

**SEMIACTIVE AND HYBRID SEISMIC CONTROL
OF BUILDING FRAMES USING MR DAMPERS**

By

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Certificate

This is to certify that the thesis entitled, “**Semiactive and Hybrid Seismic Control of Building Frames using MR Dampers**”, being submitted by **Mr. Diptesh Das**, to the Indian Institute of Technology, Delhi, for the award of ‘**DOCTOR OF PHILOSOPHY**’ in Civil Engineering is a record of the bonafide research work carried out by him under our supervision and guidance. He has fulfilled the requirements for submission of this thesis, which to the best of our knowledge has reached the requisite standard.

The material contained in the thesis has not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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Abstract

Although extensive researches have been carried out in the area of structural control, relatively less work is reported on semi active and hybrid control of building frames for earthquakes using MR dampers and employing control algorithms based on fuzzy logic and neuro-fuzzy techniques. In particular, Fuzzy logic controller has not been used for semi active control of building frames using MR dampers..There have been some works on the use of neuro-fuzzy controller for the semi active control of building frames with MR dampers, but they have been not extended for cases with a number of MR dampers employed in the structures. Fuzzy and neuro-fuzzy controllers have many attributes like, they can accommodate uncertainties and nonlinearities of systems more effectively than other types of controllers. In hybrid control, no study has been made to investigate the advantage of the effectiveness of a hybrid system consisting of semi active MR dampers and passive TMDs, which are easy to install.

With the aim of bridging this gap, the present work is undertaken. The overall objective of the work is to study the semi active and hybrid control of building frames with MR dampers subjected to earthquake excitation. Further, an experimental study with the help of an existing setup is conducted in order to implement ANN and fuzzy rule based control scheme in LabVIEW platform for online close loop control of a model frame mounted on a shake table using MR dampers. The specific objectives of the study are:

1. To develop a fuzzy logic semi active control algorithm, based on fuzzification of the MR damper characteristics, for building frames subjected to earthquake ground excitation.
2. To develop a neural network-cum-fuzzy semiactive control strategy using

fuzzy logic theory and neural networks, taking the advantages of each technique and making it effective in controlling large size structural systems..

3. To conduct an experimental test with an available model on a shake table to investigate the feasibility of real-time implementation of the ANN-cum-fuzzy control scheme and to validate the theoretical results.
4. To formulate a hybrid control method using MR dampers and a TMD in order to augment the control of response achieved by using fuzzy semiactive control alone.
5. To conduct a detailed parametric study with the help of three building frames of different heights to investigate the effects of different factors on the relative effectiveness of the control schemes..

A semi active control algorithm, based on fuzzy logic theory, is developed. In this method, the MR damper characteristics are directly fuzzified in place of representing it by a mathematical model. The method is developed by simulating the force-velocity hysteretic curve of MR damper under sinusoidal actuation by using fuzzy if-then rules. The algorithms developed are first tested by applying them to control a three story frame, whose controlled responses obtained by other algorithms are available in the literature and then to another ten storey frame also available in literature. Further, a detailed parametric study is conducted to investigate the effectiveness of the control algorithms. Some of the important conclusions of the study are: (i) the proposed control scheme provides nearly the same maximum percentage reduction of responses as that obtained by clipped-optimal control with a much less control force. Thus, the control scheme is found to be highly efficient; (ii) position of the damper has significant effect on the control of response. The position of the damper in the lowest storey provides the maximum control of response for all storeys. However, the control force requirement does not change

significantly with the change in the position of the damper; and (iii) more number of MR dampers is required for desirable control of top storey displacement than what are needed for other response quantities; percentage reduction of base shear can be achieved most effectively with the help of minimum number of dampers.

A semi active control algorithm is developed using ANN-cum-fuzzy technique. The training data sets are generated with the help of the fuzzy control algorithm using nine real earthquake records. Three layer back-propagation neural networks, consisting of an input layer, a hidden layer and an output layer, are considered and each damper is represented by a neural net. The input to the networks consists of measured structural responses, which include displacement, velocity and acceleration, and a target percentage reduction of response. The output quantities are the control force generated by the MR damper and the command voltage required to generate that force. The trained networks are tested with known and unknown data sets and the effectiveness of the ANN-cum-fuzzy technique verified implementing it to the example frames mentioned above. Some of the important conclusions of the study include: (i) a minimum number of response measurements is required to be provided as inputs to train an ANN so that it can capture the overall structural behaviour and can effectively predict for known and unknown data; (ii) a back-propagation training algorithm with three layer (input, hidden and output) architecture can be effectively used for training an ANN for structural control applications. The earthquake ground acceleration records used for generating the training data, however, play a major role in proper training of the ANN; and (iii) outputs obtained by using the trained ANN are in good agreement with those obtained from the fuzzy controller for the two building frames, indicating that the ANNs are well trained.

An experimental study is carried out to investigate the real-time implementation of ANN-cum-fuzzy control algorithm in semi active control of a four storey model frame

fitted with MR dampers. Training data sets are generated using fuzzy control algorithm and subjecting the structure to sinusoidal base motions of different frequency and amplitude. A neural network is trained offline considering some of the measured structural responses as inputs and the control force and command voltage as outputs. The closed loop control scheme consists of different operations, which are data acquisition, calculus, ANN, D-A conversion for output and input signal to MR damper. Data acquisition is done with the help of four accelerometers attached to the four floors and the acquired data is processed through LabVIEW software. The connection weights and bias are extracted from the trained network and are incorporated in the closed loop in LabVIEW in the form of text files. The theoretical findings are thus validated with the experimental results. Some of the important conclusions of the study are: (i) ANN-cum-fuzzy semiactive control can be implemented with much ease in real-time close loop control with the trained neural networks in LabVIEW platform; (ii) the control of responses is more when the structure is vibrating under a sinusoidal base motion which has a frequency near to its natural frequency of vibration; and (iii) results obtained from the experimental study follow closely the results obtained by numerical simulations using ANN-cum-fuzzy technique. Hence, the findings of the theoretical study are validated with the help of the experiment conducted.

A hybrid control system with MR dampers and a TMD is developed and investigated through numerical simulations. The ten storey building frame is considered for application. MR dampers are installed in the lower storeys and the TMD is placed on the top of the structure. The control algorithm is developed by considering the structure-TMD together. The backbone curves, the fuzzy control algorithm and the nine different earthquake records mentioned in chapter 4 are used for simulations. The effectiveness of the following control schemes are compared: (i) only TMD, (ii) only MR dampers and

(iii) TMD and MR dampers. A detailed parametric study is carried out by varying the TMD mass and TMD damping, and the number of MR dampers used. Some of the important conclusions of the study are: (i) the TMD mass has a significant effect on the reduction of responses for both the passive control and the hybrid control. Also, it is observed that the TMD mass required to achieve the maximum percentage of control for hybrid control case does not necessarily decrease with increase in the number of MR dampers employed; (ii) The benefit or advantage of the hybrid control is greatly reduced with more number of MR dampers in position; and (iii) out of different controlled response quantities, the gain by having the hybrid control is maximum for the absolute acceleration.

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