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Momentary Optimization of the Performance of High-Rise Metal Structures, Equipped with MR Damper using Artificial Intelligence

Amin Radinmehr[1] | Seyed Ali Razavian Amraiee[2]

[1]M.A., Student of Civil Engineering, Faculty of Civil Engineering, North Tehran Branch, Payame Noor University, Tehran, Iran
[2]PhD, Faculty Member of Civil Engineering Department, Payame Noor University, Tehran, Iran

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ABSTRACT

Dampers are the most usable tool for passive control of structures that are used to reduce the response of structures to seismic excitation. In this regard, extensive parametric studies have been carried out to investigate the performance of this type of dampers in reducing the seismic response of structures under the influence of different types of ground motion and soil type. The aim of determining proper level for changing the type of bracing on the height of the structure is to improve the seismic performance of high-rise structures. Therefore, in this study, the momentary optimization of the performance of high-rise metal structures equipped with MR dampers was investigated using artificial intelligence and the results showed that the accuracy of simulations in Opensees software is higher than that of Matlab software in each case. Also, as far as the amount of displacement is greater in a record, the maximum acceleration of the structure is greater in those displacements.

KEYWORDS: *MR Dampers, Metal Structures, Artificial Intelligence*

I. INTRODUCTION

From the beginning of creation, man has always faced natural disasters. Among the natural disasters, it is safe to say that the earthquake is considered to be the greatest threat to man of the present century. One of the main objectives of structural engineering is the optimization of structures from different structural, applied and economics aspects. There are various methods for optimizing structures. One of the most important methods is artificial intelligence (Salehi and Zahraei, 2012). With the advancement of technology, new needs and demands had emerged in the field of engineering of metal structures. The time factor has become more important in the construction of metal structures and this has led to a tendency towards the prefabricated metal structures. Also, with the increase of the population of human societies, the interest in having large spaces without pillars in the middle has become much sought. In this regard, from the beginning of this century, a number of experts have been attracted to the unique capabilities of space structures and have found the responses of many new needs in these structures and have achieved very positive results. Space structures are made in a variety of forms, the most important of which are flat single or multi-layer grids, barrels, domes and arches. In addition, space structures have a variety of texture. Thus, by changing the arrangement of the elements, a new texture can be created, and it is clear that the effectiveness of each texture should be measured in comparison with other textures. There are several examples of space structures made in the world and Iran including sports stadiums, cultural centers, community halls, shopping centers, train stations, aircraft nests, recreational centers, radio towers and etc. (Kim, 2008).

Different methods have been used to retrofit existing buildings, including increasing the side hardness by adding metal braces. Several analytical and laboratory studies have been carried out on reinforcing concrete frames with metal brace. Nevertheless, less attention has been paid to the analytical review of this method in high reinforced concrete structures based on performance (Ghodrati Amiri et al., 2009). In terms of engineering, a structure can be called high, when its height makes the lateral forces, caused by wind and earthquakes, dramatically affect its design. Also in spite of gravity forces, the impact of lateral forces on structures is quite changeable and increases rapidly with increasing height. The three basic factors which should be considered in designing all tall structures are strength, rigidity, stability. In the design of tall structures, structural systems should be tailored to these needs. The need for resistance is the dominant factor in the design of short structures, but rigidity and stability becomes more important with increasing height. Therefore, in a tall structure, the resistant system to lateral and vertical loads will vary according to the height of the structure and type of use as well as the nature and type of forces (Rezaei Namdar et al., 2010).

One of the most important issues in structural engineering is confronting to lateral loads (such as earthquakes, winds, etc.). In recent years, many efforts have been made to increase the lateral strength of the building during designing and seismic reconstruction phase. Structural control is one of the mentioned issues. In the semi-active control method, the force that semi-active control equipment produces is a resisting force and, make changes in the energy dissipating system of structure with a small amount of energy (for example, as a battery for MR dampers), to absorb a part of the energy generated by earthquake loading to energy dissipating system. The semi-active control method is rapidly developing due to its high flexibility and efficiency and the need for less energy resources. One of the most-used tools for semi-active control are the MR dampers that consist of piston, cylinder filled with MR fluid, coil and accumulator (Fayezi and Muharrami, 2014). Also, MR dampers are very much considered in controlling structures due to the mechanical simplicity, the high performance range and the lack of need to powerful external energy sources.

Therefore, selecting a reliable and fast controller will maximize the power of this damper. It is obvious that in the use of the neural network (artificial intelligence), there is no limit in the use of design profiles, and non-standard sections such as compound sections can be used without the need for re-analysis (Mehri and Safari, 2009)

In this regard, the purpose of the present study is to answer whether the use of artificial intelligence is effective in momentary optimizing the performance of high-rise metal structures equipped with MR dampers.

II. Materials and Methods

2.1 Modeling and Optimizing Magnetic Fluids of Damper

Different types of neural networks and neuro-fuzzy methods with different architectures are provided by the researchers to adjust the parameters model for numerical expression of the inverse model of damper. In this paper, first, the new objective function (j) has been suggested that includes the criteria related to the reduction of relative lateral displacement, absolute acceleration and energy absorbed by structural members of floors, as well as the reduction of applied voltage to the dampers. Then, in order to accurately and directly calculate the force generated by the MR, the equations related to the motion behavior of the damper are considered to be involved in the structure and the optimal control method has been used to calculate optimal voltages (Fayezi and Muharrami, 2014).

In this method, the values of optimal voltages were obtained numerically for each specific earthquake. Finally, using numerical responses obtained from optimal control, several parallel-ANFIS neural networks have been trained as an integrated controller that has the optimal control process and the inverse model of dampers. Magnetorheological Damper controlled dampers are semi-active control devices that have been very much considered in recent years. . This kind of control instrument over the application of the magnetic field shows a significant change in the flow behavior of the fluid and turns from a fluid with free flow and viscous linear to a solid-like material with controllable resistance; MR dampers are highly considered in controlling structures due to its mechanical simplicity, High performance range and no need for high power external energy sources. In this thesis, the bookvan model is used to simulate dynamic behavior of the damper. The performance of MR dampers has been evaluated in all-scale structures of 3 and 20 nonlinear benchmark classes under the influence of different stimuli. In this study, a fuzzy-genetic control algorithm has been used to control the dampers. The multi-objective optimization that has been used is a genetic algorithm with fast successful ordering. In order to evaluate the usefulness of the control system, its performance is compared with other control algorithms.

2.1.1 Equations of the structure's motion equipped with MR dampers

The motion equation of a structural system under the stimulation of earthquake acceleration is as follows:

$$K_S v + C_S \dot{v} + M_S \ddot{v} = -M_S\{1\}\ddot{v}_g$$

Where Ks, Cs and Ms are the stiffness matrix, damping and total mass of the structure respectively nd nd ü also are the vector of displacement, velocity and acceleration of system freedom degrees than to the ground (üg) ground acceleration and {1} is a vector with values of 1. The damping matrix is also obtained as follows:

$$C_S = M_S \left(\sum_{i=1}^{n} \frac{2\xi\omega}{\varphi_i^T M_S \varphi_i} \varphi_i \varphi_i^T \right) M_S$$

Where ξi is the damping coefficient, wi 2 nd φi are the value and special vector of the matrix Ms - 1 Ks in the oscillation mode ith and n, the number of system freedom degrees, respectively. To analyze the structure controlled by the damper, the equation of structure motion and the equations of the damper dynamics must be solved simultaneously:

$$K_S v + C_S \dot{V} + M_S \ddot{V} + D f_d = -M_S\{1\}\ddot{V}_g$$

$$f_{sj} = (c_{0aj} + c_{0bj}u_j)\dot{x}_j + (\alpha_{aj} + \alpha_{bj}u_j)z_j \quad , \quad j = 1 \sim m$$

$$\dot{z}_j = -y_j|\dot{x}_j|z_j|z_j|^{N_j - 1} - \beta_j \dot{x}_j |z_j|^{N_j} + A_j \dot{x}_j$$

$$\dot{u}_j = -\eta_j (u_j - v_j)$$

Where fd is the damper forces vector, D is the effect of the number and position of the dampers, the relative velocity vector of the two ends of the dampers, k is the storey number in which the jth damper is located, m is the number of stories in which the damper is located, the subscript j related to j damper and E is defined as follows:

$$E = \begin{cases} E_{i,i} = 1, i = 1 \square n \\ E_{i,i-1} = 1, i = 2 \square n \\ E_{i,j} = 0, i, j = 1 \square n, j \neq i, i-1 \end{cases}$$

2.2 Data collecting method

The method of collecting data in this research is a library method. In order to collect data on theoretical foundations and literature, books, Iranian and foreign articles of IEEE, Springer and ELSEVIER databases were used.

2.3 Data analysis method and data collecting tool:

In the research process, after data collection, the next step is to analyze the data. One of the important necessities of each study is the availability of reliable data and the speed and ease of access to it. With this information, researchers have the opportunity to follow the study process and data analysis for evaluating the study objects. The researcher will also be able to achieve the desired goals by spending the minimum cost and time. In this research, the AnSys or OpenSees finite element software was used for dynamic modeling and Matlab or NeuroSolutions software for neural network modeling.

III. Results

3.1 Characteristics of the selected accelerogram

In selecting records, the distance from the fault, the type of soil and the time of strong ground motion have been considered. The soil considered in the present study is of type III and the records are from the stations located in the mean distance (20 to 40 km from the epicenter) from the fault. According to standard 2800, the time of strong ground motion in accelerogram should at least equal to10 seconds or three times greater than the original period of the structure. In the selection of earthquake records, the above mentioned criteria have also been observed.

Table 1 Specifications of selected records for Dynamic Time History Analysis

Earthquake	station	Year	Seq
Northern calif	Ferndale city hall	1941	8
San fernando	Pearblossom pump	1971	81
Friuli Italy	barcis	1976	121

The pair of selected acceleration is scaled for the current study in accordance with standard 2800. First, each acceleration pair is scaled up to its maximum value. This means that the maximum acceleration in the component with the largest maximum is equal to g gravity acceleration.

A 20-story building is considered and the height of each story is 3.2 meters. The building has a steel moment frame system along with a damper.

Table 2 Seismic Plot Information of 2800 Earthquake Act (Edition 4)

Soil parameters					Importance coefficient	The height of the structure from the base level	Earthquake acceleration coefficient
Soil type	So	S	Ts	To	I	H	A
II	1	1.5	0.5	0.1	1.2	60	0.3

The acceleration response spectrum of each scaled acceleration pairs was determined with a 5% damping ratio. The response spectra of each acceleration pair are combined using Square Root of the Sum of the Squares (SRSS) method and a single hybrid spectrum for each pair is constructed. Each acceleration pair is scaled in such a way that for every period in the range of 0.2T to 1.5T, the mean value of SRSS spectrum of the whole component pair does not exceed ten percent of 1.3 times of equivalent value of the spectrum of standardized design. The scale factor was then multiplied by scaled accelerations and used in dynamic analysis.

The basic acceleration of the design considered in the present study is 0.3, because the structure under study is tall. The importance coefficient of the structure is considered 1.2, because the structure studied is in the category of tall structures. Table 3 shows the coefficient of the record scales considered in this study for scaling with the 2800 spectrum.

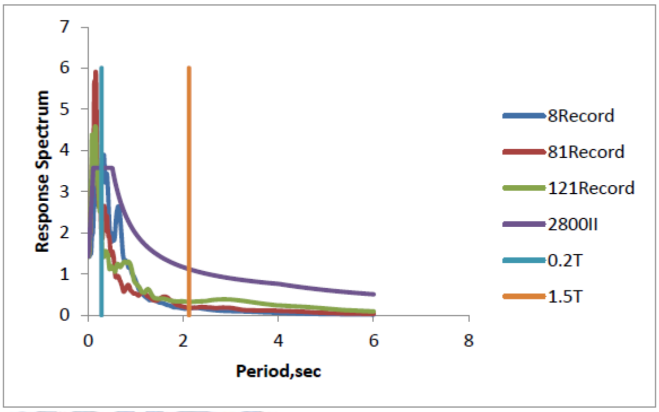

Figure 1. The spectrums of Initial and standard 2800 accelerometer designs

Table 3. The scale coefficient of the records

	Scale coefficient
Northern calif record	2.01
San Fernando record	2.92
Ferioli record	2.66

Figure 3 shows the plan of considered structure. The frame openings are 5 meters.

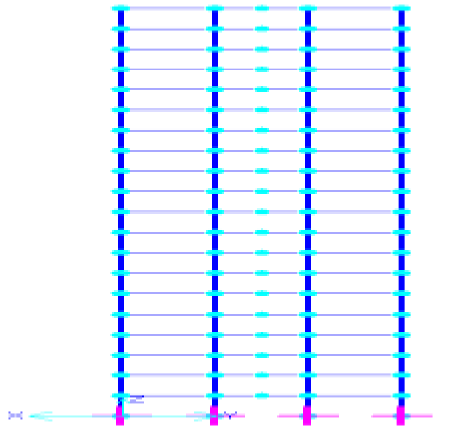

Figure 2. A view of the height of the desired structure

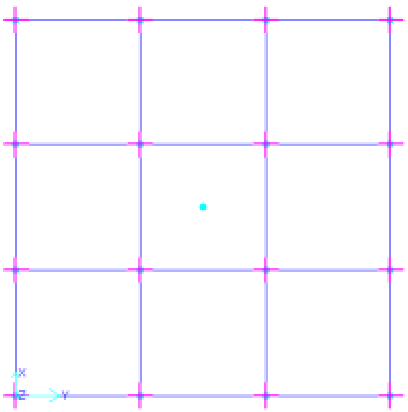

Figure 3. Plan of the desired structure

In this study, the Bouc-Wen model is used for the behavior of the MR damper, as presented by Yi et al, in the form of the following equations.

$$f_{damper} = c_0 \dot{x} + \alpha z \qquad (1A)$$

$$\dot{z} = -\gamma |\dot{x}| z |z|^{N-1} - \beta \dot{x} |z|^{N} + A\dot{x} \qquad (1B)$$

$$c_0 = c_{0a} + c_{0b} u \ , \ \alpha = \alpha_a + \alpha_b u \qquad (1C)$$

$$\dot{u} = -\eta (u - V) \qquad (1D)$$

Where f_{damper} is the force created by the damper, x is the relative velocity of the two ends of the damper, u is the actual voltage and V is the inlet voltage to the damper. Z is a variable of hysterical behavior that actually determines the internal state of the damper and has memory by virtue of equation (1B); in other words, this variable contains precedent status. The required parameters are obtained using the results of the seismic tests on the damper in the lab. Equation (1D) is a "first order" filter, which is used due to the consideration of the dynamics resulting from the presence of resistance and induction in the magnetic circuit of the MR damper, as seen in the figure below. The damper force is proposed in this model as a slippery damper and the Bouc-Wen hysterical behavior that works in parallel.

3.2 Motion equations of structure equipped with MR dampers

The motion equation of a structural system under the earthquake acceleration excitation is as follows:

$$K_S v + C_S \dot{v} + M_S \ddot{v} = -M_S \{1\} \ddot{v}_g$$

Where Cs, Ks, and Ms are the stiffness matrix, damping, and mass of the structure respectively. v, v 'and V'' are the displacement vector, velocity and acceleration of system freedom degrees than the earth, respectively. V'' g is the base acceleration and a vector with value 1. The damping matrix is also obtained as follows

$$C_s = M_s \left(\sum_{i=1}^{n} \frac{2\xi_i \omega_i}{\varphi_i^T M_s \varphi_i} \varphi_i \varphi_i^T \right) M_s$$

Where ξ is the damping coefficient, and are respectively the value and special vector of the matrix in the ith oscillation mode and n is the number of system freedom degrees. To analyze the structure controlled by the damper, it is necessary to solve the motion equation of the structure and the equations of dynamics of the damper simultaneously.

$$k_S v + C_S \dot{V} + M_S \ddot{v} + D f_d = -M_s \{1\} \ddot{v}_g$$

$$f_{dj} = \left(c_{0aj} + c_{obj} u_j\right) \dot{x}_j + \left(\alpha_{aj} + \alpha_{bj} u_j\right) z_j \qquad , \text{ j=1}$$

$$\dot{z}_j = -\gamma_j |\dot{x}_j| z_j |z_j|^{N} + A_j \dot{x}_j$$

$$\dot{u}_{j=} \quad \dot{u}_j = -\eta_j \left(u_j - V_j\right)$$

Where fd is the damper forces vector, D is the effect matrix on the number and position of the dampers, X 'is the relative velocity vector of the two ends of the dampers, X'j = v'i, k is the story number where the jth damper is located, m is the number of story in which the damper is located, the j subscript related to jth damper and E are defined as follows:

$$E = \begin{cases} E_{i,j} = 1, i = 1 \square n \\ E_{i,j} = -1, i = 2 \square n \\ E_{i,j} = 0, i, j = 1 \square n, j \neq i, i-1 \end{cases}$$

The MR dampers used in the present study are of a hundred tons damper type. To examine how the damper functions over time, a criterion other than the maximum response of the structure should be studied. Since the maximum response only occurs in a single moment, the study of the effects of MR dampers is not sufficient to conclude on its performance merely from the point of view of its impact in reducing the maximum response. Therefore, it is suggested that the "Root Mean Square" of the structure response is investigated over the analysis period. The equation below gives you how to calculate RMS.

$$YRMS = \sqrt{\frac{\sum_i^n Y_i^2}{n}}$$

It should be noted that Yi represents the response of the structure, including the displacement, acceleration or base shear of stories at time ti, and n denotes the number of time steps that the structure response will be measured within that range. This criterion will be used as an indicator for evaluating response improvements. In different structures, the percentage reduction in the RMS criterion is determined in comparison to the non-application of this damper. The higher the percentage is, the greater the MR damper effect has on reducing the structure response. The inherent inertia of all modes of structure is supposed 0.2%. For voltage feedback matrix, the value of is assumed to avoid apply of maximum voltage to the damper for a long time, and also damper consume less electric energy. The table below shows the characteristics of a damper which has a capacity to produce force value 1000 kN during maximum voltage application.

3.3. Evaluation of results

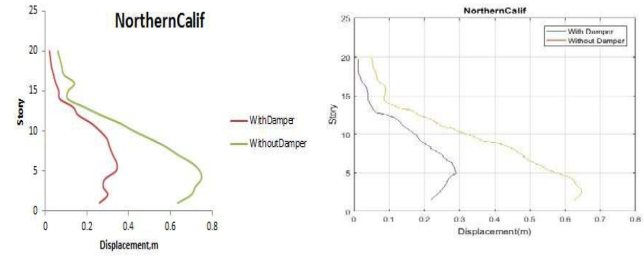

Figure 4: Maximum relative lateral displacement of the controlled and uncontrolled structure under the NorthernCalif record (the left figure is obtained from OpenSees software and the right one is executed by Matlab software)

By comparing these two results, we want to compare the displacements in the number of stories calculated in both Softwares. As it is seen in the Software, the displacement in With Damper mode is less than without Damper mode that represents the optimality of our proposed approach.

For example, the displacement of the 10th story in the Opensees software equal approximately to 0.23 in With Damper mode and in Without Damper mode is approximately equal to 46.0.

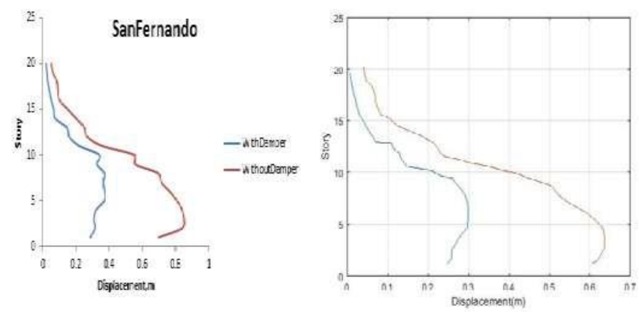

Figure 5: Maximum relative lateral displacement of the controlled and uncontrolled structure under the San Fernando record (the left figure is executed by the Open Sees software and the right one is executed by Matlab software)

As the simulation results of San Fernando earthquake show, displacements in this type of earthquake are less in the With Damper mode than the Without Damper mode. NorthernCalif earthquake shows that displacement occurs more in this type of earthquake. For example, in NorthernCalif earthquake, displacement is around 0.23 in the 10th floor in WithDamper mode. In SanFernando earthquake, this displacement on the 10th floor is about 0.28in With Damper mode.

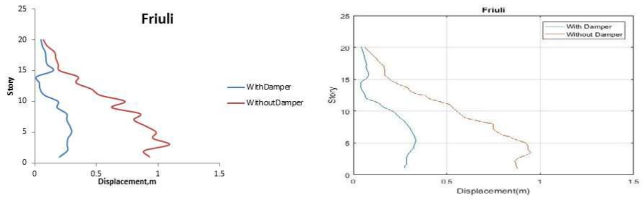

Figure 6: Maximum relative lateral displacement of the controlled and uncontrolled structure under the Friuli record (the left figure is executed by the Open Sees software and the right one is executed by Matlab software)

As the simulation results relate to this type of earthquake show, the displacements in this type of Earth quake in With Damper mode are much lower than the Without Damper mode. Comparing this type of earthquake with earthquake 1 and 2 show that the displacement ratio in this earthquake is much lower. For example, the displacement in the 10th floor is about 0.3

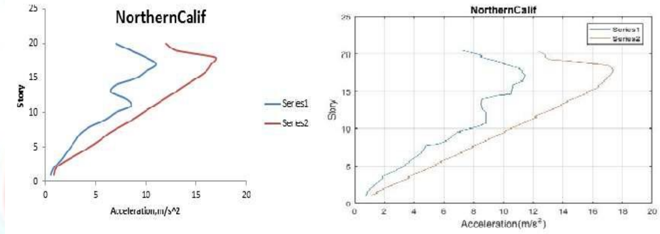

Figure 7: Maximum acceleration of the controlled and uncontrolled structure under the NorthernCalif record (the left figure is done by the OpenSees software and the right one is executed by Matlab software)

The maximum acceleration of a controlled and uncontrolled structure in the Opensees and Matlab software shows the acceleration of the structures in different stories and it can be seen that in controlled conditions, the maximum acceleration of the structure is lower than the uncontrolled mode. For example, in 10th floor, the maximum acceleration of the structure is 5.6 in controlled mode, while this value equals to 15.3 in uncontrolled mode.

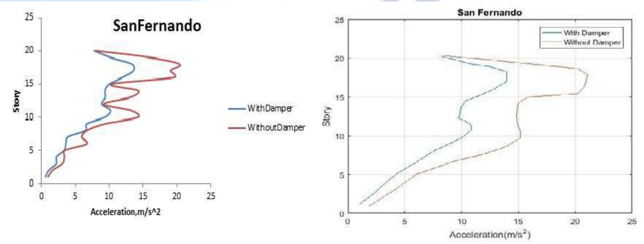

Figure 8: Maximum acceleration of the controlled and uncontrolled structure under the SanFernando record (the left figure is executed by the OpenSees software and the right one is executed by Matlab software)

As can be seen, the maximum acceleration of the structure is less in this type of record in controlled mode, than the uncontrolled mode. The maximum acceleration in this record is higher than the NorthernCalif record. For example, in the NorthernCalif record on the 10th floor, the maximum acceleration of the controlled structure is around 5.6, while the SanFernando record is almost 5.9.

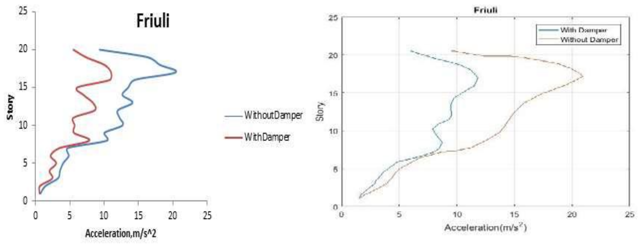

Figure 9: Maximum acceleration of the controlled and uncontrolled structure under the Friuli record (the left figure is executed by the OpenSees software and the right one is executed by Matlab software)

As the results of the simulations show, in this type of record, the maximum acceleration of the structure in the controlled mode is less than the uncontrolled mode. As can be seen, the maximum acceleration of the structure in both modes is much lower in this record than in Figures 4 and 5. For example, in the 10th floor, the maximum acceleration of the structure is approximately 5.5. The maximum relative lateral displacement of the controlled and uncontrolled structures were compared under different records, as well as the maximum acceleration of the controlled and uncontrolled structures under different records, and we found that the accuracy of simulations in Opensees software is much higher than Matlab software in any record mode. Also, as far as the amount of displacement in a record is greater, the maximum acceleration of the structure is even greater in those displacements.

IV. Conclusion

This study aims to optimize the momentary performance of high-rise metal structures equipped with MR damper using artificial intelligence, in order to increase the safety and efficiency of structures in major dynamic movements, such as earthquakes and severe winds. It is always the priority of those who calculate high-rise structures. First, we determined the accelerograms of earthquake by Matlab and Opensees software, and the results show that the use of MR dampers is very effective in controlling the seismic response of structures , because the dampers reduce the response of the structure to a significant degree by consuming only a small amount of energy. By using Matlab and Opensees software, we aimed to control the performance of these structures, and we found that the proposed method was effective for controlling structures in order to reduce the effects of external forces and seismicity on structures and especially in tall buildings. According to this proposed method, the structure will be lighter and can be performed at a lower cost.

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