ACTIVE CONTROL OF BUILDINGS UNDER SEISMIC EXCITATION

By

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DEDICATED TO

☼ OF MY INSP[redacted]TIONS

CERTIFICATE

This is to certify that the thesis entitled, "**Active Control of Buildings Under Seismic Excitation**", being submitted by **Mr. Sarbjeet Singh**, to the Indian Institute of Technology, Delhi, for the award of the Degree 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 this 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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!! *Even thousands of lives are short to acknowledge this environment* !!

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SARBJEET SINGH

ABSTRACT

Safety of tall structures, specially high rise buildings, under earthquake excitation is a problem of major concern. Many types of active control strategies have been proposed in recent years for increasing the safety of such structures against large seismic shocks. Also, they are proposed for protecting vital equipments housed in important buildings against strong ground motion and for improving living comforts during earthquakes of moderate intensity. Despite intensive research on the subject, research is still continuing in order to develop more effective control strategies and to understand the parametric behaviour of controlled responses. The present work is aimed at developing a few control strategies for idealized building frames under seismic excitation, whose relative efficiencies are investigated with respect to the conventional feedback control strategy. These control strategies include linear and nonlinear open-closed loop control strategies; linear closed and open-closed loop control with improved performance function; continuous sliding mode control; and nonlinear continuous sliding mode control. The effectiveness of each control strategy is investigated through parametric studies which are also aimed at understanding the nature of controlled responses under the variation of important parameters.

A linear open-closed loop active control strategy is developed to control the response of idealized building frames by employing an AMD placed at the top story. The AMD is tuned to different frequencies in the vicinity of the first two frequencies of the structure and the predominant frequency of the ground

motion. The open-closed loop control strategy is formulated by expressing the ground motion (acceleration) as a filtered white noise. As a result, structure-filter system has state vector containing both structural motions and outputs from the filters. The control law is derived by minimizing a quadratic function of state variables and of control force. The control force is obtained by solving the Riccati equation. Both controlled and uncontrolled responses are obtained by solving the state space equation of motion in time domain using Runge-Kutta third order integration method. The responses of interest are obtained from 20 simulation results. It is shown that the open-closed loop control strategy provides better reduction in response than that provided by the closed loop control strategy. Further, if provision of both active and passive controls is intended, then the open-closed loop control strategy is desirable.

Both linear closed loop and open-closed loop control strategies with AMD placed at the top story of the frames are presented by minimizing an improved performance function which includes acceleration response, without incorporating the actuator dynamics. The weightage of the participation of the structural acceleration in the performance function is regulated by incorporating an acceleration weighting factor. The control force is obtained by minimizing a quadratic performance function. The results of the study indicate that the proposed control strategies provide a better reduction in acceleration response only compared to the conventional control strategies (closed and open-closed).

A nonlinear open-closed loop control strategy based on higher order performance function is presented for the control of the responses of building frames using AMD. The control law is derived by minimizing a higher order performance function expressed in terms of the state variables and the control force. The control force consists of a linear and a nonlinear part. The gain matrices for both are obtained by solving the Riccati equation. The nonlinear part of the control force is controlled by a weighting factor α. The controlled responses are obtained by solving the state space equation in time domain as mentioned before. Relative efficiency of the nonlinear control strategy is compared with those of nonlinear closed loop, and linear open-closed loop control strategies under a set of parametric variations. Results of the study indicate that nonlinear open-closed loop control strategy provides better control of responses compared to the conventional linear control strategies and the nonlinear closed loop control strategy.

Sliding mode control is implemented for controlling the response of building frames. Control strategies are developed for both cases i.e for state vector containing structural displacement and velocity, and for state vector containing ground excitation variables in addition to the structural displacement and velocity. The sliding surface for the control is designed consisting of a linear combination of the state variables. The sliding surface is generated by minimizing a quadratic function of the variables. The continuous controller is designed to drive the state trajectory into the sliding surface by considering the Lyapunov function and by taking into the consideration of the matched uncertainty in the input control. Also a continuous controller is designed to provide bounded motion about the nominal sliding mode dynamics in the presence of bounded matched uncertainty in control input and unmatched uncertainty in the excitation input (referred as nonlinear continuous sliding

mode control). Both types of sliding mode control strategies are implemented with the help of AMD placed at the top story. In addition, the first sliding mode control strategy is implemented with (i) only actuator placed at a floor of the building frame and (ii) TMD placed at the top story and an actuator applied at a floor. Extensive parametric study is conducted to evaluate the relative effectiveness of the sliding mode control strategies. The results of the study indicate that the sliding mode control provides better control gains compared to the conventional control strategies over a certain range of control force. Also, the sliding mode control strategies are more stable than the conventional control strategies.

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