

Vibration Control of MDOF Structure under Earthquake Excitation using Passive Control and Active Control

M. Reza Bagerzadeh Karimi, M. Mahdi Bagerzadeh Karimi

Abstract—In the present paper, active control system is used in different heights of the building and the most effective part was studied where the active control system is applied. The mathematical model of the building is established in MATLAB and in order to active control the system FLC method was used. Three different locations of the building are chosen to apply active control system, namely at the lowest story, the middle height of the building, and at the highest point of the building with TMD system. The equation of motion was written for high rise building and it was solved by state-space method. Also passive control was used with Tuned Mass Damper (TMD) at the top floor of the building to show the robustness of FLC method when compared with passive control system.

Keywords—Fuzzy Logic Controller (FLC), Tuned Mass Damper (TMD), Active control, passive control

I. INTRODUCTION

THE developments in engineering science in vibration control of structures, and security needs for occupants to feel safe against earthquake cause researchers to study more in the field of vibration control of structures. Vibration control systems can be divided into Passive and Active control systems. Passive control systems add damping to the structure, naturally, when an earthquake occurs. However, their control capacity is limited. But these systems have been widely used because of their simplicity and low cost. The active control systems use external energy when an earthquake happens. This energy produced by algorithm and applied to the structure has the advantage of having stronger capacity than Passive control systems. Also it can be designed to influence a number of vibration modes, and it is the most suited for an MDOF structure. On the other hand, passive control systems and active control systems are used together in order to decrease the energy requirements. Researches show that increasing the height of buildings could increase the flexibility; thus, the importance of the active control systems has increased [1]. Rahmi and et al. [1] studied about vibration control of structures using fuzzy logic and PD controller and an actuator was applied at the highest point of the structure where the TMD had been located. Seung-Yong and et al. [2] investigated about vibration control of structure using a technique with fuzzy logic method.

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Mahmud and et al. [3] examined an optimized control for an earthquake excitation on a structure. Hasan and et al. [4] studied about FSMC which is one of the active control algorithms. Pourzeynal and et al. [5] studied about vibration control of structure against earthquake excitation using GFLC and LQR algorithms and compared with TMD controller. Bijan and et al. [6] used experimental analysis and investigated a five-story building where ATMD system was controlled by FLC and LQR method. As it is clear by researches only the effects of control systems are studied and investigated on civil engineering structures, but the effects of the opportunities and the location of control systems, namely applying at the heights of the building in order to reach optimized responses, are not investigated. The present paper studied and investigated a 10-story building using active control system which was applied at the lowest floor, at the middle height of the building and at the highest point of the building (with TMD). The results were compared with the responses of the TMD control system in order to show robustness of FLC in example building.

II. STRUCTURAL MODEL

The equation of motion for a multi-degree-of-freedom structure subjected to seismic excitation $\ddot{x}_g(t)$, without any control system, can be written as:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = -[M]\{r\}\ddot{x}_g(t) \quad (1)$$

In which the $n \times 1$ vector $\{x\}$ designates the relative displacement of each story; n is the number of stories; the $n \times 1$ vector $\{r\}$ is the influence vector representing the displacement of each degree of freedom resulting from static application of a unit ground displacement; and $n \times n$ matrices $[M]$, $[C]$ and $[K]$ represent the structure mass, damping, and stiffness matrices, respectively. The structural damping matrix $[C]$ is assumed to be a proportion of the mass and stiffness matrices, as given in the following [5]:

$$[C] = a_0[M] + b_0[K] \quad (2)$$

Where $a_0 = \xi_i \times \frac{2\omega_i \times \omega_j}{\omega_i + \omega_j}$ and $b_0 = \xi_i \times \frac{2}{\omega_i + \omega_j}$
 a_0 and b_0 are the proportional coefficient; ω_i and ω_j are the structural modal frequencies and ξ_i and ξ_j are the structural damping ratio for modes i and j , respectively. This paper also studied the effects of TMD, a classical engineering device consisting of a mass, a spring and a damper, on multi-degree

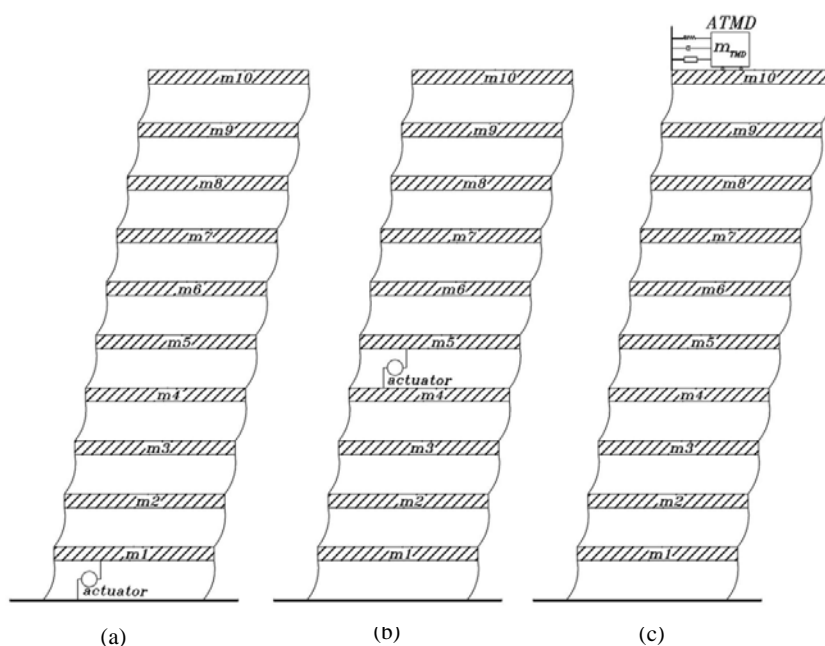


Fig. 1 Example building using active control system: a) applied to the first floor, b) applied at the middle height, c) applied to the TMD system

of-freedom structure. For this purpose, as shown in Fig. 1, a TMD system is mounted on the top floor of the building. The equation of motion of multi-degree-of-freedom linear system which is subjected to a seismic excitation $\ddot{x}_g(t)$ and active control action $\{f\}$ can be written as:

$$[M_T]\{\ddot{x}_T\} + [C_T]\{\dot{x}_T\} + [K_T]\{x_T\} = -[M_T]\{r_T\}\ddot{x}_g(t) + [D]\{f\} \quad (3)$$

In which the $n \times 1$ vector $\{x_T\}$ designates the relative displacements of each story. Square matrices $[M_T]$, $[C_T]$, $[K_T]$

and $\{r_T\}$ are the same explained in Eq. 1, and $n \times 1$ vector $\{f\}$ contains the externally applied control forces whose locations are identified through the matrix $[D]$.

III. NUMERICAL STUDY

In order to investigate the effects of active control system and TMD to decrease the responses under the earthquake excitation of BAM earthquake, happened in 2003 in IRAN (Fig. 2), a 10-story building was modeled in MATLAB (Fig. 1). The structure properties of example building are provided in Table 1.

TABLE I
 EXAMPLE BUILDING STRUCTURAL DATA

Stories	Mass (kg)	Stiffness (kg/m)
1	42180	114938011
2	42180	114938011
3	41791	87486851
4	41791	87486851
5	41430	65258739
6	41430	65258739
7	41097	47547051
8	41097	47547051
9	40791	33696384
10	40791	33696384
TMD	4146	177333

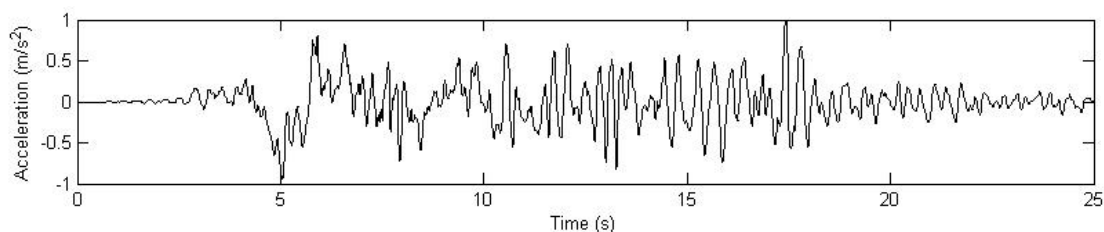


Fig. 2 Bam earthquake excitation input to the structure

To passive and active control the vibration, TMD system is mounted on the top floor of the building and active control system is applied in three different locations at the heights of the building, (at the first floor, at the fifth and so applied to TMD) respectively. In order to reach maximum decrease of vibration using TMD system, the mass of the TMD obtained by trial and error about 1% of the whole buildings mass. To find the stiffness of the passive control system the natural frequency of TMD is tuned to the main natural frequency of the structure, as follows:

$$\omega_i^2 \times m_{TMD} = k_{TMD} \quad (4)$$

In which m_{TMD} and k_{TMD} and ω_i are the mass, stiffness, and the main frequency of the first mode, respectively. The most optimized parameter of this system is defined by maximum decrease of responses of the building. Also the same parameters of the mass were used for active control

system when applied at top. In this study, Matlab simulink with fuzzy toolbox is used. The aim of the fuzzy logic control system for the structural system uses e and de as inputs and u as an output where the active control system is applied. For each of inputs, five rectangular membership functions are used which cover the amplitude of each input. Also, nine rectangular membership functions are used for outputs (Fig. 3). Fuzzy logic controller with Mamdani and Centroid methods were used in fuzzification and defuzzification, respectively. Scaling factors (se , sde , su) are used to set in Fig. 4. The fuzzy input and output variables' membership function abbreviations used to define the fuzzy space are: (X/V)NB = negative big; (X/V)NS = negative small; (X/V)ZE = zero; (X/V)PB = positive big; (X/V)PS = positive small (for input variable); and (U)NL = negative large; (U)NB = negative big; (U)NM = negative medium; (U)NS = negative small; (U)ZE = zero; (U)PL = positive large; (U)PB = positive big; (U)PM = positive medium; (U)PS = positive small (for output variable).

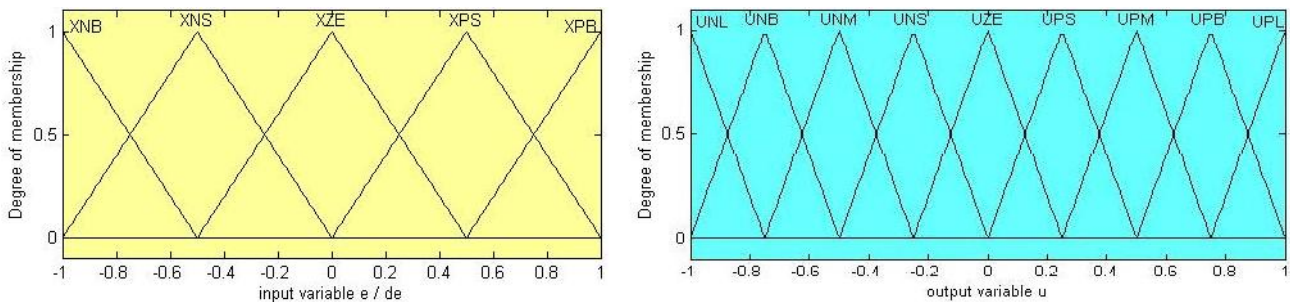


Fig. 3 Membership function

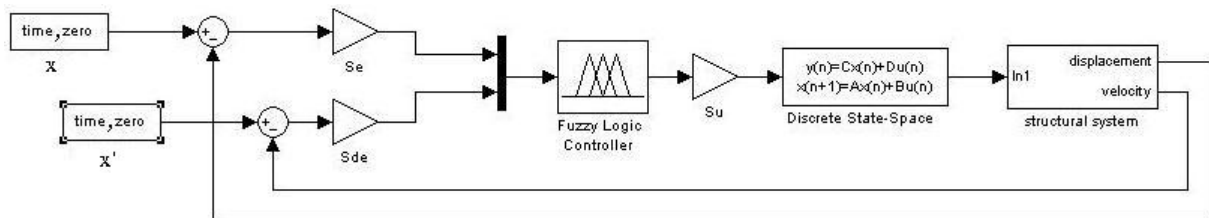


Fig. 4 Closed-loop model of the structure with fuzzy logic controller

TABLE II
 COMPARISON BETWEEN THE EFFECTS OF CONTROL SYSTEM ON STRUCTURE UNDER BAM EARTHQUAKE

stories	Max. responses of uncontrolled structure	Max. responses of controlled structure				[2]/[1]	[3]/[1]	[4]/[1]	[5]/[1]
		TMD	FLC (down)	FLC (middle)	FLC (up)				
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Displacement (m)									
10 th	0.036	0.031	0.01	0.0025	0.003	0.861	0.278	0.069	0.083
Velocity (m/s)									
10 th	0.247	0.187	0.073	0.020	0.0366	0.757	0.296	0.081	0.148
Acceleration (m/s²)									
10 th	2.505	2.221	0.833	0.353	0.643	0.887	0.333	0.141	0.257

As it is clear from table 2, responses of the structure for the top floor of the building (10th floor) show the proportion of controlled structure, the results are 86.1%, 27.8%, 6.9%, 8.3% for displacement, 75.7%, 29.6%, 8.1%, 14.8% for velocity and

88.7%, 33.3%, 14.1%, 25.7% for acceleration controlled by TMD and FLC systems (at three different locations), respectively. Figures 5, 6, 7 and 8 show the responses (displacement and acceleration) for the uncontrolled and the

controlled structure. As it can be seen from figures 5 – 8 the amplitude of vibration has decreased. Also, to clarify the

results, displacements are illustrated in fig. 9.

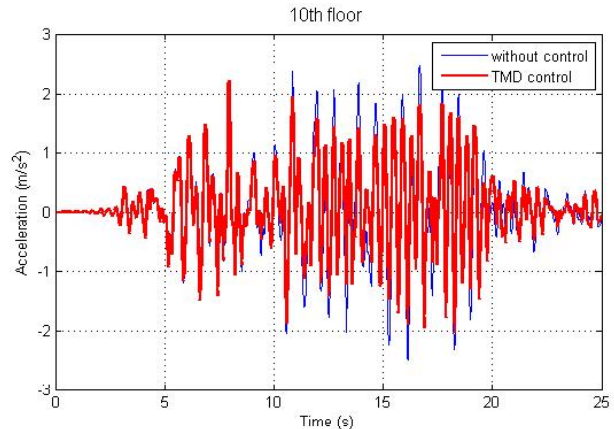
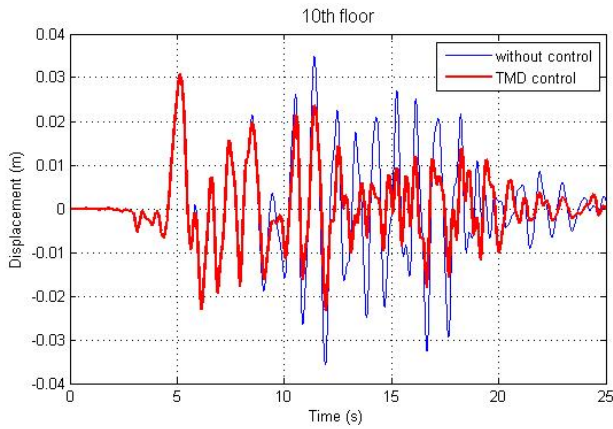


Fig. 5 passive control of displacement and acceleration for the 10th floor with TMD

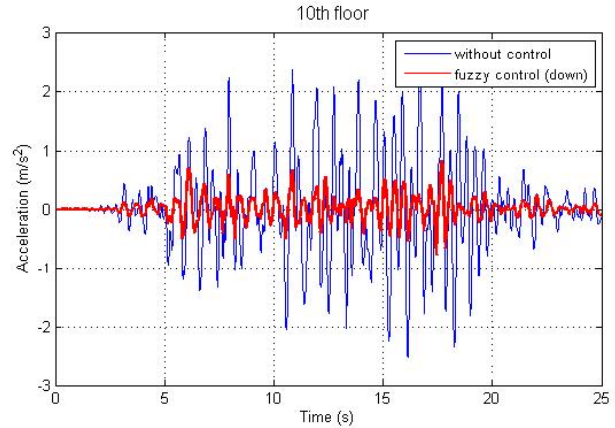
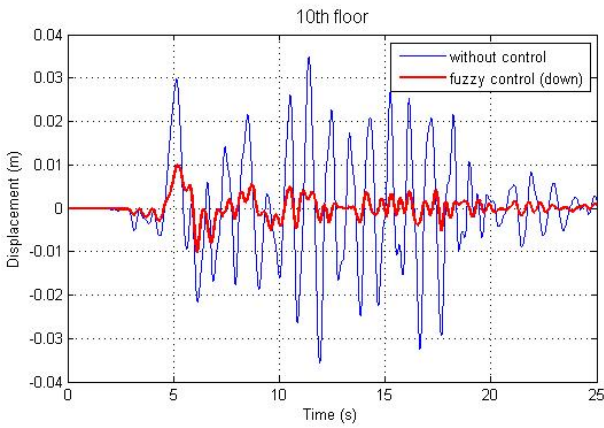


Fig. 6 Active control of displacement and acceleration for the 10th floor with FLC when control system applied at the lowest floor of the building

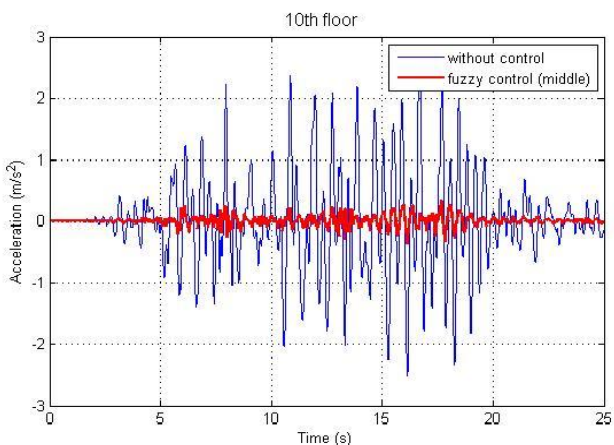
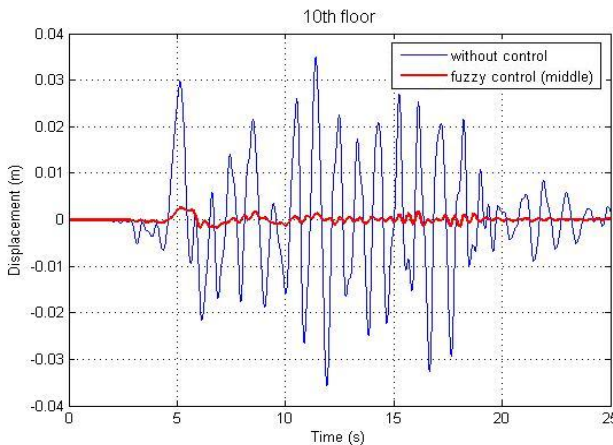


Fig. 7 Active control of displacement and acceleration for the 10th floor with FLC when control system applied at the middle height (5th) of the building

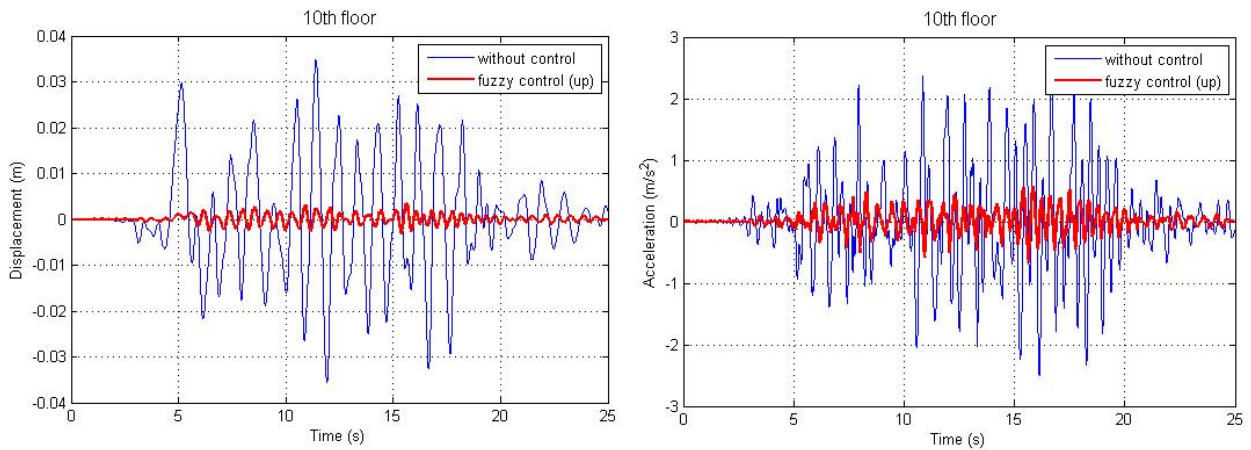


Fig. 8 Active control of displacement and acceleration for the 10th floor with FLC when control system applied to the TMD system

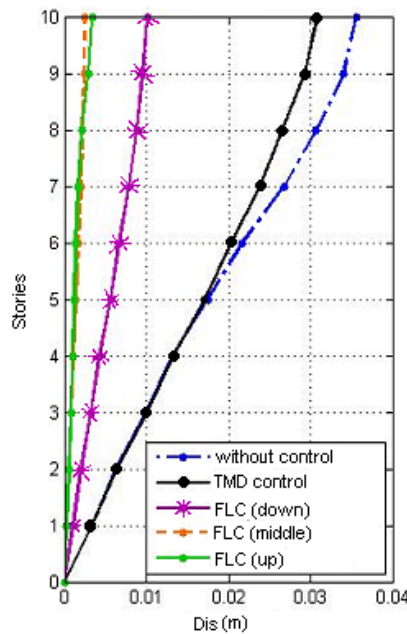


Fig. 9 Displacements

On the other hand, the fuzzy logic application is investigated against different disturbance using ground motion of TABAS earthquake, happened in 1999 in IRAN, the acceleration was about 0.84g, also the mass of each floor

increased about 25%. Robustness of FLC has been investigated through this variety of buildings' parameters. The results in Table 3 show the robustness of FLC even for different parameters of inputs in example building.

TABLE III
 COMPARISON BETWEEN THE EFFECTS OF CONTROL SYSTEM ON STRUCTURE UNDER TABAS EARTHQUAKE FOR DISPLACEMENT

stories	Maximum responses of uncontrolled structure	Maximum responses of controlled structure			
		TMD	FLC (down)	FLC (middle)	FLC (up)
10	0.313	0.301	0.085	0.023	0.034

IV. CONCLUSION

From the numerical results of the study, it is found that:

- 1) In view of the time history of the responses, the results show that when the active control system is applied in three different locations at the height of the example building are more satisfactory compared to the time when the passive control system (TMD) is only used.
- 2) In this study as it is clear by table 2, the most satisfactory control case was found for acceleration and velocity when the active control system was applied at the middle height of the building, but It can be seen that it is more negligible in displacements (also shown in fig. 9).
- 3) Performance of designed FLC is checked for different disturbance using ground motion of TABAS, and also changed some properties of structure. Simulation's results show that proposed controller (FLC) has a satisfactory performance and does not get worse. Decrease in vibration amplitudes supports this result (Table III).

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