DAMPING OF FOOTBRIDGE VIBRATIONS BY TUNED LIQUID COLUMN DAMPERS: A NOVEL EXPERIMENTAL MODEL SET-UP

Michael Reiterer[1], Research Assistant, Markus J. Hochrainer[2], Senior Engineer
[1]Institute of Rational Mechanics, Vienna University of Technology
Wiedner Hauptstraße 8 / E201, A-1040 Vienna - Austria
[2]Geoconsult Wien ZT GmbH, Geyschlägergasse 14, A-1150 Vienna – Austria

The highly publicized closure of London's Millenium Footbridge due to excessive lateral vibrations at its opening day in June 10, 2000 has highlighted a potentially unexpected problem in footbridge constructions. During the investigations of the Bridge a number of other instances of bridges suffering excessive lateral vibrations under crowd loading have been coming to light, e.g. the Toda Park Bridge in Japan. The following extensive retrofit of the Millenium Bridge involved the use of fluid viscous dampers and conventional tuned mass dampers (TMDs) to increase the structural damping with, finally a total cost of 10 million Euro.

In the present investigation it is proposed to apply the more efficient and more economic tuned liquid column damper (TLCD) for suppressing the pedestrian induced vibration of footbridges. The TLCD relies on the motion of a liquid mass in a sealed tube-like container to counteract the external motion, while a built in orifice plate induces turbulent damping forces that dissipate kinetic energy. For optimal tuning of the TLCD the natural frequency and equivalent linear damping coefficient have to be chosen suitable, likewise to the conventional TMD, as indicated by Den Hartog [1]. The great advantages of TLCDs over other types of damping devices are: simple tuning of natural frequency and damping, where the damping can be controlled by the opening angel of a built in orifice plate, low cost of design and maintenance and a simple construction.

In order to study the damping effectiveness of optimal tuned TLCDs a small scale bridge model has been constructed in the laboratory of the TU-Institute. A side view and front view of the experimental model set-up is shown in Fig. 1. The three degree of freedom (DOF) model is given by the rigid bridge profile on top of a skeletal box girder, where the deformation of the bridge cross-section is given by the horizontal displacement, vertical displacement and rotation with respect to the center of stiffness.

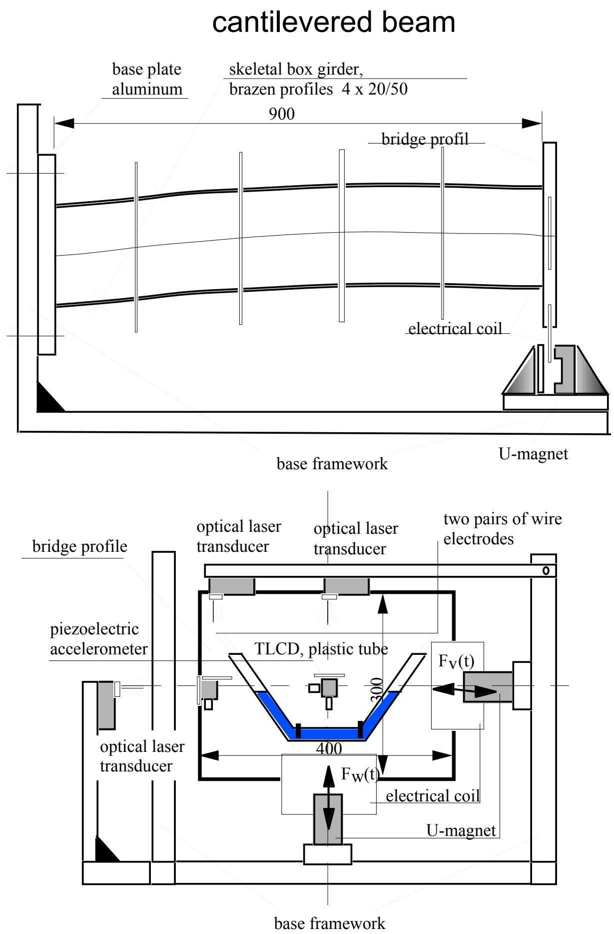

Fig. 1: Side and front view of the constructed three DOF bridge model with attached TLCD

A lightweight cantilevered beam, made of brazen profiles 4 × 900/20/50, provides the spring supports. To prevent undesired natural vibrations of the brazen profiles, several stiffening elements, made of Styrofoam, are mounted along the cantilevered beam. The TLCD made of plastic tubes is fixed symmetrically to the bridge profile, where several orifice plates induce over-linear turbulent damping forces.

Furthermore, a novel contactless excitation device has been developed to simulate the moving pedestrian. Although it is widely known that people walk with a natural frequency of about $2\,Hz$, it is not commonly known that about 10% of the vertical dynamic force acts laterally. The frequency of this lateral dynamic force is always half the walking pace, thus about $1\,Hz$. Therefore, the excitation device must induce different dynamic forces in horizontal $F_v(t)$ and vertical $F_w(t)$ directions. Subsequently, the bridge profile is equipped with two electrical coils, which are located in the environment of a homogenous magnetic field. Feeding the electrical coils with a defined time periodic current excites the bridge model in the desired manner.

The time periodic excitation signals are provided by the latest LabView version 7.0. Furthermore, the deformation of the rigid bridge profile is measured by means of contactless laser transducers, Type optoNCDT 1605. The measured signals are recorded by means of the software BEAM-DMCplusV3.7 through the board of Digital Amplifier System DMCplus. To measure the liquid surface displacement inside the TLCD an electronic resistance measurement device is used. Therefore the piping system is equipped with two pairs of wire electrodes whose resistance depends on the water level inside the pipe. Further details of the used measurement device are given in *Reiterer and Hochrainer* [2].

Series of free vibration tests were performed to determine natural frequencies and linear viscous damping coefficients of the three DOF bridge and TLCD. Furthermore, forced vibration tests were performed with different time periodic excitation forces in horizontal and vertical directions. Thereby, the damping effect of the attached optimally tuned TLCD is investigated and compared with results of numerical simulations. In the presented investigation the TLCD is modally tuned to the fundamental frequency of the bridge, whose corresponding mode has a dominant horizontal response, which is similar to the vibration characteristics of London's Millenium Bridge. The optimal tuning process adjusts the design parameters δ, which is the frequency ratio of natural frequency of the TLCD to the considered natural frequency of the bridge, and the linear viscous damping coefficient ζ_A of the TLCD, by an analogy to the corresponding TMD. In order to confirm the experimentally obtained results, a sufficient mathematical model has been derived and analyzed numerically. Thereby, the parameters are chosen according to the laboratory model. The equations of motion for the complex hybrid bridge/TLCD system are derived by a substructure synthesis method. The modified Bernoulli equation along the relative non-stationary streamline in the moving frame and in an instant configuration, which is given in Ziegler [3, p. 497], yields the nonlinear parametric excited equation of motion for the separated TLCD. Further details of the mathematical model and the comparison of theory and experiment, which are in an excellent agreement, are discussed in the recent paper of *Reiterer and Ziegler* [4].

The experimentally obtained DMF of the bridge's horizontal displacement is shown in Fig. 2.

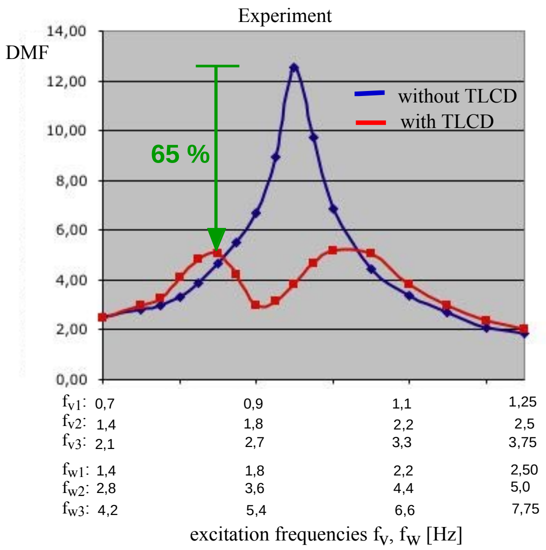

Fig. 2: Experimentally obtained DMF, horizontal displacement of the bridge

It can be seen that the optimal tuned TLCD reduces the resonant peak of the first vibration mode by 65%. In conclusion the experimentally investigated TLCD turn out to be an effective damping device for the undesired pedestrian induced footbridge vibrations.

References

[1] DEN HARTOG, J.P.: Mechanical Vibrations, Reprint of the 4th ed., McGrawHill, 1956.

[2] REITERER, M., HOCHRAINER, M.J.: Parametric Resonance In Tuned Liquid Column Dampers: An Experimental Investigation, IAZ, 2004, in print

[3] ZIEGLER, F.: Mechanics of Solids and Fluids, 2nd reprint of 2nd edition, Vienna-New York, Springer Verlag, 1998

[4] REITERER, M., ZIEGLER, F.: Control Of Pedestrian-Induced Vibrations Of Footbridges Using Tuned Liquid Column Dampers, in: Proc. 5th Int. Conf. On Bridges across the Danube, 2004