Measurement of Cable Damping in a Long-span Cable-stayed Bridge

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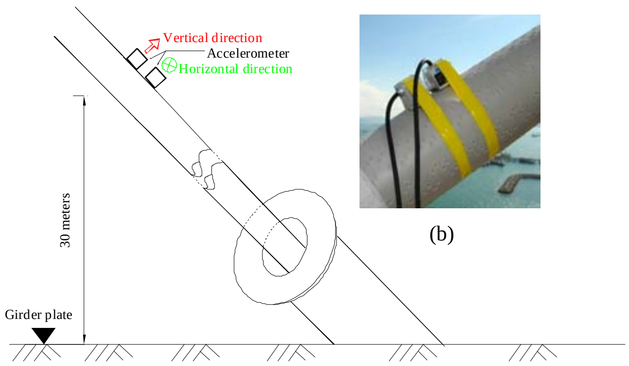
1. Introduction

Vibration of stay cables with large amplitudes have occurred in many long-span cable-stayed bridges. Complex mechanisms including rain-wind excitation and possibly cable–deck interaction have been responsible. However, for all mechanisms, very low damping of stay cables is a primary cause of the vibration and addition of damping to stay cables can reduce the amplitude of vibrations significantly or even suppress the vibration completely. Hence dampers have been installed to the long cables of most of long-span cable-stayed bridges. Recently measurements of cable damping have been made on many cable-stayed bridges to investigate the additional damping from the dampers [1]. In this paper to investigate the damping performance of the cables of the Stonecutters Bridge in Hong Kong, a field testing to measure the cable damping was carried out. The measurement process and the results are introduced as below.

2. Cable damping measurement

To ensure that the verification measurement covers at least one damper of each type of damper in side span and main span, the representative 10 cables were selected for damping measurement. The sensors were installed on the cable. The installation location is about 30 meters high from the bridge girder surface. Two accelerometers were attached and they measured the vibration in vertical direction and horizontal direction, respectively (Figure 1(a)). The photo of the devices installation in the trial measurement also is given in Figure 1(b).

Ambient vibration test was first carried out to determine the natural frequencies of cables. Then each cable was excited manually in the vertical direction and in the incline direction respectively, in time with vibrations in its fundamental mode determined by the ambient vibration, using a rope tied around the cable. After several minutes the excitation was abruptly halted and the vibrations left to decay freely for the damping to be estimated. Each test was repeated at least 3 times to obtain multiple damping estimates for each cable. Accelerometers monitored in-plane and out-of-plane cable vibrations at the excitation location. The wind velocity was recorded simultaneously. The damping for the first mode of each cable was calculated from the free decay of vibrations as follows. The recorded signals were filtered in the time domain with a digital low-pass Butterworth filter with a cut-off frequency close the fundamental frequency. The filtered acceleration signals, from a typical cable-damping test, are shown in Figure 2.



(a)
Figure 1 Installation of the devices

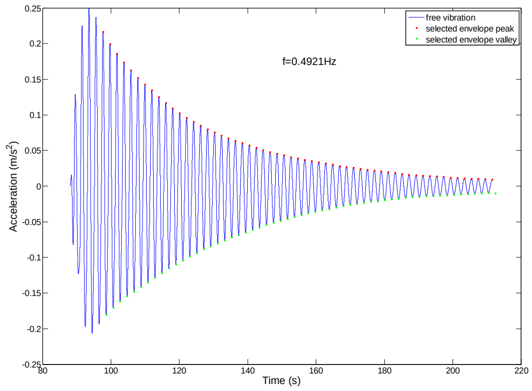


Figure 2 Typical filtered free decay of cable vibrations

Keyword: Long-span cable-stayed bridge; Cable Damping; Field measurement
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3. Cable damping evaluation method

After the single-mode free vibration parts are obtain by the low-pass filter, three methods were used in the damping evaluation of the test, which will be introduced in the following chapter. The filtered signal was assumed to represent the free decay response of a single-degree-of-freedom oscillator, for which the logarithmic decrement method, could be used, from which the damping ratio is given by $\delta = \frac{2\pi}{\sqrt{1-\xi^2}} = \ln \frac{v_n}{v_{n+m}} \Big/ m = b$. where b is the gradient of $\ln(y_{peak})$ plotted against time, where y_{peak} is the amplitude of each cycle.

This variation of the method is more accurate than the basic logarithmic decrement method, which just considers the relative amplitudes at two distinct times, since random errors can be averaged out by considering the best-fit straight line of the $\ln(y_{peak})$-time plot. Also, any variation in damping during the decay of vibrations can be seen by a change of gradient. To implement the method for the cable vibrations, the maxima and minima were picked out from the filtered time history, and the natural frequency estimated from the average period between maxima. Consecutive half peak–peak amplitudes were calculated. Natural logarithms of these values were plotted against time and the least-squares best-fit straight line fitted, as shown in Figure 3. The average damping ratio over the minute was then determined from the gradient and natural frequency.

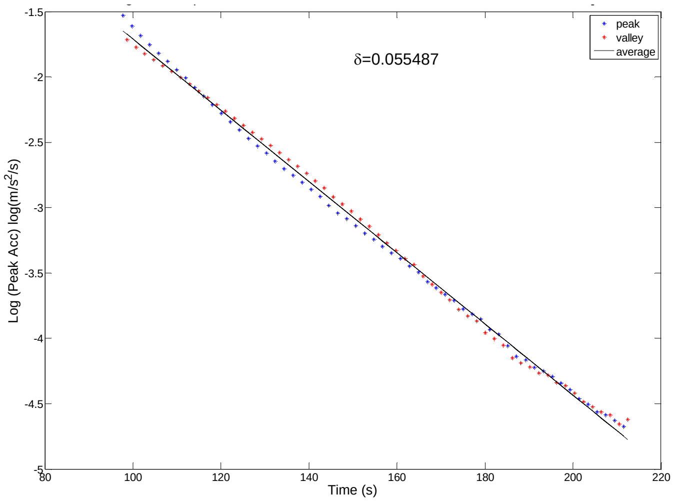

Figure 3. ln(amplitude) of time history with best-fit straight line

4. Measurement results

Summarize all the measurement results in Table 1, including the natural frequencies and the damping evaluation. It can be seen from the list that with the dampers, the cable damping increases significantly. Even for No.10 Cable, which is the longest cable with the length 540.43 m, the logarithm damping can reach 3.3%, which can effectively control the cable vibration induced by the environmental factors.

Table 1. Natural frequencies and damping of stay cables with dampers

Cable No.	Span	Length (m)	Predicted frequency (Hz)	Measured frequency (Hz)	Measured Damping
1	Side span	148.28	0.901	0.9193	0.085
2	Side span	199.80	0.648	0.6676	0.076
3	Side span	266.43	0.469	0.4921	0.055
4	Side span	316.21	0.386	0.4044	0.046
5	Side span	356.95	0.345	0.3643	0.046
6	Main Span	258.71	0.46	0.4845	0.078
7	Main Span	361.80	0.332	0.3471	0.057
8	Main Span	414.83	0.29	0.3109	0.052
9	Main Span	450.50	0.267	0.2899	0.055
10	Main Span	540.43	0.229	0.2556	0.033

5. Conclusion

The damping performance of the cables was successfully measured in the field testing. The measured natural frequencies of the cables have a good agreement of the theoretical values. The performances of the dampers installed in the stay cables were fully verified in this file measurement.

Reference

[1] H. Yamaguchi, Y. Fujino, Stayed cable dynamics and its vibration control, Proceedings of the International Symposium on Advances in Bridge Aerodynamics, Copenhagen, Balkema, 10–13 May 1998, pp. 235–253.