Structural Protection of Elegant Structures from Wind and Seismic Events

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Summary

At the hand of three slender structures, the authors propose required characteristics of an optimum protection system with Tuned Mass Dampers (TMD) from wind and earthquake and highlight their benefits. Such protection systems consisting of TMDs do not only ensure structural safety, but might also be of commercial relevance, as they may reduce the total construction costs.

Keywords: high-rise buildings, bridges, slender structures, seismic protection, structural protection, wind loads, damping, Tuned Mass Damper, viscous damper, semi-active damping

1. Introduction

Slender structures are relatively soft structures that may display considerable deflections when exposed to wind or earthquake. While vibrations caused by wind occur frequently and may make us feel uncomfortable, earthquake may never happen but when happens it will damage the structure. Both load cases lead to a different optimum protection. And, if a structure has to be protected from both service loads like wind and ultimate loads like earthquake, a protection against earthquake alone will neglect the demands caused by wind or other live loads. For example, an optimum protection system against earthquake will be unsuitable to mitigate vibrations caused by frequent service loads, and so in service stage we end up with an unprotected structure that is ultimately exposed to increased fatigue effects. It may fail if not regularly subject to maintenance.

2. Required characteristics for a structural protection system for service and ultimate loads

In case a structure has to be protected against both service loads (wind, live loads) and ultimate loads (wind, seismic), a protection system consisting of TMDs shall not just be optimised for the more dangerous case, like earthquake. For example, a high friction coefficient within bearings, dampers or high damping performance within damping devices to ensure a superior energy dissipation in case of earthquake will prevent relative displacements of the TMD mass in case of lower but frequently occurring service loads, thus being unsuitable for protection in service stage.

The system must be also designed for the direction of the attack and also cater for unplanned load cases like a remote earthquake. The dampers of such a TMD protection system must display a low back ground friction such that their function can be triggered at smaller amplitudes already. The compressibility or elasticity of dampers shall be as low as possible such that in case of millions of load cycles which occur over the life time of a structure, like wind, the piston will only give in 1-1.5% of the piston stroke. Consequently the accumulated displacement within the structure shall be kept as low as possible, such as to extend their lifetime avoiding fatigue and wearing effects.

The total TMD protection system shall also fit into the spatial constraints, which for example on the top of an office tower could be the length of a pendulum or a TMD which can be derived from the natural frequency to be damped. In case that more than just one natural frequency has to be damped, a semi-active damping system might be the superior choice, as such a system adapts itself with its response force (and thus damping) to the prevailing natural frequency. These damper types induce positive or negative stiffness to the system, what results in +/-10-20% real time frequency adaptation. Such semi-active damping systems can be extended with a monitoring system at little extra cost, as the infrastructure for the monitoring system is already provided with the semi-active damping system.

A well designed structural protection system with TMD may more than compensate its costs. Apart from increasing the structural safety, a minimisation of response forces or of accumulated displacements leading to premature wear, can reduce the total costs of the structure, for example by way of less reinforcing steel. In so far it is important not only to compare the costs of alternative structural protection systems, but in particular also the savings they bring about in the total structure.

3. Case studies

3.1 SOCAR Tower, Baku, Azerbaijan

A 200 m high office tower receives a 450t pendulum Tuned Mass Damper for a lowest frequency tuning of 0.16Hz, which fits into the spatial constraints (max. height of 7m) on top of the building, and which damps different frequencies depending on the direction that the structure swings. This is achieved by subdividing the length of the pendulum into two parts (double pendulum), one each per x- and y-direction. The tuning tolerance is kept to a maximum of 0.01 Hz.

3.2 Volgograd Bridge, Russia

The longest road bridge in Europe is exposed to vertical vibrations caused by wind, triggering amplitudes of ± 400 mm and thus had to be closed to traffic. It turned out that the first 3modes are sensitive to vibration. In a retrofit action 12nos. semi-active Tuned Mass Dampers with 5200kg each were installed inside of the bridge deck, which adapt to the prevailing natural frequency. These 12nos. semi-active TMDs do not only provide with a small mass ration of 0.8% superior damping characteristics of 3-4% part of critical damping, but they are the commercially more attractive solution, as in standard passive mode a total of up to 36nos. TMDs should have to be installed to achieve the same damping effect. Since completion of the retrofit in October 2011, no more vibrations occurred.

3.3 The Danube City Tower, Austria

With a height of 220m and comprising 60 stories the Danube City Tower 1 is the tallest building in Austria. The structural analysis brought about a lateral acceleration at the top of up to 0.18 m/s^2 caused by wind. Moreover, the structure had to be protected against accelerations caused by earthquake, which, albeit relative unlikely, cannot fully ruled out. The mass of the pendulum TMD was connected to semi-active viscous dampers, which in case of service (i.e. wind loads) display a little response force and provide about 3% damping together with the 300t pendulum mass (~0.7% mass ratio). The protection against vibrations to wind loads can be likened to a strategy "Maintaining the comfort criteria", while not being of structural relevance. In case of wind, the achieved reduction of horizontal acceleration to 0.06 m/s^2 is no longer noticeable. Moreover, the adaptive system recognizes an earthquake and immediately modifies its damping strategy to "protection of structure", by way of increasing the damping of the viscous dampers to 18%, while the pendulum will be limited in its amplitude of +/-750mm and contribute with significant energy dissipation in case of earthquake.

A by-product of the semi-active damping is a monitoring system, which is web-based and in real-time allows the user to check the natural frequency, the displacement of the pendulum as well as the response force of the viscous dampers.

4. Conclusion

Elegant structures which are prone to vibrations and deflections shall be optimally protected both for service stage (e.g., wind) and ultimate limit stage (e.g., earthquake). Passive or semi-active TMDs are the tools to achieve such optimum structural protection, being even commercially viable by reducing overall construction costs.