

APPLICATIONS OF DAMPERS FOR VIBRATION CONTROL OF STRUCTURES: AN OVERVIEW

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Abstract

Dampers have become more popular recently for vibration control of structures, because of their safe, effective and economical design. This paper presents an overview of literature related to the behavior of dampers on seismically affected structures. The review includes different types of dampers like metallic dampers, viscoelastic dampers, frictional dampers etc.

Keywords: Seismic response, dampers, structural control systems.

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1. INTRODUCTION

Over the past few decades world has experienced numerous devastating earthquakes, resulting in increased loss of human life due to collapse of buildings and severe structural damages. Occurrence of such damages during earthquakes clearly demonstrates the high seismic hazards and the structures like residential buildings, lifeline structures, historical structures and industrial structures need to be designed very carefully to protect from earthquakes. Structural design approach using seismic response control is now widely accepted and frequently applied in Civil Engineering. In recent years, much attention has been paid to the research and development of structural control techniques such as passive control system, active control system, and semi active control system giving special importance on improvement of wind and seismic responses of buildings and bridges. Passive control systems do not require any power supply. Active control systems require external power supply and operate based on sensors which are attached within the structures. Semi active control systems are combination of both passive and active control systems which require external power supply and they operate based on sensors attached to within the structures. But when there is no power supply, passive control systems control the vibration of structures. Both control systems can be used for strong wind motion and earthquakes. Serious efforts have been undertaken to develop the structural control concept into a workable technology and such devices are installed in structures.

2. LITERATURE REVIEW

Structural control systems increase the energy dissipation capacity of structures during an earthquake by converting mechanical energy into heat energy. Different kinds of energy dissipation systems are given below:

Tuned Mass Dampers (TMDs): Tuned mass dampers (TMDs) are as shown in Fig.1 (Chakraborty and Roy, 2011 [1]) comprising a mass, spring attached to the structure and are used for vibration control of structures when subjected to earthquake excitations. It is a frequency dependent device. Recently, much research has been carried out such as analytical, numerical, experimental and optimum solutions of structures to study the effectiveness of TMDs in reduction of seismic response of structures. The passive tuned mass damper (PTMD) was developed and implemented by Lin et al., 1999 [2] for seismic reduction of irregular buildings. Here, five real earthquakes were considered for numerical and statistical analysis of five storeys torsionally coupled building. Results demonstrate that PTMD effectively reduces the response on building during earthquake. Zuo et al., 2004 [3] have developed multi degree of freedom tuned mass damper. To obtain the optimal solution experiments were conducted sequentially to optimize the two degrees of freedom system. TMD can be tuned to damp the first two flexural modes of a free-free beam. Pinkaew et al., 2003 [4] have reported that structure with tuned mass damper was less effective for seismic damage reduction. Peter, 2006 [5] has discussed the theoretical and experimental studies on tuned mass damper for the seismic retrofitting of existing structures. Almazan et al., 2007 [6] have observed that new bidirectional and homogenous tuned mass dampers are very effective in reducing the seismic response of structures. Marano et al., 2007 [7] have proposed a linear tuned mass damper for seismic control of structures by using constrained reliability based on optimization technique. Further, Marano et al., 2010 [8] have investigated the optimum parameter of tuned mass damper for minimization of displacement of the structure. From the results it was concluded that the design variable mass of the TMD considered was more capable compared to the solutions obtained without it.

Tuned Liquid Mass Dampers (TLDs): Tuned liquid mass damper basically consists of liquid sloshing tanks and liquid mass depth. Due to liquid sloshing, the damper response of TLDs is highly nonlinear in nature and also frequency dependent device. The effectiveness of TLD is increased by using multiple tuned mass dampers (MTLDs) in which number of liquid sloshing tanks are increased to reduce the dynamic response of the structures. These MTLDs can be used for high rise buildings to reduce the wind and earthquake vibrations. Advantages of TLDs are low initial and maintenance cost, easy to install as compared to TMDs. Fujino et al., 1992 [9] have developed 2D rectangular model of the tuned liquid damper (TLD) to reduce the dynamic response of structures. Experiments were performed to make out the characteristics of TLD and the interaction between the TLD and structure using the shake table test with a harmonic external loading. Chakraborty and Debbarma, 2011 [10] have examined the uncertainty of the bounded system parameters to study the optimum design of liquid column vibration absorber (LCVA) for seismic vibration control of structures. The LCVA is modeled as a SDOF system as shown in Fig.2 which consists of stiffness of k_0 , mass of m_0 , structural damping c_0 , length of horizontal portion B_h and length of vertical portion L_e , $x(t)$ & $y(t)$ are horizontal and vertical displacements and $\ddot{z}_b(t)$ base acceleration due to earthquake ground motion. Results show that LCVA tends to reduce the level of uncertainty. It was also observed that neglecting the effect of system parameter uncertainty may overestimate the damper performance.

Friction Dampers: Friction dampers are as shown in Fig. 4 (Pall et al., 1980 [11]) work based on the mechanism of solid friction for dissipation of vibration energy. Mualla and

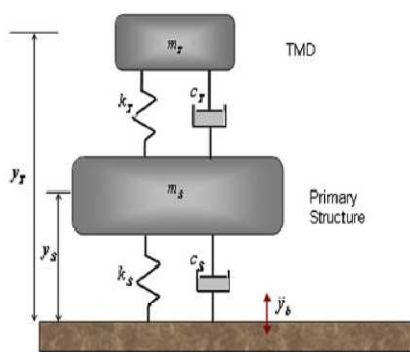


Fig.1 The primary structure with TMD system (Chakraborty and Roy, 2011[1])

Viscoelastic Dampers: Viscoelastic damper as shown in Fig. 7 (Soong and Spencer, 2002 [18]) consists of viscoelastic layers bonded with steel plates with viscous materials such as co-polymers or glassy substances. The energy is dissipated in

Borislav, 2002 [12] have investigated the performance of a friction damper installed in a single storey steel frame subjected to seismic loading. Experimental and numerical results show that the friction damper can improve the dynamic response of innovative structures as well as the existing building compared to the conventional design. The effectiveness of bidirectional frictional forces for the analysis of piping system when subjected to earthquake ground motion with friction supports was given by Jangid and Patil, 2009 [13]. The slotted bolt connection type friction damper was investigated on the seismic retrofitting of the structure by Robert Levy et al., 2001 [14]. The conceptual design of three storey steel frame building of seismic retrofitting of existing building using friction damper was investigated by Lee et al., 2008 [15] and Tabeshpour & Ebrahimian, 2010 [16].

Metallic Dampers: First hysteretic dampers were implemented by Skinner et al., 1980 [17] for seismic protection of buildings. It was implemented to bridges and base isolated buildings. Metallic dampers were made up of mild steel plates as shown in Fig. 4 (Soong and Spencer, 2002 [18]). These devices dissipate energy through the inelastic deformation of metals. Thus, the purpose of metallic damper was increased in the dynamic response of structures and was implemented in full scale structures. Curadelli and Riera, 2004 [19] have proposed the metallic damper for seismic retrofitting of building frames based on reliability method. Vargas, 2007 [20] has investigated metallic damper with a viscous damper for reducing the dynamic response of single degree of freedom system (SDOF). Gang and Hongnan, 2008 [21] have presented new metallic damper with dual functions such as stiffness and seismic energy dissipation.

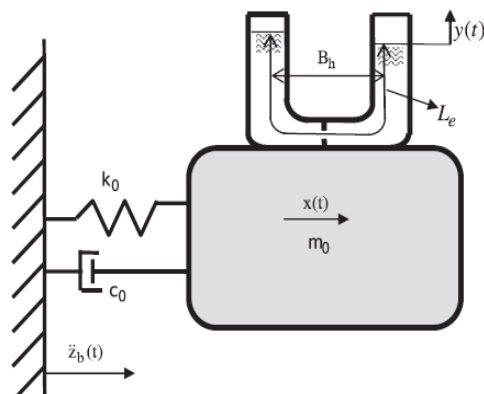


Fig. 2 The LCVA -SDOF system (Chakraborty and Debbarma, 2011 [10])

the form of shear deformation when mounted on a structure and they are highly dependent on ambient temperature and frequency excitation. Diclelia and Mehta, 2007 [22] have carried out parametric study of steel chevron braced frame

system equipped with and without viscoelastic damper when subjected under seismic load. Choi and Kim, 2010 [23] have proposed new method of installing viscoelastic cables into building for seismic control of structures. Chen et al., 2010 [24] have analytically studied the seismic performance of wenchuan hospital structure using viscoelastic damper.

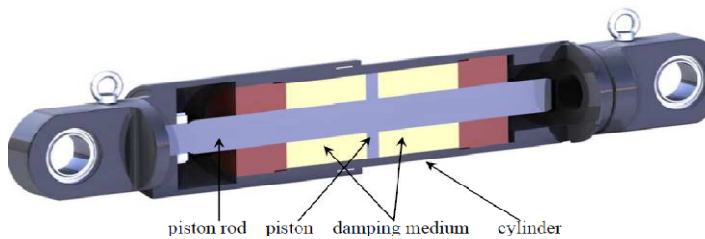


Fig. 3 A typical fluid viscous damper (Feng Qian et al., 2012 [25])

Viscous Dampers: Viscous dampers work based on fluid flow through orifices. Viscous damper is as shown in Fig.3 (Feng Qian et al., 2012 [25]) consisted viscous wall, piston with a number of small orifices, cover filled with a silicon or some liquid material like oil, through which the fluid pass from one side of the piston to the other. Stefano et al., 2010 [26] have manufactured the viscous damper and it was implemented in 3 storey building structure for seismic control

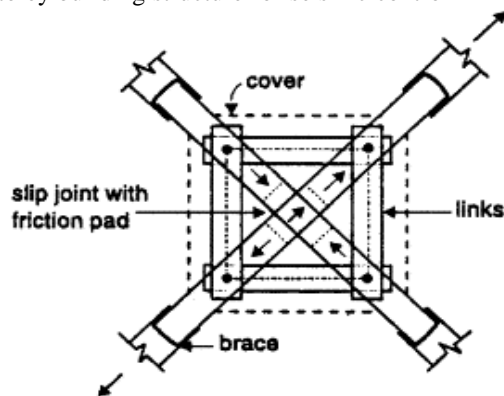


Fig. 4 Friction damper (Pall et al., 1980 [11])

Shape Memory Alloys (SMAs): Shape memory alloys are special kind of materials capable of retaining their original shape when heated at certain temperature. SMAs are as shown in Fig.5 (Sun et al., 2012 [31]) have great potential for use within the seismic resistant design and retrofit applications due to following properties i.e. energy dissipation capabilities, large elastic strain capacity, hysteretic damping, high and low-cycle fatigue resistance, re-centering capabilities and excellent corrosion resistance property. Applications of shape memory alloy in seismic control on structures like seismic rehabilitation of bridge, and in civil engineering structures.

of structure with additional viscous damper. Attar et al., 2007 [27] have proposed optimal viscous damper to reduce the interstory displacement of steel building.

Elasto Plastic Damper or X Plate Dampers: X plate dampers are thin metallic plates of X or V shape. They consist of single or group of plates and are made up of mild steel or copper material having different thicknesses. The mechanism of dissipating the energy of X plate damper is more effective during the earthquake by absorbing input energy of the structure. Satish Kumar et al., 2003 [28] have proposed an elastoplastic passive energy absorbing (PEA) devices as shown in Fig.8 and carried out the experimental and analytical studies to reduce large seismic deformation on pipelines when subjected to earthquake. Parulekar et al., 2009 [29] have discussed about retrofitting of reinforced concrete (RCC) structures by using elasto plastic damper (EPD) under seismic loads. Pujari and Bakre, 2011 [30] have studied the effect of X- plate damper (XPD) for seismic response control of structures. Dampers were located at 5 different places of square shaped multistoried building. One building frame considered was without XPD and one with XPDs in all bays and time history analysis was carried out using SAP2000. Numerical results show that the optimum location of XPDs was found to be most effective in reducing the seismic response of multistoried building.

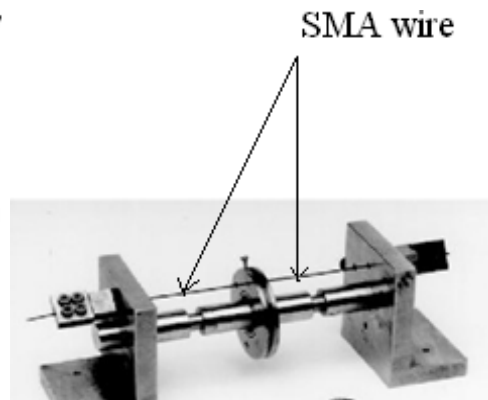
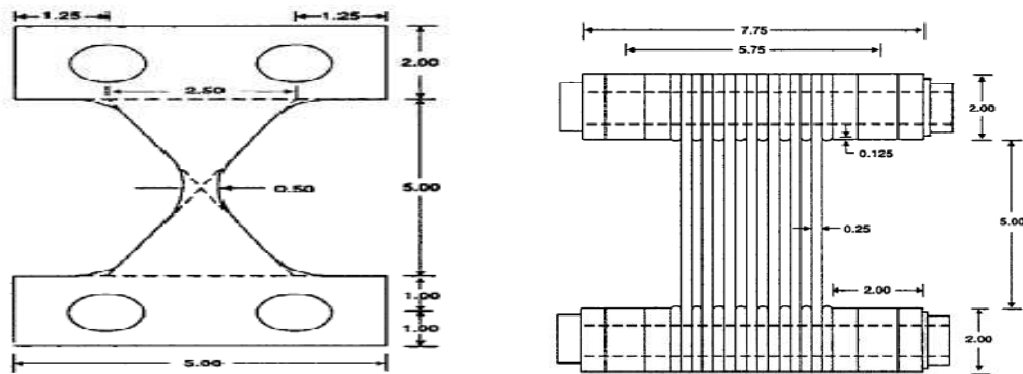


Fig. 5 SMA wire based device (Sun et al., 2012 [31])

Baratta and Corbi, 2002 [32] have observed that SMA wires certainly improve the dynamic response capacity of structures.



All dimensions are in inches

Fig. 6 X-shaped metallic damper or ADAS (added damping and stiffness) devices
(Soong and Spencer, 2002 [18])

Saadat et al., 2002 [33] have studied the unique thermo mechanical behavior of shape memory alloy and seismic applications of NiTi Shape memory alloys. Han, 2003 [34] has investigated a shape memory alloy wire based damper for seismic control of structures using finite element method. Justin et al., 2004 [35] have investigated the effectiveness of shape memory alloy connecting steel beam- column. Results show that energy dissipation from these connections is very high after being subjected to cycles up to 4% drift level. Ocel and Hurlebaus et al., 2010 [36] have given the overview of pseudoelasticity effect and characteristics of shape memory alloy and applications for passive, active and semi active seismic control of civil structures. Song et al., 2006 [37] have developed analytical models of concentrically braced frames with superelastic shape memory alloy (SMA) braces to

evaluate the seismic performance of frames. The two chevrons (inverted V) braced of three and six story buildings were selected. The nonlinear dynamic time history analysis was carried out using the open system for Earthquake Engineering Simulation (OpenSEES) to determine the dynamic response of braced frames. The results demonstrate that the SMA braces are very effective compared to conventional methods. Jason et al., 2007 [38] have investigated four different types of shape memory alloy (SMA) dampers based on different crystallographic phases of SMA to reduce structural damage of the system during an earthquake. The different damper systems were implemented in a given structure and the behaviors of the systems were compared analytically with the buckling restrained steel bracing system.

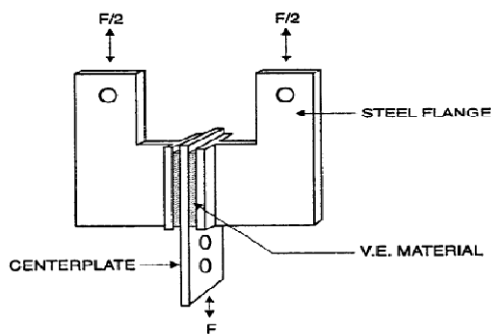


Fig. 7 Viscoelastic damper
(Soong and Spencer, 2002 [18])

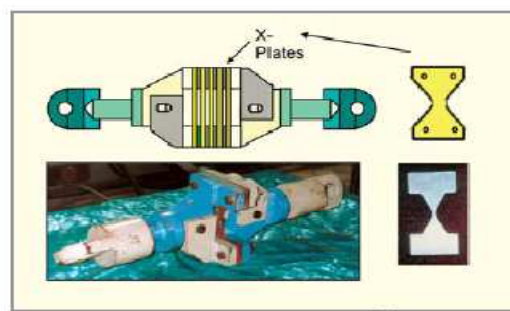


Fig. 8 Elasto plastic damper
(Satish Kumar et al., 2003[28])

Later, Motaharia et al., 2007 [39] have discussed the passive energy dissipation systems and their modern applications for seismic protection of structures. Charney et al., 2008 [40] have developed the tension/compression device using NiTi shape

memory alloy. The designed elements were used as bracings in the building for seismic response control on structures. The proposed device showed good damping behavior to form the basis for a Nitinol damping devices. The seismic performance

of a sliding-type base isolation system was studied by Matthew et al., 2009 [41] with the effect of temperature. A multi-span continuous bridge was modeled with a steel-Teflon sliding bearings and an SMA device. A multi-objective genetic algorithm optimization process was considered to obtain the design parameters of SMA device such as length and cross sectional of NiTi wires. Neuro-fuzzy model was used for simulating the superelastic behavior of NiTi shape memory alloys. A time domain method was used to generate the ground motion records for time history analysis of an isolated bridge, for a given design spectrum. Chuang et al., 2010 [42] and Mohamed Omar, 2011 [43] have investigated the design and analysis of steel braced frame structures with shape memory alloy braces for seismic control on structures. Sun et al., 2012 [31] did a review on three different stimuli-responsive SMMs, namely shape memory alloys (SMA), shape memory polymers (SMP) and newly emerged shape memory hybrids (SMHs) and also discussed their engineering applications and implementation in engineering design and practice.

CONCLUSIONS

Recently, use of seismic control systems has increased but choosing best damper and installing it into a building is very important for reducing vibration in structures when subjected to seismic loading. The controlling devices reduce damage significantly by increasing the structural safety, serviceability and prevent the building from collapse during the earthquake. Therefore many researches are being carried out to find the best solution. This paper attempts to provide an overview of different types of seismic response control devices, and highlights some of the recent developments. The experimental and analytical investigations carried out by various researchers clearly demonstrate that the seismic control method has the potential for improving the seismic performance of structures.

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