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SEMI-ACTIVE SEISMIC CONTROL OF MID-RISE STRUCTURES USING MAGNETO-RHEOLOGICAL DAMPERS AND TWO PROPOSED IMPROVING MECHANISMS*

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Abstract– This research examines performance of semi-active control of structures using Magneto-Rheological (MR) dampers. Mechanical specifications of this smart fluid damper change by falling into the magnetic field, so by increasing intensity of magnetic field the resulting damper power consequently increases. In this paper, two models of 9 and 20-story buildings were first selected as case studies and respective specifications of these structures (mass, stiffness and damping matrices) were calculated using valid sources as well as analysis of structures ignoring axial deformations against imposed loads. Then, sample structures were simulated in a Simulink environment. Consequently, optimum force determination processor, control system and MR damper were modeled in Simulink environment and were installed on a structural system. Finally, the obtained results from damper equipped structure were compared with non-controlled structure. In semi-active control case, clipped optimal algorithm was considered as control algorithm and optimal classic linear control method was used to determine control power. Based on the obtained results, it is observed that using this control method will significantly decrease structure response, such that MR damper can be about 12% to 36% effective in reducing maximum lateral drift and up to 21% in reducing maximum acceleration. Two mechanisms are eventually offered to improve the function of dampers and their performance. The proposed mechanism is shown to be effective in reducing the capacity and number of dampers required.

Keywords– Smart fluid dampers, magneto-rheological (MR) dampers, clipped optimal algorithm, linear optimal control algorithm, simulink modeling, mid–rise structures

1. INTRODUCTION

Seismic sources in most parts of the world cause earthquakes to occur and consequently leave severe damage behind. Accurate calculation of gravity loads is possible because of their simple behavioral nature, but obtaining the same result in earthquake induced loads is far beyond our reach as mid-rise buildings might be more affected by earthquake due to their special structural specifications. On the other hand, there are a large number of people in such residential or office buildings, making it more crucial that they be useable during and after earthquakes as any damage will jeopardize the lives of many people. Some research studies have already been carried out on MR dampers. Dyke et al. studied modeling and reduction of vibrating response of a 3-story building by using an MR damper and obtained suitable results to control the model. The semi-active control performance of MR damper to reduce the maximum drift, while requiring less energy, was better than active control performance [1, 2].

Qu and Xu in 2001 conducted research on using ER/MR damper for semi-active control of vibration response of high rise structure connected to the podium structure. This smart material damper was used to

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connect tower structure to podium structure to reduce the impact effect of tower structure when exposed to vibration excitations [3].

Iwata et al. in 2002 have described the applicability of the MR damper to base-isolated building structures. They proposed a simple semi-active control algorithm, which aims at controlling the hysteresis shape. In order to verify the effectiveness of the proposed method, shaking table tests were carried out using a newly-developed MR fluid damper. It was shown that the MR damper significantly improves the performance of base-isolated structures [4].

Jung et al. proposed a semi-active control strategy using MR dampers by investigating the ASCE first generation benchmark control problem for seismic responses of cable-stayed bridges. The modified Bouc-Wen model was considered as a dynamic model of the MR damper. The numerical results demonstrated that the performance of the proposed control design is nearly the same as that of the active control system. In addition, semi-active control strategy has many attractive features, such as the bounded-input, bounded-output stability and small energy requirements. The results of this preliminary investigation, therefore, indicated that MR dampers can be effectively used to control seismically excited cable-stayed bridges [5].

Amini and Karagah studied optimal placement of semi-active dampers by pole assignment method and showed that the optimal control analysis results in less control force and a small number of controllers in comparison with the non-optimal case. In most cases, the number of controllers does not have a great effect on the desired control performance and controlling can be done with fewer optimal controllers [6].

Chooi and Oyadiji conducted research on designing, modeling and testing of MR dampers using analytical flow solutions [7]. Ahmadian and Norris by making an experimental model in 2008 analyzed the performance of MR damper against the impact loads. Their model included a 55-pound load which dropped from 12, 24, 48, 72 and 96 inch heights and made impact velocities of 86, 127, 224, and 260 inch per second [8].

Zahrai and Shafieezadeh studied the application of semi-active variable dampers for wind response control of tall buildings and demonstrated that the fuzzy controller is more effective than the passive controller in retuning the damping of the semi-active device and reducing the structural response due to wind excitations[9].

In 2009, Zasso and Resta investigated using MR damper in high rise building to reduce structure response against vibrations due to wind. Dampers were connected to the structure in two forms of internal and external braces. To improve that performance, a lever mechanism was used with MR damper. Their proposed mechanism had a noticeable effect on reduction of capacity and number of needed dampers [10].

Since research projects on seismic control of high and mid-rise structures by using magnetic smart fluid dampers still suffer from some deficiencies, there is a lack of information in this regard and presenting control algorithms as well as desirable creative strategies can significantly improve performance of this kind of damper. In this paper, using magnetic smart fluid dampers for seismic control of mid-rise structures is discussed.

For successful function of MR dampers, they should connect two points that might have noticeable displacement. Therefore two mechanisms for improving the function of these kinds of dampers are offered and a combination of them is eventually used and comparison between the results of using new methods and using dampers in normal condition is made. Since the displacement across the damper is shown to be small, a lever mechanism is also proposed for motion magnification. Control algorithm of clipped optimal showed that MR dampers with the proposed lever mechanism are effective in reducing responses under earthquake excitations in all three models.

2. DAMPER WITH MAGNETIC SMART FLUID

Damping system with smart fluid is considered a kind of semi-active control instrument. This group of instruments includes dampers in which fluid viscosity is changeable. This change in viscosity changes stiffness of dampers and consequently increases or decreases their desire to absorb energy.

These dampers include magnetic polarized particles floating in oil and have the ability to change from fluid state to semi-solid matter with controllable obedience resistance in a few milliseconds or vice versa. This change is done by increasing or decreasing the intensity of magnetic field and as a result makes them helpful to controllable dampers.

The main benefit of these dampers, compared to other semi-active vibration absorbers, is that they have no moveable parts except pistons and thus are very simple and reliable. Two practical examples of dampers application in structures are: i) two dampers containing 30-ton magnetic fluid were used in Tokyo in 2001, to improve response of national science and innovation museum between floors 3 and 4, regarded as the first application of damper (containing magnetic fluid) in an actual scale building; ii) the first application of magnetic fluid dampers in bridges was implemented in a cable-stayed bridge on Dongting Lake in Hunan, China).

a) Dynamic analysis by semi-active control

In the case where initial structures are controlled by dampers, system movement equation due to imposing control forces on linear structure is written as follows [11]:

$$M_S\ddot{X} + C_S\dot{X} + K_SX = \Lambda f(t) - M_S\{1\}_{N\times 1}\ddot{X}_g(t) \tag{1}$$

f (t): control forces vector

Λ: Matrix 0, 1 (n×1) shows the location of active dampers at freedom degrees of structure (if damper is installed on a stated freedom degree, corresponding element will be 1, otherwise, it is 0).

In the case that backward–forward system is used to control structure, in which linear function control force is in terms of location change vector, velocity (measured responses of the structure) and input stimulation, we have :

$$f(t) = C_1\dot{X}(t) + K_1X(t) - M_1\{1\}_{N\times 1}\ddot{X}_g(t) \tag{2}$$

Where C_1, K_1, M_1 are the matrices of corresponding control.

By substituting corresponding control force to equation 1, we have:

$$M_S\ddot{X} + (C_S - \Lambda C_1)\dot{X} + (K_S - \Lambda K_1)X = -(M_S + M_1)\{1\}_{N\times 1}\ddot{X}_g(t) \tag{3}$$

Comparing equations 1 and 3 shows the influence of forward control is modification of mechanical specifications of the structure (stiffness and damping) in order to improve its seismic performance. In addition, choosing control matrices C_1,K_1, M_1 depends on the type of selected control algorithm.

b) Modified Bouc–wen dynamic model

This model consists of a viscous damper tied with original Bouc-wen model in series and a spring which works in parallel with the whole system [12].

Produced force by damper in modified Bouc-wen model is described as follows:

$$F = \alpha z + C_o(\dot{x} - \dot{y}) + K_0(x - y) + K_1(x - x_0) = C_1\dot{y} + K_1(x - x_0) \tag{4}$$

Where z is an evolutionary variable that accounts for the history dependence of the response. The evolutionary variables z and y are governed by:

$$\dot{z} = -\gamma|\dot{x} - \dot{y}|z|z|^{n-1} - \beta(\dot{x} - \dot{y})|z|^n + A(\dot{x} - \dot{y}) \tag{5}$$

$$\dot{Y} = \frac{1}{C_0 + C_1}\{\alpha z + C_0\dot{x} + k_o\ (x - y)\} \tag{6}$$

In which K_1=accumulator stiffness; C_o=viscous damping at large velocities; C_1=viscous damping for force roll off at low velocities; K_0=stiffness at large velocities; x =relative displacement of one end of the

MR damper; $\dot{x}$=the piston velocity, y=internal displacement of the MR damper, and x_0=initial displacement of spring K_1.

To determine a model which is valid under fluctuating input voltage, the functional dependence of the parameters on the input voltage must be determined. Since the fluid yield stress is dependent on input voltage, α can be assumed as a function of the input voltage v. Moreover, as determined from the experiment results, C_o, and c1 are also functions of the input voltage.

γ, β , and A are the parameters that control the shape of the hysteresis loops in Bouc-Wen yielding element. Finally, α and n are other parameters that refer to the internal state z and determine its coupling with the force f and its evolution.

To specify a model dependent on volatile magnetic field, relation of damper parameters with exerted voltage should be determined. Since MR fluid yielding resistance changes directly with intensity of magnetic field, parameter α in Eqs. (7) to (9) is regarded as a function of an exerted voltage.

Changes in obedience tension depend on linear input voltage and have initial value of non-zero at voltage 0. This non-zero value is related with additive matter to MR fluid in order to sustain its sedimentary endurance. In addition, fixed damping coefficients change with exerted voltages in a linear manner. Therefore parameters, C_0, C_1 should be considered as functions of input current into the damper. The relationship between MR dampers input current and input voltage using these coefficients is defined as follows [13]:

$$\alpha = \alpha(u) = \alpha_a + \alpha_b u \tag{7}$$

$$C_1 = C_1(u) = C_{1a} + C_{1b} u \tag{8}$$

$$C_0 = C_0(u) = C_{0a} + C_{0b} \tag{9}$$

In these equations, value of u is calculated from the following differential equation, where V is input voltage to MR damper:

$$\dot{u} = -\eta(u - V) \tag{10}$$

The above Eq is necessary to model the dynamics involved in reaching rheological equilibrium and in driving the electromagnet in the MR damper.

Other parameters (η, n، A، y، β، α_b ، α_α، x_0، k_I، k_o، C_{1b}، $C_{1\alpha}$، C_{0b}، $C_{0\alpha}$) are fixed coefficients that are calculated by adjusting the behavior of MR damper obtained from the laboratory data.

Table 1 provides the optimized parameters for the dynamic model that were determined to best fit the data based on the experimental results of a 20-ton MR damper [5]. In order to obtain the parameters for the 100-ton (i.e., 1000kN) damper considered in this study, the experimental data of the 20-ton damper have been linearly scaled up 5 times in the damper force.

Table 1. Parameters of the dynamic model for MR damper [5]

Parameter	Value	Parameter	Value
$C_{0\alpha}$	110 kN.sec/m	α_α	46.2 kN/m
C_{0b}	114.3 kN.sec/m/V	α_b	41.2 kN/m/V
k_o	0.01 kN/m	γ	164 m^{-2}
$C_{1\alpha}$	8359 kN.sec/m	β	164 m^{-2}
C_{1b}	7482.9 kN.sec/m/V	A	1107.2
k_I	0.485 kN/m	n	2
x_0	0 m	η	100 sec^{-1}

c) Algorithm of clipped optimal control

The most effective algorithm for semi-active control using MR damper is Clipped Optimal control method which was proposed by Dyke (1996). When i^{th} MR damper produces a force equal to desirable optimal force$(f_i = f_{opt})$, exerted voltage remains fixed. If $f_i < f_{opt}$ and both forces are of the same sign, exerted voltage reaches its maximum level, in this case produced force by damper increases to desirable control force. Otherwise, exerted voltage becomes zero. By this algorithm, current with maximum or minimum value becomes clipped. Active control algorithms (Linear Optimal Control) can be used to determine optimal control force [14]. Algorithm for proposed signal selection is defined by the following relation [9]:

$$V_i = V_{max} H(\{f_{opt} - f_i\} f_i) \tag{11}$$

3. NUMERICAL MODEL

To confirm the correctness of the calculations, a 5-story building was used and then two models of 9 and 20-story structures were studied. The reason for choosing these 2 structures was that they are used as reference structures for SAC, and therefore provide the ability to compare other results.

a) Verification of proposed algorithm and developed program in Simulink software

Control algorithm function was evaluated by numerical example, as shown in Fig. 1. The above model is a 5-story steel frame which was made in Technology University of Sydney. MR damper was installed between the ground and the first floor.

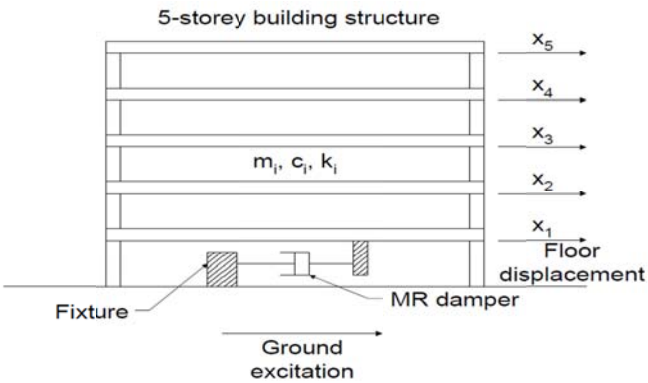


Fig 1. 5-Story steel frame model made in Technology University of Sydney [15]

Mass, Stiffness and damping matrices with fixed amounts were used in this section to examine the correctness of written programs. Mass, Stiffness and damping matrices are [15]:

$$M = \begin{bmatrix} 337 & 0 & 0 & 0 & 0 \\ 0 & 330 & 0 & 0 & 0 \\ 0 & 0 & 330 & 0 & 0 \\ 0 & 0 & 0 & 330 & 0 \\ 0 & 0 & 0 & 0 & 370 \end{bmatrix} \text{kg} \tag{12}$$

$$K = \begin{bmatrix} 3766 & -2869 & 467 & -234 & 27 \\ -2869 & 5149 & -2959 & 446 & -70 \\ 467 & -2956 & 5133 & -2836 & 280 \\ -124 & 446 & -2836 & 4763 & -2277 \\ 274 & -70 & 283 & -2277 & 2052 \end{bmatrix} \frac{\text{kN}}{\text{m}} \tag{13}$$

$$\mathrm{C} = \begin{bmatrix} 225 & -157 & 26 & -7 & 2 \\ -157 & 300 & -126 & 25 & -4 \\ 26 & -126 & 299 & -156 & 16 \\ -7 & 25 & -156 & 279 & -125 \\ 2 & -4 & 16 & -125 & 125 \end{bmatrix} \frac{\mathrm{Ns}}{\mathrm{m}} \tag{14}$$

Normal structure fundamental frequency is 2.5 Hz and during an examination, the sample structure was under excitations due to the Northridge earthquake. The results of previous studies [15] and those of this paper are compared in Table 2. The related results of peak lateral drift of structure in two controlled and uncontrolled conditions (by clipped optimal control algorithm) for the first and fifth floors are shown in Fig. 2.

Table 2. The results of previous study [15] and comparison to those of this paper

Story No. / Maximum displacement	Previous study		This Study	
	Uncontrolled(mm)	Controlled(mm)	Uncontrolled(mm)	Controlled(mm)
1	9	8	9	6.7
2	13	10	12.5	9.3
3	15	11	14.7	11
4	16	12	16	12
5	16	12	16	12

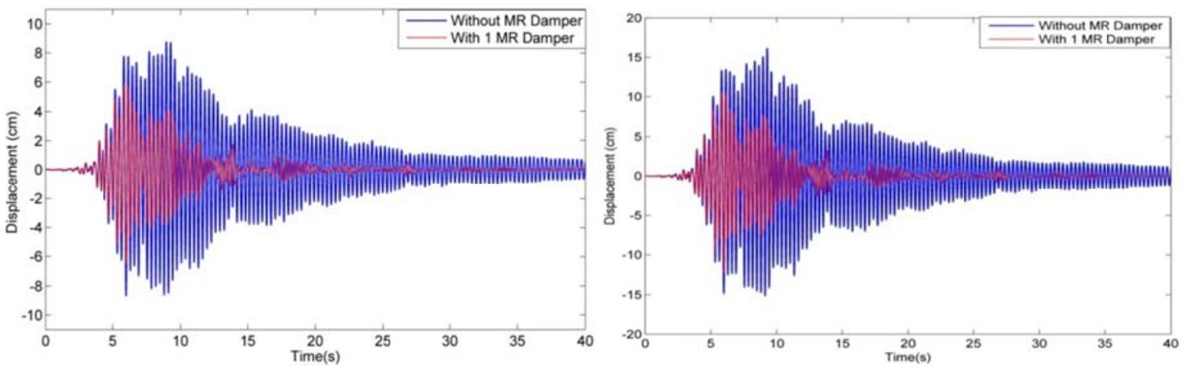


Fig. 2. Floor lateral displacement, 1st and 5th floors of 5-story steel frame model

As presented in Table 2, the peak displacement results of this study are in good agreement with those obtained by previous research [15]. So, it can be concluded that the proposed algorithm and developed program in this study work well.

b) 9-Story Model

9-story building has length and width equal to 45.73 m with height of 37.19 m. Length of its spans in both directions is 9.15 m. The number of spans in north-south and east-west directions is 5. Columns of moment frame are of the wide–flange type [16]. The structure model is shown in Fig. 3.

c) 20-Story Model

20-story building has length and width equal to 30.48 and 36.58 m respectively with the height of 80.77m. Lengths of its spans in both directions are 6.1 m, and the number of spans in north-south and east-west directions is 5 and 6 respectively [16]. The structure model is shown in Fig. 4.

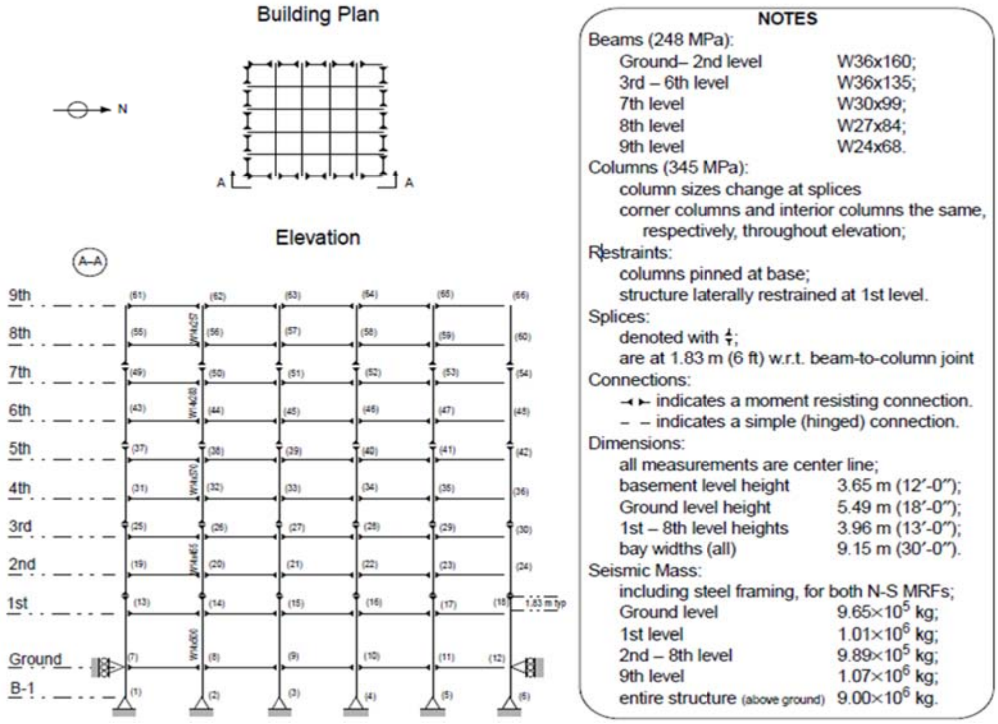


Fig 3. 9-Story Benchmark Building N-S MRF [16]

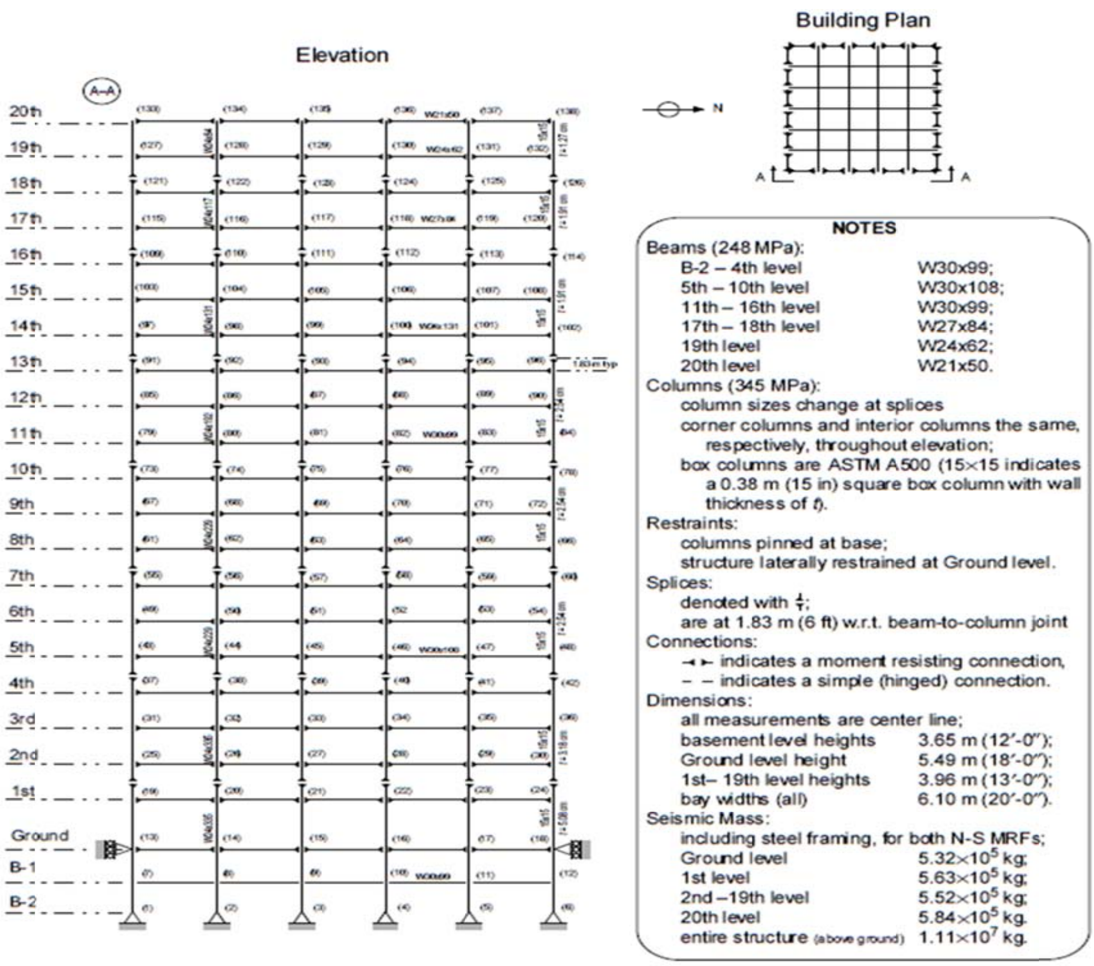


Fig 4. 20-Story Benchmark Building N-S MRF [16]

4. STRUCTURAL NUMERICAL MODEL AND INTRODUCING SEISMIC STIMULATIONS

For modeling structures in each story, a model with one degree of freedom mass-spring-damper is used. By using dynamic equations written by Matlab [17], matrices of mass, stiffness and damping for 9 and 20-story structures (which are matrices with dimensions of 9 and 20) are obtained.

Simulink software [18] (in Matlab environment) was used to examine the effect of MR damper on these structures. Equations of this paper in sections (2-1) and (2-3) were modeled in Simulink as shown in Fig. 5, where the input is ground acceleration and the outputs are drift and absolute acceleration of structure.

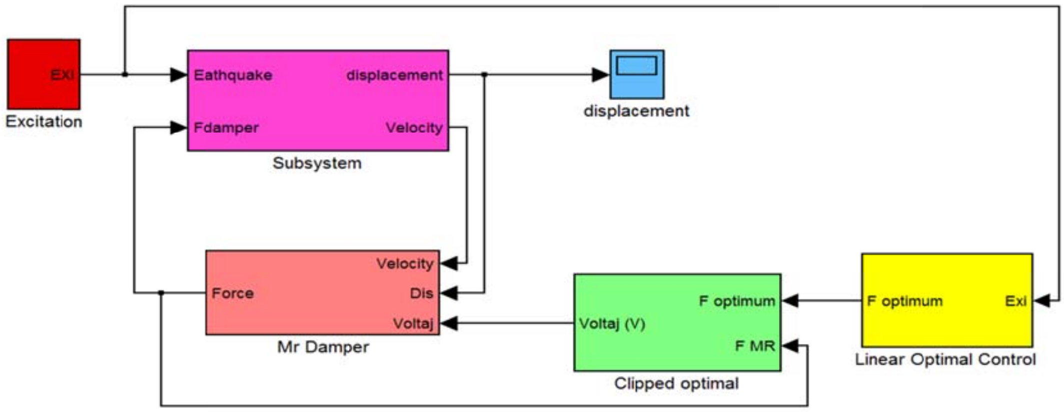


Fig. 5. Schematic view of Simulink model

For modeling MR damper, Modified Bouc–wen dynamic model was used. Equations (4) to (8) were modeled in Simulink as shown in Fig. 6, where the inputs are voltage (output from clipped optimal algorithm), displacement and velocity, and the output is force of MR damper.

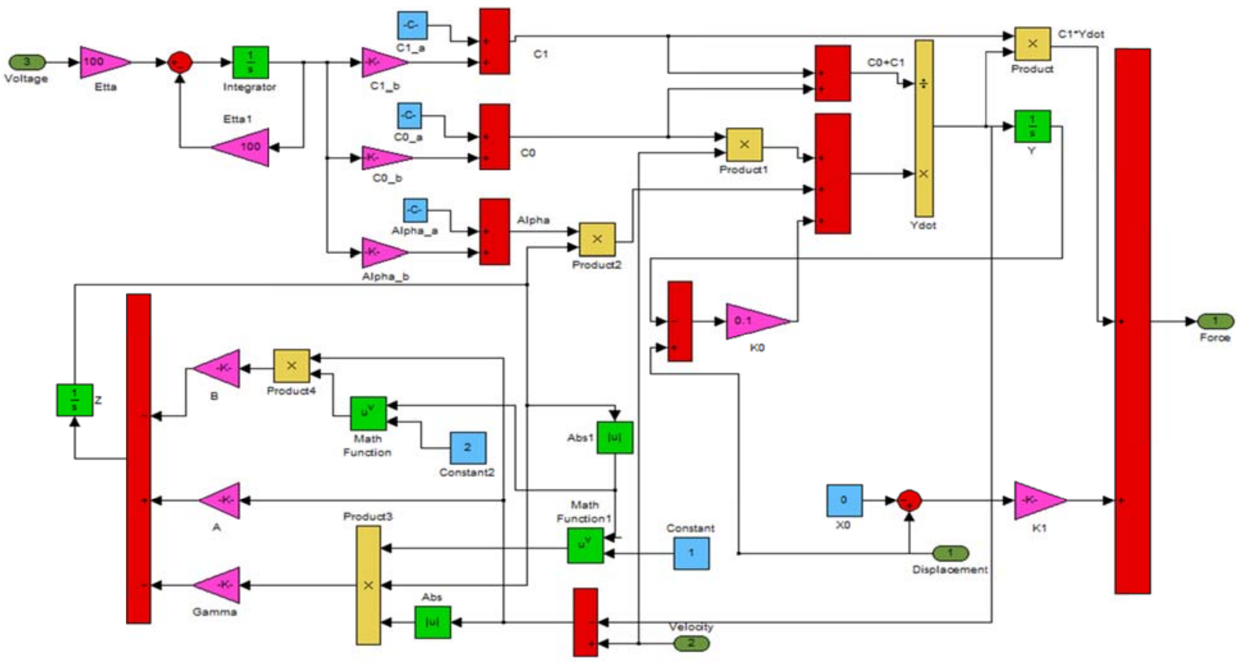


Fig. 6. Schematic view of code written in Simulink for used MR damper

This paper uses two records of well-known earthquakes (the Kobe and Northridge earthquakes) as input seismic excitations imposed to structure. UBC 97 code instructions were used to determine scaling.

Seven appropriate record ground-motion time-history pairs were considered. For each pair of horizontal ground-motion components, the square root of the sum of the squared (SRSS) data of the 5%-damped site-specific spectrum of the scaled horizontal components were constructed. The motions were scaled such that the average value of the SRSS spectra does not fall below 1.4 times the 5%-damped spectrum of the design-basis earthquake for periods from 0.2T second to 1.5T seconds. The average value of the response parameter of interest was used for design.

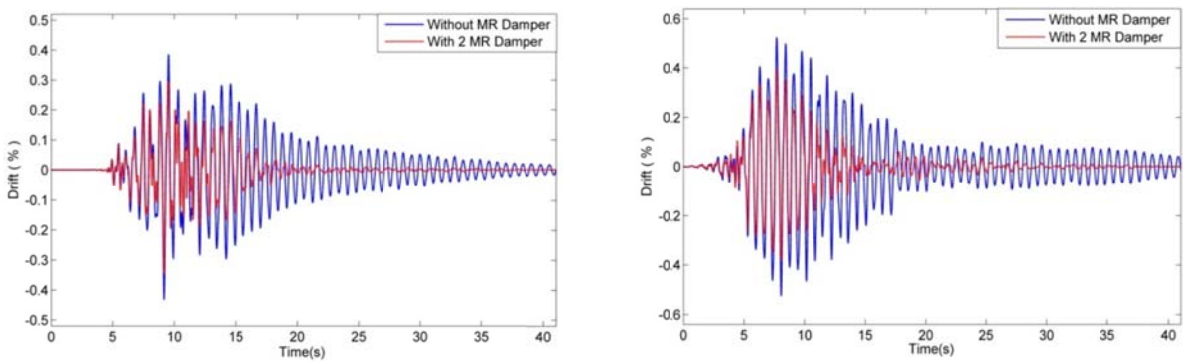
Note that since MR dampers used in this study are of the 100-ton damper type, with respect to mass and size of structures implemented in them, different numbers of MR dampers were used: in 9-story building, two MR dampers were used in the first and fifth floors and in the 20-story building, three MR dampers were used in the first, 10^{th} and 15^{th} floors.

5. NUMERICAL RESULTS

a) Comparing drift responses

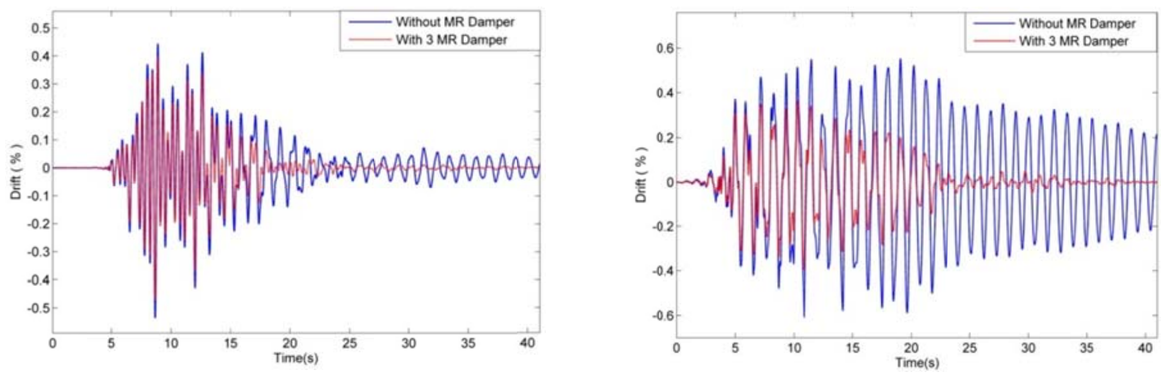
In this section, from maximum drift perspective, performance of controlled structure in reducing response is compared against that of uncontrolled structure.

One of the most important required parameters to control structures is amount of structure maximum drift. Drift of the structure should be in code allowed range so that it can provide stability for the structure and comfort for the residents. As shown for instance, in Figs. 7 and 8, reflection of controlled structure by MR damper can be about 12% to 36% effective in reducing structural horizontal maximum drift. This amount of reduction is different in structural response regarding charts presented for different structures as well as under various earthquakes.



(a) (b)

Fig. 7. Drift response of 9-story structure under a: the Kobe and b: the Northridge earthquake



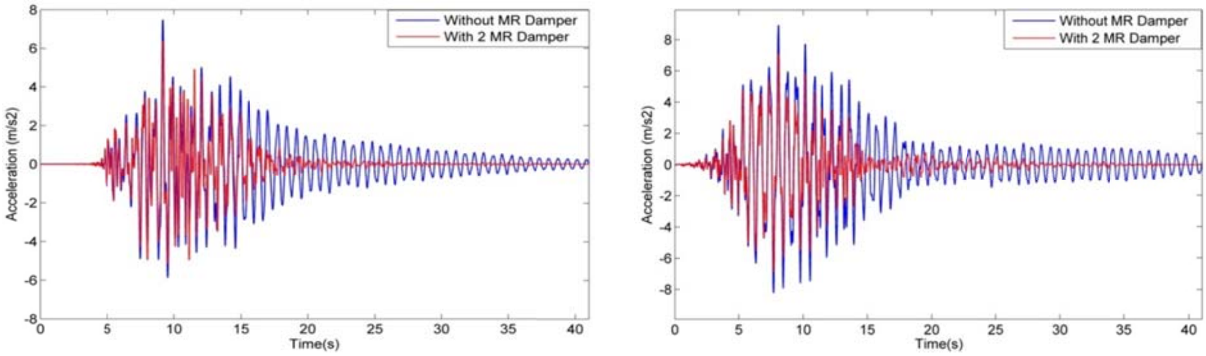
(a) (b)

Fig. 8. Drift response of 20-story structure under a) the Kobe and b) the Northridge earthquake

b) Comparing absolute acceleration responses

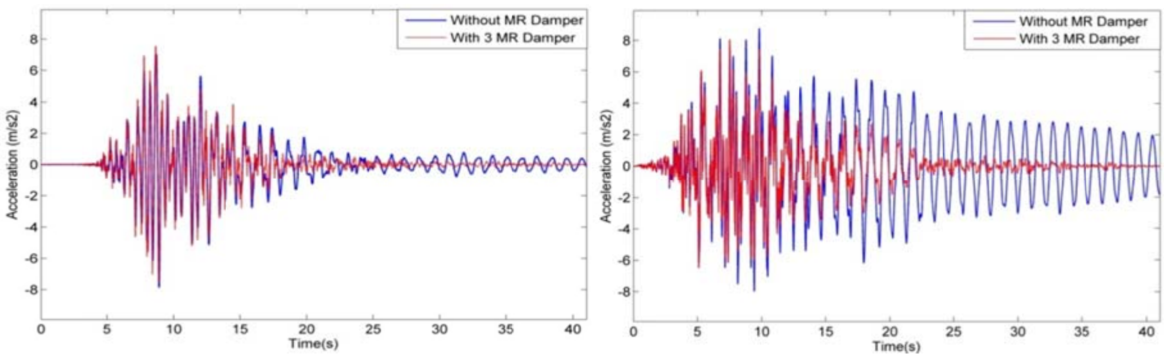
The other required parameter to control structures is amount of structural absolute maximum acceleration. In this section, performance of controlled structure in reducing acceleration response is compared against uncontrolled one.

As shown in Figs. 9 and 10, response of controlled structure by MR damper is less than that of uncontrolled one. This amount of reduction is different in structural response regarding charts presented for different structures as well as under various earthquakes, such that MR damper can be about 0% to 21% effective in reducing maximum structural acceleration.



(a) (b)

Fig. 9. Acceleration response of 9-story structure under a) the Kobe and b) the Northridge earthquake



(a) (b)

Fig. 10. Acceleration response of 20-story structure under a) the Kobe and b) the Northridge earthquake

Since the response by upper floors is greater than lower ones, after testing all floors, acceleration response by the highest floor of each of the 9 and 20-story structures is regarded as maximum acceleration response of the buildings.

c) Comparing RMS structure displacement and absolute acceleration response

To examine performance of a damper during earthquake excitations, a criterion other than structure maximum response is generally used. Since maximum response happens just in an instant, examining effect of MR damper (merely from amount of its effect in reducing maximum response perspective) is not enough to conclude about its performance, particularly in terms of low-cycle fatigue. Therefore, it is proposed that RMS (Root of Mean Squared) of structure response during time of analysis is examined. Equation (15) shows how to calculate the RMS.

$$\mathrm{Y_{RMS}} = \sqrt{\frac{\sum_{i=1}^{n} y_i^2}{n}} \tag{15}$$

It is worth mentioning that Y_i represents structure response including location change, acceleration or cross section of floors in time t_i and n shows number of time steps in which structure response in that scope is quantified. This criterion is used as an index to evaluate response improvement. In different structures, amount of reduction percentage of RMS is compared to the case without control. By increasing this percentage, MR damper will have a more desirable effect in reducing structure response. As shown in Figs. 11 to 14, displacement and absolute acceleration response RMS in controlled structure by MR damper are less than that of uncontrolled one. In Table 3 related diagrams as proposed in previous sections are quantitatively compared.

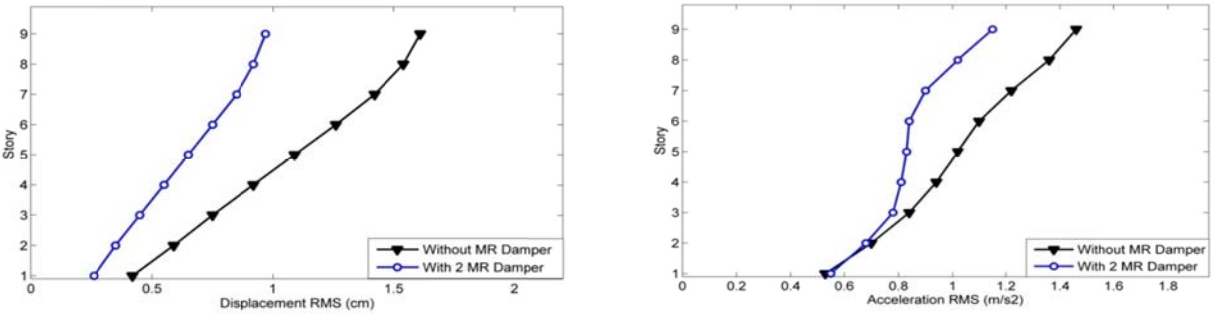


Fig. 11. Comparing RMS of displacement and absolute acceleration response in 9-story structure under the Kobe earthquake

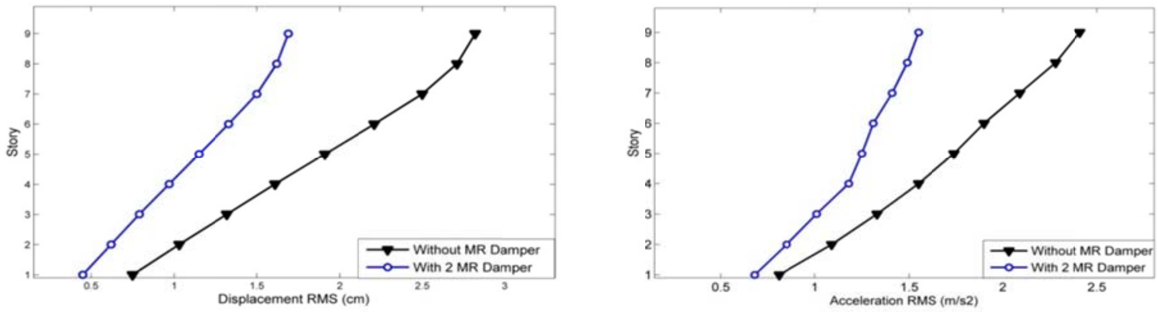


Fig. 12. Comparing RMS of displacement and absolute acceleration response in 9-story structure under the Northridge earthquake

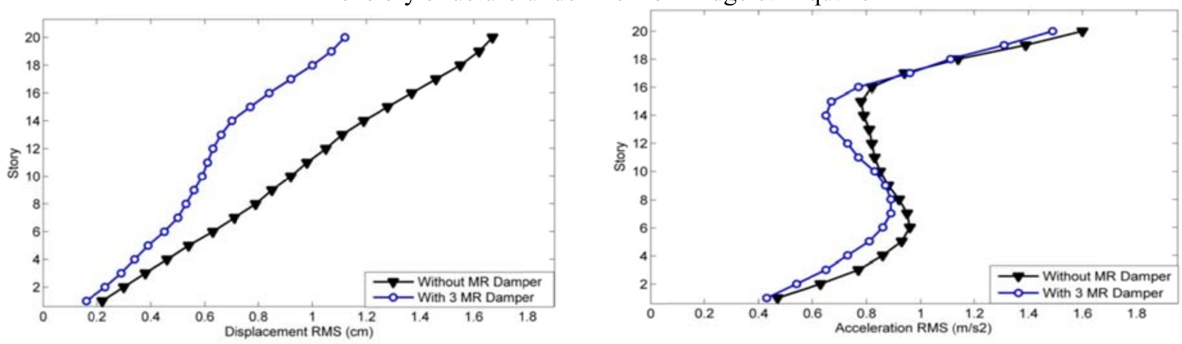


Figure 13: Comparing RMS of displacement and absolute acceleration response in 20-story structure under the Kobe earthquake

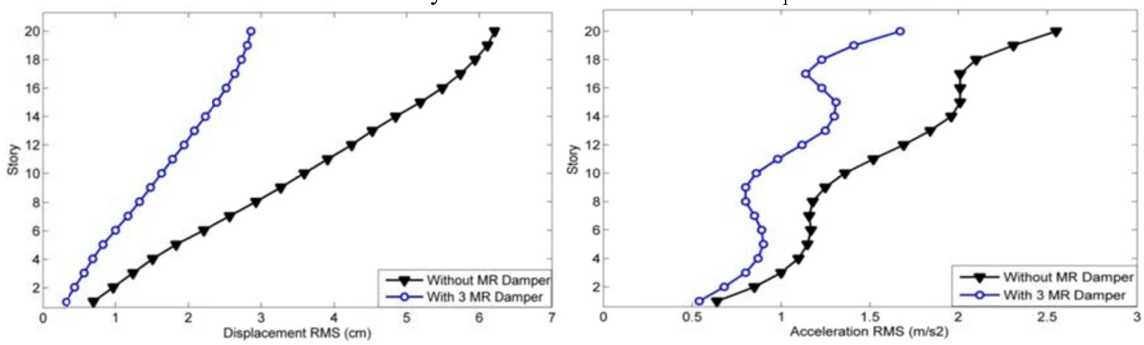


Fig. 14. Comparing RMS of displacement and absolute acceleration response in 20-story structure under the Northridge earthquake

Table 3. The responses reduction for the controlled models subjected to the Kobe and Northridge earthquakes

Number of Story / Percent of reduction	Kobe		Northridge	
	Drift	Absolute acceleration	Drift	Absolute acceleration
9	21%	15%	27%	21%
20	12%	1%	36%	9%

d) Hysteretic curves

Dampers by producing hysteretic curves generally dissipate input energy to the structure. By equation introduced for MR damper, it is specified that the amount of energy dissipated by this damper depends on velocity and displacement of MR damper. Therefore, two kinds of hysteretic cycles can be considered, in one of which, damper force is a function of relative velocity of its ends and in another one, damper force is specified by displacement of MR damper ends.

The sum of these areas is equal to the value of energy dissipation through the proposed damping system. Figures 15 and 16 show hysteretic curves for such seismic excitation. It is shown in these figures that imposed cycles pace a suitable path and dissipate noticeable energy of earthquake and greatly reduce the share of structural elements in energy absorption.

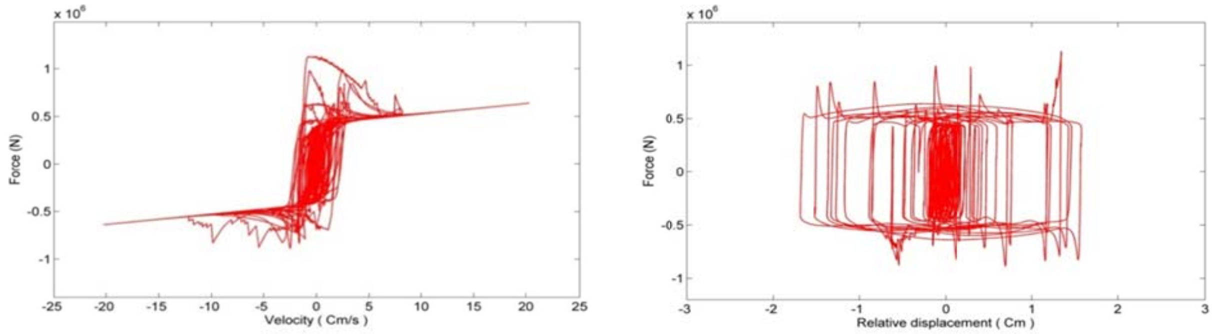


Fig. 15. Hysteretic curves of 9-story structure under the Northridge earthquake

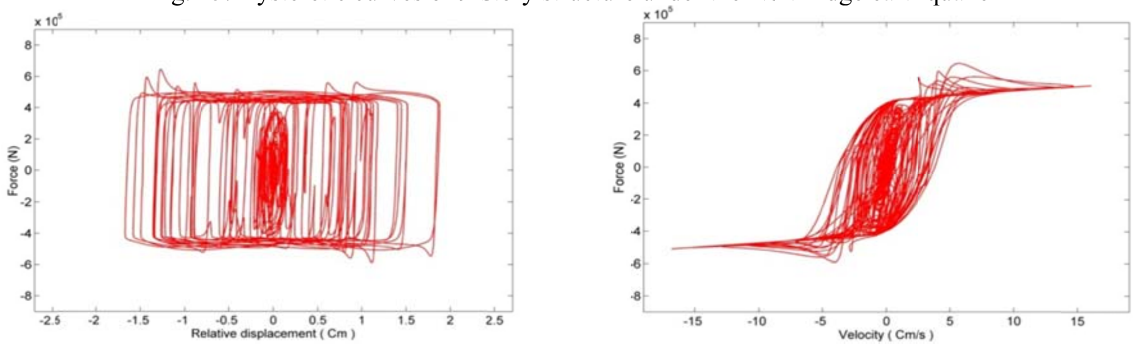


Fig. 16. Hysteretic curves of 20-story structure under the Northridge earthquake

e) Proposed mechanism for better efficiency of MR damper

It is obvious from the obtained results that for successful function of MR damper, the damper should be connected between two points that have noticeable displacement. Therefore, two mechanisms for improving the function of these kinds of dampers are offered and at the end, a combination of them is used and comparison between results of using new methods and using dampers in normal condition is conducted.

The first offered solution is that, for high and mid-rise structures, instead of installing dampers between adjacent stories, one can install them between two or more stories not necessarily adjacent. Therefore, more relative displacement can be found between those stories and two ends of MR damper.

Another solution is to use lever mechanism at the junction point of braces to the column such that, by installing a lever as shown in Fig. 17, two velocity and relative displacement in two sides of damper's piston would be increased.

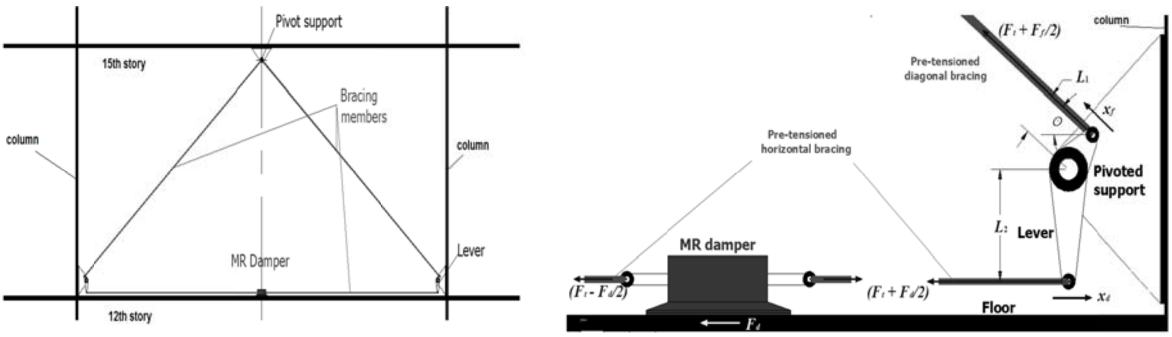


Fig. 17. MR damper between floor and lever mechanism connection [10]

Finally, to combine the two advantages mentioned above, both can be used for sample structure. To conduct the first method in the 9-story structure, instead of installing damper on the first and fifth floors, a damper was used in first floor and another one between the second and fifth floors. Also, for the 20-story structure, instead of installing damper in the first, 10th and 15th floors, first damper was used in the fifth floor, the second damper between the 7th and 10th floors and another one between the 12th and 15th floors (Fig. 18).

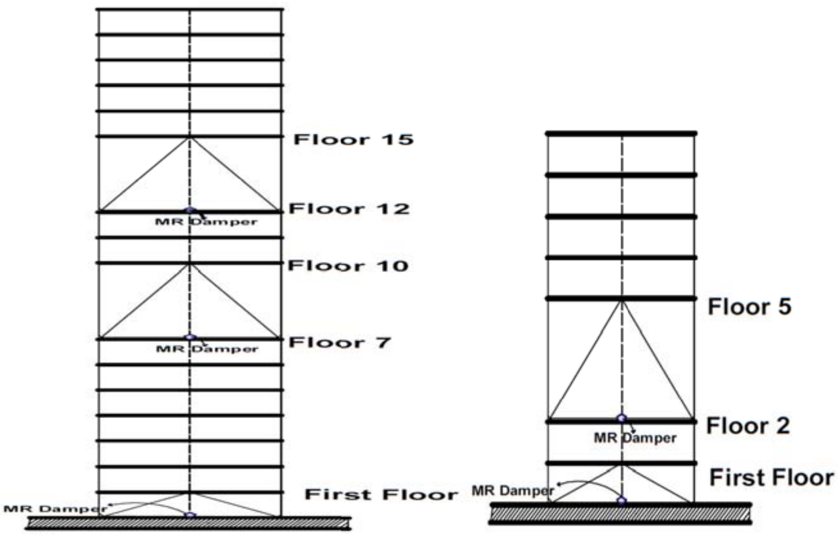
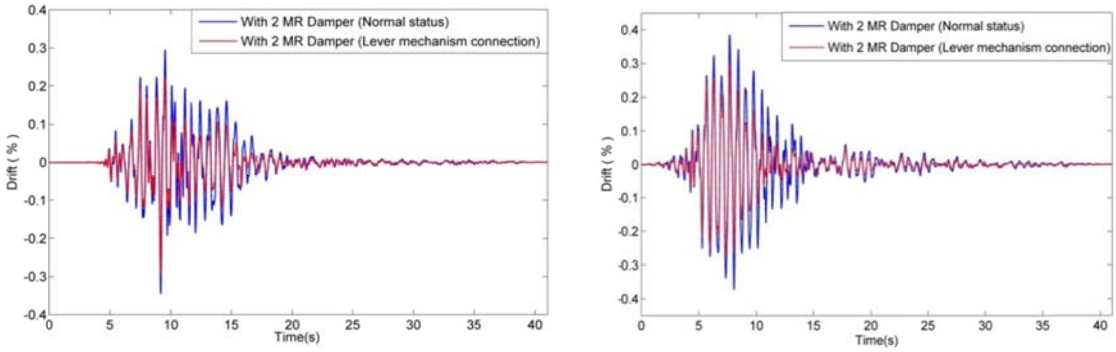


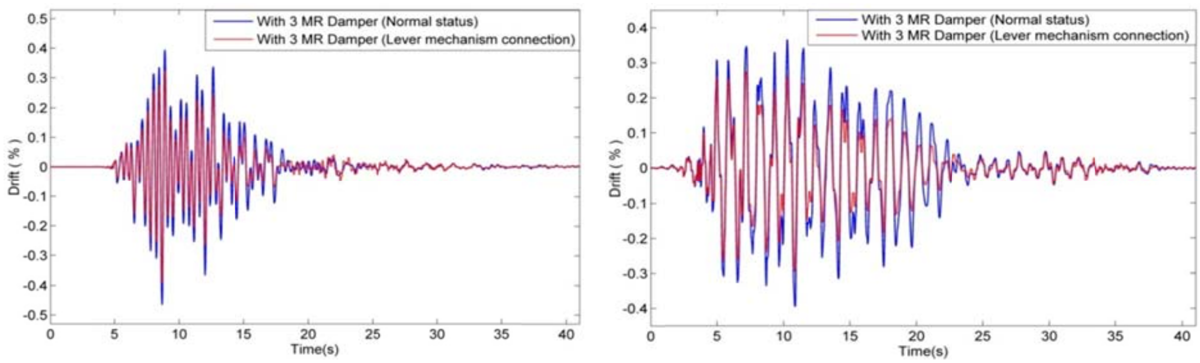
Fig. 18. Suggested positions for dampers placement

Similarly, for conducting the second method, the same mechanism was used in which feedback relative displacement and relative velocity were increased five and three times for 9 and 20-story structures, respectively. As shown, for instance in Figs. 19 to 22, response of controlled structure by MR damper in the case of lever mechanism connection can be effective in maximum drift and acceleration. In Table 4, the diagrams proposed in this section are quantitatively compared. Results obtained from these Tables showed that using MR damper with lever mechanism can reduce drift and absolute acceleration.



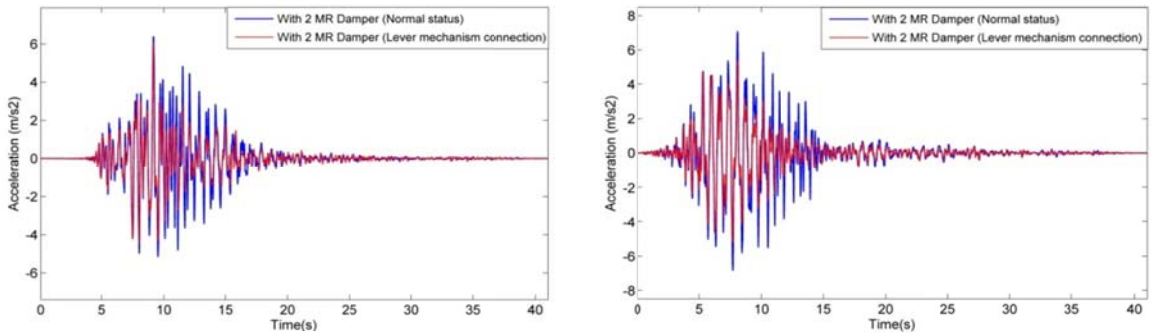
(a) (b)

Fig. 19. Drift response of 9-story structure under a) the Kobe and b) the Northridge earthquake



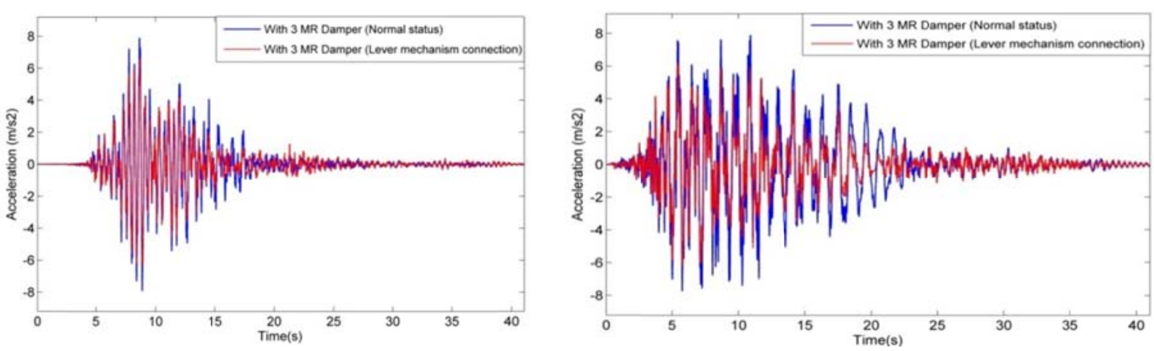
(a) (b)

Fig. 20. Drift response of 20-story structure under a) the Kobe and b) the Northridge earthquake



(a) (b)

Fig. 21. Acceleration response of 9-story structure under a) the Kobe and b) the Northridge earthquake



(a) (b)

Fig. 22. Acceleration response of 20-story structure under a) the Kobe and b) the Northridge earthquake

Table 4. The response reduction for the controlled models with lever mechanism subjected to the Kobe and Northridge earthquakes

Number of story / Percent of reduction	Kobe		Northridge	
	Drift	Absolute acceleration	Drift	Absolute acceleration
9 (With 2 Dampers)	15%	6%	24%	23%
20 (With 3 Dampers)	19%	12%	26%	22%

6. CONCLUSION

In this paper, two models of 9 and 20-story buildings were first selected as case studies and then sample structures, optimum force determination process, control system and MR damper were simulated in a Simulink environment. In semi-active control case, clipped optimal algorithm was considered as control algorithm and optimal classic linear control method was used to determine control power.

1. With respect to the results obtained in this study, it is found that using MR damper is extremely effective in structural seismic response control. In maximum drift reduction perspective, the damper can be effective to reduce peak lateral drift about 12% to 36 %. For the above amounts the maximum reduction is for the Northridge earthquake with 36% and the least amount is related to the Kobe earthquake with 12% in the 20-story structure.
2. In maximum absolute acceleration reduction perspective, the damper can be effective in reducing structural peak acceleration 1- 21%. The maximum reduction is related to the 9-story structure with 21% and the least amount is related to the 20-story structure subjected to the Kobe, earthquakes while the peak accelerations in controlled and uncontrolled state are equal.
3. RMS displacement and absolute acceleration were reduced 33-71 % and 7-58%, respectively.
4. When moving MR dampers to the upper floors, they have better contribution to relative displacement reduction. It is due to the fact that displacement and velocity are assumed as main input values and by increasing these amounts, better performance for damper would appear.
5. In structures with high number of floors, drift can be desirably decreased by increasing the number of dampers.

Two mechanisms are eventually offered to improve the function of dampers and their performance. Lever mechanism improved MR damper function 15-26% and 6-23%, respectively in maximum drift and absolute acceleration reduction perspectives, compared to normal condition.

The results of this limited investigation, therefore, indicate that the two proposed mechanisms for MR dampers can not only be effectively used to seismically control mid-rise structures, but also to reduce the required number of dampers.

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