

Active Tuned Mass Dampers for Control of Seismic Structures

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Abstract: Structural control has been implemented to major structures that are exposed to excitations which have random vibration behavior including strong winds, traffics and especially ground accelerations resulting from strong earthquakes. It is possible to apply passive and active control methods. In passive, structures are controlled via additional mechanical components, while and external force generating by a powered motor is needed for active control. In the practice of this study, active tuned mass dampers (ATMDs) are used to reduce vibration and responses of structures. The parameters of Proportional-Integral-Derivative (PID) type controllers used in ATMD was found via trial-error method, while mechanical properties of mass damper are optimized via metaheuristic algorithm called Jaya Algorithm. The results were compared with passive tuned mass damper (TMD) and uncontrolled structure. The tuned ATMD is effective to reduce structural vibrations better than TMD. In future studies, both mechanical and controller parameters can be optimized via metaheuristic algorithms.

Key-Words: Active Tuned Mass Dampers, Structural Control, Optimization, Metaheuristic.

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1 Introduction

Structural control systems that are used for damping energy due to external loads such as earthquake or wind, are generally classified under two headings as active and passive. In general, passive control systems are based on the principle of providing energy distribution between the building and the system without the need an external energy source and as a result, a significant part of the energy is consumed by control system. Active control systems, on the other hand, damp the structural reactions by applying time-varying forces, and thus ensure the structure to be rapidly stabilized even in the face of high-impact dynamic effects. However, large energy sources may be needed to generate these control forces.

Active tuned mass dampers (ATMDs), a type of active control, can be defined as a system derived by adding an active control mechanism including sensor, controller and actuator to the tuned mass dampers (TMD) to increase the applicability of the TMD systems at variable frequencies. According to principle of ATMD, after real-time data obtained by sensors are evaluated, appropriate force is applied to the structure via actuators. Because these control forces are calculated according to the control algorithms pre-defined to the controller or control computer, control algorithms have a big role in the structural control systems.

Some of these algorithms are sliding mode control (SMC), linear quadratic regulator (LQR), linear quadratic Gaussian (LQG), fuzzy logic controller (FLC) and

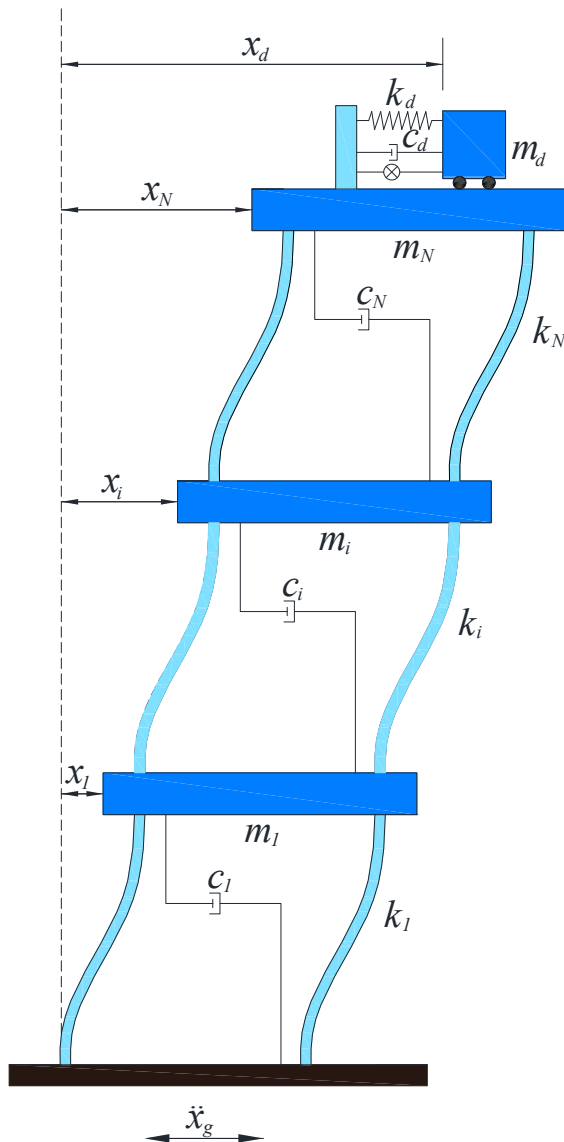


Fig. 1. A structural model with ATMD on the top.

The PID controller parameters, which are tuned according to trial and error method, are namely proportional gain (K_p), derivative time (T_d) and integral time (T_i). $e(t)$ is the error signal which is wanted to be eliminated. In the present study, the error signal is taken as the top story velocity of the structure. In that case, velocity feedback control is done.

3 The optimization methodology

For the best performance of TMDs for seismic structures, the parameters are needed to optimally tuned. Since the nonlinear and complex nature of the problem, it is not suitable to use mathematical methods in optimization. Due to that, the use of metaheuristic method is the recent trend in this

subject. The metaheuristic algorithms use a metaphor for the inspiration, and several algorithms such as genetic algorithm [14-17], particle swarm optimization [18-19], harmony search [20-22], ant colony optimization [23], artificial bee colony optimization [24], teaching learning based optimization [25] and flower pollination algorithm [26] have been employed for the design of TMDs.

The parameters such as stiffness (T_d) (Eq.(10)) and damping coefficient (ζ_d) (Eq.(11)) of ATMD are optimized via Jaya Algorithm (JA). This method can be also used to optimize passive TMDs.

$$T_d = 2\pi \sqrt{\frac{m_d}{k_d}} \quad (10)$$

$$\xi_d = \frac{c_d}{2m_d \sqrt{\frac{k_d}{m_d}}} \quad (11)$$

JA is a single-phase metaheuristic algorithm using Eq. (12). The name “JAYA” comes from the Sanskrit word meaning victory [27]. To gain victory by using the optimum solution, the best (g^*) and worst (g^w) existing solutions are used to converge and diverge to optimum result. Two randomly defined numbers between 0 and 1 (r_1 and r_2) are used to update the existing solution (x_i^t) of I^{th} population and t^{th} iteration. The new solution (x_i^{t+1}) of the new iteration is saved if the value of the objective function, which is minimization top story displacement under the critical earthquake excitation of set of records.

$$x_i^{t+1} = x_i^t + r_1(g^* - |x_i^t|) - r_2(g^w - |x_i^t|) \quad (12)$$

The problem is constrained with Eq. (13) for the limitation of the stroke of TMD. It must less than a user defined st_max value. x_d and x_N represent the displacement of TMD and top story of the structure, respectively.

$$g_1 = \frac{\max(|x_d - x_N|)_{withTMD}}{\max(|x_N|)_{withoutTMD}} < st_max \quad (13)$$

The flowchart of the stages of the optimization are summarized in the flowchart given as Fig. 2.

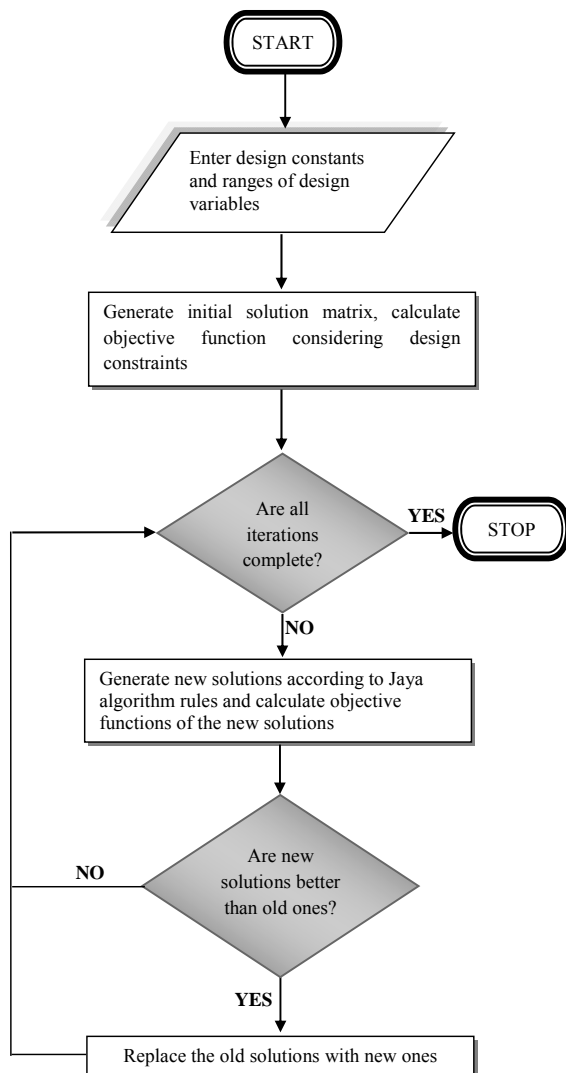


Fig. 2. The flowchart of the optimization process.

4 The numerical example

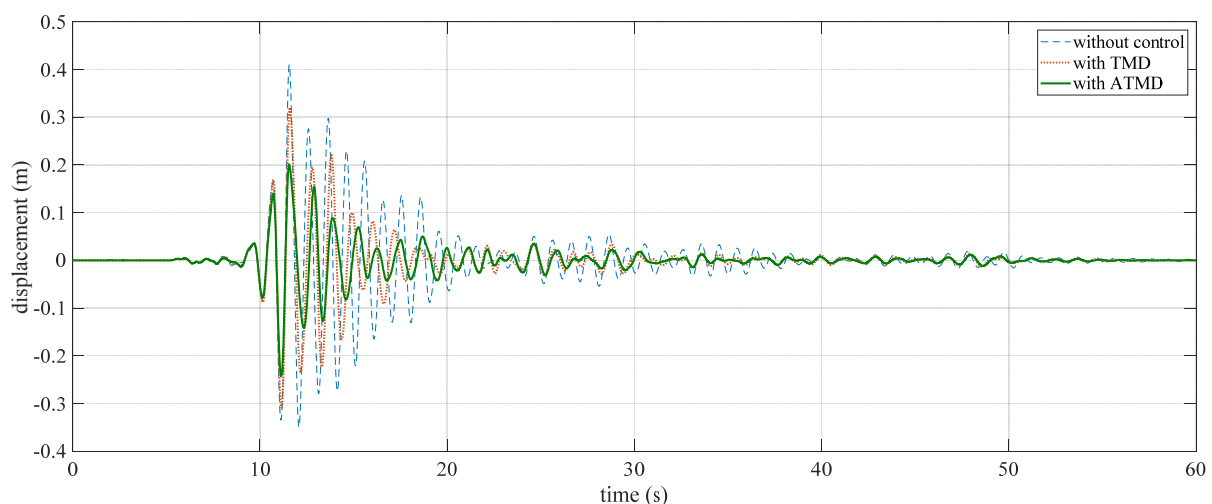


Fig. 3. Time Histories of the structure with and without structural control

A ten-story shear structure model with an ATMD on the top was investigated. The properties such as mass, stiffness and damping coefficients are 360t, 650MN/m and 6.2MNs/m, respectively for each story [16]. The mass of TMD is taken as the 5% of the total mass of the structure (180t). The optimum stiffness and damping coefficients of TMD are configured according to the optimum period and damping ratio values found as 0.9023 s and 0.2821, respectively for $st_max=1$.

The constant parameters in active control are taken as follows: $R=4.2 \Omega$, $K_f=2 \text{ N/A}$; $K_e=2 \text{ V}$. The tuned PID controller parameters via trials were found as $K_p=-3000 \text{ Ns/m}$, $T_d=235 \text{ s}$; $T_i=10000 \text{ s}$.

The optimization of TMD was done for set of far-field ground motions presented in FEMA P-695: Quantification of Building Seismic Performance Factors [28]. These records are listed in Table 1. The time history results obtained for BOL090 earthquake record, which is determined to be critical earthquake among 44 different earthquake data, are given in Figure 3 for uncontrolled structure and structures with TMD and ATMD.

According to this, it is shown that when there is no structural control, maximum displacement is 0.4101 m. When the attaching the TMD to structure, this maximum value is decreased to 0.3202 m. However, ATMD provides more effectively reducing to maximum displacement, and this value decreases up to 0.2428 m.

Table 2. FEMA P-695 far-field ground motion records [28]

Name	Date	Component 1	Component 2
Northridge	1994	NORTHR/MUL009	NORTHR/MUL279
Northridge	1994	NORTHR/LOS000	NORTHR/LOS270
Duzce, Turkey	1999	DUZCE/BOL000	DUZCE/BOL090
Hector Mine	1999	HECTOR/HEC000	HECTOR/HEC090
Imperial Valley	1979	IMPVALL/H-DLT262	IMPVALL/H-DLT352
Imperial Valley	1979	IMPVALL/H-E11140	IMPVALL/H-E11230
Kobe, Japan	1995	KOBE/NIS000	KOBE/NIS090
Kobe, Japan	1995	KOBE/SHI000	KOBE/SHI090
Kocaeli, Turkey	1999	KOCAELI/DZC180	KOCAELI/DZC270
Kocaeli, Turkey	1999	KOCAELI/ARC000	KOCAELI/ARC090
Landers	1992	LANDERS/YER270	LANDERS/YER360
Landers	1992	LANDERS/CLW-LN	LANDERS/CLW-TR
Loma Prieta	1989	LOMAP/CAP000	LOMAP/CAP090
Loma Prieta	1989	LOMAP/G03000	LOMAP/G03090
Manjil, Iran	1990	MANJIL/ABBAR--L	MANJIL/ABBAR--T
Superstition Hills	1987	SUPERST/B-ICC000	SUPERST/B-ICC090
Superstition Hills	1987	SUPERST/B-POE270	SUPERST/B-POE360
Cape Mendocino	1992	CAPEMEND/RIO270	CAPEMEND/RIO360
Chi-Chi, Taiwan	1999	CHICHI/CHY101-E	CHICHI/CHY101-N
Chi-Chi, Taiwan	1999	CHICHI/TCU045-E	CHICHI/TCU045-N
San Fernando	1971	SFERN/PEL090	SFERN/PEL180
Friuli, Italy	1976	FRIULI/A-TMZ000	FRIULI/A-TMZ270

4 Conclusions and future works

According to the results, ATMD is effective to reduce maximum displacement under the critical excitation by 41%, while a passive TMD reduces the same response by %22. The reduction of responses by using active control may be more than the reduction values, if the PID controller parameter are also optimized via metaheuristic method.

In the future studies, the PID controller parameters such as K_p , T_d and T_i will be also taken as design variables. There are two options to optimize HTMDs. The first option is to use separate optimization processes for mechanical parameters (period and stiffness of mass damper) and controller parameters. Thus, it may be effective to find and optimum design for a hybrid mass damper which

can work as passive without energy and active with energy. The second option is to optimize all parameters in an optimization process, and the most reduction can be provided for ATMD.

The difficulties of applying metaheuristic-based optimization to PID parameters can be summarized as follows; if the optimization is done according time-domain solutions.

- The range of PID controller parameters may give a physical solution in a high range. This situation may increase the computation time. For that reason, a suitable range can be defined by trials.
- The structure with ATMD for several PID parameters may give infinitive results due stability error. This situation interrupts the optimization process. A threshold must be defined to check this situation.

- Several limits such as control force must be considered as design constraints. For the best set of PID parameters, the control force may not be physical or economical to apply.
- Realistic control can be provided by considering time-delay effects.

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