IMPROVING THE EARTHQUAKE RESPONSE OF HIGH BUILDINGS BY BIONICALLY OPTIMIZED PASSIVE TUNED MASS DAMPERS

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1. Abstract

To prevent high buildings in endangered zones to suffer from seismic attack, Tuned mass dampers (TMD) are applied successfully. In many applications the dampers are placed along the height of the edifice to reduce the damage during the earthquake. The dimensioning of TMD is a multidimensional optimisation problem with many local maxima. To find the absolute best or a very good design, advanced optimization strategies have to be applied. Bionic optimization proposes different methods to deal with such tasks but requires many repeated studies of the buildings and dampers design. To improve the speed of the analysis, the author proposes a reduced model of the building including the dampers. A series of consecutive generations shows a growing capacity to reduce the impact of an earthquake on the building. The proposals found help to dimension the dampers. A detailed analysis of the building under earthquake loading may yield an efficient design.

2. Earthquakes and TMD to reduce their impact

Among the disasters people are exposed to, earthquakes are one of the most damage causing ones [1]. Large numbers of fatalities and big economic losses are reported in many cases. In consequence engineering since long times is trying to design buildings that may withstand the dynamic attack or don’t suffer too much from it. The local physical event of a seismic may be handled as a series of horizontal and vertical shock waves which excite the base of a building. The building will show a dynamic response. This dynamic response may cause severe damage or even the total collapse of the structure. To prevent such destruction different approaches are available. They may be classified by increasing the static strength, isolation from the excited ground or compensation by elastically coupled masses along the buildings’ height.

Tuned Mass Dampers (TMD) [1] do the damping of the impact by sets of masses, springs and dampers. They might be active, driven by fast reacting control systems or passive, without any specific response to the actual loading. In any case the compensating system has to respond to a certain range of excitations. But as space in high buildings is expensive the total mass and space requirements of the TMD system have to be limited.

Designing efficient passive TMD requires a proposal of position, number and dimension of the compensators. This may include a certain number of compensators each defined by mass, stiffness and damping. As such a system with many degrees of freedom may have many local maxima, the optimization of a set of TMD’s could be a non-trivial task. Bionic strategies like Evolutionary Strategy (ES) or Particle Swarm Optimization (PSO) [3, 4] may help to cover larger regions of the parameter space and increase the probability to find good values if not even the best ones.

3. Tuned Mass Dampers

Tuned mass dampers, absorbers and compensators are terms used interchangeably for a class of systems that reduce the dynamic impact on structures. TMD are used to reduce the dynamic response of oscillating systems. Most of the basic formulations are derived in the famous book written by Den Hartog [2]. Resonances that would cause inacceptable vibrations are removed by the elastic coupling of additional masses which shift the Eigen frequencies and the amplitudes to regions and values that do not affect the usability of the system. The improvement of the dynamics of bridges and chimneys by compensators is well-known. If only one or two such absorbers are used, the dimensioning is relatively easy to do. As soon as there are many absorbers, the optimisation problem becomes more difficult as many local maxima inhibit an easy finding of the best dimensioning of the dampers.

4. TMD applied to a reduced building model

Dealing with real earthquakes and their impact on buildings requires the use of qualified models of the building including many details. Such models will have large numbers of degrees of freedom (dof). To come up with fast and realistic proposals of the dimensioning of TMD, we developed a new beam element representing a segment of a high and slender building including the TMD. Each element is used to model one or more floors of the edifice under consideration. The absorbers are an integral part of this element. The masses, dampers and stiffness associated with these segments' TMD are the free variables in the optimisation process. So each node has 8 degrees of freedom (dof), 3 dof for the nodes' translations, 3 dof for the nodes' rotations and the 2 dof for the in plane displacements of the TMD. Using this beam element we achieve a model with a small number of variables which may be used to determine the response of the proposed design without consuming too much computing time.

As the problem is multidimensional we use bionic optimization methods like Evolutionary Optimization or Particle Swarm Optimization [3, 4]. The mass, stiffness and damping of the compensators are the free parameters for the optimization of this TMD system. We observe a significant reduction of the dynamic load, so the proposals of TMD by the optimization process seem to be at least interesting. After the initial impact, the TMD-system reduces the oscillations of the top of the structure and the energy intake, so the consequences may be less severe than in the case without a damping system. This model may easily be expanded to more detailed structures by using the 8-dof-per node beams as columns of an edifice and adding their horizontal connections by additional beams or shells to model the floors stiffness and masses.

5. References

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