Design, Implementation and Measurement of Cable Dampers for Large Cable-stayed Bridges

Limin SUN
Professor, Dr.
SLDRCE
Tongji University
Shanghai, China
lmsun@mail.tongji.edu.cn

Limin Sun, born 1963, received his civil engineering degree from the Univ. of Tokyo in 1991.

Hongwei HUANG
Dr.
SLDRCE
Tongji University
Shanghai, China
hongweih@mail.tongji.edu.cn

Hongwei HUANG, born 1976, received her civil engineering degree from Univ. of California, Irvine in 2006.

1. Introduction

Long stay cables are very sensitive to ambient excitations, such as wind, wind-rain or traffic loads, due to their low inherent damping and rich vibration modes. The vibration of stay cables of existing bridges are frequently observed and vibration control countermeasures have to be considered for the cables. The vibration control countermeasures usually adopted are aerodynamic means, cable cross ties and mechanical dampers. This paper focuses on the performance study of the vibration mitigation countermeasure for stay cables using mechanical dampers which are usually passive or semi-active dampers installed near the anchorages of cables in transversal direction and are effective for all kinds of vibrations. For a long cable, due to the height limitation of damper installing position, it is necessary to improve the damper efficiency to match the required additional cable damping. In practice, the additional damping of a cable with installed dampers is influenced by the vibration modes, the nonlinearity of damper devices and the stiffness of damper, respectively. So the optimal damping estimated by the linear theory is hard to be obtained. Long cables also have rich vibration modes, and therefore, the cable damper has to be designed to cover a wide range of modal frequencies. This paper carries out experimental studies on damper performance and additional cable damping with tests conducted using a 215 meter long full-scale stay cable. The reasons causing the damping loss, namely, the deference between the theoretical and the measured damping, were discussed. Improved design methods were proposed and the cable damping of a large span cable-stayed bridge was measured.

2. Experimental studies on damper performance

In this study, some typical dampers were tested by applying a sinusoidal load to investigate their basic performance and the damping forces were measured. From the test results, it is clear that the dampers have nonlinear behaviour and the conventional linear design theory is not suitable for nonlinear dampers. The test results also imply the existence of inherent stiffness of damper, Which will cause the loss of additional cable damping. Finally, the durability test shows that the deterioration of damper performance during its lifetime is also needed to be considered for design.

A full-scale cable experiment was conducted and 7 sets of mechanical dampers were tested. The experimental results show that these dampers performed very well in mitigating vibrations of stay cables. A damper efficiency factor, which is defined as the ratio of the additional damping calculated from experimental results and that from a linear damper theory, was introduced for evaluating damper performance in this study. Experimental results showed that the efficiency factors of dampers are much lower then 1.0, and the loss of additional cable damping is considered to be caused by the factors such as the nonlinearity and the stiffness of damper devices; the stiffness of damper supporter; the sag effect, especially for long cable and fundamental vibration modes; the incline and flexural stiffness of cable; the boundary condition of anchorage; the gap effect at damper installation joints; and the deterioration of damping performance for long term service.

https://doi.org/10.2749/222137908796292498

3. Optimal design of damper

In the conventional linear design theory, the damper force is proportional to the velocity of the damper. For the nonlinear factional damper, the nonlinearity and the stiffness of damper device are considered. The transversal force at the damper installing position can be expressed as

$$F_a = -c\left|\frac{dV(a,t)}{dt}\right|^{\alpha-1}\frac{dV(a,t)}{dt} - k_d V(a,t) \tag{1}$$

In case of a bilinear damper model, based on equivalent energy dissipation, the formulation can be obtained and the damping force is

$$F_d(v) = \begin{cases} c_1 v & |v| \le v_0 \\ c_2 v + (c_1 - c_2) v_0 \operatorname{sgn}(v) & |v| > v_0 \end{cases} \tag{2}$$

For engineering practice, one simple design approach is to adopt the conventional linear design theory and consider an efficiency factor as mentioned before.

4. Measurements of damper efficiency

In order to investigate the damper efficiency in real engineering practice, a field test was carried out at a large span cable-stayed bridge recently. The additional cable damping was obtained and subsequently the damper efficiency factor was evaluated, which was shown to satisfy the design requirement.

5. Conclusions

Installing mechanical dampers near the anchorage of stay cable is an often used countermeasure to mitigate cable vibration. The experiment using a full-scale cable with damper attached showed that the additional damping of a damper designed by a linear theory is hard to be obtained. Hence, the efficiency of damper has to be improved especially for a long stay cable because of the height limit of damper installing position. The factors affecting the efficiency of cable damper were discussed. The nonlinear design theories, assuming that the damper behavior is a fractional power function or a bilinear function, were proposed. With these, the additional cable damping can be evaluated more accurately when designing a cable damper that is nonlinear. For design using a conventional linear method, it is suggested to introduce an efficiency factor, which is defined as the ratio of the practical value of additional damping to its theoretical value by linear damper theory. In this study, based on the experimental results, the authors suggest that the efficiency factor should be 0.5. The additional cable damping of a large span cable-stayed bridge was measured. The measurement results showed that the cable dampers satisfy the design requirement with efficiency factors larger than 0.5. The higher modes vibrations with a frequency range of 3 Hz to 12 Hz were observed also for the bridge. This promotes that more cable vibration modes have to be considered as control targets. More than one damper may needed to be installed on one cable to tune to different groups of targeted modes if a single damper is difficult to cover all frequency range of targeted modes.

Acknowledgements

This research is partially supported by National High-tech R&D Program (863 Program) of China (Grant No. 2006AA11Z120) and National Natural Science Foundation of China (Grant No. 50678123). The writers are also grateful to Sutong Bridge Construction Headquarter and Nippon Steel Corporation for supporting research program on the experiments and measurements mentioned in this paper. The graduate student of Tongji University, Mr. Yu Dejun, helped to prepare the figures.