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Vibration control of stiffness irregular structures under near and far-field earthquakes by MR dampers and fuzzy controllers

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ABSTRACT: With the increase in the population of cities and the lack of spaces for construction, the creation of diverse uses, architecture and beauty of structures, the need for irregular structures is increasing. One way to reduce the construction hazards is to use vibration control tools in them. In the present study, the performance of a magnetic damper with a fuzzy controller to reduce the vibrations of an irregular hard structure under near and near earthquakes has been investigated. In the present study, the performance of a magnetic damper with the fuzzy controller to reduce the vibrations of an irregular stiffness structure under near and far field earthquakes has been investigated. The capacity of the introduced magnetic damper is equal to 1000kN, which is installed in the first floor between the floor level and the ceiling level of the first floor. The fuzzy system is designed based on the relative speed of the two ends of the damper to determine the relative speed of the amount of voltage and, consequently the control force that enters the structure. Three different types of irregularities in height, including hardness irregularities with a coefficient of 60%, are used in a 10-story structure and are modeled in the OpenSees software. These irregularities have been investigated in three different elevation locations including the lower half of the structure height (floors 1 to 5), the lowest floor (1st floor) and the middle floor of the structure (5th floor). Based on the numerical analyzes performed for these structures under the excitation of near and far field earthquakes, the residual displacement is reduced by an average of 23.15% and 45.64%, respectively. In addition to the improvement of criteria such as maximum displacement, base shear and moment in both types of earthquakes, the most improvement occurred in the irregular structure of the first floor and the least for the middle floor. In addition to improving criteria such as maximum displacement, base shear, and moment in both types of earthquakes, the most improvement occurred for the irregular structure on the first floor and the least for the irregular structure in the middle floor.

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1- Introduction

The seismic design regulations always lead to regular constructions and the avoidance of any irregularities in structures. Still, nowadays, irregular constructions are inevitable for various reasons such as beauty, architecture and economy. Between different stages of analysis and design of a structure against incoming loads, decision-making about configuration, geometric characteristics of the structure such as dimensions in plan and height, the role of structural and non-structural components can lead to nonlinear deformation of the load and cause local or global destructions. The behavior of multi-story structures under strong earthquakes depends on the configuration of the structure. Irregularities in plan and in height are the main causes of the rupture of structures during an earthquake. The type, intensity as well as irregular position is important issues that should be considered in the designs.

One of the most challenging goals among researchers and engineers is to control and reduce the vibrations of structures. As the damage to structures, loss of life and property following the recent earthquakes, the importance of controlling the vibrations of structures against earthquakes becomes more apparent. One way to reduce vibrations and potential hazards of structural damage is to use vibration control tools. One of these tools is MR magnetic dampers, which have intrinsic properties such as very fast response time, phase reversibility, immutability to environmental conditions and easy controllability, have been studied by many researchers [1-4].

In the present study, magnetic dampers will be used to reduce the vibrations of irregular structures in stiffness. One of the ambiguous points of previous studies is not paying attention to the characteristics of the studied structures in vibration control, because if there is the irregularity in the structure and its vibration control in one level of the structure, it can cause local stresses in other parts of the structure [5-8]. It can also behave differently in far and near field earthquakes separately because each of these

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loads is fundamentally different. On the other hand, fuzzy controllers, designed by experts in any field to make the necessary decisions at the moment, can be challenging for structures that behave more complexly than regular structures. Therefore, in order to eliminate the shortcomings in the studies conducted in this field, various variables such as the type of earthquake, irregularity of stiffness in different floors and the performance of the controller will be studied.

2- Studied structures

In order to evaluate the performance of the MR damper and the control system, a 10-storey structure with a floor height of 3m and width of 5m in each direction has been used [9]. The lateral system of the structure is defined in both directions, a special steel bending frame and a roof system of two-sided concrete slab type with a rigid diaphragm. The structure is designed for an area with a high relative seismic risk and a site with type II soil. The amount of extensive dead load is equal to 700 kg/m^2 and the live load of the floors is equal to 200 kg/m^2. To model irregularity in height, by applying changes in regular structure, irregular structures in height are modeled with different states of non-geometric irregularity. For this purpose, in a class of structure where an irregularity in height is to occur, the stiffness value is changed by applying an irregularity coefficient according to Equation (1). In order to keep the other variables constant and merely to study irregularly, the main characteristics of a regular and irregular structure, including the first mode cycle time, stiffness, and shear base of the yield point, are kept constant.

$$IF = \frac{K_I}{K_A} \tag{1}$$

where IF the coefficient of irregularity, K_I the stiffness of the irregular floor and K_A the stiffness of the adjacent upper floor.

3- MR damper modeling and fuzzy control system

This model consists of a Bouc-Wen element and a viscous damper that operate in parallel [10]. The specifications of the MR damper and fuzzy controller are such that it is not possible to model it directly by OpenSees software; Therefore, the force corresponding to this damper is calculated by MATLAB software and at each step, the level at which the damper is located is entered in the OpenSees software. This connection is created between OpenSees and MATLAB softwares through the TCP-IP method.

4- Earthquake records applied to structures

In this study, in order to evaluate the performance of MR damper and controlling algorithm in reducing structural responses, 7 far-field earthquakes and 7 near-field earthquakes have been used for excitation. Before analyzing the time history, the regulations require that the excitation would be scaled. In the present study, the scale of maximum earthquake acceleration has been performed and incremental dynamic analysis has been performed. The maximum values of earthquake acceleration are from 0.1 g to 1.0 g. In order to evaluate the performance of MR dampers in reducing the vibrations of response and acceleration of the roof floor and base shear and bending moment of the structure in two controlled modes with MR dampers and uncontrolled are examined. For this purpose, 8 evaluation criteria, 4 of which are related to the maximum answers and the other 4 are related to the mean squared of the answers.

5- Conclusions

In the present study, MR magnetic dampers were used to control the vibrations of irregular structures in stiffness. To evaluate the performance of this control system on irregular structures in stiffness, a regular structure and three irregular structures that are similar in terms of the period of the first mode, stiffness and base shear yield are used as reference structures. Irregular structures are developed by reducing stiffness in different floors of regular structures. These irregularities have been applied to the first to fifth floors, the first floor and the fifth floor. These structures were subjected to 7 far-filed earthquakes and 7 near-field earthquakes in order to separately examine the performance of the controlled structure. The magnetic damper used by the fuzzy controller, which determines the required voltage by receiving the relative velocity input by the sensors, controls the performance of the structures under consideration.

To evaluate the performance of the control system, the results of the residual displacements in the structures under different earthquakes were examined. The results of this study showed that the use of MR dampers, decreases residual displacement in different classes of regular structures, irregular structures with reduced stiffness in floors 1 to 5, irregular structures with reduced stiffness in floors 1 and irregular structures with reduced stiffness in floors 5, 21.19%, 17.85%, 38.34% and 15.24%, respectively, in the input excitation of far-field earthquakes, and 42.83%, 48.29%, 51.24% and 40.18%, respectively, in the input excitation of near-field earthquakes. Other defined criteria also showed that this control system, regardless of the irregularity in the structure, can significantly reduce the maximum displacement, base shear and bending moment of the structures.

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