STRUCTURAL CONTROL OF BUILDING FRAMES SUBJECTED TO EARTHQUAKE INDUCED EXCITATIONS USING SHAPE MEMORY ALLOYS

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by

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Dedicated

to

My Parents

Certificate

This is to certify that the thesis entitled, **"Structural Control of Building Frames Subjected to Earthquake Induced Excitations using Shape Memory Alloys"**, being submitted by **Mr.Vimal Kumar Gupta,** 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.

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Vimal Kumar Gupta

Abstract

The Ni-Ti Shape memory alloys (SMAs) display the large ductility (Superelasticity), higher resistance to corrosion and fatigue, stable transformation temperatures and ability of shape recovery on heating i.e. Shape memory effect (SME) make them an attractive material for structural control devices and therefore their applications has been extended to semi-active control, hybrid control and smart passive control in the present study. Shape memory alloy has shown vast potential for engineering applications in the field seismic hazard mitigations of civil engineering structures. Although extensive researches have been carried out in the area of structural control, relatively less work has been reported on semi-active and hybrid control of building frames subjected to earthquake excitation using SMA devices. The superelasticity and SME are the two fundamental properties of SMAs associated with the stress-induced or thermal-induced reversible hysteretic phase transformation between austenite and martensite. These unique properties enable SMA to be used as control devices for civil engineering structure control. The SMAs can be employed as passive, semi-active or active component in structural control. The most applications of Ni-Ti SMAs in civil structural control are focused on using passive control devices which takes advantage of the damping property of super-elastic shape memory alloys.

The present study is based on the analytical investigation of the structural behavior of Ni-Ti SMA, a smart material, for potential application in vibration control of building frames subjected to the ElCentro and San Fearnando cover the aspect of far – field motion and the Kobe and Northridge cover the aspect of near-field motion.

In particular, the Nitinol (Nickel Titanium Naval Ordinance Laboratory) SMA is proposed for implementation in the form of Ni-Ti wires as the core component of the SMA based smart structural control devices for semi-active control, smart passive

control, smart base isolation, and hybrid control of building frames subjected to earthquake ground motions. The objectives of the present study may be summarized by the following tasks:

i) Integration and implementation of realistic and efficient hysteretic models of Ni-Ti SMA in simulated structural control systems based on available experimental data.

ii) Analytical modeling and simulation of semi-actively controlled building frames using Ni-Ti based SMA devices under the influence of earthquake ground motions.

iii) Analytical evaluation of the suitability and efficacy of SMA dampers in smart passive control of building frames.

iv) Analytical investigation of the feasibility of SMA based devices in seismic base isolation. The SMA base-isolation devices may be passive or semi-active in nature.

v) Formulation of a hybrid control method using passive SMA dampers and an active mass damper (AMD) for structural control of building frames.

vi) Validation of the proposed SMA based structural control systems by examining the stability of the conceptual designs using frequency domain analysis.

The semi-active control of earthquake induced vibrations in building frames based on smart stressing of building frame using shape memory alloys. Smart cables composed of (Ni-Ti) shape memory alloy (SMA) wires are proposed to be installed externally with concrete building frame elements. In principle, the cables can be designed such that the SMA wires are elongated beyond their plastic limit under the action of earthquake loads on the frame. Upon regulating electrical heating, the Ni-Ti SMA wires will undergo a martensite to austenite phase transformation resulting in large shrinkage strains. The strain energy, thus induced can be used to generate a significantly effective control force in the building frame. The concept is analytically investigated by numerical simulations of proposed semi-active control scheme in an idealized single degree of freedom and multi degree of freedom structural frame model. Some of the important conclusions of the study are: i) the proposed semi-active control technique implementing the SMA based tendon is distinctly effective in the response reduction of the building frame; ii) position of tendons has significant effect on the control of response. The semi-active tendons at alternate floors provide the maximum control of response for all storeys; iii) the Ni-Ti Semi-active tendons are more effective in response reduction than the Ni-Ti Passive dampers.

The new concept of smart passive control of earthquake induced vibrations in building frames based on the dissipation of energy by using shape memory alloy (SMA). The proposed smart passive control scheme originates from a passive control system, based on martensite & austenite co-exist wires. In this version, the system monitors the feedback measurements and accordingly strain is adjusted continuously in the Nitinol wires for safe functioning of dampers of building frame subjected to earthquake. Some of the important conclusions of the study are: i) the smart passive control show the significant reduction of response in term of displacement, velocity & drifts; ii) the SMA based smart passive control system provides the protection for a wide range of earthquakes. Thus the adaptable nature of the smart passive control allows a structure to be protected against to all sizes of earthquake ground motions.

Base isolation strategy provides a very effective passive method of protecting buildings against earthquakes. The proposed smart base isolation system is composed of laminated rubber bearings and shape memory alloy (SMA) dampers. The smart base isolation utilizes the potential of the SMA dampers to control the responses of the base isolated building frames subjected to various ground motions. Three cases for isolation system are considered, base isolation alone, isolation with passive mode of SMA and Semi-active mode of SMA. Some of the important conclusions of the study are: i) the semi-active SMA damper system provides the superior protection; ii) the adaptable nature of the semi-active SMA damper system allows a structure to be protected against extreme earthquakes, without sacrificing performance during mild & moderate earthquakes.

The proposed hybrid control system consists of Active mass damper and passive damper in the form of Shape memory alloy wire damper. Passive SMA Dampers are installed in the lower storey and the AMD is placed on the top of the building frame. The control algorithm is developed by considering structure AMD together. The effectiveness of the following control schemes is compared: i) only AMD, ii) only SMA dampers and iii) AMD and SMA dampers. Some of the important conclusions of the study are: i) hybrid control technique is more efficient than active control in that the smaller actuator is required; ii) it is adaptable in nature to change in ground motion; iii) the SMA based hybrid control system possesses the same response reduction capacity as SMA passive control, but it requires smaller control force than a passive control system for mild and moderate earthquakes.

In the frequency domain approach, the transient response performance is specified in terms of the phase margin, gain margin and resonant peak amplitude. In this study the one of the frequency domain approach, bode plot is used. The advantage of frequency response analysis is that the stability of a closed loop system can be determined from the frequency response of an open loop system. The performance of the control methods is investigated for a single story building frame and an eight story building frame connected with shape memory devices. Some of the important conclusions of the study are : i) the transfer function is stable and bode plots support the low response at higher frequency input and the peak of transfer function is observed at the natural frequency of the structure; ii) the H_2 control performed a better response at a smaller control force.

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