Engineering Structures 33 (2011) 2716–2723

Contents lists available at ScienceDirect

Engineering Structures

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

Estimating optimum parameters of tuned mass dampers using harmony search

Gebrail Bekdaş*, Sinan Melih Nigdeli

Department of Civil Engineering, Istanbul University, 34320 Avcılar, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 12 November 2010
Received in revised form
24 May 2011
Accepted 25 May 2011
Available online 18 June 2011

Keywords:
Earthquake
Structural control
Structural dynamics
Tuned mass damper
Optimization
Harmony search

ABSTRACT

In this paper, the optimum parameters of tuned mass dampers (TMD) are proposed under seismic excitations. Harmony search (HS), a metaheurestic optimization method, which has been successfully applied for several engineering problems, is revised for tuning passive mass dampers. A Matlab program is developed for numerical optimization and time domain simulation. Optimization criteria are the peak values of first storey displacement and acceleration transfer function. In order to find best results, all properties of TMD are searched. For a fast and general optimization, a harmonic loading is utilized for numerical iterations. Also, final TMD parameters are checked under earthquake excitations. This new approach is compared with several other documented methods. Comparisons show that the new approach is more effective than other documented methods and more feasible due to smaller TMD parameters.

1. Introduction

The tuned mass damper (TMD) is a passive control system consisting of mechanical components such as mass, springs and viscous dampers. Tuned mass dampers have been installed in high rise buildings for damping vibrations. Examples include: Citigroup Center in New York City, Yokohama Landmark Tower in Yokohama, Burj Al Arab in Dubai, Trump World Tower in New York City, Taipei 101 in Taipei. A pendulum type TMD was implemented to Taipei 101 building in Taipei, Taiwan in order to reduce vibrations (Fig. 1).

Although active vibration control is more effective for control of structures, passive control techniques are still important for practical use because of high costs and unreliability of active systems. Also, passive systems especially tuned mass dampers are very practical for retrofit of structures. Tuned mass dampers can be easily attached to a floor or especially to the top of a main structure without any renovation.

In 1909, Frahm invented a device for damping resonance vibrations and this device is the basic form of tuned mass dampers [3]. This device was effective only when the absorbers' natural frequency was very close to the excitation frequency because it did not have any inherent damping. Ormondroyd and Den Hartog attached viscous dampers with a certain amount of damping in order to obtain beneficial results under changing excitation frequency [4]. Den Hartog developed closed form expressions of optimum damper parameters which are frequency ratio and damping ratio of the TMD [5]. These expressions are for only undamped main systems with a single degree of freedom (SDOF). Later, damping in the main system was included by several researches [6–9]. Warburton and Ayorinde showed that when obtaining optimum TMD parameters for complex systems, the problem may be thought as an equivalent SDOF system if its natural frequencies are well separated [10]. Thompson obtained optimum damper parameters with a frequency locus method [11]. Warburton derived simple expressions for optimum TMD parameters for undamped SDOF main systems under harmonic and white noise random excitations [12]. Villaverde et al. suggested that TMDs performed successfully when the first two modes of the modal damping ratio were equal [13–15]. Sadek et al. extended the study of Villaverde [13] because Villaverde's formulation does not result in equal damping in the first two modes of vibration, especially for big mass ratios [16]. Kareem considered the dynamics of base isolated buildings with passive mass dampers and compared different layouts of dampers [17]. Rana and Soong designed a TMD with numerical optimization in order to control a single structural mode only. Also they investigate the possibility of controlling multiple structural modes using multi-tuned mass dampers (MTMD) [18]. Also, optimum parameters of MTMDs were investigated in several studies [19–21]. Carotti and Turci designed an inertial tuned damper using phasers in the Argand–Gauss plane [22]. Chang derived optimum TMD design formulas in closed forms for both wind and earthquake types of loading [23]. Lin et al. used an extended random decrement method to reduce dynamic responses of buildings with TMD. Unlike previous studies they investigated displacement and acceleration response spectra for structures with and without TMD [24]. Aldemir designed an optimum semi-active tuned mass damper

---

* Corresponding author. Tel.: +90 212 4737070; fax: +90 212 4737176.
E-mail addresses: bekdas@istanbul.edu.tr (G. Bekdaş), melihnig@istanbul.edu.tr (S.M. Nigdeli).

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.05.024

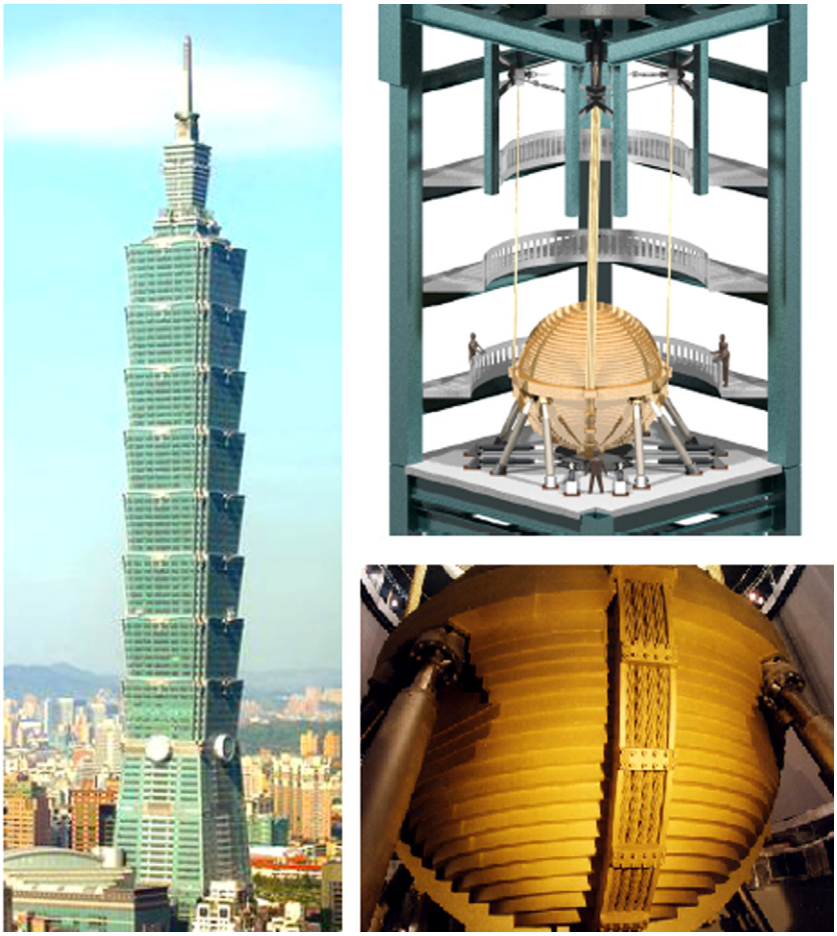

Fig. 1. Taipei 101 and main TMD of the building [1,2].

with a magnetorheological (MR) damper in order to reduce peak responses of an SDOF structure subjected to a broad class of seismic inputs [25]. Lee et al. developed a numerical optimization algorithm for buildings with TMD for decreasing performance index value [26]. By the numerical searching technique, Bakre and Jangid obtained explicit mathematic expressions for optimum parameters of TMD [27]. Rüdinger investigated the effect of tuned mass dampers with nonlinear viscous damping elements [28]. Hoang et al. researched optimum parameters of tuned mass dampers for the seismic retrofit of long-span truss bridges [29]. Marano et al. also optimized the TMD mass ratio which was a preselected parameter in previous studies about optimization of TMD [30]. Weber and Feltrin investigated the assessment of long-term behavior of TMDs by conducting experiments for different types of bridges [31].

Metaheuristic methods such as genetic algorithm (GA) [32,33], particle swarm [34], ant algorithm [35], simulated annealing [36], big bang big crunch [37] and harmony search (HS) [38] have been introduced for solving optimization problems. Also metaheuristic methods have been used for optimization of TMDs. The genetic algorithm was widely applied for tuning of TMDs [39–42]. Leung et al. studied particle swarm optimization of tuned mass dampers [43,44].

Harmony search is a memory based random search method which imitates the music improvisation process. Compared with other metaheuristic methods, harmony search uses a stochastic random search instead of a gradient search so it is not complex. This method is not a hill-climbing algorithm so that the probability of becoming entrapped in a local optimum is reduced. HS can handle problems with discrete and continuous variables [45,46]. In the HS algorithm, stochastic derivatives are important in order to reduce the number of iterations. The stochastic derivative is also useful for various scientific and engineering problems if the function's mathematical derivative cannot be analytically obtained or the function's type is step-wise or condition-wise [47]. The HS algorithm has already been successfully applied to a wide variety of optimization problems including the traveling salesman problem [38], pipe network design [48] and applied even to generalized orienteering problem [49]. For structural problems, HS has been applied successfully to optimum design of truss structures [50], optimum design of steel sway frames [51] and optimum design of grillage systems [52].

In this paper, the HS is utilized to find optimum parameters of TMD which is implemented on top of the structure. A program is developed for optimization of TMD parameters with Matlab R2009b. TMD parameters are mass, stiffness and damping coefficient. In order to obtain an economical result, none of the TMD parameters were preselected. Criterion of the optimization procedure is the maximum acceleration transfer function (TF) and displacement of first storey (x_1) under harmonic loading. Two numerical examples are utilized under different earthquake loadings and results are compared with different methods in order to show the efficacy of present approach.

2. Equations of motion

In this section, classical equations, which can be found in several structural dynamics books, are summarized [53–55]. The equations of motion of a multiple degree of freedom (MDOF) linear