Areview of the using Tuned mass dampersin the high-rise buildings

Mohsen karimi

Abstract— Tuned mass dampers (TMDs) are considered as the most common control devices used for protecting high-rise buildings from vibrations. Because of their simplicity and efficiency, they have found wide practical applications in high-rise buildings around the world. This paper proposed the application of tuned mass damper in the Construction industry for using partial floor loads as multiple TMDs at limited number of floors. Results indicate the effectiveness of the proposed control technique in enhancing the drift, acceleration, and force response of buildings to wind and earthquakes. The response of buildings to wind and earthquakes was observed to be more enhanced by increasing the story-mass ratios and the number of floor utilized as TMDs. Also, in this article referred to the use of Tuned mass damper effects on the response of multi-storied structures observed in geotechnical centrifuge tests, and Schematic diagram of a semi-active tuned mass damper.

Index Terms— Tuned mass damper, high-rise buildings, earthquakes, wind, stiffness

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1 INTRODUCTION

Vibration control of civil engineering structures using tuned mass dampers (TMDs), which has been through numerous analytical and experimental verifications, is a widely accepted control strategy[1-8].Notably, TMDs can be incorporated into any structure with less interference than other energy-dissipation devices. The TMDs have been used in high-rise buildings, observatory towers, building floors, railway bridges, and pedestrian bridges against natural and man-made loadings since 1970[9-12]. A TMD system consists of an added mass with properly functioning spring and damping elements that provide frequency dependent damping for a primary structure.

Tharwat A. Sakr in 2015 studied on Vibration control of buildings by using partial floor loads as multiple tuned mass dampers. Tuned mass dampers (TMDs) are considered as the most common control devices used for protecting high-rise buildings from vibrations. This paper proposes an innovative technique for using partial floor loads as multiple TMDs at limited number of floors. The effects of using partial loads of limited floors starting from the top as TMDs on the vibration response of buildings to wind and earthquakes are investigated. Results indicate the effectiveness of the proposed control technique in enhancing the drift, acceleration, and force response of buildings to wind and earthquakes. The response of buildings to wind and earthquakes was observed to be more enhanced by increasing the story-mass ratios and the number of floor utilized as TMDs. [13]

R.N. Jabary S.P.G. Madabhushi in 2015 investigated on Tuned mass damper effects on the response of multi-storied structures observed in geotechnical centrifuge tests. Tuned mass dampers (TMDs) are widely used to reduce vibrations in structures. However, very little research is available on the experimental investigation of TMDs and their performance in soil-structure systems. In this paper, a series of geotechnical centrifuge tests was conducted to investigate the effects of TMDs on the response of a multiple-storey sway frame structure undergoing dynamic soil-structure interaction (SSI). The effects of various damper configurations on the response of a sway frame structure were experimentally investigated in a series of geotechnical centrifuge tests. [14]

L.D. Viet & N.B. Nghi in 2014 studied on a nonlinear single-mass two-frequency pendulum tuned mass damper to reduce horizontal vibration. This paper considers a nonlinear single-mass two-frequency pendulum tuned mass damper (TMD) to reduce horizontal vibration. The numerical simulation is carried out to verify the approximate analysis. The main objective of this paper is to propose a new type of nonlinear two-DOF pendulum TMD, which has better performance at large vibration and is less sensitive than the linear TMD. These advantages are achieved because the proposed TMD at the same time has two motions excited by only one horizontal excitation the approximated solutions of the involved system can be obtained by solving only one scalar algebraic equation. The numerical simulation is carried out to justify the conclusions. [15].

Tu Hoang et al in 2016 studied on Structural impact mitigation of bridge piers using tuned mass damper. This paper proposed the application of tuned mass damper (TMD) systems to bridge piers for structural impact damage mitigation to reduce the risk of collapses. A bridge superstructure and substructure were designed in accordance with The American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications (BDS) (2012). The simulation results also showed that the proposed optimal TMD system is more effective in mitigating structural impact response than all the benchmark designs [16].

D.P. McCrum & M.S. Williams in 2016 studied on an overview of seismic hybrid testing of engineering structures. An

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[1] *MSc, Department of Civil Engineering, Ashtian Branch, Islamic Azad University, Ashtian, Iran.*

[2] *Instructor, Department of Civil Engineering, Ashtian Branch, Islamic Azad University, Ashtian, Iran.*

corresponding author email: mohsen.karimi.ashtian@gmail.com

overview of research on the development of the hybrid test method is presented. The maturity of the hybrid test method is mapped in order to provide context to individual research in the overall development of the test method. A significant amount of research and development has been performed in hybrid testing, and as a result the method has the potential to be more widely adopted by structural engineering industry in a similar way as other industries, such as aeronautical and automotive.[17].

I.F. Lazar et al in 2016 studied on Vibration suppression of cables using tuned inerter dampers. This paper considers the use of a tuned inerter damper (TID) system for suppressing unwanted cable vibrations. The TID consists of an inerter, a device that exerts a force proportional to relative acceleration, coupled with a parallel spring and damper. It has been concluded in previous research and also shown here that there is a maximum level of modal damping that can be achieved when a viscous damper is connected to a cable at a given location. [18]

Min Wang et al in 2016 investigated on Suppression of the time-varying vibration of ball screws induced from the continuous movement of the nut using multiple tuned mass dampers. The screw shaft is modeled as an Euler – Bernoulli beam with elastic supports at both ends and the position of the nut. Each tuned mass damper (TMD) is connected to the screw shaft via an elastic spring and a viscous damping element. Theoretical studies and experimental results show that the proposed design method of the MTMD can remarkably improve the lateral dynamic stiffness of the screw shaft. [19].

2 A REVIEW OF THE USING TMD IN THE CONSTRUCTION INDUSTRY

A. System modeling and equation of motion

A-1- Resettable variable stiffness TMD (RVS-TMD)

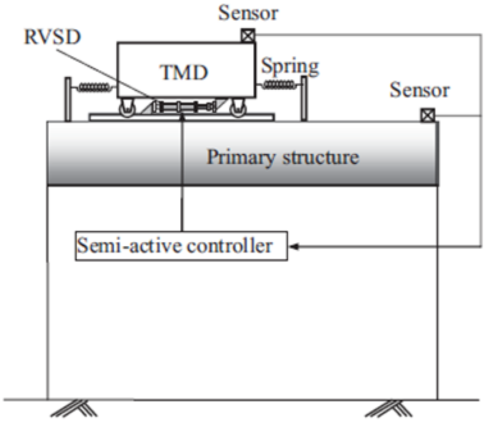

Figure. 1. Schematic diagram of a semi-active tuned mass damper.

Fig. 1 shows the schematic diagram of a primary structure equipped with the RVS-TMD. The TMD is supported on a sliding platform, consisting of guide rails, sliding blocks, and springs. The springs provide stiffness, resilience, and tuning frequency. Moreover, the RVSD consists of a variable stiffness and resettable device as seen in Fig. 2(a). Symbols ud(t) and kd(t) denote the force and controllable stiffness of the RVSD, respectively; de(t) represents the elongation of variable stiffness; and ds(t) denotes resettable Device displacement. For comparison, Fig. 2(b) and (c) show mathematical models of the on–off type and continuous type VSDs, respectively. The RVSD combines the functions of both VSDs. Fig. 3 shows the overall mathematical model of a structure equipped with the RVS-TMD. The stiffness of the RVS-TMD sliding platform is modeled by a spring with stiffness k_s. The masses of the RVSTMD and primary structure are denoted by m_s and m_p, respectively; and c_p and k_p are the damping and stiffness coefficients of the primary structure.

Control philosophy of RVS-TMD

The control philosophy of RVS-TMD is illustrated in this section. The only controllable device in the RVS-TMD system is the RVSD, which is composed of a resettable element and a controllable stiffness element. To alleviate the detuning effect, the dynamic response of the RVS-TMD can be attenuated by altering the variable stiffness k_d (t) in real time. The target stiffness $k_d^{\wedge}$ (t) at any instant is computed as

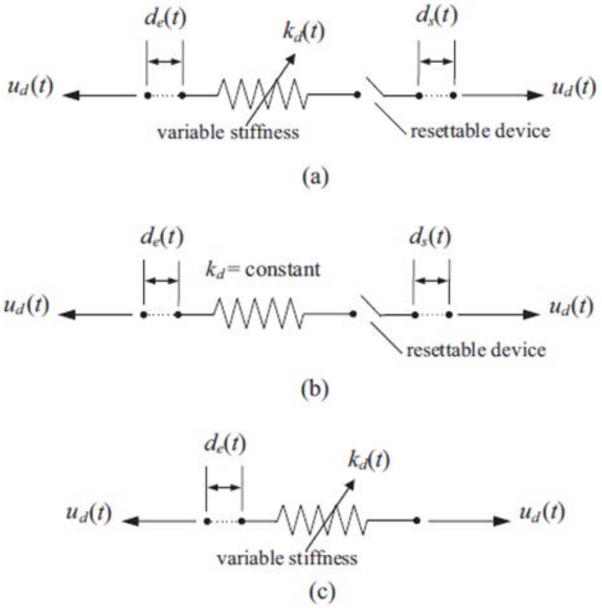

Figure.2. Mathematical models for different types of variable stiffness devices.
(a)Proposed RVSD. (b) On–off type VSD. (c) Continuous type VSD.

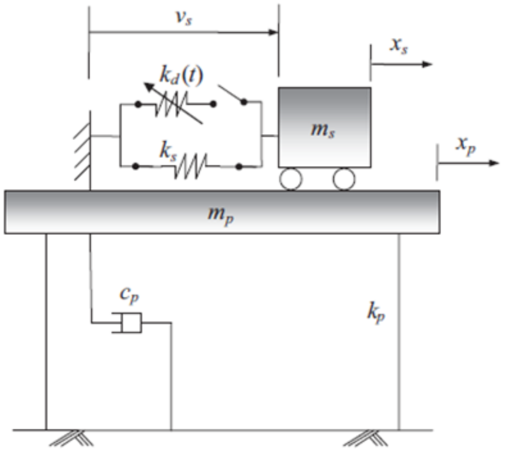

Fig. 3.Mathematical model of a primary structure controlled by a RVS - TMD.[20]

3 Geotechnical centrifuge modeling

A. Principle of centrifuge modeling

Since soil behavior is highly non-linear and sensitive to stress level, testing under increased gravitational fields may be performed to accurately recreate prototype stresses and strains in a small-scale experimental model. This may be achieved in a geotechnical centrifuge. The need for geotechnical centrifuge modeling arises when the constitutive behavior of the soil is not fully known or if there is uncertainty about the mechanisms of failure to expect under a given set of loading conditions. In such scenarios physical modeling is preferred to Finite Element Analysis. Contrary to full-scale field testing which is often very expensive and may not be practical when dealing with earthquake related problems, scaled models can be put to effective use in understanding the behavior of an idealised prototype as described by Madabhushi. [14].

B. Scaling laws

A centrifuge model in flight is subjected to an increased gravitational field which is the product of 1gandageometrical scaling factor, N, to which model dimensions are scaled down relative to the prototype. Scaling laws defining the relationships between model and prototype response parameters were derived by Schofield. [14]. All tables and figures will be processed as images. You need to embed the images in the paper itself. Please don't send the images as separate files.

4 Mathematical model of multiple-story TMDs

Consider the multistory building with multiple-story TMDs shown in Fig. 4. The building is composed of N stories with Nd TMDs located at different floor levels. The dynamic equation of motion of the building modeled as a shear building with lumped masses can be expressed as

$$M\ddot{x} + C\dot{x} + Kx = F \tag{1}$$

Where M, C, and K are the mass, damping, and stiffness matrices of the building, respectively, considering the effect of TMDs; these matrices are defined as

$$M = M_s + M_d \tag{2}$$

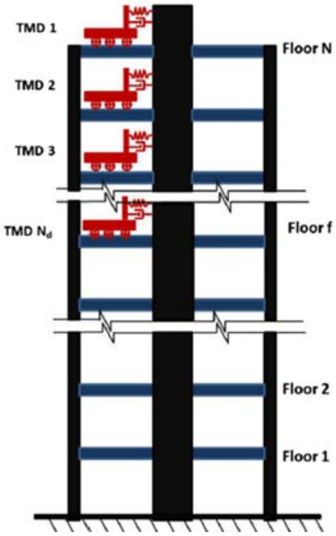

Figure. 4. Model of building with MTMD. [13]

5 STUDY OF CABLES WITH ATTACHED DAMPERS

Several numerical solutions have been proposed for the case when dampers are attached to cables, starting from the partial differential equation describing the cable vibration and by proposing different functions for the cable's mode shapes. Such algorithms are described in greater detail. However, the analysis of the TID is more complex due to the additional degree of freedom within the device. In order to reduce the computational effort necessary for numerically solving a system of partial differential equations, a finite element model of the cable was created using axial elements. [18].

6 DYNAMIC RESPONSE OF FLEXIBLE STRUCTURE COUPLED

The first step is to develop a system of equations that couples the dynamics of the finite-element formulation of the flexible structure with the motion of the PTMD. A multiple degree-of-freedom (MDOF) system consisting of two translational and one vertical DOF at each floor mass, coupled with one planar and one spherical DOF for the pendulum is considered. The MDOF system includes auxiliary damping and stiffness located along the suspended length, and damping at the primary translational DOF.

A description of the coordinates and the variables is shown in Fig. 5. The origin of the system coincides with the suspension point of the pendulum mass. The vectors *u*, *v*, and *w* are the displacements of the suspension point in the *x*-, *y*-, and *z*-directions, respectively. The angle _=angle of planar motion of the pendulum and _=spherical angle. *La*=length of the pendulum and *ma*=auxiliary pendulum mass.

A linear auxiliary viscous damper and linear spring is introduced in each direction, as shown in Fig. 5. The viscous damper has a damping coefficient cx in the x-direction, and cy in the y-direction. The linear spring has a spring constant kx in the x-direction, and ky in the y-direction. The damper and spring are attached to the pendulum at a distance hx and hy from the suspension point [21].

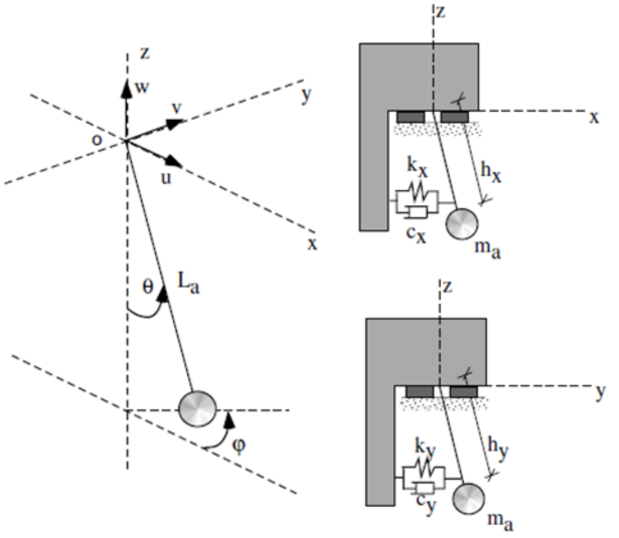

Figure 5- Geometry of the spherical PTMD coupled with the translational

6 EXPERIMENTAL VERIFICATION

Considering the structural constraint of the screw shaft and the balance between the facility of adjustment and the performance of the MTMD, the damper number and total mass of the MTMD are respectively set to 5 and 0.45 kg in our experiments. As shown in Fig. 6, the mass-spring structure of the TMD was designed as a cylindrical elastic body with two mass blocks symmetrically mounted on it.

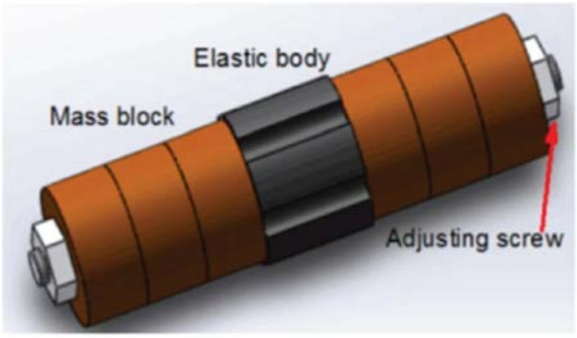

Figure. 6. Design plot of the TMD. [19]

4 CONCLUSION

A novel semi-active TMD, named RVS-TMD, is proposed to enhance the control performance of a TMD system The RVS-TMD system is composed of an un damped TMD system and a RVSD, which consists of a resettable element and a stiffness controllable element. Wind loads are considered by applying sinusoidal dynamic loads with different frequencies, whereas earthquake loads are considered by carrying out seismic analysis using the records of El-Centro, Park field, and Loma Prieta, which are known major earthquakes. In this paper, the use of a TMD device for bridge pier systems for structural vessel collision hazard mitigation has been proposed. To demonstrate the proposed TMD system, a reinforced concrete bridge pier structure under a variety of impact loads was investigated. The technical developments in the test method from the mid-1970s to present such as continuous hybrid testing and the sub structuring technique were presented. TIDs offer a promising alternative to TMDs due to the fact that inserters', which generate a force proportional to the relative acceleration, are geared and can generate a far larger apparent mass than the actual device mass; ratios of 200:1 have been reported. To obtain a high robustness of the MTMD against the frequency de tuning, the damping ratios of TMDs can be increased appropriately.

REFERENCES

[1] Sadek F, Mohraz B, Taylor AW, Chung RM. Method of estimating the parameters of tuned mass dampers for seismic applications. Earthquake Eng Struct Dynam 1997; 26(6):617–35.

[2] Rana R, Soong TT. Parametric study and simplified design of tuned mass Dampers. Eng Struct 1998; 20(3):193-204.

[3] Lin CC, Ueng JM, Huang TC. Seismic response reduction of irregular buildings Using passive tuned mass dampers. Eng Struct 2000; 22(5):513–24.

[4] Lin CC, Wang JF, Ueng JM. Vibration control identification of seismically excited MDOF structure-PTMD systems. J Sound Vib 2001; 240(1):87–115.

[5] Pinkaew T, Lukkunaprasit P, Chatupote P. Seismic effectiveness of tuned mass dampers for damage reduction of structures. Eng Struct 2003; 25(1):39–46.

[6] Wang JF, Lin CC. Seismic performance of multiple tuned mass dampers for soil irregular Building interaction systems. Int J Solids Struct 2005; 42(20): 5536–54.

[7] Wang JF, Lin CC, Lien CH. Two-stage optimum design of tuned mass dampers with consideration of stroke. Struct Control Health Monit 2009; 16(1):55–72.

[8] Xiang P, Nishitani A. Seismic vibration control of building structures with Multiple tuned mass damper floors integrated. Earthquake Eng Struct Dynam 2014; 43(6):909–25.

[9] Soong TT, Spencer BF. Supplemental energy dissipation: state-of-the-art and State -of-the-practice. Eng Struct 2002; 24(3):243–59.

[10] Wang JF, Lin CC, Chen BL. Vibration suppression for high speed railway bridges using tuned mass dampers. Int J Solids Struct 2003; 40(2):465–91.

[11] Zivanovic S, Pavic A, Reynolds P. Vibration serviceability of footbridges under human-induced excitation: a literature review. J Sound Vib 2005; 279(1–2):1–74.

[12] Chen SR, Wu J. Performance enhancement of bridge infrastructure systems: Long-span Bridge, moving trucks and wind with tuned mass dampers. Eng Struct 2008; 30(11):3316–24.

[13] Tharwat A. Sakr, 2015, Vibration control of buildings by using partial floor loads as multiple tuned mass dampers, http://dx.doi.org/10.1016/j.hbrcj.2015.04.004

[14] R.N. Jabary, S.P.G. Madabhushi, 2015 Tuned mass damper effects on the response of multi-storied structures observed in geotechnical centrifuge tests, R.N. Jabary, S.P.G.Madabhushi/Soil Dynamics and Earthquake Engineering77(2015)373–380 http://dx.doi.org/10.1016/j.engstruct.2014.06.013

[15] Jun Zhao, Huahua Dun, 2014, a restoring force model for steel fiber reinforced concrete shear walls.
http://dx.doi.org/10.1016/j.engstruct.2014.06.013

[16] Tu Hoang et al, 2016, Structural impact mitigation of bridge piers using tuned mass damper, T. Hoang et al./ Engineering Structures 112 (2016) 287–294.

[17] D.P. McCrum & M.S. Williams, 2016, an overview of seismic hybrid testing of engineering structures, D.P. McCrum, M.S. Williams / Engineering Structures 118 (2016) 240–261

[18] I.F. Lazar, S.A. Neild, D.J. Wagg, 2016, Vibration suppression of cables using tuned inerter dampers, I.F. Lazar et al. / Engineering Structures 122 (2016) 62–71.

[19] Min Wang et al,2016, Suppression of the time-varying vibration of ball screws induced from the continuous movement of the nut using multiple tuned mass dampers, M. Wangetal./International Journal of Machine Tools & Manufacture 107(2016)41–49.

[20] Ging-Long Lin et al, 2015, Vibration control performance of tuned mass dampers with resettable variable stiffness, G.-L. Lin et al. / Engineering Structures 83 (2015) 187–197.

[21] A. J. Roffel; R. Lourenco; S. Narasimhan, M.ASCE; and S. Yarusevych,” Adaptive Compensation for Detuning in Pendulum Tuned Mass Dampers ” JOURNAL OF STRUCTURAL ENGINEERING © ASCE / FEBRUARY 2011.