

A Strategy for the Optimization of Damper Configurations based on Building Performance Indices

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Summary

The objective of this research is to develop an effective and efficient design methodology for optimizing the configurations of energy dissipation devices (EDD) based on building performance objectives. Current design codes do not provide any guidelines for the optimization of EDD configurations. Previous research efforts are either limited in addressing different performance indices or not efficient. The proposed methodology uniquely combines the evolutionary approach and engineering knowledge to optimize EDD configurations for optimal structural performance under earthquake excitations. It is effective in that resulting optimal configurations minimize the response of different performance indices such as interstory drift or acceleration. It is also efficient in that the probabilistic-based exploration of the evolutionary approach is guided by modal-analysis-based heuristic knowledge.

Introduction

Addition of energy dissipation devices (EDDs) is considered one of the viable strategies for enhancing the seismic performance of building structures. It is known that the EDD configuration can have a significant effect on the structure response under earthquake excitations. For many building structures, optimal configurations of EDDs may provide considerable performance improvement or cost saving. For instance, given a fixed number of EDDs, some configurations may allow the structure to achieve its performance objective while some may not. Similarly, an optimized configuration may reduce the number of EDDs required to achieve a target performance objective.

Current design provisions (FEMA 2000, 2001) provide some design procedures for structures with added EDDs. Supplemental damping provided by added EDDs is accounted for through an effective damping ratio, which in turn is used to reduce the design seismic forces. Structural members can then be designed for the reduced seismic forces. However, no guidelines for the optimization of EDD configurations are provided.

Brief Review of Previous Research

Several parametric studies on the effect of damper capacity and damper location have been conducted. Chang et al., (1995) investigated the seismic behavior of a steel frame structure with added viscoelastic dampers. Hahn and Sathivageeswarm (1992) showed that dampers should be placed in the lower-half floors of buildings having uniform story stiffnesses. Because these studies always use simple and regular structures, their results cannot be used for optimization.

Some researchers investigated the optimal capacity of EDDs based on analytical optimization approaches. Several objective functions have been considered: maximum displacement under white noise excitation (Constantinou and Tadjbakhsh 1983), energy (Gurgoze and Muller 1992), system response and control gain matrix (Gluck et al., 1996), pre-assigned modal damping and natural frequency (De Silva 1981), norm of the transfer function (Spencer et al., 1994, Takewaki 1997), total story stiffness (Tsuji and Nakamura 1996) or the desired level of response reduction (Singh and Moreschi 2001). These approaches lead to device sizes that may not be practical for commercial products. Furthermore, it is not possible to define analytical objective functions valid for any arbitrary ground motion.

Some researchers have used heuristic approaches to obtain the optimal placement and capacity of EDDs. Zhang and Soong (1992) and Shukla and Datta (1999) proposed and extended the sequential seismic design method to find the optimal configuration of viscous dampers for buildings with specified story stiffnesses. They used an intuitive criterion to place additional dampers sequentially on the story at which the interstory drift response is a maximum. Lopez Garcia (2001) simplified this approach and showed that it is effective for drift response. These heuristic approaches are practical. However, results from Singh and Moreschi (2001) showed that the sequential approach proposed by Zhang and Soong obtains very low reduction of acceleration response, especially for buildings with non-uniform story stiffnesses.

Singh and Moreschi (1999) used a genetic algorithm to obtain the optimal configuration of EDDs for a desired level of response reduction. They showed that genetic algorithms are powerful tools that lead to optimal configurations if the number of iterations is large enough. However, this approach is computationally expensive.

Proposed Methodology

In this research, a new optimization methodology is proposed for the optimization of EDD configurations. It combines the efficiency of heuristic procedures with the effectiveness of evolutionary approaches. The proposed method searches the optimal solution by generating new configurations, which are obtained by improving previous configurations. This is achieved by increasing the damping ratio of the modes dominating the response. In doing so, the indexed structural response is reduced. The derived optimization procedure can be implemented in computer programs so that it can be used routinely by designers.

Once a performance index is selected depending on the building performance objective, an initial EDD configuration is defined. Modal analysis is then performed and the contribution of each mode to the response quantity of interest (performance index) is obtained. EDDs are then redistributed in such a way that damping ratios of the modes dominating the response are maximized. The procedure is an iterative process intended to explore the solution space and to escape local optima.

Current Status of Research Project

The developed optimization procedure is being implemented into a software package intended to provide the optimal EDD configuration given a structural model, external loads and a performance index. Results will be compared with results given by other available optimization strategies. Both the sequential approach and the genetic algorithm will be considered.

Contribution to the State-of-the-art

The proposed methodology provides an optimal solution for the EDD design problem under earthquake excitations. Different from other procedures for earthquake engineering applications, the proposed methodology uses a new approach to integrate the design of EDDs with performance-based engineering. The benefits of this new approach includes:

- It provides either the best performance or the most cost-effective design.
- It is effective for different performance indices.
- It is more efficient than random search. It adapts the powerful evolutionary approach but adds problem-specific knowledge to guide the search. Therefore, the optimal solution is obtained more efficiently.
- It is theoretically sound because the heuristics is based on structural dynamics theory and practice.

Example

The proposed optimization procedure is applied to a 10-story building structure having uniform mass and stiffness properties along its height. The story mass is equal to 2.5×10^5 kg and the story stiffness is equal to 4.5×10^5 kN/m. The natural period of the first mode is 1.0 sec. The damping ratio is assumed equal to 3%. The design load is an artificial ground acceleration history whose peak acceleration is equal to 0.40 g.

The selected initial configuration consists of 80 linear viscous dampers uniformly distributed along the stories. The damping coefficient of each damper is equal to 5×10^5 Ns/m. Two different performance indices are considered: interstory drift and absolute acceleration. Different optimal configurations are obtained for each performance index. Figure 1 shows results for performance index interstory drift. Figure 1a shows interstory drift response at each story for different EDD configurations. Maximum interstory drift is reduced by 20% after the optimization. Figure 1b shows the EDD configuration before and after optimization. Figure 2 shows results for performance index absolute acceleration. Figure 2a shows absolute acceleration response at each story for different EDD configurations. Maximum story acceleration is reduced by 8% after the optimization. Figure 2b shows the EDD configuration before and after optimization.

Future Research

There are several directions for future research.

- Improvement of heuristic search in order to use not only modal damping but also mode shapes.
- Although the methodology can be extended to other devices such as yielding metallic or friction dampers, the current formulation is limited to viscous devices only. The location effectiveness must be formulated based on different device characteristics.
- Extension of the modal-analysis-based optimization to other dynamic design problems.

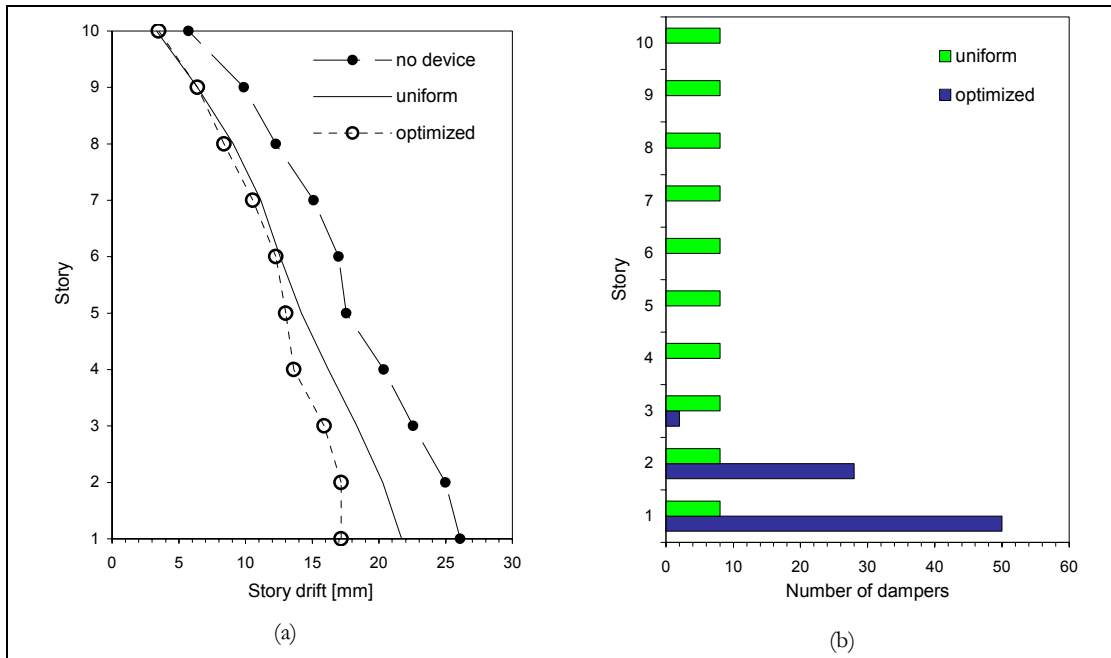


Figure 1. Optimization of EED configuration for performance index interstory drift

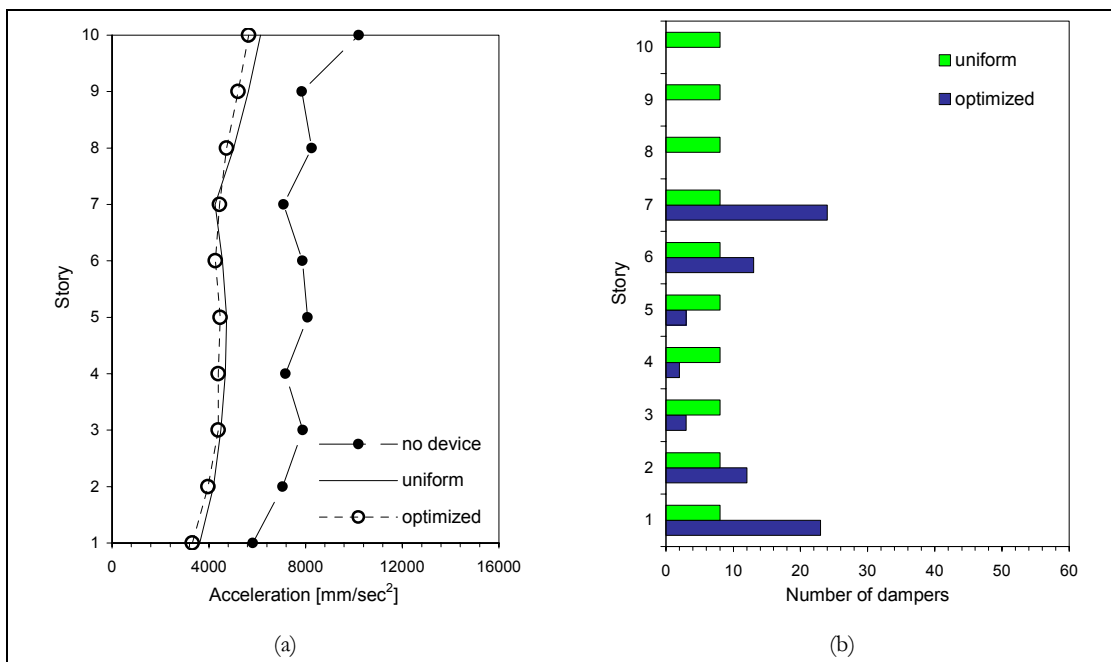


Figure 2. Optimization of EED configuration for performance index absolute acceleration

Concluding Remarks

Results of this research indicate that the optimization of EDD configurations can improve the structural performance under earthquake excitations. For a given performance level, the optimization may also reduce the cost of supplemental EDDs. The proposed optimization methodology can effectively obtain the optimal device configuration for different performance indices.

Acknowledgements

This research was carried out under the supervision of Dr. George C. Lee and Dr. Mai Tong, and supported by the Multidisciplinary Center for Earthquake Engineering Research.

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