The Tuned Liquid Column Damper as a Cost-Effective Alternative for the Mechanical Damper in Civil Engineering Structures

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The geometric analogy between the classical tuned mechanical damper (TMD) and the tuned liquid column damper (TLCD) is worked out with emphasis on the modal tuning process. To extend the frequency range of application of the TLCD, the piping system is sealed to make use of the resulting gas-spring effect on the (relative) fluid flow. Applications of the TLCD with a sealed U-shaped piping system to tall buildings and slender bridges effectively reduce dominating horizontal vibrations, equally as well as an increase of the modal structural damping. A high-rise office tower under wind loads, a skeletal structure with base isolation against seismic loads, and a footbridge under the excitation of walking pedestrians illustrate the effectiveness of the TLCD when properly attached to these main structures. In the course of the cantilever method of bridge construction, critical states are encountered in windy situations. Simulations and laboratory model testing prove that a TLCD attached to the tip of the cantilevered bridge supplies sufficient damping and thus allows longer spans. To counteract effectively structural vertical vibrations, a novel design of a pipe-in-pipe TLCD is analysed, tuned with respect to the basic mode, and built in a single span steel bridge. Converting a TLCD into smaller units subjected to fine tuning yields an even more robust control. To reduce early peaks in the response to shock load, active control of either one, TMD or TLCD, is needed to render their effect hybrid. Such an active tuned liquid column damper (ATLCD) with a controlled gas supply from a standby high pressure vessel is briefly discussed.

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1. INTRODUCTION

The basic idea of most vibration decreasing devices is the absorption of a certain, critical part of the kinetic energy, thereby reducing the ductility demand of the main structure, and thus, preventing it from serious structural damage under severe dynamic loads. In addition, discomfort of inhabitants of tall buildings under light to moderate wind loads must be avoided and the elongation of the lifetime of bridges under traffic and wind loads requires the increase of its effective structural damping. In the last decade, intensive research and development efforts have resulted in the basic concepts of active and passive energy dissipation, and in the effectiveness of a large number of testing facilities for small, medium, or real-size experiments, as well as several actual installations all over the world.[1,2] One major field of practical and successful vibration control is concerned with the application of the dynamic vibration absorber. They are broadly categorised as either passive, such as tuned mechanical dampers (TMD), or active hybrids, active tuned mechanical dampers (ATMD).[1-3] Contrary to passive control, active control schemes usually depend on an external energy supply since they accomplish a desired system behaviour by applying active forces to the main structure. In 1989, active mass driver systems (AMD) were used to mitigate bending and torsional vibrations in the first full-scale application, an 11-story structure in Tokyo, Japan.[4] To reduce the need for an external power supply, semi-active control devices have been developed which, like passive systems, cannot add mechanical energy to a structural system, but have adjustable damper properties to reduce the system response, e.g. a permanent adaptation of the actual energy dissipation.

Commonly, the structural damping of bridges is extremely low. Since relative motions are small, the direct application of dashpots and/or frictional dampers requires a complex design. To concentrate the energy consumed from the vibrating bridge, mechanical dampers are properly tuned (TMD)[5] and applied. The quite expensive reconstruction of the Millennium Bridge in London is described,[6] where both, dampers and TMD, are used to increase the effective structural damping beyond its cut-off value of the synchronisation effect observed in the excitation process of pedestrian bridges.[7] The problems of the Toda Park Bridge, which is prone to vibrations, were solved by substituting the expensive TMD with tanks and sloshing fluids.[8] Exciting forces by walking pedestrians or by runners have been analysed in detail and are applied in the course of this paper.[9]

The tuned liquid column damper (TLCD) was applied to tall buildings.[10-13] A novel active control by pressurising gas above the liquid column was invented,[13,14] thus creating an ATLCD as the cheap counterpart to the ATMD. In the passive mode, a sealed piping system with gas pressure in the equilibrium state properly adjusted extends the frequency range of application of the TLCD up to about 5 Hz.[13,14] Actually, the limitation refers to the maximum relative speed of the fluid, which keeps the fluid-gas interface intact.

Torsional bridge motions have been considered and simulations have been validated experimentally.[15-17] Effective damping of bridges is considered based on the detailed model