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Active protection systems of constructions to seismic actions

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Summary

The main scope of this thesis is the investigation and the development of the passive, active, hybrid and semi-active control concept applied to civil engineering structures in order to mitigate the vibrations produced by severe winds and earthquakes.

It aims to obtain a reorientation in the civil engineering field like European one's through the development of the information about control techniques and the presentation of the modern technologies applied to civil structures in order to increase the protection and security of the citizens live and the monitoring of the most important constructions.

The structural engineer will have the possibility to choose with respect to the economic and seismic risk criterions which of two design concepts of the seismic protection will use it – the ductility and *internal* energy dissipation concept or the *external* protection of the constructions using one of the control systems analyzed in this paper.

The thesis is systematised in seven chapters which analyse clearly and unitarly the following aspects:

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In first and second chapter, the development of the *structural concept* and the most representative literature review on structural control has been presented. However, only a limited number of references are cited. The author has done his best to present a balance view of the developments in the field of structural control.

It's presented the necessity in using of these control systems for the protection and the safety of the constructions to seismic actions.

There are described the compound elements of the main types of control and also the examples of the structures protected with control system. In the same time there are discussed the advantages and disadvantages of the methods. From the analyze of the existent system's behavior it results a number of disfunctionalities, which are possible to occur at similar functional systems or at the systems which are in design process. In final of the chapter are described smart materials which may be included in the structural elements or define components of the vibration control devices.

In the third chapter are treated the follows: vibration isolation, differences and similarities between passive and semi-active control and between active and semi-active control, active control strategies based on the integration of acceleration feedback and the integration of force feedback, analytical representation of state-space models for the response estimation of a structure at which it's attached a passive or active control system, linear quadratic optimal control (LQR), processes of energy dissipation (internal damping - viscoelastic, hysteretic; structural damping - Coulomb friction; equivalent viscous damping), energy balance and design concept on energy criterions.

The semi-active devices are distinguished from comparative analysis of control systems because they can be used for reducing the input energy and the energy dissipation introduced in a structure by strong winds and seismic actions.

The stability is guaranteed, in the sense that no instability can occur, because semi-active devices utilize the motion of the structure to develop the control forces as in the passive control, and therefore a semi-active control system needs a small power source, e.g a batery, only to change the mechanical proprieties of the device. An active control system requires large electric power, from tens kilowatts to several megawatts, to control actuators that apply forces to the structure taking into account the mass of the construction equipped so that.

The fourth chapter is a bibliographical review of the most studied semi-active techniques. A semi-active control system requires a little amount of energy in order to change the characteristics of a passive dissipation device. The semi-active control devices dissipate energy in structure and are seen as passive damper, but can achieve the performance of an active system. The semi-active devices are always stable because they remove the energy requirement for a structure, not add

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input energy in a structure as in an active control case. However, the control forces by a semi-active device may be increased or decreased by external power source through the value of voltage applied to the current driver *U*. The semi-active control methods that are included in this discussion are open loop, on-off skyhook, continuous skyhook, on-off ground-hook, continuous ground-hook, direct Liapunov, clipping, modulated homogeneous friction, bang-bang and instantaneous optimal control. The author, in programming language, elaborated and developed the semi-active control implementation algorithm for each strategy (as reference the programming language is C++).

Fifth chapter deals to the Tuned Mass Damper (TMD) and Semi-Active Tuned Mass Damper (STMD) to control vibrations of a structure. It's found that the STMD can substantially improve the steady state response of the structure controlled with TMD around the tuning frequency over the passive TMD. The control performance is not effective during transient period.

Sixth chapter is devoted to the experimental activity regarding the implementation aspect of the passive and semi-active control devices.

The research work of the author who effectuated a training period during 1 year - Marie Curie Training Site Fellowships - at the European Laboratory for Structural Assessment in Ispra, Italy, is part of Testing of Algorithms for Semi-Active Control of Bridges (TASCB) project under European Consortium of Laboratories for Earthquake and Dynamic Experimental Research (ECOLEADER) programme. The aim of the project is to evaluate and compare semi-active laws for the controllable friction devices mounted between deck and piles in a realistic bridge structure subjected to severe earthquake ground motions, using the sub-structure PsD test method that allows a realistic nearly full-scale test without having to build a real bridge.

The experimental results in passive case demonstrated that the device was able to absorb half of the total energy input of the earthquake, decreasing the maximum displacements with 30% when the PsD test was made for 30% of EC8. Also the author has been developed appropriate control algorithms for the experimental semi-active case: passive control, modulated homogeneous friction control, modulated equivalent viscous damping control and clipping control.

The final conclusion is that the structure response is approximate identical in the analyzed cases. The use of the semi-active control methods is due to the reducing of the voltage applied to the current driver *U* and the period increase of the DSF live at normal parameters, which have the economic effects in time.

Numerical and experimental results obtained in the sixth chapter are in good concordance with these obtained by the others researchers, underlining the

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advantages of the semi-active control devices in comparison with (as against) the passive control systems.

Keywords: structural control systems, seismic action, earthquake engineering, energy dissipation, seismic protection and dynamic model.

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