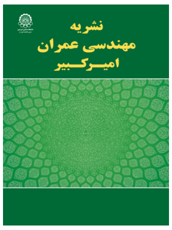

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Statistical Performance of Semi-Active Controlled 10-Storey Linear Building using MR Damper under Earthquake Motions

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ABSTRACT: Due to the advantages of semi-active control methods over passive and active methods, the development and performance of these methods to control the structural response under dynamic lateral loads has been widely considered. Magneto-Rheological (MR) Dampers are among the widely developed devices for semi-active control of buildings. Various models are proposed to simulate MR Dampers dynamic behavior. The present paper summarizes the results obtained through studying a 10-story linear shear building exposed to 28 far and near-fault earthquakes in MATLAB. A MR Damper with Clipped Optimal Control Algorithm was considered to control the vibrations of the structure. In addition to the effect of actuator saturation, the actuator's dynamics were also considered using the Modified Bouc-Wen model. Moreover, the positioning the damper at three different configurations of lower, middle and upper stories were investigated. A statistical study was carried out under different types of near and far-fault records. Results obtained through this study suggested the best performance, in terms of minimizing the roof displacements, while placing a MR damper at the first floor. Results show that the investigated control system has the best performance under near-fault records without pulse, with an average reduction of 21% in the structural response.

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1. Introduction

The use of passive control devices is already a well-appreciated and common practice among different control approaches, and many studies have tackled this topic. Despite their widespread use, the performance of passive control methods needs to be improved due to incompatibility issues and their deficiency under wideband excitations [1]. Active control is also rejected by some researchers because of its disadvantages. The well-known shortcomings of these systems are their high energy consumption, possible power failure during operation, as well as the possibility of unstable structures due to adding energy in the structure [2]. The idea of employing semi-active dampers for car suspension systems was first emerged in the 1970, [3]. the semi-active control system is a development of a passive control system; however, it has compatibility to adjust its parameters based on input vibrations. additionally, active control approaches require a large power source (from tens of kilowatts to several megawatts) while semi-active control methods require a small amount of power (up to a few watts and on the order of a normal battery) [4].

In this numerical study, a linear model of a benchmark 10-story shear building is semi-actively controlled by MR damper under 28 earthquake records. Clipped Optimal Control (COC) algorithm is employed to calculate the control force, and a linear quadratic regulator algorithm is employed to calculate the optimum control force.

To distinguish this research from previous studies, statistical seismic performance assessment of the MR damper under real records is studied while many different aspects are considered simultaneously as summarized below. (1) Using a good number of records with different features (28 records with 4 different properties) for statistical seismic performance assessment of MR damper to control different structural responses. (2) Since conventional methods of processing ground motions (filtering and base line correction)…" eliminate the fling step (FS) effect, unprocessed records are used. (3) The actuator dynamic is taken into account. (4) Saturation of the control force is included as one of the limitations of implementing active and semi-active control systems. (5) Three different configurations for the damper placement at building height are investigated to determine the effect of damper location on its performance. (6) The dimensionless answers are reported so that they can be generalized to different numerical problems.

2. Modeling and analysis

A well-known 10-story shear building with the same mass, stiffness, and damping for all stories is investigated as a numerical problem. The main frequency of the studied

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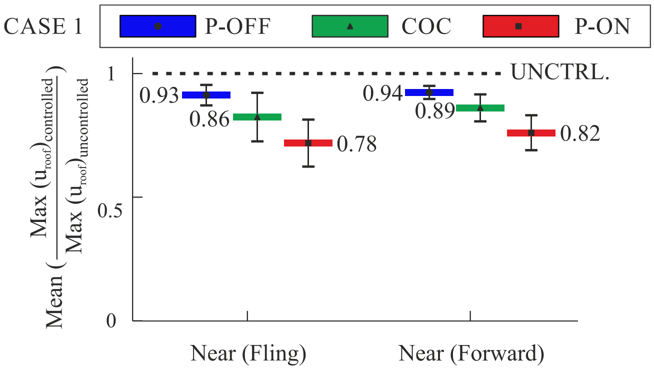

Fig. 1. Mean and standard deviation of normalized maximum roof displacement for the 1st alternative of the controlled structure (i.e., damper at the first floor) under near-filed record sets earthquakes.

structure is 1.02 Hz. For the semi-active control of the above structure, MR damper with 3kN capacity and a modified Bouc-wen model is used. Furthermore, the well-studied COC algorithm is selected to calculate the required voltage. Three different alternatives are also examined to investigate the effect of damper location at building height on its control performance:

- Case I: MR damper at the 1st floor. (Lower floors).
- Case II: MR damper at the 5th floor. (Middle floors).
- Case III: MR damper at the last floor. (Upper floors).

The responses of COC controlled buildings are compared with the uncontrolled, Passive-On (P-ON), and Passive-Off (P-OFF) controlled building.

The steps for modeling the building and controlling its vibration in MATLAB and SIMULINK software are as follows: mass, stiffness, and damping matrices are first defined and uncontrolled state-space matrices are formed afterward. Consequently, uncontrolled structural response is obtained under different records by employing appropriate blocks in SIMULINK. Next, the state-space matrices of the controlled structure are constructed based on the selected alternative of the MR damper location. Then, using linear quadratic regulator algorithm, the optimum force values are determined and compared with the force generated by the damper, thus calculating the required voltage for the MR damper at each moment. Finally, the control force is computed and applied to the structure by feeding the displacement and velocity of the stories and the calculated voltage to the controller.

3. Results and Discussion

Fig. 1 presents the mean and standard deviation of the controlled to uncontrolled maximum roof displacements for the first alternative (i.e., damper at the first floor). Two near-fault record sets, i.e. with fling step and forward directivity (FD), are presented in this figure. Although the roof displacement is decreased appropriately under all applied record sets, the minimum roof displacement is calculated under near-fault earthquakes with the fling step (FS) effect.

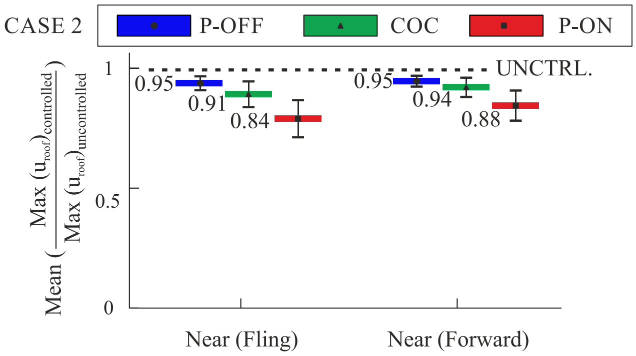

Fig. 2. Mean and standard deviation of normalized maximum roof displacement for the 3rd alternative of the controlled structure (i.e., damper at the fifth floor) under near-filed record sets earthquakes.

The maximum roof displacement of the controlled structure is decreased by 7%, 14% and 22% under near-fault earthquakes with fling step effect with the P-Off, COC, and P-ON controlled methods respectively. However, the structural response is declined by 6%, 11%, and 18%, respectively, under near-fault records with forwarding directivity.

Fig. 2 presents the results obtained for the 2nd alternative of the MR damper location. Analogous to Fig. 1, the P-OFF and P-ON control methods have the highest and lowest standard deviations respectively. However, the performance of the MR damper using all examined control methods is exacerbated compared to the first alternative e.g., under near-fault record with fling step effect and with COC method, the response reductions of 14% and 9% were observed for tthe 1st and 2nd alternatives respectively. A summary of the maximum and root mean square (RMS) of different performance criteria for the preferred configuration (i.e., damper at the 1st floor) is provided in Table 1.

Table 1. Normalized criteria for best performances for the 1st alternative of the controlled structure (i.e., damper at the first floor)

Record	Normalized parameter	P-OFF	P-ON	COC
FS 1	Max Disp.	0.90	0.77	0.76
	Max Vel.	0.90	0.73	0.81
	Max Acc.	0.91	0.73	0.74
	Max Base Shear	0.84	0.67	0.76
	RMS Disp.	0.87	0.42	0.52
	RMS Vel.	0.89	0.35	0.41
	RMS Acc.	0.87	0.46	0.55
	RMS Base Shear.	0.85	0.35	0.53
Record	Normalized parameter	P-OFF	P-ON	COC
FD 13	Max Disp.	0.92	0.74	0.82
	Max Vel.	0.92	0.76	0.83
	Max Acc.	0.92	0.76	0.95
	Max Base Shear	0.90	0.66	0.81
	RMS Disp.	0.92	0.65	0.66
	RMS Vel.	0.94	0.66	0.64
	RMS Acc.	0.93	0.69	0.68
	RMS Base Shear.	0.90	0.57	0.69

4. Conclusions

The MR damper performance was evaluated for three different configurations of damper location at story height. Reduction in the maximum roof displacement was investigated as the output. Moreover, three different control methods were assessed to determine the control voltage. Results show the remarkable performance of MR dampers in controlling the structural vibration and reducing different local and global performance criteria. Using the COC algorithm with the 1st alternative of the damper location, the mean of maximum displacement and acceleration responses were decreased by 20% to 40% for all examined record sets.

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