx

Keywords:
Earthquake
Passive response control
Structures
Tuned mass dampers
Wind

ABSTRACT

A state-of-the-art review on the response control of structures mainly using the passive tuned mass damper(s) (TMD/s) is presented. The review essentially focuses on the response control of wind- and earthquake-excited structures and covers theoretical backgrounds of the TMD and research developments therein. To put the TMD within a proper frame of reference, the study begins with a qualitative description and comparison of passive control systems for protecting structures subjected to wind-imparted forces and forces induced due to earthquake ground motions. A detailed literature review of the TMD is then provided with reference to both, the theoretical and experimental researches. Specifically, the review focuses on descriptions of the dynamic behavior and distinguishing features of various systems, viz. single TMD (STMD), multiple tuned mass dampers (MTMDs), and spatially distributed MTMDs (d-MTMD) which have been theoretically developed and experimentally tested both at the component level and through small-scale structural models. The review clearly demonstrates that the TMDs have a potential for improving the wind and seismic behaviors of prototype civil structures. In addition, the review shows that the MTMDs and d-MTMDs are relatively more effective and robust, as reported. The paper shows the scope of future research in development of time and frequency domain analyses of structures installed with the d-MTMDs duly considering uncertainties in the structural parameters and forcing functions. In addition, the consideration of nonlinearity in structural material and geometry is recommended for assessment of the performance of the STMD, MTMDs, or d-MTMDs.

Contents

* Corresponding author.
E-mail addresses: said.elias@civil.iitd.ac.in (S. Elias), matsagar@civil.iitd.ac.in (V. Matsagar).

https://doi.org/10.1016/j.arcontrol.2017.09.015
1367-5788/© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

In recent years, great attention is being paid towards research and improvement of structural response control devices in civil engineering, particularly emphasizing mitigation of their wind and seismic response. Consorted efforts have been taken since the past two decades to extend the theoretical structural control concepts to the real-life structures. Structural vibration control against natural forces is a speedily growing field and the family of control systems and technologies has now been devised including the passive, active, semi-active, and hybrid systems. The conventional design methods are based on nonlinear, yielding, or ductile response of the structures when subjected to strong winds and earthquakes. Nevertheless, the present day wind and seismic design codes recommend adopting performance-based design criteria to be satisfied more readily than relying on the conventional methods. In several of the wind and seismically active countries in the world, applications of the structural controllers to the buildings, bridges, and industrial plants have been made towards improving their performance. Efforts are being made to provide comfort to the occupants especially in the tall buildings against such ambient dynamic forces (Hansen, Reed, & Vanmarcke, 1973). Table 1 shows the family of the controllers with their sub-categories.

It is commonly stated by the researchers and engineers that the passive structural response control systems (passive systems) are the simplest and robust. The passive systems are made of mechanical devices to dissipate a portion of structural input energy, thus reducing structural response and otherwise possible structural damage. They are used to mitigate structural vibrations induced by wind and earthquake excitations. These systems require no external power or measurements/ monitoring on the structural response. Numerous passive systems have been proposed by researchers; however, the most famous among them perhaps are the friction control devices, fluid viscous dampers, seismic base isolation, tuned liquid dampers, and tuned mass dampers.

Some of the passive systems are extensively investigated and well-established in the real-life applications in several types of structures. Many researchers have reviewed the performance of the passive systems theoretically and experimentally. Jangid and Datta (1995) reviewed the seismic behavior of the isolated buildings. Housner et al. (1997) presented a detailed review on the past, present, and future of the structural control with different control schemes. Buckle (2000) reviewed the performance of the passive control of structures subjected to the seismic loads. Soong and Spencer (2002) presented the state-of-the-art review on the effectiveness of the supplemental energy dissipation against natural hazards. Kunde and Jangid (2003) reviewed the performance of the base-isolated bridges under dynamic forces. Spencer and Nagarajaiah (2003) presented a detailed review on the structural control schemes. Later, Patil and Reddy (2012) reported a review on the performance of base isolation systems used in structures. Saeed, Nikolakopoulos, Jonasson, and Hedlund (2013) presented the state-of-the-art review on the structural control strategies. The review of the literature shows that four main groups of the controllers are commonly investigated by the researchers. These four groups are passive, active, semi-active, and hybrid control strategies, as shown in Table 1.

An active control system is defined as a system that requires relatively large power source for operation since electro-hydraulic actuators are used to provide the control forces in real-time. Since building structures are usually large, huge force-generating equipment, and large external power supplies are required for the active wind/seismic response control. Thus, an active wind and seismic response control system is usually designed mainly to increase structural damping with minor modifications in the structural stiffness, which consists of three types of elements: sensors, actuators, and a controller with a predetermined control algorithm (control law). Sensors in a structural system are similar to the sensing organs in the human body. The sensors can be located near/at the base or top of the structure to measure external excitation respectively for earthquake and wind; or, installed on the structure and/or the control device to measure system's response variables, such as displacements, velocities, accelerations, and the control forces. The controller in a structure system is similar to the human brain. It receives the measurements, i.e. monitored data from the sensors, analyzes them, and generates necessary control signals (also called control commands) to drive the actuator on the basis of some predetermined control algorithm (control law). Thus, the controller is an information processor that produces actuation signals by a feedback function of the sensor measurements. Actuators are similar to the hands and feet of the human body. Actuators produce the required control forces according to the control signals from the brain to the controller. The concept is well-established and demonstrated by many researchers. Soong (1988, 1992, 1996), Datta (2003) and Tiwary, Tiwary, and Kumar (2014) have reviewed the active control systems.

The semi-active dampers are the natural evolution of the passive energy-dissipating technology, as they incorporate adaptive systems to improve effectiveness and intelligence. They are frequently referred to as the controllable passive devices or intelligent dampers. Their adaptive system gathers information about the excitation, structural response, and then adjusts the damper behavior in real-time on the basis of such information in order to enhance its performance. A semi-active damper system consists of sensors, a control computer, a control actuator, and a passive damping device. The sensors measure the excitation and/or structural response. The control computer processes the measurements and generates control signals for the actuator. Then the actuator acts to adjust the behavior of the passive device. Symans and Constantinou (1999) reviewed the performance of various semi-active controller systems reported by many researchers.

Active control systems, as noted earlier, are introduced to address the limited capacity and intelligence of passive and semi-active dampers. However, active structural control still has two main disadvantages: (i) Operation of the active controllers depend totally on an external power supply, requiring a rather complicated sensing and signal-processing system. This complexity limits its application, and reduces control reliability. (ii) To apply the active control in civil engineering structures, big capacity actuators are required as for large force-generating equipment. Current industrial technology may make it feasible to design and manufacture such a large actuator, but its cost severely limits its application.

The innovative hybrid control systems, which are achieved by combining passive to passive, passive to active, and alike control techniques, have therefore become more attractive option. A hybrid system gains the advantages of both the hybridized techniques and mostly alleviates limitations of either technique alone. Still, researchers and engineers prefer to opt for the passive systems mainly because of the simplicity of the system and proven robustness.

Upon reviewing the past studies, it is noted that a detailed review on the performance of the passive control device, tuned mass dampers (TMDs) is essential to systematically summarize research developments in vibration control of structures using the TMDs. Earlier, Sun, Jolly, and Norris (1995) only had provided an excellent review on the history of the tuned vibration absorbers. After this review, nonetheless, many developments took place and progresses have been made by the researchers in this technology. Therefore,

Please cite this article as: S. Elias, V. Matsagar, Research developments in vibration control of structures using passive tuned mass dampers, Annual Reviews in Control (2017), https://doi.org/10.1016/j.arcontrol.2017.09.015