1 INTRODUCTION

1.1 Motivation

The modern approach to seismic design of buildings includes life safety as well as performance and for this reason it is named *performance-based design*. Thus a level of seismic protection can be chosen in accordance to the importance of the building and on the requirements of the owner. In case of hospitals for example, the post-earthquake damage can't compromise the normal efficiency of the aid system. Another example concerns high tech industry buildings which house sensitive and expansive equipment. Repairing the damage undergone by these instruments can be much more expansive than the preventive retrofitting of the structure. In all these cases the design of the building is made on the base of the allowable damage relative to a certain expected performance.
There are several ways to achieve these performances both in new constructions and in retrofitting. Conventional techniques of strengthening, active or passive control systems or base isolation can be used. Among them, viscous dampers have received particular attention in rehabilitation of structures because of several advantages discussed in chapter 2. These devices increase the capacity of the structure to absorb the energy due to seismic excitation controlling the vibrations of the building.
Although, since the costs of such a technology are not negligible, the placement of such devices must be as effective as possible. In order to do that and thus allow their diffusion in civil engineering, the use of optimization methods are recommended.
Several methods of optimization have been proposed but a serious comparison on their efficiency still lacks. Since these procedures make use of different types of analyses and, consequently, seismic inputs, the results should be compared in order to highlight the relative advantages and disadvantages. Note however that the observations are dependent on the typology of structure considered and therefore general conclusions can't be achieved.
The present thesis addresses the comparison between the final configurations of damping achieved by these optimization methodologies and their relative performances.

1.2 Theoretical background

Based on the concept of the controllability index proposed by Cheng and Pantelides (1988), Zhang and Soong (1992) developed the so called sequential search algorithm. In this procedure damping was added sequentially in correspondence to the locations where the mean square value of inter-story drifts is maximal. Initially proposed for viscoelastic dampers, the method is easily adaptable for viscous devices and its efficiency was proved by Shukla and Datta (1999).

Optimal control theory for linear dynamic systems was exploited by Gluck et al. (1996). The linear quadratic regulator solution, used in active control, was adapted for passive control devices, such as viscous and viscoelastic dampers.
Frequency domain analysis is the base also of the method of Takewaki (1997) and its second improved version Takewaki and Yoshitomi (2010). In this case the amplitude of the transfer function relative to the first mode of vibration is considered and the initial damping configuration is modified due to its first order sensitivities. Developed from a formal optimization solution this method attempts to minimize the sum of the amplitudes of the transfer function, in the first version, or their maximal value, in the most recent development. This method was extended to three-dimensional structures by Takewaki et al. (1999).
Singh and Moreschi (2001) were the first to apply the Genetic Algorithm to the problem of optimal placement of viscous dampers. Although this procedure is not considered in the present thesis since it requires a wider knowledge of optimization techniques which are not part of the engineering practice background.
Garcia (2001) proposed the first method that makes use of time domain analysis. The concept is the same of the sequential search algorithm: damping increments are sequentially added in correspondence to the location where a certain performance index is maximal. Since this index is obtained from a more common time-history analysis, the method was named as simplified sequential search algorithm.
Finally, based on the results of formal optimization approaches like the gradient derivation (Levy and Lavan 2004 and 2006), Levy and Lavan (2005) presented an iterative procedure that, using time-history analysis, leads to the configuration of dampers that assures certain performances. In order to decrease the effort due to the number of ground motions to be run, the time-history analysis was substituted with the solution obtained by Lyapunov's equations Levy and Lavan (2009). This solution in fact represents the stochastic response of the structure excited by a white noise seismic input and thus can be used as performance indicator.

1.3 Research method

First a presentation of each method is carried out in order to get familiar with the mathematical algorithms. General observations on the efficiency of the different procedures are reported at the end of each chapter. The three-story building presented in (Gluck et all 1996) is taken as example in order to give the possibility to compare the results if someone is interested in the implementation of such method. The MATLAB codes are finally reported.
In the second part of the thesis a more realistic application of these optimization processes is presented. The nine-story building studied in the SAC project is taken into account and equipped with the damping systems resulting from the different methods. A

verification is finally carried out with the same seismic input used for the design and the different performances are compared.

1.4 Thesis structure

The basics of structural dynamics that are used in the explanations of the different methods are presented in Annex A. Besides the common time domain analyses, particular attention is given to frequency domain analyses and stochastic response of structures.
Chapter 2 describes the theoretical background more specifically related with the passive control of structures. A brief explanation of the most known passive control devices is presented in order to highlight the advantages of viscous dampers. Then this latter specific type of device is considered and its modeling as well as its classical design are presented.
The explanation of the different methodologies occurs from Chapter 3 to 6. First the oldest of these methods is considered: the linear quadratic regulator Gluck et all (1996). This procedure comes from the optimization tools used for linear dynamic systems and hence represents a particular case.
Chapter 4 describes the analysis-redesign methodologies, that is, procedures that achieve the final configuration iteratively updating the current damping distribution on the basis of the previous analysis. The first version was developed from observation on the achievement of the final damping configuration using formal optimization formulation, i.e. gradient derivation. In the second version the time-history analysis is substituted by the Lyapunov's solution bringing to a computationally slighter algorithm.
Chapter 5 presents the so called sequential search algorithms, that is, methods where low increment of damping capacity are placed sequentially along the structure according to a location index. This location index can be derived from frequency domain analysis, as in the case of Zhang and Soong (1992), or from time domain procedures, as in the simplified version of Garcia (2001).
Chapter 6 is spent for the method developed by Takewaki and Yoshitomi (2010) which uses the frequency transfer function sensibilities. This procedure is developed from a formal optimization approach developed using frequency domain analysis.
The comparison of the results and the performances obtained from these methodologies are finally discussed in Chapter 7 after the description of the structure and of the seismic hazard used. The different configurations of dampers are evaluated for each procedure using the same total amount of damping. Then the performance in term of inter-story drifts is computed using time-history analysis in order to compare the efficiency of each distribution.

1.5 Main results

The damping configurations obtained from the different designs are quite different and three trends can be observed. The performances in terms of inter-story drifts of time-domain analysis-redesign and the simplified sequential search algorithms are well concentrated near to the level of the allowable values.

Algorithms developed by Takewaki and Yoshitomi (2010) and Zhang and Soong (1992) bring to similar configurations also if the seismic input considered, a sinusoidal wave in the first case and a power spectral density in the second one, are conceptually different. Their performances highlight the trend to concentrate damping in the soft story of the structure leading to higher drifts on the last floors.

On the other hand the solution given by the linear quadratic regulator presents instead a lower amount of damping in correspondence to the soft floors and for this reason its use it is not recommended. Despite of this, the performances of this method are quite similar to the ones obtained from time-history analysis-redesign. This could be due to the particular type of structure analyzed which requires a spread distribution of damping rather than a concentration of it.

Lyapunov’s solution finally, also if brings a damping configuration similar to the one of time-history analysis-redesign, presents performances more similar in shape to the minimum transfer function method.

It is to underline however that the choice of the procedure to use does not depend only from the obtained performances. Also the availability of computational tools and the velocity of the process must be considered.