Application of a first order optimization method for the seismic retrofitting of buildings using MTMDs

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ABSTRACT:

The main criterion in seismic design under strong ground motions has long been limiting the amount of casualties. The financial consequences of recent ground motion (e.g. Northridge, 1994; Kobe, 1995; Christchurch, 2011) led to the notion that financial criteria should also be considered. This led to the development of performance-based design (PBD) philosophy, where limiting damage under less severe ground motions is also considered. This also motivated retrofitting of existing structures.

One of the advanced means for retrofitting such structures, relies on passive control devices. These devices dissipate a portion of the structure's input energy, hence reduce its dynamic responses. One type of such a device is the tuned-mass damper (TMD), adopted herein as the means of control. Such devices are comprised of a mass that is connected to the structure by a spring and a dashpot in parallel. It can efficiently reduce the response of a linear system to a harmonic loading over a specific narrow band of frequencies. Therefore, the application to wind design is straight-forward. Under seismic events, it has been shown that multiple TMDs (MTMDs), tuned to various frequencies have an advantage over a single TMD.

Several methodologies for the seismic design of structures using MTMDs (determination of locations, tuning frequencies and damping coefficients) exist. However, a methodology that allows a formal optimal design for this PBD problem, using a relatively small computational effort, without predefining the amount of added devices, their locations, modes to be dampened, or sizes, has not yet been proposed. This paper presents a first-order formal optimization methodology to constrain various structural responses, while minimizing the amount of the

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added masses of TMDs. This is enabled by efficiently performing a sensitivity analysis, using the adjoint-analytical method (the adjoint method is especially beneficial in problems, such as the one formulated herein, which have many design variables and only a few constraints). The equations of motion are solved using Lyapunov's equation, to obtain RMS responses of interest.

The example herein, of an 8 story asymmetric structure, was executed several times, using either total accelerations, inter-story drifts, or both, as constraints. When the optimization was carried out using acceleration constraints solely, TMDs were allocated only to locations where the total accelerations reached their allowable values. This confirms part of the intuitive optimality criteria proposed by Daniel and Lavan [1]. Furthermore, it is confirmed that MTMDs may present an efficient alternative for seismic retrofitting, making it attractive for multi-hazard mitigation of both winds and earthquakes. Other results show that the design methodology can efficiently and successfully consider constraints on multiple responses, and that the design methodology could also iteratively take into consideration desired reduction in peak envelope responses in time-domain.

REFERENCES:

[1] Y. Daniel O. Lavan, Seismic Design Methodology for Control of 3D Buildings by Means of Multiple Tuned-Mass-Dampers, Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2011), Greece, May 2011, paper No. 147, 2011.