PERFORMANCE OF ACTIVE, SEMI-ACTIVE AND HYBRID CONTROL SCHEMES FOR SEISMIC PROTECTION OF BUILDING FRAMES

By

MUNISH KUMAR BHARDWAJ
DEPARTMENT OF CIVIL ENGINEERING

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Dedicated to

My Parents

CERTIFICATE

This is to certify that the thesis entitled, "**Performance of Active, Semi-Active and Hybrid Control Schemes for Seismic Protection of Building Frames**", being submitted by **Mr. Munish Kumar Bhardwaj**, 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 my supervision and guidance. He has fulfilled the requirements for submission of this thesis, which to the best of my 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.

(Prof. T. K. Datta)
Professor
Civil Engineering Department
Indian Institute of Technology
New Delhi – 110 016, INDIA

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ABSTRACT

Although there have been intensive work in the area of structural control in the recent past for the development, testing and implementation of passive, active, semi-active and hybrid control schemes, yet there are not many studies on the relative evaluation of different control schemes. Further, robustness of different control schemes against different kinds of disturbance/error is not precisely established. The present study is aimed at partly bridging this gap and also to develop and test some new control strategies using the concept of hybrid, semi-active and ANN control. The precise objectives of the study are:

1. To investigate the robustness of control algorithms for sliding mode control, LQR feedback (closed loop) control and LQR feedforward-feedback (open-closed loop) control against the measurement errors in the feedback responses and ground excitation, and also against the error in the determination of system parameters.
2. To develop a methodology for hybrid control of building frames using viscoelastic dampers (VEDs) and ATMD/actuator at the top.
3. To develop a fuzzy rule based semi-active control of building frames using semi-active hydraulic dampers and investigate its robustness and efficiency.
4. To develop an ANN based active control strategy using actuator at the top, which directly considers a predetermined target reduction and the time delay effect, and investigate its robustness and efficiency.

5. To compare between the relative efficiencies in controlling the responses obtained by (i) sliding mode control with ATMD/actuator at the top, (ii) LQR feedback control with ATMD, (iii) LQR feedforward-feedback control with ATMD, and (iv) hybrid control using VED and ATMD/actuator at the top.

The robustness of the sliding mode control, feedback control and feedforward-feedback control schemes is investigated for the errors in feedback response measurement and errors in the determination of mass and stiffness properties of the structure. The errors are systematically introduced one at a time. A ten-storey building frame is taken as an illustrative example for the control problem. Three types of ground excitation namely, narrow band, broad band, neither narrow nor broad band are considered in the study. These ground excitations are synthetically generated from the specified PSDF of ground acceleration. No time delay is considered in the control algorithms. In order to investigate the robustness of the control algorithms, errors are introduced in the feedback measurement and in the measurement of the ground excitation. The changes in the response reductions and the control forces for varying degrees of measurement errors are obtained for each of the algorithms used. Similarly, error in the determination of system properties namely, mass matrix and stiffness matrix are introduced to obtain the changes in the responses. In both cases, the optimum control parameters are kept same as for the no error condition. The results are analysed and systematically compared. Some of the important conclusions are: (i) sliding mode control strategy is not as robust as it is claimed, at least in terms of the variation in mass and feedback measurement errors; and (ii) in terms of robustness against feedback measurement error, sliding mode control is found to be slightly better than LQR algorithms.

A hybrid control strategy using VEDs and ATMD/actuator is developed by modeling VEDs as Maxwell element and developing a control law based on theory of sliding mode control. The same 10-storey building frame is analysed for three types of excitation as mentioned earlier. The efficiency and robustness of the hybrid control scheme are investigated and compared with active control schemes by an extensive numerical study. Some of the important conclusions of the study include: (i) there exists some optimum combination of the elements of the weighing matrix which provides best control of response quantities of interest and they may vary with excitation; (ii) hybrid control scheme with VEDs is not an effective proposition, since its performance is marginally better than the active control scheme; and (iii) its robustness in marginally better than the active control scheme.

A method of semi-active control of building frames using fuzzy logic and multiple semi-active hydraulic dampers (SHDs) is developed in MATLAB environment using SIMULINK and FUZZY toolbox. The composite dynamic resistance of the bracing and SHD are modeled as Maxwell element. Three rule bases namely, drift, velocity, and drift and velocity based, are considered for design of fuzzy controller. Fuzzy controller that drives the SHD is designed for only one SHD at the bottom floor, and the damping coefficients to be generated by SHDs at other floors are assumed to hold a definite ratio with that of the bottom floor SHD. Thus, an additional parameter, the ratio of damping coefficient is introduced in the control scheme. Best combination of different parameters, which leads to maximum reduction of a response quantity of interest, is obtained by a systematic search. In order to compare the performance of fuzzy rule base algorithm, a five-storey building under ElCentro earthquake excitation is analysed and results are compared with those of LQR algorithm. Then, the same 10-storey building frame under three different types of excitation is considered for the parametric study, to investigate the efficiency and robustness of the control scheme. Some of the important conclusions of the study show that: (i) fuzzy rule based semi-active control scheme is highly effective in controlling the response of the building frame under seismic excitation; (ii) the combination of the optimum parameters for best control of response varies with the rule base used and the excitation; and (iii) within practical range of errors (upto a limit of 10%), the semi-active control scheme is found to be quite robust.

Finally, a simple ANN based active control scheme which directly takes into account the time delay effect, a target reduction of response and a limited number of response measurement is developed. The training of the neural net is based on the principle that the frequency contents (in the form of PSDF) of excitation and the control force have the same nature of variation. This enables to model future earthquakes and the corresponding control force. First, a single-degree-of-freedom (SDOF) system is controlled by training a neural net having inputs as ground acceleration, structural responses (displacement, velocity and acceleration) and a target percentage reduction of response. The output of the net is the control force. For generating the training data, the SDOF system is analysed for synthetically generated data from different types of PSDFs. Control force is simulated from similar shapes of PSDFs. The concept is then extended for multistorey frame by taking feedback responses from three arbitrarily selected storeys. The same ten-storeyed building frame is taken as an illustrative example.

ElCentro earthquake record is considered as the unknown problem for testing the efficiency and robustness of the ANN control scheme. Some of the important conclusions of the study are: (i) the proposed ANN scheme provides reasonably effective control of responses in comparison to the other control schemes; (ii) the effectiveness of the ANN control scheme is quite satisfactory even with a time delay of $2\,\Delta t$; and (iii) the proposed ANN control scheme is quite robust within practical range of errors in the estimation of structural properties.

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