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Vibration control of buildings by using partial floor loads as multiple tuned mass dampers

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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 proposes an innovative technique for using partial floor loads as multiple TMDs at limited number of floors. This technique eliminates complications resulting from the addition of huge masses required for response control and maintains the mass of the original structure without any added loads. 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. The effects of applying the proposed technique to buildings with different heights and characteristics are also investigated. A parametric study is carried out to illustrate how the behavior of a building is affected by the number of stories and the portion of the floor utilized as TMDs. 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.

Introduction

Tuned mass dampers (TMDs) are considered as the most commonly used devices for controlling the dynamic response of structures because of their effectiveness, robustness, and relative ease of installation [1,2]. Because of the efficiency of TMD systems, they have been used in many structures around the world, such as buildings and bridges [1–3]. Although TMDs have been installed in many buildings around the world, such as the CN tower at Toronto, 1975 and Shanghai World Finance Center at Shanghai, 2008, the 660-ton TMD installed at the top of the Taipei Tower at Taiwan, 2004 is considered as the largest and most known TMD [2]. The use of TMDs was studied as a control technique, focusing on the directions of research in the US in structural control [1]. Many investigations have been carried out regarding the mathematical formulations, numerical applications, and

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response of TMD-controlled systems [4,5]. TMDs are used in buildings not only to control the dynamic response under lateral loads but also to mitigate the torsional behavior of extremely torsionally coupled buildings [6,7]. The seismic response of severe torsionally coupled buildings was investigated by conducting a large-scale parametric study to obtain the optimum values for the parameters of a TMD system, such as the location of the added mass damper, tuning frequency ratio, tuning mass ratio, and tuned damping ratio [6]. A parametric study was conducted to investigate the effectiveness of multiple TMDs (MTMDs) in reducing the response of a torsionally coupled system [7]; the study concluded that systems with MTMDs were more effective than single TMD systems, even for torsionally coupled systems, for a wide range of design parameters. However, the relative advantage of MTMDs over a single TMD decreases with an increase in the eccentricity ratio.

In addition to passive TMDs, other types of TMDs have been investigated, such as a hybrid mass damper (HMD) system driven by a fuzzy logic controller (FLC) [8], semi-active variable stiffness TMD (SAIVS-TMD) [9], and bidirectional and homogeneous TMD (BH-TMD) [10]. The SAIVS-TMD employed a single mass with a variable stiffness spring [9] to control the response of a wind-excited benchmark 76-story concrete building; the results indicated that the top-floor displacement and acceleration response reduced to 32% and 53%, respectively, relative to the corresponding response of an uncontrolled building. This effect is similar to that of an active TMD, although with less power consumption [9]. The BH-TMD, which allows vibration control in both the principal directions, was reported to reduce the displacement response to earthquakes by 60% [10]. Because TMDs were successful in controlling the dynamic response of buildings, the concept of a roof-garden TMD was proposed and investigated [11,12]. As the mass ratio of such a system can be altered, mass-uncertain TMDs (MUTMDs) have been studied by subjecting them to harmonic and earthquake loading [11]. If properly designed, MUTMDs represent a viable alternative to traditional TMDs, compensating for some reduction in effectiveness with their advantages of flexibility and multitasking [11]. From this perspective, a roof-garden MUTMD was shown to be a promising tool for developing a single device that could combine the two functions of structural and environmental protection [11]. Translational and pendulum roof-garden TMDs were compared [12].

The optimization of TMD parameters and position has been increasingly investigated using different optimization techniques [13,14,8]. TMD parameters were optimized using a genetic algorithm (GA) [8] and a hybrid-coded GA (combination of binary- and real-coded GAs) [15] considering the location of the TMD. An HMD system driven by an FLC was optimized using a two-branch tournament GA [8]. The use of MTMDs has also attracted considerable attention. Different MTMD systems were mathematically formulated and evaluated on single degree of freedom (SDOF) and multiple degree of freedom systems [16]; an active TMD was also mathematically formulated and evaluated on an SDOF system [17]. Numerical studies on the effectiveness of MTMDs concluded that their effectiveness increases with an increase in the mass ratio and that the use of double TMDs is considerably more effective than the use of a single TMD with the same mass ratio for vibration mitigation under earthquake conditions as well as under sinusoidal acceleration [18,19]. Different scenarios for optimizing MTMD parameters are investigated through the study of an SDOF system with an MTMD [20–22].

This paper presents the theoretical bases of an innovative idea for utilizing a portion of the load of multiple floors to act as MTMDs. A part of the weight of floor slab, floor finishes, and architectural partitions can be utilized, especially in case of steel deck floors, if such weight is isolated using bearing devices similar to that used for base isolation. The realization of relevant special detailing that would allow such building behavior will help us bypass the need to install huge TMDs, which add to the structure load and affect the columns and foundation of a building. In addition, complicated TMD installation procedures can be avoided and the space occupied by the TMD equipment can be saved. In this paper, a technique based on the abovementioned idea is presented and its effects on building response are discussed. The effects of different design variables such as the ratio of the floor load utilized, number of floors used, and excitation characteristics are investigated. Wind effects are considered by applying sinusoidal dynamic loads with different frequencies, whereas earthquake effects are considered by applying three known ground motions. The effects are investigated for low-, mid-, and high-rise buildings.

Mathematical model of multiple-story TMDs

Consider the multistory building with multiple-story TMDs shown in Fig. 1. The building is composed of N stories with N_d 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

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

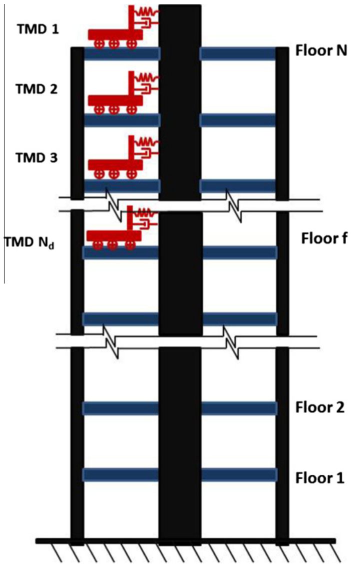

Fig. 1 Model of building with MTMD.

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