Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(8) (2020) 509-512
DOI: 10.22060/ceej.2019.15883.6064

Seismic Control of a 10-Storey Shear Frame Using Active Tuned Mass Dampers and Particle Swarm Optimization Algorithm

M. Fahimi Farzam*, B. Alinejad, S. A. Mousavi Gavgani

Department of Civil Engineering, Faculty of Engineering, University of Maragheh, Maragheh, Iran

ABSTRACT: Due to structural safety and residential comfort, the vibration control of buildings under earthquake and wind excitations has always been one of the important issues in the structural engineering context. One of the well-established approaches for controlling the structural vibration is the use of Tuned Mass Dampers (TMDs) employed with different methods in structures. In this paper, a 10-storey shear building with linear behavior is studied under 28 Far-Fault (FF) and Near-Fault (NF) earthquakes in MATLAB. Active Tuned Mass Damper (ATMD) is used to control the structural vibration. According to the random nature of earthquake excitation, Fuzzy Logic controller (FLC) and Mamdani Inference System are applied to determine the control force. In addition, the Particle Swarm Optimization (PSO) algorithm is used to determine the optimum TMD actuator power, and in this study, the effect of the actuator saturation is also considered. Furthermore, a method is introduced for robust optimum design of the suggested controller. Using the proposed control system and the optimum actuator power, structural responses decline about 44 pct. Additionally, due to the existence of uncertainty in earthquake records, applying a controller with average actuator power generally results in 33 pct. structural response reduction, and the performance of the active controlled system always outperforms the passive controlled system with utmost 16 pct. structural response reduction.

Review History:

Received: 2019-02-27
Revised: 2019-04-26
Accepted: 2019-04-30
Available Online: 2019-05-13

Keywords:

Active Control
Fuzzy Logic
Tuned Mass Damper
Near-Field Earthquake
Particle Swarm Optimization Algorithm

1. INTRODUCTION

Over the past years, extensive researches have been conducted on the structural response reduction under dynamic loads resulted in the introduction of various control methods such as passive systems and their corresponding devices. Due to the inefficiency of these apparatuses especially under wide frequency band excitations i.e., earthquakes and their detuning drawbacks, the idea of active control systems was emerged in the early 1970s [1].

Despite the remarkable excellence of the active control approaches in structural response reduction, they have not been well appreciated by structural engineers. Their practical problems i.e., actuator saturation, spillover, time delay, high energy consumption and the possibility of structural instability because of applying external energy to the structure hindered their widespread acceptance. Furthermore, in the process of the control methods evolution, the semi-active control systems was developed which solved the two last problems of the active control methods. However, semi-active control techniques decline structural responses by changing their damping and stiffness and have a nonlinear behavior and hysteresis. Therefore, the design and implementation of semi-active control techniques are difficult [2]. Consequently, in the recent decades, passive, active and semi-active control procedures in parallel have been studied extensively by many different researchers to assess and improve their performance under dynamic lateral excitations.

*Corresponding author's email: m.farzam@maragheh.ac.ir

In this study, ATMD with FLC is applied to control the seismic response of a benchmark 10-story linear shear building model under 28 earthquake records, and the performance of the controller is optimized by PSO algorithm. A proper number of natural ground motion records with different characteristics are employed to investigate the statistical performance of the controlled and uncontrolled building. Finally, a method for increasing the control robustness is proposed and its efficiency is assessed under all Mentioned earthquake motions.

2. MODELING AND ANALYSIS

A benchmark 10-story linear shear building model is considered with same dynamic characteristics (mass, stiffness and damping) in all stories. A schematic representation of the controlled structure is depicted in Fig. 1. Although the common buildings usually enter the nonlinear region under the moderate and large earthquake excitations, and the nonlinear modeling will be required, in order to compare the effectiveness of different control approaches a simple linear model is frequently used by researchers [3]. Writing the equation of motion in state space makes dynamic system modeling and analyzing simpler, so in this research, the state space form of vibration equation is addressed and the analyses

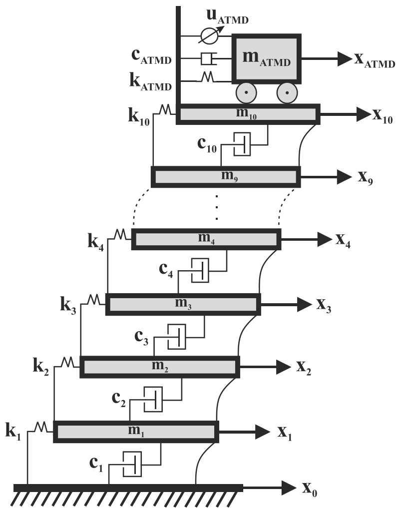

Fig. 1. Schematic representation of a controlled building with ATMD [6]

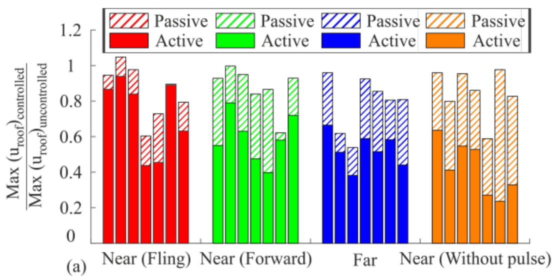

Fig. 2. Structural responses with optimum actuator power (under 28 records)

are performed in Matlab environment.

ATMD with FLC is used to mitigate the structural responses, the optimized free parameters of TMD (i.e., stiffness and damping ratios) and the FLC parameters are respectively taken from Hadi and Arfiadi [4] and Shariatmadar et al [5]. Additionally, PSO is employed to find the optimum actuator power, and the actuator saturation is envisaged as a practical constraint for this optimization problem. Finally, the proposed controller performance is assessed using linear response history analysis under 28 different earthquake excitations with different characteristics, and all records are scaled to 0.3g to eliminate the effect of peak ground acceleration variability between the considered records.

3. RESULTS AND DISCUSSION

In this section, the performance of the passive and active controlled 10-story shear building is carried out under four suites of 7 natural earthquake excitations (NF earthquakes without pulse, with forward-directivity, fling-step and FF earthquakes). In Fig. 2, the peak roof displacements of the active and passive controlled structures are plotted with solid and hatched bar charts respectively. Furthermore, the controlled maximum roof displacements are normalized to the corresponding peak roof displacement of the uncontrolled

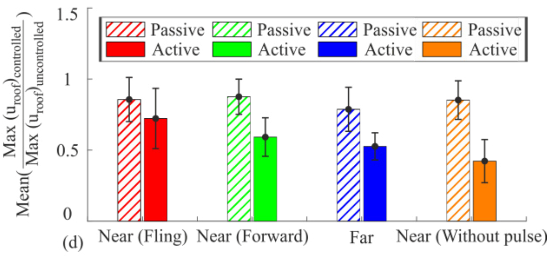

Fig. 3. Structural responses with optimum actuator power (average and standard deviation of structural responses under 4 type of records)

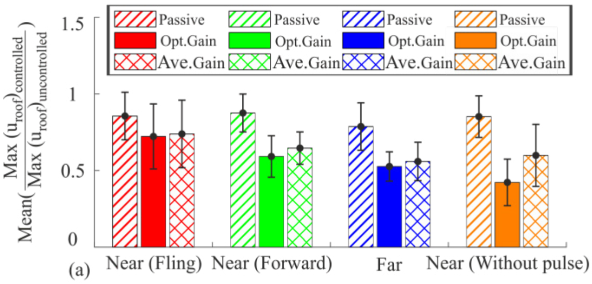

Fig. 4. Comparison of average and standard deviation of structural responses with optimum and average actuator power

structures under all 28 earthquake excitations. In almost all plotted Fig.s the structural response are suppressed significantly with active control methods and generally they have more efficient performance than the passive control method.

In Fig. 3, for each of four earthquake sets, the average of controlled to uncontrolled peak roof displacement over 7 records in corresponding database with its one standard deviation confidence interval is plotted as a solid and hatched bar chart respectively for passive and active controlled structure using optimal actuator power. Regarding the earthquake excitation random nature, using the optimum actuator power calculated under a specific ground motions is not robust. Therefore, the average of optimum actuator power over 7 records in each suites of ground motion is employed, and the statistical performance of this approach is calculated and compared with two previously mentioned methods in Fig. 4. As expected, generally active control approaches outperforms the passive methods and the controlled building response reduction with optimum actuator power has the best performance among all considered technique. However, the maximum roof displacement of the controlled structure with average actuator power is reduced to a proper level.

4. CONCLUSIONS

This paper attempts to assess the statistical performance of a controlled building with ATMD under a large set of NF and FF earthquakes with different features and proposes a robust control method. In all investigated cases the active control system performance dominated the passive one.

Though, the best and the worst performance of the optimum ATMD are realized respectively under NF earthquake with no pulse (57.71 pct. average response reduction) and fling step feature (27.71 pct. average response reduction). Using the average actuator power instead of the optimal actuator power is also able to reduce the maximum roof displacement to an acceptable level.

5. References

[1] G. Warburton, E. Ayorinde, Optimum absorber parameters for simple systems, Earthquake Engineering & Structural Dynamics, 8(3) (1980) 197-217.

[2] L. Xu, Y. Yu, Y. Cui, Active vibration control for seismic excited building structures under actuator saturation, measurement stochastic noise and quantization, Engineering Structures, 156 (2018) 1-11.

[3] C.-W. Lim, Active vibration control of the linear structure with an active mass damper applying robust saturation controller, Mechatronics, 18(8) (2008) 391-399.

[4] M.N. Hadi, Y. Arfiadi, Optimum design of absorber for MDOF structures, Journal of Structural Engineering, 124(11) (1998) 1272-1280.

[5] H. Shariatmadar, S. Golnargesi, M.R. Akbarzadeh Totonchi, Vibration control of buildings using ATMD against earthquake excitations through interval type-2 fuzzy logic controller, Asian Journal of Civil Engineering-Building And Housing, 15 (2014).

[6] R. Guclu, H. Yazici, Vibration control of a structure with ATMD against earthquake using fuzzy logic controllers, Journal of Sound and Vibration, 318(1-2) (2008) 36-49.

HOW TO CITE THIS ARTICLE

M. Fahimi Farzam, B. Alinejad, S.A. Mousavi Gavgani, Seismic Control of a 10-Storey Shear Frame Using Active Tuned Mass Dampers and Particle Swarm Optimization Algorithm, Amirkabir J. Civil Eng., 52(8) (2020) 509-512.

DOI: 10.22060/ceej.2019.15883.6064