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Effect of selecting different membership functions on semi-active fuzzy control of adjacent buildings with MR damper

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ABSTRACT: The selection of appropriate membership functions for fuzzy control systems has always been a topic of discussion among researchers and has been generally determined by trial and error based on the experience of the control system designer. In this study, the control performances of type-1 and type-2 fuzzy systems with different membership functions in semi-active fuzzy control of two adjacent three- and nine-story buildings connected using MR damper under seismic excitations are discussed. In this study, two fuzzy systems have been used considering the type of membership function as well as the number of defined membership functions for each input. The examined membership functions are defined symmetrically and at the same intervals for comparison. The results of the control systems used for the type-1 and type-2 fuzzy algorithms are examined and compared to the uncontrolled mode by considering the triangular, Gaussian, and trapezoidal membership functions. The results obtained from the defined performance criteria show that in general, type-2 fuzzy systems perform better than type-1 fuzzy systems, due to the consideration of uncertainties and the use of membership functions intermittently. Fuzzy control systems with triangular membership functions have the best performance compared to other membership functions and the Gaussian membership function has shown close control performance to triangular function. Also, when more membership functions are used to determine the degree of membership of fuzzy language values, the fuzzy system becomes less sensitive to the type of membership function used.

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1- Introduction

Fuzzy logic systems are widely used for control, system identification, pattern recognition problems, and many other applications from industry to academia. Membership functions play an essential role in the overall performance of the fuzzy system. These functions are the building blocks of fuzzy theories and actually the fuzzification process in a fuzzy set is determined by them. Based on this, the shape of fuzzy functions in any specific problem is considered an important parameter because it directly affects the fuzzy inference system. Membership functions may have different shapes such as triangle, trapezoid, Gaussian, etc. By reviewing the research done, it can be concluded that the triangular membership function is widely used due to its simplicity. The triangular membership function consists of straight lines, which makes it easy to use, as well as the high speed of fuzzy system execution. In addition to triangular membership function, trapezoidal and Gaussian functions have performed better than other membership functions [1, 2].

In fuzzy control systems, uncertainties have always been controversial issues among control system designers. Using inputs without applying uncertainties is one of the characteristics of type-1 fuzzy systems. in type-2 fuzzy systems, by defining the membership functions as intervals, this problem is solved to some extent, and the fuzzy system becomes flexible and resistant to uncertainties, and therefore the performance of the fuzzy inference system improves [3]. In the design of fuzzy systems, trial and error and the experience of the system designer are generally used in choosing the membership function. In this research, by considering a case study and applying different seismic excitations, the performance of the considered control systems with different membership functions has been investigated and the effect of using different membership functions in terms of type (to take into account the uncertainties in the problem), number and shape (to include the distribution of the degree of membership of the variables) has been discussed and investigated in the fuzzy control of buildings.

2- Methodology

In this study, to investigate the control performance of the fuzzy algorithm with different membership functions, two buildings of three and nine floors, which are related to the SAC project in the California-Los Angeles region [4],

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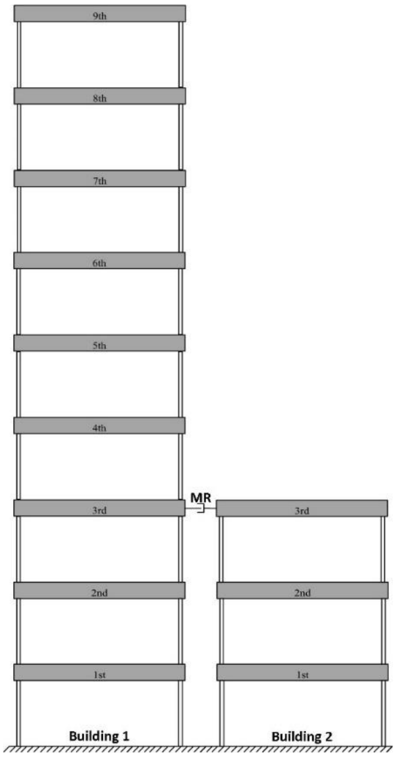

Fig. 1. Model of two adjacent buildings [14] connected with MR damper

Table 1. The performance criteria for maximum responses

criterion	equation	title
J_1	$\frac{\max\lvert x_c(t)\rvert}{\max\lvert x_{un}(t)\rvert}$	Displacement of roof story
J_2	$\frac{\max\lvert \ddot{x}_c(t)\rvert}{\max\lvert \ddot{x}_{un}(t)\rvert}$	Acceleration of 9th story
J_3	$\frac{\max\lvert V_c(t)\rvert}{\max\lvert V_{un}(t)\rvert}$	Base shear of structure
J_4	$\frac{\max\lvert d_c(t)\rvert}{\max\lvert d_{un}(t)\rvert}$	Relative displacement of structure
J_5	$\frac{\max \Delta_c(t)}{\max \Delta_{un}(t)}$	Minimum required gap

are considered to be connected. The finite element model has been prepared by assuming the linear behavior of the buildings in OpenSees software. Also, for implementing the fuzzy logic algorithm and calculating the control force, MATLAB software has been used in parallel with OpenSees software. Figure 1 schematically shows the two adjacent buildings. Also for modeling MR damper, the Bouc-Wen model has been used in simulating the dynamic behavior of the damper [5]. To verify the validity of the Bouc-Wen model, the results of the hysteresis behavior of the damper modeled in the study of Ok et al. [6] were used.

Due to the non-aligned vibrations of the buildings based on their different dynamic characteristics, to prevent the collision of adjacent buildings, the fuzzy rules used in this study have been determined based on the equalization of the movement of the two buildings during an earthquake. The fuzzy inference rules used in this research were adapted from the study of Abdeddaim et al. [7] in 2016. Type 1 and type 2 fuzzy controllers with membership functions and different fuzzy rules are considered.

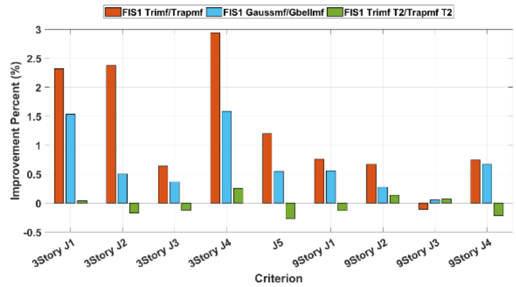

Fig. 2. Comparison of type 1 and type 2 FIS1 systems with different membership functions

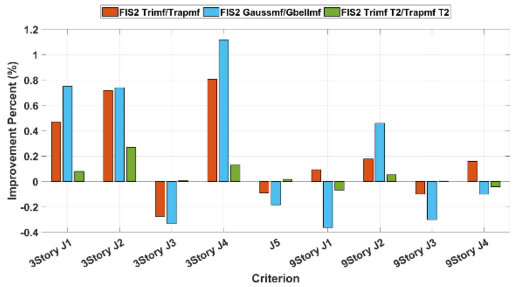

Fig. 3. Comparison of type 1 and type 2 FIS2 systems with different membership functions

3- Results and Discussion

The performance criteria used to evaluate the control performance of fuzzy systems are shown in table 1. the performance of fuzzy systems with different membership functions in terms of shape and number are shown in Figures 2 and 3. As observed, in the FIS1 system, type 1 fuzzy systems with triangular and Gaussian membership functions have performed better than type 1 fuzzy systems with trapezoidal membership functions, which is more obvious in the three-story building. In type 2 fuzzy systems, the situation has been different because the difference between using triangular and trapezoidal membership functions becomes more limited when we use interval membership functions. These results show that when there is uncertainty in the selection of the membership function and the knowledge of the fuzzy system designer to determine the type of membership function is limited, the use of type 2 fuzzy systems accommodates the uncertainties well.

4- Conclusions

According to the results obtained from the dynamic analyzes performed on benchmark buildings connected with MR dampers, it is concluded that the fuzzy systems used to calculate the damper voltage have a good performance and improve the response of the buildings under seismic exitations. Also, based on the comparison of type 1 and type 2 fuzzy systems, in general, type 2 fuzzy systems that use interval membership functions have a better performance in reducing the responses of buildings compared to type 1 fuzzy systems. Also, the designed fuzzy systems have shown better control performance in far-field earthquakes compared to near-field earthquakes.

By examining the evaluation criteria used to compare different membership functions, it is clear that fuzzy systems with triangular membership functions performed best compared to other membership functions in improving the performance of buildings against earthquakes. Gaussian membership functions have also shown a close performance to triangular membership functions. Also, by examining the results obtained for two fuzzy systems with different numbers of fuzzy sets, it has been observed that in the fuzzy system with a larger number of fuzzy sets, the sensitivity of the fuzzy system to the selection of the membership function decreases.

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