17th ASCE Engineering Mechanics Conference
June 13–16, 2004, University of Delaware, Newark, DE
EM2004

FUZZY CONTROL STRATEGY FOR SEISMIC RESPONSE REDUCTION OF SMART BASE ISOLATED BENCHMARK BUILDING

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ABSTRACT

Control strategy based on fuzzy algorithm is presented for response reduction of the seismically excited base-isolated building, which is an eight story base isolated non-linear building similar to existing buildings in Los Angeles, California. When a control method based on fuzzy algorithm to a structure is used for vibration reduction, it has inherent robustness, easiness to treat the uncertainties of input data from the ground motion and structural vibration sensors and its ability to handle the non-linear behavior of the structure because of no need of exact mathematical model of the structure. This fuzzy algorithm is applied to both of active and semiactive control systems. The results of the numerical simulations show that the proposed control systems could be beneficial in reducing seismic responses of base isolated structures.

Keywords: Fuzzy control, MR damper, vibration control, base isolated system

INTRODUCTION

Many aseismic construction designs and technologies have been developed over the years in attempt to mitigate the effects of earthquakes on buildings. Base isolation systems are one of the most widely applied structural control strategies under seismically excited structures. Base isolation systems, such as sliding and elastomeric bearing systems, reduce the super-structure response, but with increased base displacements in near-fault motions. Current practice is to provide non-linear passive dampers to limit the bearing displacements, however, this increases the forces in the superstructures and also at the isolation level. Active and semiactive devices present attractive alternatives to passive non-linear devices (i.e., Hybrid control system). A hybrid using two types of control device could alleviate some of restrictions and limitations that exist when each system is acting alone. Many hybrid protective systems have been explored for applications to seismically excited structures both analytically and experimentally.

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Narasimhan, et al. (2002, 2003) have developed the smart base isolated benchmark problem, based on input from the ASCE structural control committee, with capability to model three different kinds of base isolation systems: linear elastomeric systems with low damping or supplemental high damping, frictional systems, bilinear or nonlinear elastomeric systems or any combination thereof. In this study, a hybrid control systems of linear elastomeric system with low damping or nonlinear friction isolation system in combination with hydraulic actuators (HAs) or Magneto-Rheological (MR) dampers, are investigated by using smart base isolated benchmark building. The passive control part of the hybrid control systems can reduce the earthquake induced forces in the structure and the active/semiactive control part can further reduce the building responses, especially base displacements. For the active control part, a fuzzy control algorithm is adopted to produce desired control force, whereas for the semiactive control part, a fuzzy control algorithm is adopted to calculate the command signal into the MR dampers based on structural responses.

HYBRID CONTROL SYSTEM DESIGN

A hybrid control system combining passive and active/semiactive control devices could be used for civil infrastructures which need large control forces and good controller robustness to apply to real structures.

Linear elastomeric isolation system consists of 92 low damping elastomeric bearings. The fundamental period T_b=3 sec in the linear elastomeric isolation case. The damping in the linear elastomeric isolation system is considered to be 3% of critical. Nonlinear isolation system consists of 61 friction pendulum bearings and 31 linear elastomeric bearings-for a total of 92 bearings. The fundamental period, T_b=3 sec in the nonlinear friction isolation case. Coefficient of friction μ=0.06 is considered for the friction bearings. Damping of 3% of critical is considered for the linear elastomeric bearings. In all cases total of 16 active or semiactive control devices, 8 in the X and 8 in the Y direction, are placed at the isolation level.

Fuzzy controller is presented for illustrating the implementation of active and semiactive control system in the linear isolation case and nonlinear friction case. For the case of active fuzzy and semiactive fuzzy control design, sensors placed on the isolation level measure the responses of two translational (EW and NS) direction.

Active Control System Design

The simple strategy of the active fuzzy control algorithm for linear elastomeric isolated or nonlinear friction isolated building structure is presented in Fig. 1. The design of the active fuzzy controller selects the response quantities to be used as input to the fuzzy controller and the distribution and type of membership functions to be used for the selected input variables. In the example, the controller is designed using two input variables (i.e. one the displacement in base isolated level and the other is the velocity in base isolated level), each one having three membership functions, and one output variable (i.e. desired control force) with five membership functions. The membership functions chosen for the input and output variables are triangular shaped, as illustrated in Fig. 2. Definitions of the fuzzy variables of input membership functions are as follows: NE=Negative, ZE=Zero and PO=positive. A reasonable range of input values must be selected for the input membership functions since, if the range is too large or too small, the outermost membership functions will rarely or essentially be used, respectively, and thus limit the variability of the control system.. The definitions of the fuzzy variables of the output membership function are as follows: NL=Negative Large, NS=Negative Small, ZE=Zero, PS=Positive Small and PL=Positive Large. The control force is the fuzzy control system output. The fuzzy inference rule is shown in Table 1.

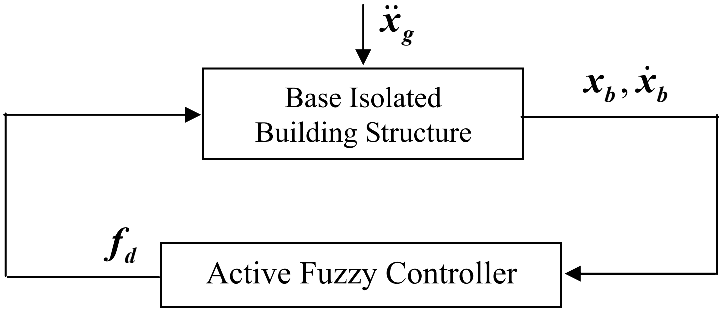

FIG. 1. Control diagram of the active control system of base isolated building.

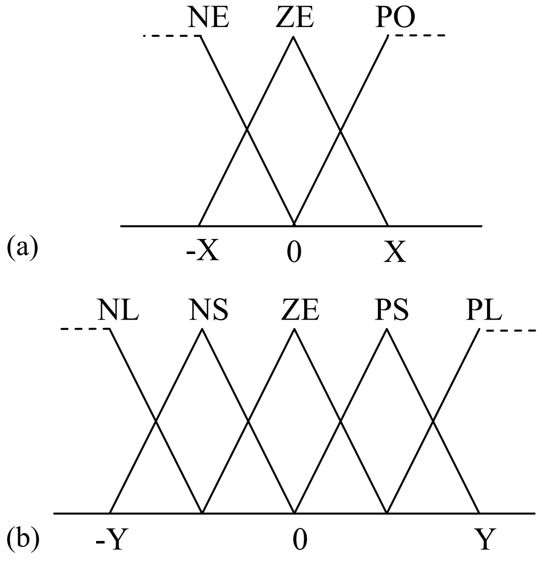

FIG. 2. Input and output membership functions: (a) input membership function; and (b) output membership function.

TABLE 1. Fuzzy inference rule

	NE	ZE	PO
NE	PL	PS	ZE
ZE	PS	ZE	NS
PO	ZE	NS	NL

Semiactive Control System Design

The simple strategy of the semiactive fuzzy control algorithm for linear elastomeric isolated or nonlinear friction isolated building structure is presented in Fig. 3.

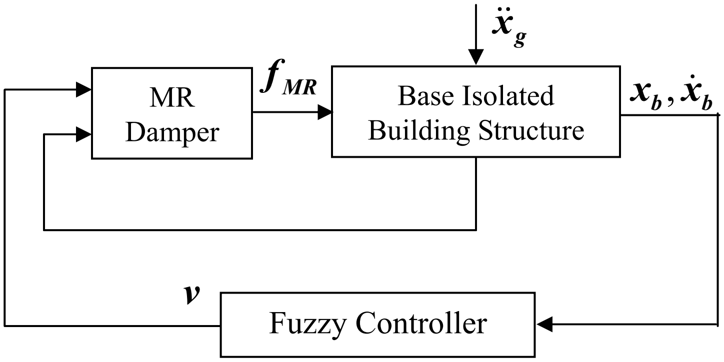

FIG. 3. Control diagram of the semiactive control system of base isolated building.

The force generated by the damper is a function of the voltage supplied. The damper is modeled using a spring, a dash pot and hysteretic element in parallel as shown in Fig. 4.

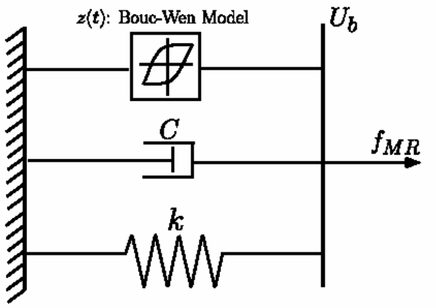

FIG. 4. MR damper model.

The controller is designed using two input variables (i.e. one the displacement in base isolated level and the other is the velocity in base isolated level), each one having three membership functions, and one output variable (i.e. command voltage) with three membership functions. The membership functions chosen for the input and output variables are triangular shaped, as illustrated in Fig. 5. The command voltage is the fuzzy control system output. The fuzzy inference rule is shown in Table 2.

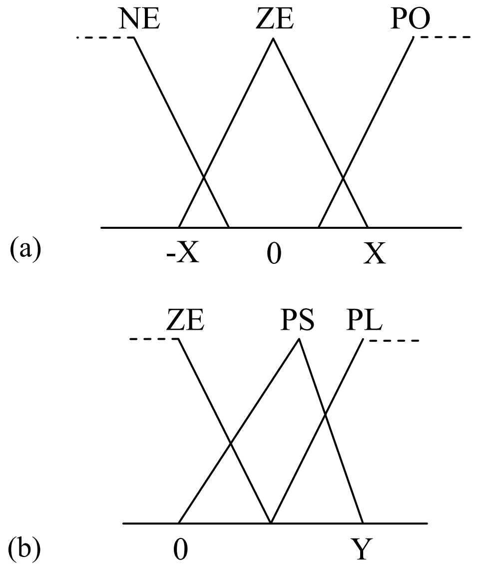

FIG. 5. Input and output membership functions: (a) input membership function; and (b) output membership function.

TABLE 2. Fuzzy inference rule

	NE	ZE	PO
NE	PL	PS	ZE
ZE	PS	ZE	PS
PO	ZE	PS	PL

CONTROL RESULTS

Active and semiactive control – linear elastomeric isolation system

The results of active control of the benchmark problem with linear elastomeric isolation system are summarized in Table 3. Actuators are used apply the active control forces to the base of the structure. As seen from the table, most of responses in the active control of the benchmark problem with linear elastomeric isolation system are reduced substantially form the uncontrolled cases. The benefit of active fuzzy control strategy is the reduction of base displacements of up to 50% with a little increase in floor accelerations.

Table 4 shows the values of 9 evaluation criteria related to structural responses for semiactive fuzzy control of the benchmark problem with linear elastomeric isolation system. The semiactive force is applied to the base of the structure by sixteen MR dampers, eight is the X and eight in the

Y direction. Fourteen of the MR dampers are located in the periphery of the base slab and two near the center of mass of the base slab. The advantage of semiactive fuzzy control is evident in significant reductions in floor accelerations as well as base displacements as compared to the active control case.

TABLE 3. Evaluation criteria related to structural responses for active fuzzy control (FP – X and FN – Y)

	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9
Newhall	0.96	0.98	0.68	**1.01**	**1.10**	0.19	0.43	0.73	0.71
Slymar	1.00	**1.01**	0.94	0.95	**1.03**	0.12	0.82	0.85	0.50
El Centro	0.97	0.94	0.50	0.81	**1.07**	0.28	0.45	0.54	0.77
Rinaldi	**1.08**	**1.06**	0.96	**1.03**	**1.04**	0.13	0.79	0.84	0.59
Kobe	0.98	0.96	0.53	0.87	**1.15**	0.20	0.50	0.59	0.71
Jiji	0.90	0.90	0.92	0.92	0.94	0.08	0.88	0.85	0.39
Erzinkan	**1.08**	**1.11**	0.85	0.96	**1.11**	0.12	0.90	0.84	0.53

TABLE 4. Evaluation criteria related to structural responses for semiactive fuzzy control (FP – X and FN – Y)

	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9
Newhall	0.91	0.93	0.69	0.94	0.94	0.12	0.52	0.77	0.60
Slymar	0.96	0.96	0.92	0.94	**1.02**	0.09	0.71	0.85	0.53
El Centro	0.95	0.92	0.62	0.83	0.90	0.14	0.55	0.63	0.63
Rinaldi	**1.02**	**1.02**	0.89	**1.01**	**1.04**	0.10	0.72	0.77	0.54
Kobe	0.88	0.87	0.63	0.83	**1.02**	0.12	0.59	0.68	0.61
Jiji	0.91	0.91	0.86	0.91	0.93	0.06	0.75	0.85	0.39
Erzinkan	0.97	1.00	0.75	0.86	0.98	0.09	0.76	0.80	0.52

To compare performances of three kinds of controller of the benchmark problem with linear elastomeric isolation system, the maximum values of 9 criteria of three kinds of controller performances for all seven earthquakes are summarized in Table 5. The overall performance of the active fuzzy control system is comparable to that of sample controller (LQG). However, the overall performance of the semiactive fuzzy control system is slightly better than those sample controller (LQG) and active fuzzy controller.

TABLE 5. Maximum evaluation criteria related to structural responses for seven earthquakes (FP – X and FN – Y)

	Sample controller (LQG)	Active fuzzy	Semiactive fuzzy
J_1	**1.07**	**1.08**	**1.02**
J_2	**1.09**	**1.11**	**1.02**
J_3	0.97	0.96	0.92
J_4	**1.01**	**1.03**	**1.01**
J_5	**1.06**	**1.15**	**1.04**
J_6	0.18	0.28	0.14
J_7	0.80	0.90	0.76
J_8	0.89	0.85	0.85
J_9	0.52	0.77	0.63

Active and semiactive control – nonlinear frictional isolation system

The results of active and semiactive control of the benchmark problem with nonlinear frictional isolation system are summarized in Tables 6 and 7, respectively. As seen from the tables, the overall performance of active control case is comparable to that of semiactive control case. Even though semiactive controller is applied to frictional isolation system, it does not represent evident performance improvement. It causes that active and semiactive fuzzy control system is designed for purposed to reduce base displacements, not to increase floor accelerations not so much.

TABLE 6. Evaluation criteria related to structural responses for active fuzzy control (FP – X and FN – Y)

	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9
Newhall	**1.06**	0.99	0.87	**1.02**	**1.07**	0.18	0.81	**1.10**	0.21
Slymar	**1.08**	**1.09**	0.95	**1.02**	**1.21**	0.13	0.88	**1.10**	0.21
El Centro	**1.09**	**1.06**	0.82	**1.18**	**1.16**	0.22	0.80	**1.05**	0.12
Rinaldi	**1.07**	**1.06**	0.92	**1.08**	**1.27**	0.14	0.91	**1.18**	0.22
Kobe	**1.09**	**1.14**	0.84	**1.26**	**1.16**	0.20	0.77	**1.14**	0.22
Jiji	0.92	0.93	0.84	0.99	**1.03**	0.09	0.81	0.99	0.17
Erzinkan	**1.12**	**1.10**	0.92	**1.08**	**1.12**	0.14	0.86	**1.07**	0.21

TABLE 7. Evaluation criteria related to structural responses for semiactive fuzzy control (FP – X and FN – Y)

	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9
Newhall	**1.08**	0.96	0.87	**1.02**	**1.01**	0.20	0.81	**1.13**	0.21
Slymar	**1.07**	**1.07**	0.91	**1.01**	**1.26**	0.16	0.82	**1.12**	0.27
El Centro	**1.03**	**1.04**	0.89	**1.05**	**1.06**	0.19	0.94	**1.06**	0.09
Rinaldi	**1.10**	**1.06**	0.92	**1.04**	**1.35**	0.18	0.91	**1.20**	0.25
Kobe	**1.02**	**1.19**	0.83	**1.33**	**1.10**	0.22	0.76	**1.14**	0.22
Jiji	0.91	0.92	0.81	0.99	**1.03**	0.12	0.78	1.00	0.22
Erzinkan	**1.09**	**1.07**	0.86	**1.09**	**1.18**	0.18	0.80	**1.05**	0.27

CONCLUSIONS

Active fuzzy controller using hydraulic actuators (HAs) and semiactive fuzzy controller using MR dampers (MRDs) are presented for benchmark problem with linear elastomeric isolation system and nonlinear frictional isolation system, respectively. When a control method based on fuzzy algorithm to a structure is used for vibration reduction, it has inherent robustness, easiness to treat the uncertainties of input data from the ground motion and structural vibration sensors and its ability to handle the non-linear behavior of the structure because of no need of exact mathematical model of the structure. Therefore, the fuzzy algorithm could be applied simply to linear and nonlinear base isolated systems.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of this research by the National Research Laboratory (NRL) program from the Ministry of Science and Technology in Korea.

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