A NEW APPROACH FOR TUNİNG ATMD İN ORDER TO İMPROVE SEİSMİC RELİABİLİTY İNDEX OF STRUCTURE

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ABSTRACT

Active structural control systems are used to protect structures against seismic excitations.One of the difficulties in the design of structures consideringprotective systems is the explicit consideration of uncertaintyabout the structural model and the potential variability of futureexcitations (Jensen andSepulveda, 2011). According to the uncertain nature of the earthquake phenomena, tuning of an active structural control system for a specific seismic record may not necessarily leads to the optimum performance (Soleymani and Khodadadi, 2013).

The tuned system must be fitted for a wide range of seismic excitations. In this paper, a new approach for tuning an ATMD system designated for a tall building is proposed. For this purpose, an 11-stories structure located in vicinity of a certain fault with a characteristic magnitude is considered. According to the assumed site hazard; 1000 physically-based ground motion record is generated. The ground motion records are clustered based on their spectral features. As a result; a representative record is constructed by employing the cluster centers. The constructed record is used for tuning procedure. Results reveal that this method of tuning arises the seismic reliability index; comparing with the other well-known approaches. The robustness of the proposed approach is analyzed with more details.

INTRODUCTION

Tuned mass damper is one of the oldest yet most effective systems presented for attenuating amplitude of the transmitted vibrations to the structures from wind or earthquake excitations (Pourzeynali et al.,2007). Not only, this system is reliable, but also it is very simple and affordable. These advantages make this system a popular one among the structural control systems. On the other hand, optimal performance of this system is limited to a very limited frequency range (Wongprasert and Symans, 2004). This limitation can be resolved by adding a force actuator to this system and widen the operating frequency range by this mean. The TMD system accompanied with an actuator whose force is controlled via a feedback control system is called active tuned mass damper (ATMD) system.

Due to uncertain nature of seismic excitations, reliability of the ATMD system during occurrence of earthquake in a certain geographical region is a concern which should be considered. Some works have been done on the reliability of the systems equipped with active control systems in recent years e.g. Battainiet al.

(1997), Yao andNatke (1992),Venini,Mariani (1999), Battaini (1999), and Yao andNatke (1992).

There are several sources of uncertainty which affects optimal performance of a ATMD system; among them model uncertainly due to unmodeled dynamics and implementation uncertainties due to poor assembly may be named (Yao andNatke1992) and(Datta, 2003).Tuning of the ATMD controller plays a key role for achieving optimal performance in confrontation of various excitations (Soleymani and Khodadadi, 2013). The purpose of this paper is to propose a new approach to tune the ATMD based on maximizing the reliability index considering the uncertainties resulting from seismic excitations. In this paper, a new approach for tuning an ATMD system designated for a tall building located in vicinity of a certain fault is proposed. For this purpose, 1000 different possible earthquakes with identical magnitudes are regenerated for the region. The earthquakes are then clustered based on the PGA and structural response variables using a fuzzy-clustering approach. The ATMD system is tuned for each of the cluster centers separately. Moreover, a combined representative earthquake profile is proposed employing the cluster centers and the controller is tuned for the combined disturbance as well.

Simulation results reveal that, first, the controller tuned according to each cluster center has the best performance in the presence of the corresponding disturbance. Furthermore, the controller tuned based on the proposed combined seismic profile works effectively for a wide range of the regenerated earthquakes. In this case, a considerable increase in the reliability index is calculated.

INTRODUCTION TO STRUCTURAL AND CONTROL SYSTEM

The studied structure in this paper is an eleven story buildingemployed in a previous study by Pourzeynali and Lavasani (2007).The ATMD system is placed on the top story as a lump mass single degree of freedom system. In Fig. 1 a schematic view of this structure is shown. The mass of the TMD isconsidered three percent of the structure total mass.Moreover, the natural frequency of the TMD system is set according to PourzeynaliandLavasani (2007)work.The controller used in this work is the genetic-fuzzy oneproposed by Soleymani and Khodadadi (2013).

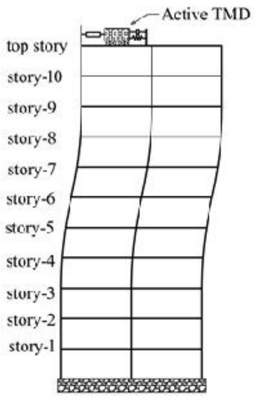

Figure 1.Schematic view of the 11 story structure whit active TMD

PROBLEM DEFINITION VIA AN EXAMPLE

Let's consider a very basic single degree of freedom structure (Fig.2). The structure is equipped with the ATMD system and its performance is examined when it is subjected two different earthquake loads i.e. Manjil and Chichi ones. The controller is tuned for the Manjil earthquake and the structure is subjected to both earthquakes separately. Response histories are depicted as Fig.3. Moreover, Fig.4 illustrates the root mean square (RMS) values for various stories in a diagram. Finally the results are summarized in table number.1.

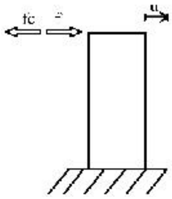

Figure 2.Sample structure

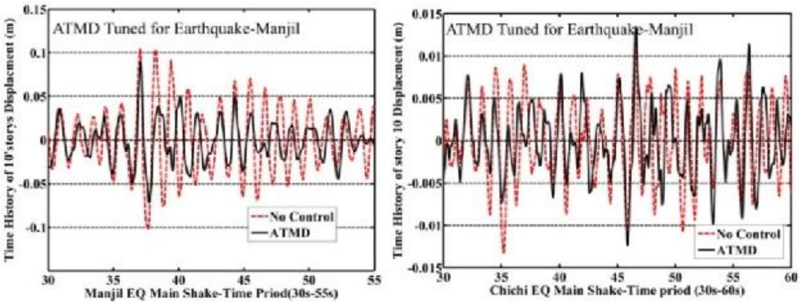

Figure 3. Displacement of top story against Manjil, Displacement of top story against Chichi

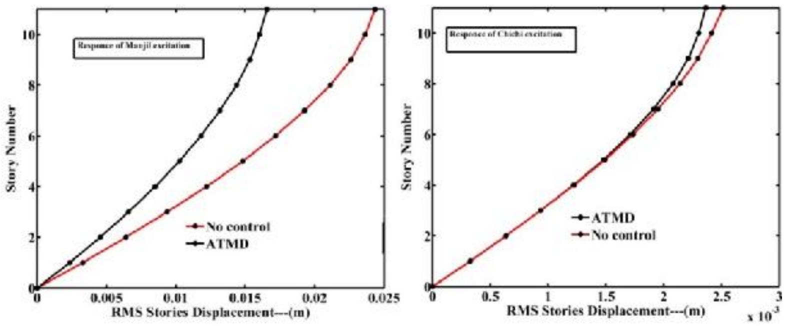

Figure 4. RMS Stories Displacement against earthquake A) Manjil B) Chichi

Table 1.response improvement of structure equipped with ATMD

	RMS story No.11 Displacement		RMS story No.11 Acceleration	
	Chichi EQ	Manjil EQ	Chichi EQ	Manjil EQ
No Control	0.0025	0.024	0.133	1.829
ATMD	0.0023	0.016	0.127	1.464
improvement percent	6.5	32	4.9	19.9

According to the obtained results, the ATMD system tuned for Manjil earthquake called Manjil ATMD works successfully in the presence of the same disturbance where a 32 percent drop in the top story displacement is reported. However, when the Chichi earthquake is applied to the structure equipped with the Manjil ATMD, performance of the controller is not very satisfactory where only 6.5 percent reduction for the top story displacement is calculated. Therefore, the ATMD system tuned for the Manjl earthquake is not very reliable for being employed during occurrence of the Chichi earthquake. So it could be a good idea if one can tune an ATMD system in a way that it works satisfactorily for a wide range of seismic excitations.

RELIABILITY ESTIMATION FRAMEWORK

In order to have a more realistic estimation of the reliability of a seismic system, we have to designate the basic component of earthquake occurrence. For simplicity the structure is assumed to locate in a site 30 km away from the fault. The potential earthquake produced by this fault has magnitude of $M_w = 7$and 200 years return occurrence period. Therefore, the rate of seismicity of that is $\nu_{M_w,R} = 0.005$. It is assumed that for this scenario, there are a lot of natural recorded earthquake and also the peak relative displacement of the stories is assumed as failure index. The peak relative displacement of structure equal to 0.005 is assumed as desired performance limit state. So the probability of annual failure can be computed as below:

$$\lambda_{IM}(x) = P[IM > x|event] = \nu_{M_w,R} \cdot \frac{\sum_i I_{IM_i > x}}{totalno.\,ofrecords} \qquad (1)$$

Where $I_{IM_i}$is the i_{th} intensity measure (here maximum relative displacement of stories). This parameter equals to 1 for $IM_i > x$ and equal to 0 for other conditions.

The only limitation of proposed framework, to consider the accuracy of direct estimation of the risk rate, is the lack of sufficient number of records for specific scenario. To overcome this challenge, using simulated record is inevitable. In order to simulate the records, EXSIM software package has been used (based on finite fault method). In coming section the results of a structural system is presented.

TUNING ATMD SYSTEM BASED ON MAXIMIZING RELIAILITY

In order to tune the ATMD system for maximizing the reliability index for a desired scenario, a representative seismic profile is required. To do that, 1000 generated earthquakes were clustered based on maximum RMS story displacement and peak ground acceleration (PGA). Clustering has been done using fuzzy clustering method in MATLAB software. Applying clustering algorithm to the earthquake data, 8 clusters have been identified as shown in Fig.5.The representative earthquake profile is generated base on the idea of maximum contribution of the samples. For this purpose, the centers of the clusters which represent their corresponding cluster members have been selected and the final representative profile is generated by aggregating the cluster centers in a profile.

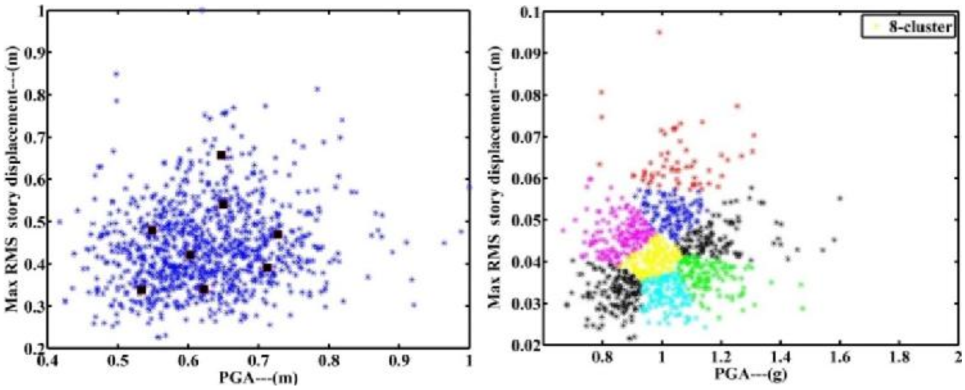

Figure 5.Response to 1000 earthquake and centers of clusters,Eight fuzzy cluster

The ATMD system is then tuned based on the representative profile using a multi-objective genetic algorithm. The objective functions for the genetic algorithm optimization are RMS values for the base shear and the maximum drift of the top story.

RESULTS AND ANALYSIS

In order to evaluate the performance of the proposed ATMD system, first, the ATMD system is tuned based on each cluster center separately and is named ATM-i where iis the cluster center according which the controller is tuned. Furthermore, the ATMD is tuned according to the representative earthquake profile and is called ATMD-comb. Finally, implementing the ATMD systems to the model, the displacement and acceleration responses for all stories are calculated in the presence of 8 different excitations i.e. the cluster centers.

Figures 6 to 13 depict the simulation results. As it can be seen in Fig.6, ATMD-1 shows the best performance in reduction of displacement and acceleration responses in the presence of the first cluster center disturbance. Nevertheless, the ATMD-comb shows the best correlation with the ATMD-1 controller among the other controller. The same trend is shown for the other disturbances a shown in the figures 7 to 13 implying reliability of the proposed controller in confrontation with various seismic disturbances.

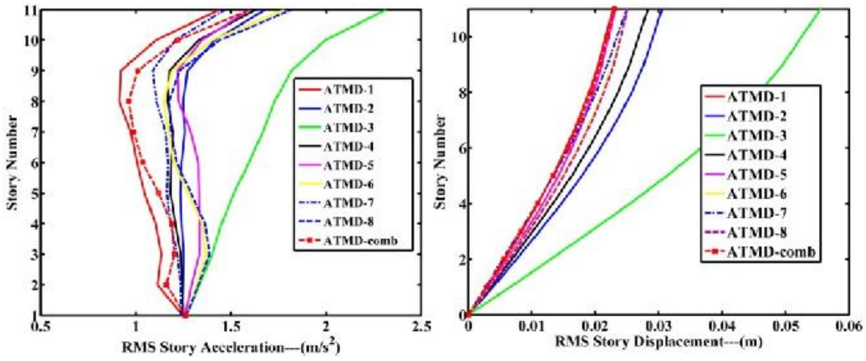

Figure 6. RMS story acceleration and displacement for 9 ATMD systems against center-1 earthquake excitation

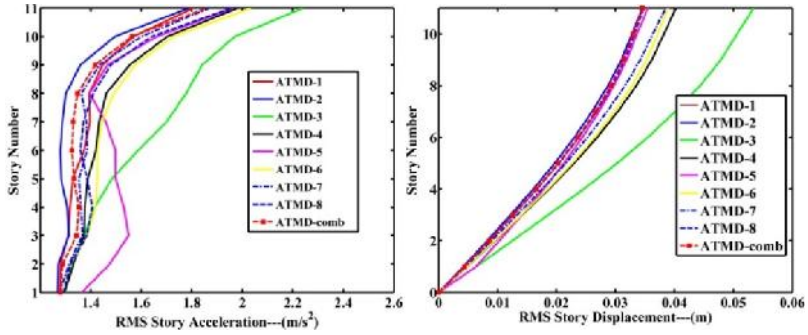

Figure 7. RMS story acceleration and displacement for 9 ATMD systems against center-2 earthquake excitation

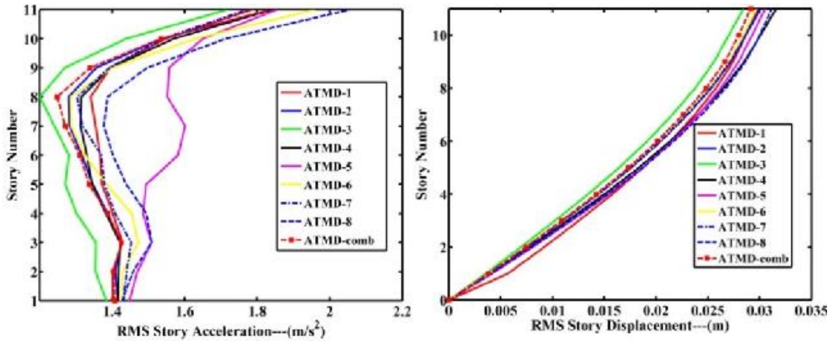

Figure 8. RMS story acceleration and displacement for 9 ATMD systems against center-3 earthquake excitation

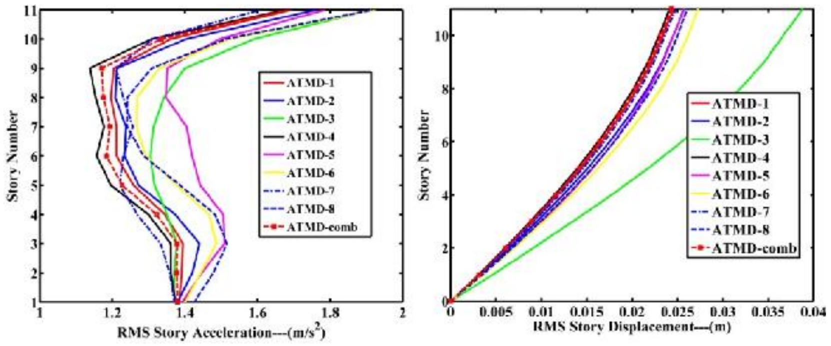

Figure 9. RMS story acceleration and displacement for 9 ATMD systems against center-4 earthquake excitation

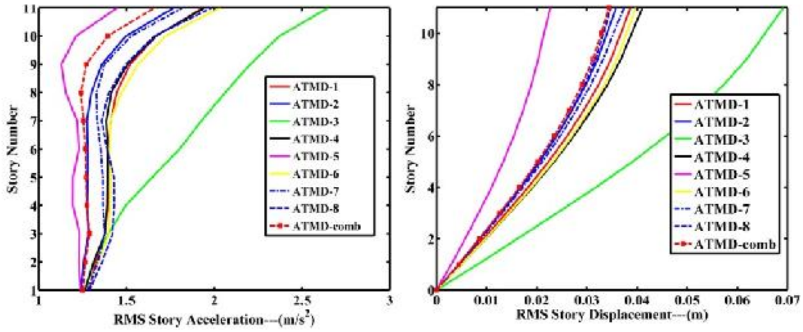

Figure 10. RMS story acceleration and displacement for 9 ATMD systems against center-5 earthquake excitation

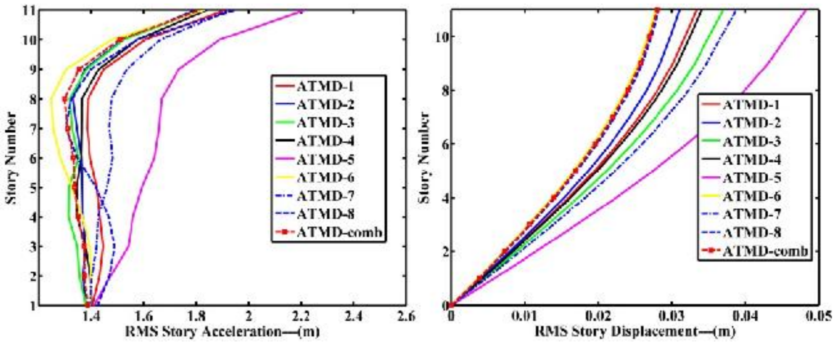

Figure 11. RMS story acceleration and displacement for 9 ATMD systems against center-6 earthquake excitation

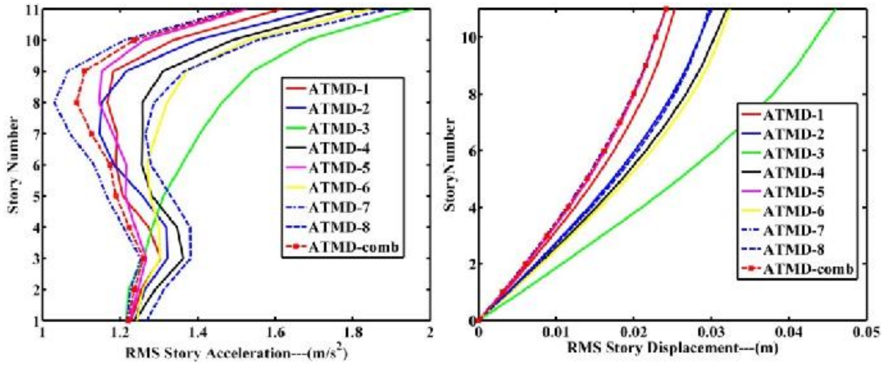

Figure 12. RMS story acceleration and displacement for 9 ATMD systems against center-7 earthquake excitation

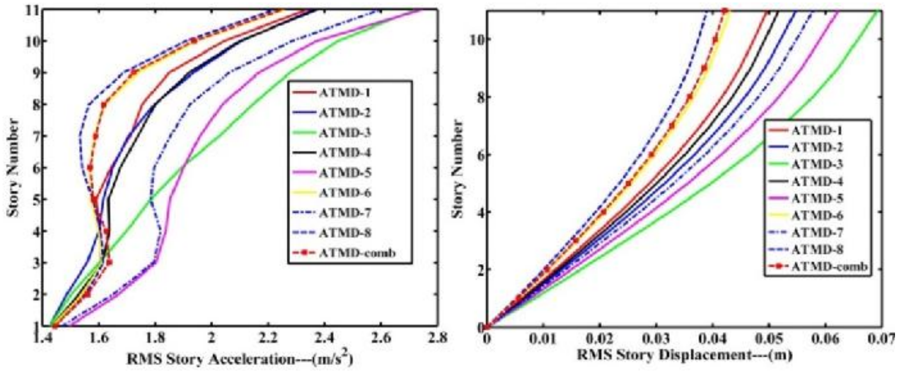

Figure 13. RMS story acceleration and displacement for 9 ATMD systems against center-8 earthquake excitation

Tablenumber.2 also summarizes the reliability index and annual failure rate for various cluster center excitations employing various ATMD systems.

Table 2.Summarized values of reliability index with and without ATMD

Earthquake used for tuning	Reliability index for limit state=0.005		Annual failure rate $(\lambda)_{IM}$	
	Without ATMD	With ATMD	Without ATMD	With ATMD
Center of cluster-1	2.69	2.9	0.00355	0.00205
Center of cluster-2	2.69	2.68	0.00355	0.00186
Center of cluster-3	2.69	2.84	0.00355	0.00364
Center of cluster-4	2.69	2.75	0.00355	0.00219
Center of cluster-5	2.69	2.87	0.00355	0.00297
Center of cluster-6	2.69	2.82	0.00355	0.00201
Center of cluster-7	2.69	2.87	0.00355	0.00239
Center of cluster-8	2.69	2.87	0.00355	0.00203
Representative earthquake	2.69	3.17	0.00355	0.000745

As it can be seen in this table, the ATMD system tuned based on the representative profile has the best performance among the controller in the sense of reliability index and annual failure rate. Table number.3 also compares the annual failure rate improvement with various ATMD systems. As it is seen in this figure, 80 percent improvement in the annual failure rate is calculated which is twice that for the best controller among the other ATMDs.

Table 3. Percent of annual failure rateimprovement for each control system

	ATMD tuned for center-1	ATMD tuned for center-2	ATMD tuned for center-3	ATMD tuned for center-4	ATMD tuned for center-5	ATMD tuned for center-6	ATMD tuned for center-7	ATMD tuned for center-8	ATMD tuned for Representative earthquake
Percent of improvement	42.25	47.61	2.54	38.31	16.34	43.38	32.68	42.82	79.01

CONCLUSIONS

A new approach for tuning ATMD system in order to enhance reliability of this system in confrontation with a seismic scenario was proposed in this paper. For this purpose, 1000 potential earthquakes from a seismic scenario generated for a certain cite is considered. The earthquake profiles were then clustered as 8 separate groups using fuzzy clustering approach. A representative profile was then developed employing the fuzzy cluster centers. A genetic-fuzzy controller is employed for the ATMD system control. The controller was tuned based on the representative seismic profile. Simulation results prove that the ATMD system tuned based on the proposed approach could effectively improve displacement and acceleration responses for all cluster center disturbances. Furthermore, the reliability and annual failure indices have been improved substantially for a wide range of the seismic disturbances.

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