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Effects of multiple MR dampers controlled by fuzzy-based strategies on structural vibration reduction

Cláudia Mara Dias Wilson*

New Mexico Institute of Mining and Technology, Socorro, NM, USA

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Abstract. Fuzzy logic based control has recently been proposed for regulating the properties of magnetorheological (MR) dampers in an effort to reduce vibrations of structures subjected to seismic excitations. So far, most studies showing the effectiveness of these algorithms have focused on the use of a single MR damper. Because multiple dampers would be needed in practical applications, this study aims to evaluate the effects of multiple individually tuned fuzzy-controlled MR dampers in reducing responses of a multi-degree-of-freedom structure subjected to seismic motions. Two different fuzzy-control algorithms are considered, a traditional controller where all parameters are kept constant, and a gain-scheduling control strategy. Different damper placement configurations are also considered, as are different numbers of MR dampers. To determine the robustness of the fuzzy controllers developed to changes in ground excitation, the structure selected is subjected to different earthquake records. Responses analyzed include peak and root mean square displacements, accelerations, and interstory drifts. Results obtained with the fuzzy-based control schemes are compared to passive control strategies.

Keywords: MR damper; semi-active control; fuzzy logic; fuzzy control; structural control

1. Introduction

Damages and losses incurred during earthquakes can be caused by direct fault displacement, soil settling, landslides, soil liquefaction, earthquake-induced fires, and evidently severe structural shaking. Different types of control devices have been proposed over the years to help dissipate incoming seismic energy and hence reduce vibrations sustained by civil structures. Examples of commonly used seismic control systems are passive and active tuned mass dampers, base isolators, and friction or viscous dampers. A very interesting control device is the magnetorheological (MR) damper which consists of a hydraulic cylinder filled with a suspension of magnetically polarizable iron particles. Normally free-flowing, this fluid has the ability to change its viscosity to semi-solid with the application of a magnetic field. This is a very quick and reversible process that can be controlled by changing the current applied to the dampers.

Because the relationship between the current supplied to the dampers and the resulting damping force is nonlinear, control of these devices is not an easy task. Different strategies have been proposed and compared over the years. Some are model-based, that is, they require a mathematical

*Corresponding author, Associate Professor, E-mail: cwilson@nmt.edu

model of the system. The most prominent controller in this category is the clipped-optimal algorithm developed by Dyke *et al*. (1996). Other controllers that also rely on system models are the optimal controllers (Xu *et al.* 2000, Zhou *et al.* 2002, Lu *et al.* 2008), the algorithms based on Lyapunov stability theory (Dyke and Spencer 1997, Yi *et al.* 2001), the skyhook and the continuous sliding mode controllers (Hiemenz *et al.* 2000, Lu *et al.* 2008, Neelakantan and Washington 2008). Because accurate system models may be difficult to obtain or so sophisticated and computationally intensive that they become impractical for control applications, intelligent control algorithms have been proposed. In this category are neural network–based controllers (Dalei and Jianqiang 2002, Ni *et al.* 2002, Xu *et al.* 2003), neuro-fuzzy based algorithms (Schurter and Roschke 2001), and fuzzy-logic based control (Zhou *et al.* 2002, Choi *et al.* 2004, Wilson 2005, Wilson and Abdullah 2009, 2010).

Fuzzy controllers are an attractive alternative to model-based algorithms because they use simple "IF-THEN" statements instead of complex equations to relate the values of the inputs to the output. Although simple and robust, these algorithms employ a very large number of parameters which render their tuning somewhat challenging (Yager and Filev 1994, Li and Gatland 1996). Popular tuning strategies focus in adjusting scaling factors used to map inputs and outputs to their respective universes of discourse. Some of the tuning methods proposed include heuristic approaches (Driankov *et al.* 1993, Faravelli and Yao 1996, Li and Gatland 1996), neuro-based systems (Chao and Teng 1997), evolutionary algorithms (Zhao *et al.* 2003, Shook *et al.* 2008, Ali and Ramaswamy 2009), self-tuning strategies (Zhao 2001, Wilson and Abdullah 2010), and gain-scheduling of one of the scaling factors (Zhao 2001, Wilson and Abdullah 2009).

Some of these strategies have been applied to the control of MR dampers. For instance, Zhou *et al.* (2002) minimized the difference between the actual and the desired responses of a single degree-of-freedom (SDOF) structure equipped with an MR damper through the use of an adaptive law combined with a fuzzy controller. A single fuzzy-controlled MR damper was also used by Choi *et al.* (2004) to reduce structural vibrations of a 3-story building. First and third floor velocities were used as inputs to the controller which effectively reduced responses to the El Centro earthquake and to its 150% scaled version. Unfortunately, the algorithm did not perform as well when the structure was subjected to a 50% scaled version of that same seismic motion. Evolutionary strategies such Micro-Genetic Algorithm and Particle Swarm Optimization were used by Ali and Ramaswamy (2009) to modify the fuzzy controllers' rule bases and improve the performance of two structures equipped with a single MR damper: a SDOF and a 3-DOF. Finally, gain-scheduling and self-tuning were employed by Wilson and Abdullah (2009, 2010) to control a single MR damper and reduce vibrations of a SDOF structure. Results of these studies showed that the controllers developed were effective and robust to changes in seismic motion and structural characteristics.

The studies cited above show that fuzzy strategies can be effectively employed in conjunction with MR dampers. However, all of these papers were limited to the use of a single damper. Nevertheless, in practical applications, the use of multiple smaller dampers would be preferable. It would reduce not only the amount of space required for the installation of the devices, but also the costs associated with their structural support. Therefore, when linking two structures with dampers, Jing *et al.* (2004) used three MR dampers. Logic-based algorithms were developed to control these devices. The inputs to the controller were selected as the relative displacements and velocities of the floors to which the dampers were connected. Multiple MR dampers were also used by Shook *et al.* (2008) to reduce vibrations of a 3-story structure. In that study, a genetic algorithm with four optimization objectives was proposed to optimize the fuzzy algorithms used to control the two MR dampers employed.

The objective of this study is to evaluate the effects of using multiple individually tuned fuzzy-controlled MR dampers in reducing responses of a multi-degree-of-freedom structure subjected to seismic motions. The significance and uniqueness of this work lie in the fact that very few researchers have addressed the viability of using multiple fuzzy-controlled MR dampers and none has addressed the effects of their placement within the structure. To determine the effects of damper placement, different configurations are considered, as are different numbers of MR dampers. Robustness of the fuzzy controllers developed to changes in ground excitation is also determined by subjecting the structure selected to different earthquake records.

2. System description

The equation of motion describing the responses of a multi-degree-of-freedom (MDOF) structure equipped with damper(s) and subjected to ground excitation can be written as

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{C}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = -\mathbf{\Gamma}\mathbf{f} - \mathbf{M}_v\ddot{x}_g \tag{1}$$

where $\mathbf{M}$, $\mathbf{C}$, and $\mathbf{K}$ are the mass, damping, and stiffness matrices, respectively, and $\mathbf{x}, \dot{\mathbf{x}}$ and $\ddot{\mathbf{x}}$ are the vectors of structural displacements, velocities, and accelerations, also respectively. Matrix $\mathbf{\Gamma}$ denotes the location of the MR dampers in the structure, vector $\mathbf{f}$ contains the control forces, $\mathbf{M_v}$ is a vector of structural masses, and $\ddot{x}_g$ is the ground acceleration. In this study, the structure selected was the three-story model building described in Park *et al.* (2002). Each floor of this structure has a mass of 345,600 kg, a stiffness of 120,000 kN/m, and 1% modal damping ratios were assumed for all modes. Mass, damping, and stiffness matrices are presented in Eqs. (2) to (4), respectively

$$\mathbf{M} = 10^5 \times \begin{bmatrix} 3.456 & 0 & 0 \\ 0 & 3.456 & 0 \\ 0 & 0 & 3.456 \end{bmatrix} \text{kg} \tag{2}$$

$$\mathbf{C} = 10^5 \times \begin{bmatrix} 1.745 & -0.512 & -0.111 \\ -0.512 & 1.634 & -0.623 \\ -0.111 & -0.623 & 1.122 \end{bmatrix} \text{Ns/m} \tag{3}$$

$$K = 10^8 \times \begin{bmatrix} 2.4 & -1.2 & 0 \\ -1.2 & 2.4 & -1.2 \\ 0 & -1.2 & 1.2 \end{bmatrix} \text{N/m} \tag{4}$$

The MR damper model used in the numerical simulations was the phenomenological model developed by Spencer Jr. *et al.* (1997), due to his ability to closely reproduce the force-displacement and the force-velocity behaviors of the device. According to this model, the force (f) produced by each MR damper can be expressed as

$$f = \alpha z + c_o(\dot{x} - \dot{y}) + k_o(x - y) + k_1(x - x_o) = c_1\dot{y} + k_1(x - x_o) \tag{5}$$

$$\dot{z} = -\gamma|\dot{x} - \dot{y}|z|z|^{n-1} - \beta(\dot{x} - \dot{y})|z|^n + A(\dot{x} - \dot{y}) \tag{6}$$

$$\dot{y} = \frac{1}{c_o + c_1}\{\alpha z + c_o\dot{x} + k_o(x - y)\} \tag{7}$$

where α is the Bouc-Wen element used to describe the yield stress of the MR fluid, z is an evolutionary variable defined as the integral of Eq. (6), c_o is the viscous damping at large velocities, x is the damper displacement, y is an internal damper displacement, k_o is the stiffness at large velocities, k_1 is the damper force due to the presence of an accumulator, c_1 reproduces the roll-off observed in the experimental data when velocities are close to zero, and x_o is an initial deflection. The values of these parameters were obtained experimentally by Yang (2001) and Yang *et al.* (2002) for a 20-ton MR damper: $A = 2679.0$ m^{-1}, $\gamma = \beta = 647.46$ m^{-1}, $k_o = 137{,}810$ N/m, $n = 10$, $x_o = 0.18$ m, and $k_1 = 617.31$ N/m. The remaining variables: α, c_o, and c_1, are functions of the current (i) applied to the damper (Yang 2001, Yang *et al.* 2002), as described in Eqs. (8) to (10)

$$\alpha(i) = 16566i^3 - 87071i^2 + 168326i + 15114 \tag{8}$$

$$c_o(i) = 437097i^3 - 1545407i^2 + 1641376i + 457741 \tag{9}$$

$$c_1(i) = -9363108i^3 + 5334183i^2 + 48788640i - 2791630 \tag{10}$$

In addition, to accommodate the dynamics of the MR fluid reaching rheological equilibrium, Yang (2001) and Yang *et al.* (2002) proposed the inclusion of the following first order filter

$$H(s) = \frac{31.4}{s + 31.4} \tag{11}$$

At this point, it is important to stress that although a model of the damper was required to conduct numerical simulations in Matlab and Simulink, it was not used in the development of the fuzzy controllers.

3. Fuzzy control algorithms

In this study, two fuzzy control strategies were developed to regulate the properties of the various MR dampers distributed throughout the structure. The first controller is a more traditional fuzzy algorithm, where all parameters were selected as constants. A block diagram of this system is presented in Fig. 1. For simplicity, in this paper, it will be referred to as "fuzzy controller." The second fuzzy algorithm uses a gain-scheduling strategy to vary the value of one of the scaling factors. Its block diagram is presented in Fig. 2. For simplicity, it will be referred to as "gain-scheduled controller."

Both control schemes used a decentralized approach, that is, each damper was individually controlled using responses of the floor to which it was connected. The inputs to the controllers were chosen as the respective floor's displacement and velocity, while the output was the current supplied to the damper. For the inputs, seven triangular membership functions with 50% overlap were defined on the normalized universe of discourse [-1,1] (Fig. 3(a)). The labels selected: NL, NM, NS, ZO, PS, PM, and PL stand for: negative large, negative medium, negative small, zero, positive small, positive medium, and positive large, respectively. Four triangular functions, also with 50% overlap, were selected for the controller output on the normalized universe of discourse [0,1], as

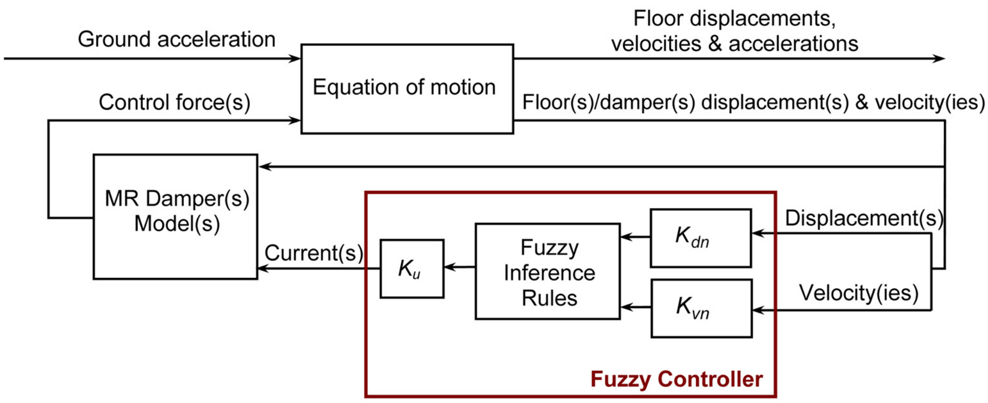

Fig. 1 Block diagram of fuzzy controller with constant scaling factors K_u, K_{dn}, and K_{vn} which are associated with current, displacement(s), and velocity(ies), respectively. Subscript n refers to the floor to which the MR damper is connected

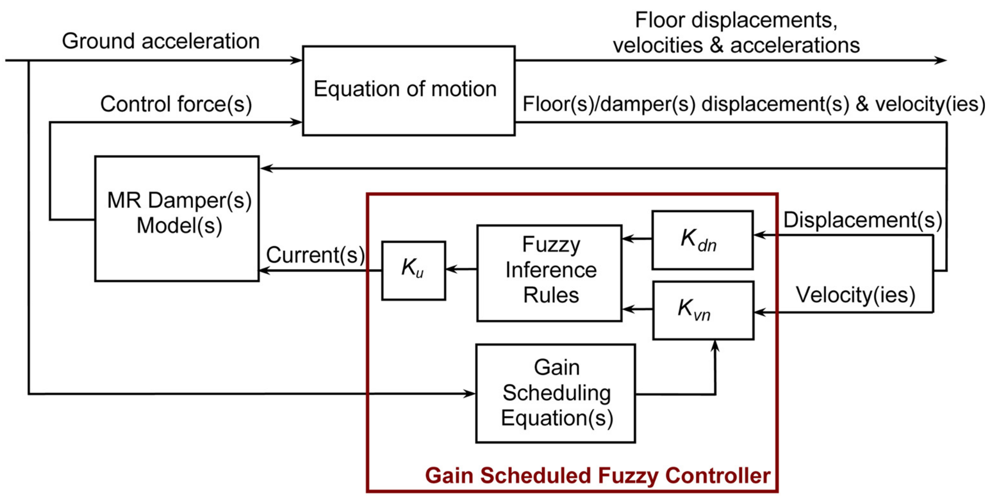

Fig. 2 Block diagram of gain-scheduled fuzzy controller. Scaling factors K_u, K_{dn}, and K_{vn} relate to current, displacement(s), and velocity(ies), respectively. Subscript n refers to the floor to which the MR damper is connected

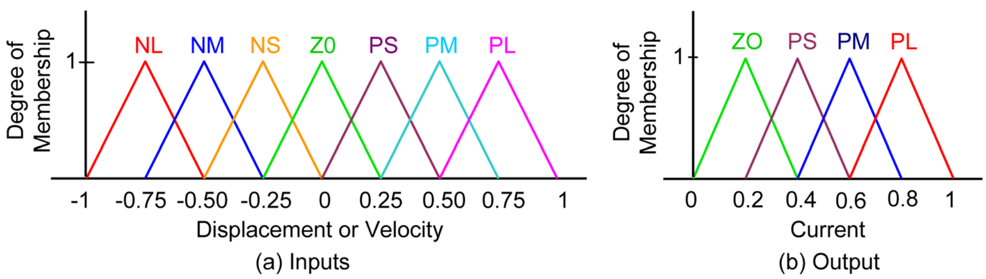

Fig. 3 Membership functions

depicted in Fig. 3(b).

Scaling factors were necessary to map the inputs and the output of the controllers to their respective normalized universes of discourse. These factors were labeled K_{dn}, K_{vn}, and K_u for displacement, velocity, and current, respectively; subscript n refers to the n^{th} floor. For the traditional fuzzy controller, a parametric analysis was conducted to select the values of these factors that produced the best reductions in structural responses to the El Centro earthquake. Values considered for scaling factors K_{dn} and K_{vn} included those obtained with the equations proposed by Yager and Filev (1994)

$$K_{d_n} = \frac{1}{d_{\max_n}} \tag{12}$$

$$K_{v_n} = \frac{1}{v_{\max_n}} \tag{13}$$

as well as those proposed by Liu *et al.* (2001)

$$K_{d_n} = \frac{3}{d_{\max_n}} \tag{14}$$

$$K_{v_n} = \frac{3}{v_{\max_n}} \tag{15}$$

where $d_{\max_n}$ and $v_{\max_n}$ are the n^{th} floor maximum structural displacement and velocity, respectively. In this paper, these values were taken as the peak uncontrolled responses of the building to the following earthquakes: El Centro, Hachinohe, Northridge, and Kobe. For K_u, the following values were considered: 2, 4, and 6, which include the value obtained with the equation proposed in Liu *et al.* (2001)

$$K_u = \frac{i_{\max} - i_{\min}}{3} \tag{16}$$

where $i_{\min}$, the minimum current, was set to 0A, and $i_{\max}$, the maximum current, was set to 6A (Yang 2001). The values that yielded the best structural responses and hence were used in this paper's numerical simulations are presented in Table 1.

For the gain-scheduled fuzzy controller, parametric analyses were conducted to determine the relationships between scaling factors K_{vn} and the amplitude of the ground motion. The following scaled versions of the El Centro earthquake were used to excite the 3 DOF structure and determine the equations required for gain-scheduling these variables: 25%, 50%, 100%, 150%, and 200%. Equations relating ground acceleration ($\ddot{x}_g$) to scaling factors K_{vn} are presented in Table 2, along with the constant values used for scaling factors K_{dn} and K_{un}.

The selection process for the rule-base to be used in the fuzzy control algorithms started with the

Table 1 Scaling factors selected for the fuzzy controller with constant scaling factors

Location of dampers	K_{un}	K_{dn}	K_{vn}
First floor	$K_{u1} = 2$	$K_{d1} = 5$	$K_{v1} = 0.66$
Second floor	$K_{u2} = 2$	$K_{d2} = 3$	$K_{v2} = 0.36$
Third floor	$K_{u3} = 2$	$K_{d3} = 2$	$K_{v3} = 0.29$

Table 2 Scaling factors values and equations selected for the gain-scheduled controller

Location of dampers	K_{un}	K_{dn}	K_{vn}	R^{2*}
First floor	$K_{u1} = 2$	$K_{d1} = 5$	$K_{v1} = 14.80\ddot{x}_g^2 - 22.49\ddot{x}_g + 9.18$	0.9377
Second floor	$K_{u2} = 2$	$K_{d2} = 3$	$K_{v2} = 9.98\ddot{x}_g^2 - 15.16\ddot{x}_g + 6.19$	0.9378
Third floor	$K_{u3} = 2$	$K_{d3} = 2$	$K_{v3} = 8.96\ddot{x}_g^2 - 13.60\ddot{x}_g + 5.54$	0.9382

*Coefficient of determination

Table 3 Rule-base adopted for both fuzzy controllers (Liu *et al.* 2001)

x \ $\dot{x}$	NL	NM	NS	ZO	PS	PM	PL
NL	PL	PL	PL	PM	ZO	ZO	ZO
NM	PL	PL	PL	PS	ZO	ZO	PS
NS	PL	PL	PL	ZO	ZO	PS	PM
ZO	PM	PL	PS	ZO	PS	PM	PL
PS	PS	PM	ZO	ZO	PL	PL	PL
PM	ZO	PS	ZO	PS	PL	PL	PL
PL	ZO	ZO	ZO	PM	PL	PL	PL

consideration of the standard rule-base developed by MacVicar-Whelan (1976) and adjusted by Liu *et al.* (2001) because it appeared to adequately describe the relationship between the controller's inputs and output. Some of the rules were then modified and their effects on the structural responses were assessed. Because no systematic method exists to develop fuzzy-control rules, this is a commonly used approach (Yager and Filev 1994). The rule-base proposed by Liu *et al.* (2001) was ultimately adopted since the modifications attempted caused no considerable changes in the structural responses. These rules are reproduced in Table 3.

4. Results and discussion

Three damper placement configurations were considered in this paper. Dampers were initially placed on the first floor, then equally distributed between the first and the second floors, and finally evenly distributed among all three floors of the structure. Six criteria were used to evaluate the effectiveness of the control strategies in reducing root mean square (RMS) and peak responses for each configuration considered. They are described in Eqs. (17) to (22) and consist in the division of the controlled responses by the corresponding uncontrolled responses

$$J_{1n} = \frac{RMS(x_n(t))}{RMS(x_{unc_n}(t))} \tag{17}$$

$$J_{2n} = \frac{RMS(\ddot{x}_n(t))}{RMS(x_{unc_n}(t))} \tag{18}$$

$$J_{3n} = \frac{\max|x_n(t)|}{\max|x_{unc_n}(t)|} \tag{19}$$

$$J_{4n} = \frac{\max|\ddot{x}_n(t)|}{\max|\ddot{x}_{unc_n}(t)|} \tag{20}$$

$$J_{5n} = \frac{RMS(x_n(t) - x_{n-1}(t))}{RMS(x_{unc_n}(t) - x_{unc_{n-1}}(t))} \tag{21}$$

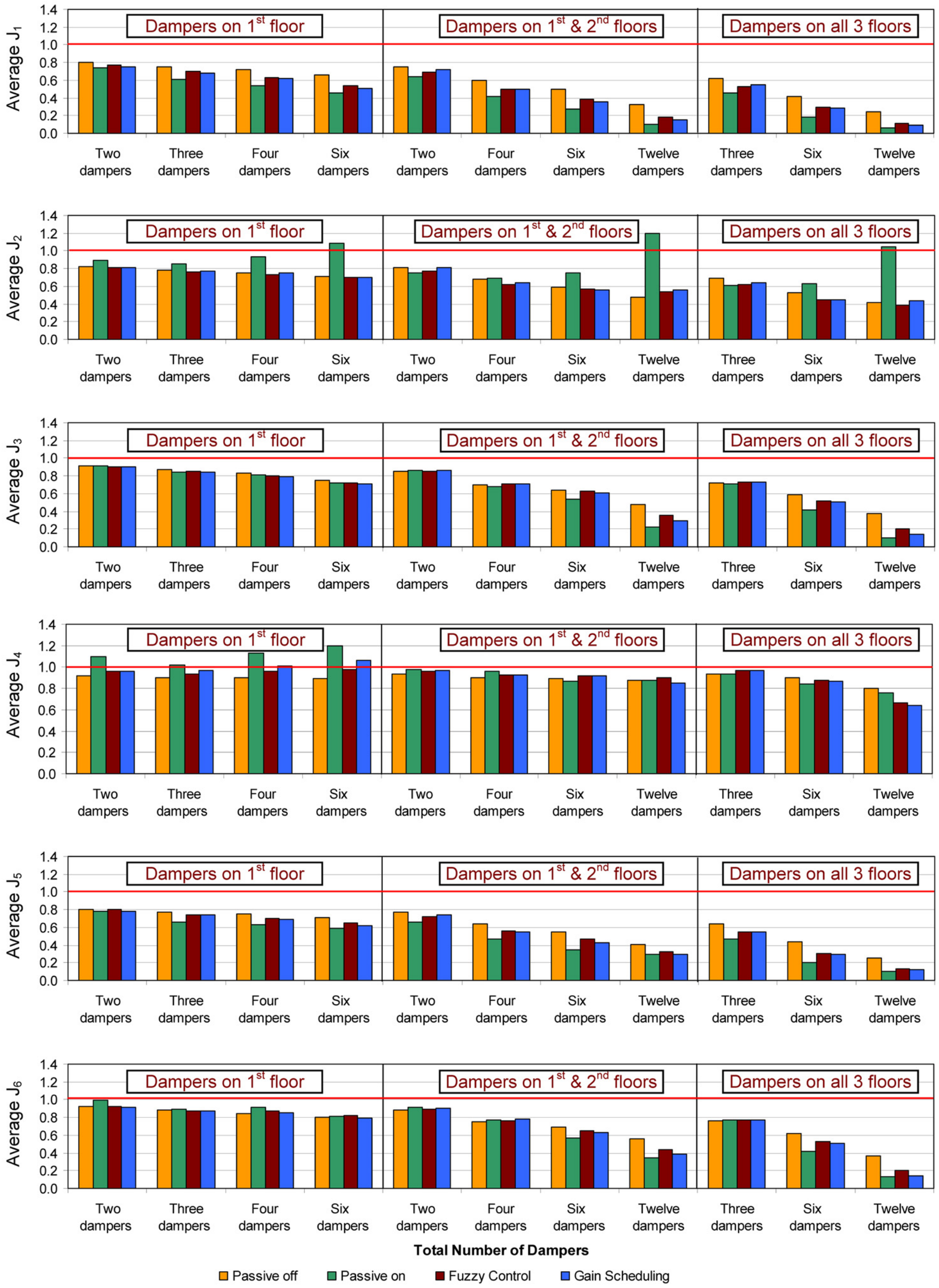

Fig. 4 Average values of evaluation criteria for the El Centro earthquake

$$J_{6n} = \frac{\max|x_n(t) - x_{n-1}(t)|}{\max|x_{unc_n}(t) - x_{unc_{n-1}}(t)|} \tag{22}$$

where x_n and $\ddot{x}_n$ represent the n^{th} floor controlled floor displacement and acceleration, respectively, while x_{unc_n} and $\ddot{x}_{unc_n}$ represent the n^{th} floor uncontrolled floor displacement and acceleration, also respectively.

Because both controllers were tuned using responses of the structure to the El Centro earthquake, this seismic motion was first used in the numerical simulations. Although a value for every evaluation criteria was obtained for each floor of the structure, for succinctness, only average values are presented in Fig. 4. This figure also shows results obtained with two passive configurations: "passive on", where the current to the MR dampers was set at its maximum value: 6A (Yang 2001) and "passive off", where it was set to 0A. These results show that both fuzzy controllers developed successfully reduced structural responses for all criteria considered. The only exception was the slight increase in maximum acceleration (J_4) observed when six dampers were placed on the first floor of the structure and the gain-scheduled controller was used. The increase in peak acceleration observed actually occurred on the second floor of the structure, where the value for J_4 was 1.35. J_4 values of 0.92 and 0.90 were obtained for the first and third floors, respectively.

Results presented on Fig. 4 also show that for the same number of dampers, larger response reductions are obtained for all six criteria when the devices are evenly distributed among the floors. It can be seen that a much smaller number of dampers could be used if these were distributed throughout the structure. In fact, for both fuzzy control strategies, similar responses were obtained with six MR dampers placed on the first floor of the structure, four MR dampers equally distributed between the first and the second floors, and three dampers, one on each floor of the structure. When comparing the responses obtained with the two fuzzy schemes, it was observed that, in general, responses were very similar. However, gain-scheduling scaling factors K_{vn} lead to slightly better responses, especially when a larger number of dampers was used. This may be due to the fact that this control strategy allows a greater control over this larger force. This difference in performance is especially noticeable for reductions in RMS and peak displacements and interstory drifts (J_1, J_3, J_5, and J_6).

It did not come as a surprise that the passive on strategy was more effective in reducing displacements and interstory drifts than the passive off controller. Also expected were the larger accelerations observed with the passive on strategy, which in some cases resulted in responses worse than the ones obtained with the uncontrolled structure. The main purpose of varying the current supplied to the MR dampers with the fuzzy control strategies developed was to reduce structural displacements as effectively as possible without increasing the acceleration responses like the passive on scheme. Results presented in Fig. 4 showed that, with the exception of peak acceleration reductions, both the fuzzy controller and the gain-scheduled control scheme were more effective than the passive off setting. More importantly, the fuzzy controllers effectively reduced not only displacements and interstory drifts, but also accelerations, which could not always be achieved when maximum current was constantly supplied to the dampers (passive on case).

To determine the robustness of the strategies proposed to changes in ground motions, the 3-DOF structure equipped with the MR dampers (controlled by the fuzzy strategies tuned using structural responses to the El Centro earthquake) was subjected to three additional seismic excitations: Hachinohe, a far field earthquake like El Centro, and two near fault motions: Kobe and Northridge. Results for the six evaluation criteria are presented in Figs. 5 to 7. Once again, only average values

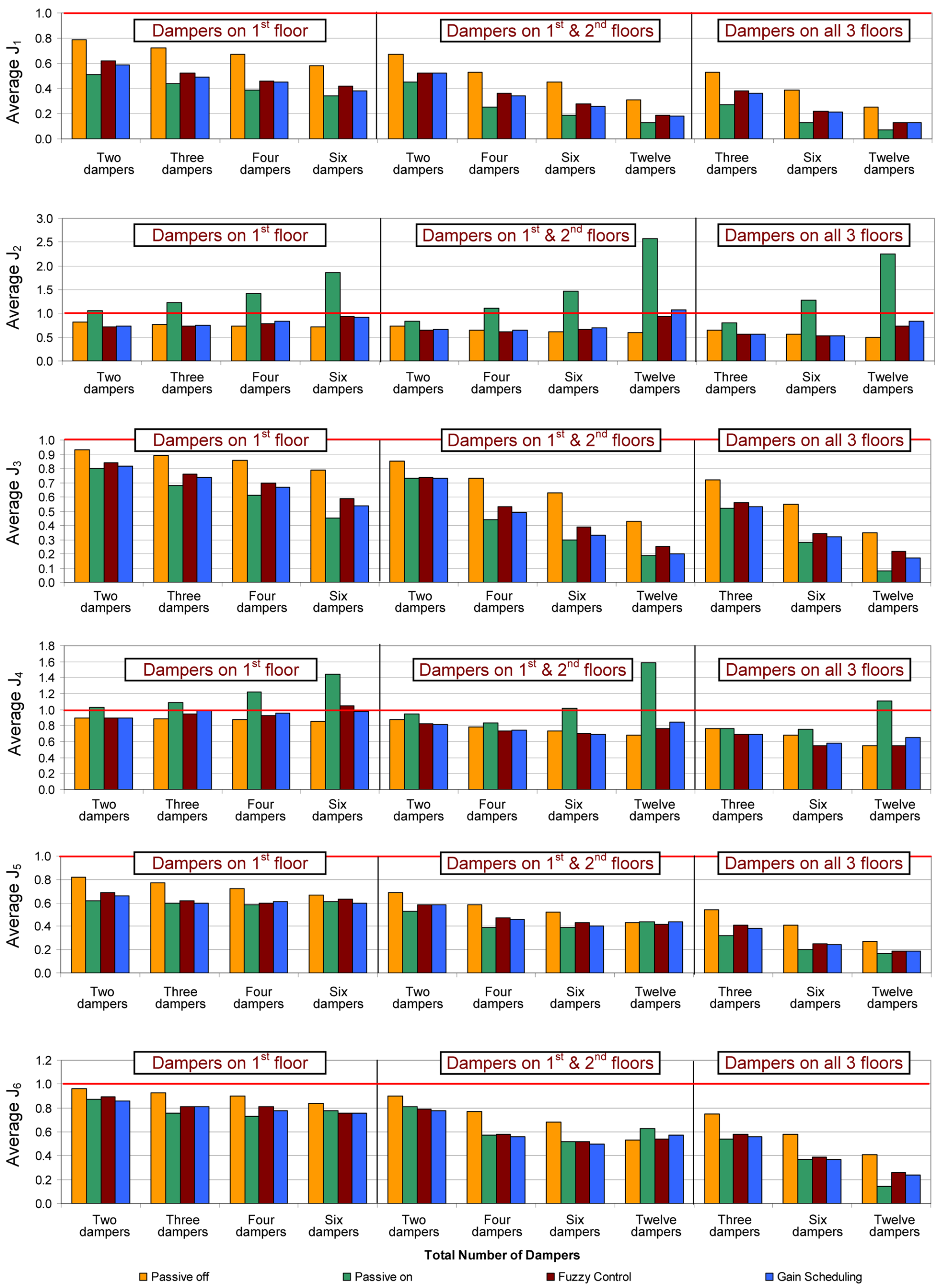

Fig. 5 Average values of evaluation criteria for the Hachinohe earthquake

are presented for conciseness. Results obtained show that, overall, the controllers were robust and successfully reduced structural responses. Very few exceptions were observed; they involved small increases in acceleration and occurred when dampers were concentrated on the first floor of the

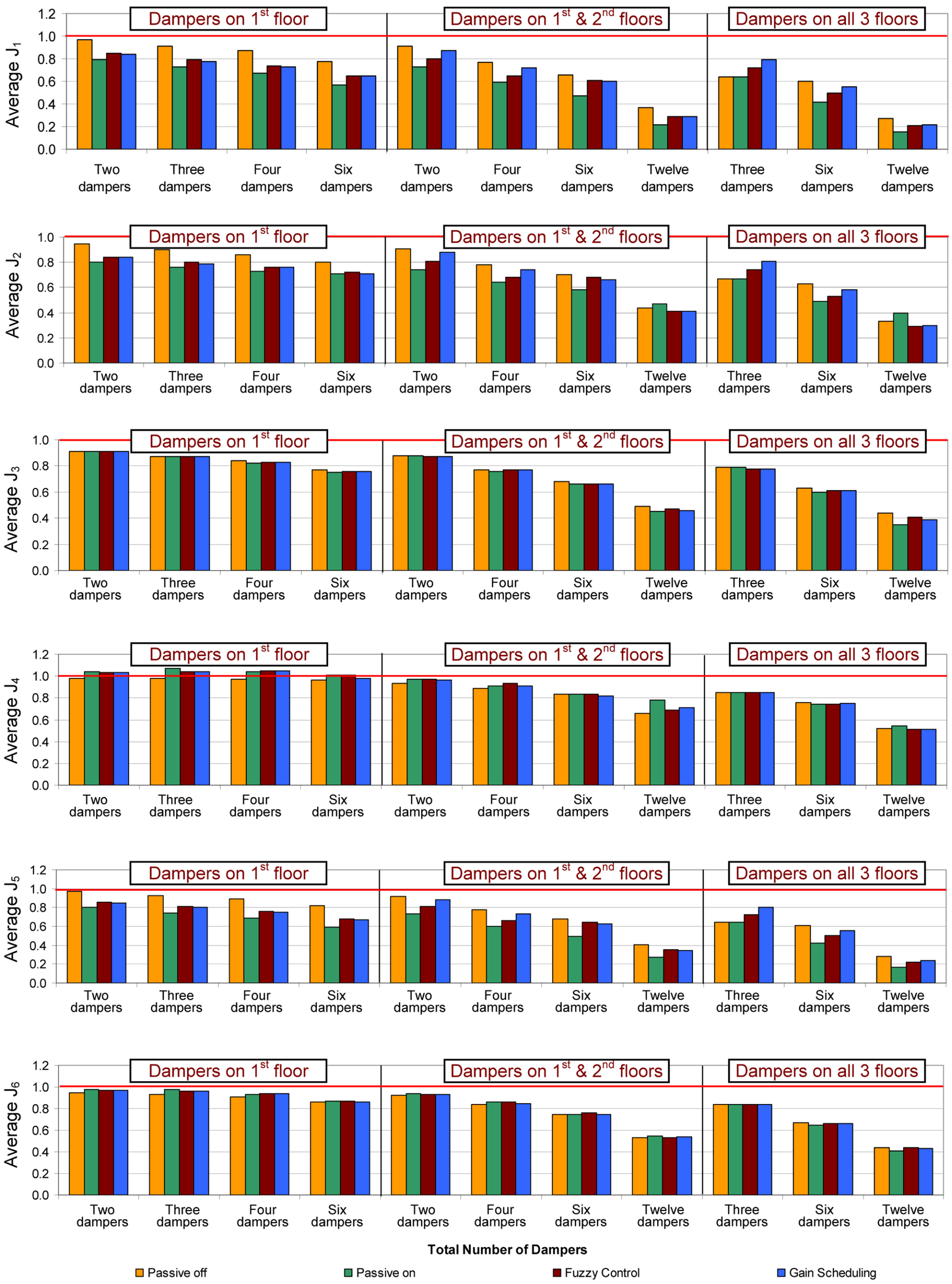

Fig. 6 Average values of evaluation criteria for the Kobe earthquake

structure. Generally, results similar to the ones obtained for the El Centro earthquake were observed with respect to the effects of damper placement and number of dampers used. Not much difference was observed between the fuzzy controller with constant scaling factors and the gain-scheduled strategy. For the Hachinohe earthquake, the gain-scheduled controller performed a little better than

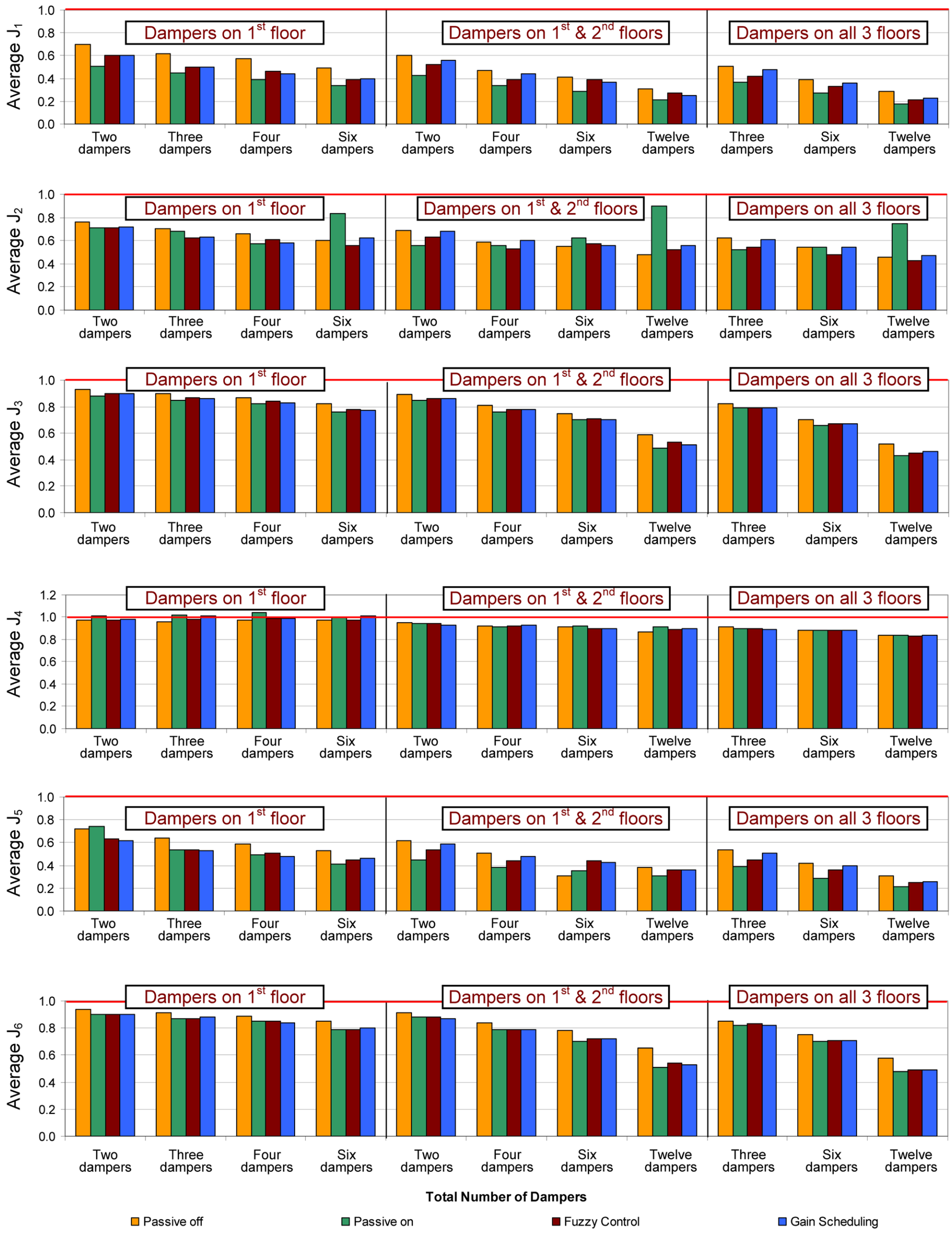

Fig 7 Average values of evaluation criteria for the Northridge earthquake

its fuzzy counterpart with respect to displacements (J_1 and J_3). Like results obtained for the El Centro earthquake, this was more evident when a larger number of dampers was used. For the near-fault seismic motions, all results obtained with the two fuzzy controllers were very similar. However, the fuzzy algorithm with constant scaling factors seemed to slightly outperform the gain-scheduled one on several occasions. When compared to the passive schemes, the fuzzy algorithms still seemed to provide a good balance between the two passive strategies. Both fuzzy algorithms reduced displacements more effectively than the passive off setting, and accelerations more effectively than the passive on setting.

5. Conclusions

Although fuzzy logic controllers have recently been proposed for regulating MR dampers' properties and reduce structural vibrations, so far, most of the studies conducted have focused on a single damper. However, on multi-story structures, the use of multiple smaller dampers would be preferable over the adoption of one larger device. This is mainly because of the costs associated with structurally supporting these larger devices as well as space requirements. Therefore, the objective of this study was to evaluate the effects of using multiple individually tuned fuzzy-controlled MR dampers in reducing responses of a multi-degree-of-freedom structure. Two different fuzzy-control algorithms were considered: a controller with constant scaling factors and a gain-scheduled control strategy that varied the values of the scaling factors associated with floor velocities. Different damper placement configurations were considered, as were different numbers of MR dampers. Results showed that: (1) Multiple MR dampers individually controlled by fuzzy algorithms are capable of effectively reducing peak and RMS displacements, accelerations, and interstory drifts for all placement configurations considered. Very few exceptions were observed. In these cases, peak or RMS accelerations were slightly increased when all dampers where placed on the first floor of the structure. However, these unfavorable responses were avoided when the dampers were distributed among the different floors. (2) The distribution of the individually controlled MR dampers over the floors of the structures lead to better results than the grouping of these devices. In fact, similar results were obtained with the following three configurations: six dampers on the first floor, four dampers evenly distributed between the first two floors, and three dampers, one on each floor of the structure. These observations lead to the conclusion that a much smaller number of dampers could be used if they are distributed throughout the structure. (3) While, in general, responses obtained with the two fuzzy strategies proposed were very similar, the gain-scheduled controller was found to be more effective when a larger number of dampers was used. This was apparent for responses to the El Centro earthquake since these responses were used in the tuning of the controller, and for responses to Hachinohe, a far field earthquake like El Centro. (4) Although the fuzzy algorithms were tuned using responses to the El Centro earthquake, they were able to effectively reduce vibrations caused by different seismic motions. This robustness to changes in ground excitation was more apparent when another far field earthquake was used. However, reductions obtained for the two near fault seismic records were also satisfactory. (5) Finally, the fuzzy controllers proposed were shown to be a good medium between the two passive settings. That is, like the passive on strategy, they outperformed the passive off approach with respect to displacement reduction. In addition, these reductions were obtained without the increases in accelerations observed with the passive on controller.

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