FULL-SCALE EXPERIMENTAL VERIFICATION OF SEMI-ACTIVE CONTROL ON CABLE -MR DAMPER SYSTEM

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ABSTRACT

Mechanical dampers have been proved to be one of the most effective countermeasures for vibration mitigation of stay cables in various cable-stayed bridges over the world. However, for long stay cables, as the installation height of the damper is restricted due to the aesthetic concern, using passive dampers alone may not satisfy the control requirement of the stay cables. Therefore, semi-active MR dampers have been proposed for the vibration mitigation of long stay cables. However, the highly nonlinear feature of the MR damper leads to a relatively complex representation of its mathematical model, and makes it difficult to be applied to suppress cable vibration with an efficient control algorithm. Simulation study has previously been carried out for the cable-MR damper system using a semi-active control algorithm based on the universal design curve of dampers and a bilinear mechanical model of the MR damper. This paper aims to verify the effectiveness of MR damper using the same approaches as in the simulation study for vibration mitigation of stay cable by full-scale experimental test. A long stay cable fabricated for a real bridge was set-up with MR damper installed. The cable was excited under free vibrations. Different test scenarios were considered where the MR damper was tuned as passive damper with minimum or maximum input current, or the input current of the damper was changed according to the proposed semi-active control algorithm. The effectiveness of the MR damper for controlling the cable vibration was assessed through computing the damping ratio of the cable for free vibration and the root mean square value of acceleration of the cable for forced vibration.

Keywords: MR damper, semi-active control, vibration mitigation of cable, full scale cable test.

1. INTRODUCTION

With the application of new materials and new construction technologies, the main span of cable-stayed bridge increases significantly and has exceeded 1000m. As the main force-bearing components in cable-stayed bridges, the length of stay cables increase as well. Thus, using passive dampers alone may not satisfy the control requirement of the stay cables and semi-active MR dampers have been proposed for the vibration mitigation of long stay cables for the advantage of lower energy consumption, adjustable input and wide control range. Wu and Cai (2006) carried out

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performance test on MR damper and studied the effect of input current, frequency, type of excitations and temperature on damper behavior, and they also conducted the scaled cable vibration tests and found that MR damper is effective for mitigating cable vibrations. Liu et al (2006) conducted series of scaled cable vibration tests to verify the control effectiveness of semi-active MR damper as compared to the passive dampers. Weber et al (2007a-c) applied the energy equivalent approach to model MR damper as equivalent linear viscous damper or nonlinear friction damper in the theoretical and experimental studies of cable vibration control using MR dampers. Besides theoretical work and lab testing, MR dampers have also been applied to real bridge projects, such as the Eiland bridge nearby Kampen, The Netherlands (Weber et al. 2005), the Dongting Lake Bridge (Chen et al. 2001, Wang et al. 2003, Duan et al. 2006), Third Qiantang River Bridge (Wu et al. 2004), Bingzhou Yellow River Highway Bridge (Li et al. 2007) and Sutong Bridge in China.

Although various theoretical and experimental studies have been carried out on the implementation of MR dampers on stay cables, the highly nonlinear feature of the MR damper lead to a relatively complex representation of its mathematical model, and makes it difficult to be applied to suppress cable vibration with an efficient control algorithm. Huang et al (2012) conducted a performance test on MR damper and derived a simple bilinear mechanical model of the damper, consequently, proposed an efficient semi-active control strategy based on the universal design curve for linear dampers. Simulation study was carried out and showed that MR damper is effective as a semi-active control device for the vibration mitigation of stay cable.

In this paper, a full-scale cable test will be conducted to investigate the optimal damping performance of the cable-MR damper system and to verify the proposed semi-active control algorithm for suppressing the cable vibrations.

2. EXPERIMENTAL SET-UP

The full-scale cable test was conducted in Liuzhou OVM Machinery Co., LTD. A 170m galvanized steel wire strand cable (OVM250-37) with parameters given in Table 1 was used. The cable was manufactured for real bridge project and was tested before installed to the bridge. Ignoring the effects of sag and inclination, the cable was tensioned horizontally using hydraulic jack as shown in Figure 1. A MR damper (RD-1005-03) provided by Lord Company was installed at 3.4m (2% of the cable length) from the anchorage of the cable, whose parameters are summarized in Table 2 and configuration is shown in Figure 2.

Table 1: Parameters of cable

L [m]	T [kN]	m [kg/m]	D [mm]	f_1 [Hz]	x_d [m]	c [N·s/m]
170	3826	44.067	110.5	0.8756	3.4	0.31

Figure 1: Full-scale cable

Table 2: Parameters of MR damper

Compressed length （mm）	Tensile length （mm）	Body diameter （mm）	Axle diameter （mm）	Maximum force （N）	Maximum temperature （℃）
155	208	41.4	10	4448	71℃

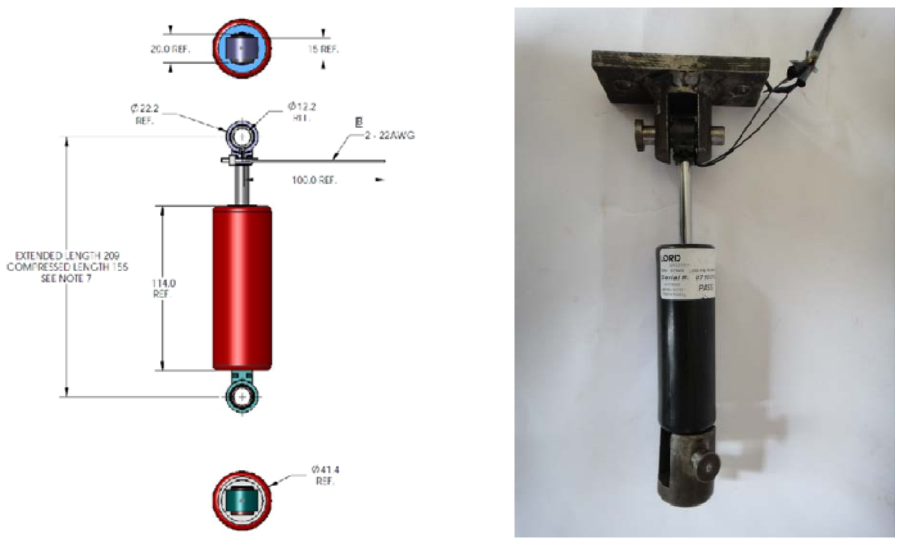

Figure 2: MR damper

Displacement sensors and accelerometers were installed to collect the dynamic responses of the cable during vibration test. The detail set-up is illustrated in Figure 3.

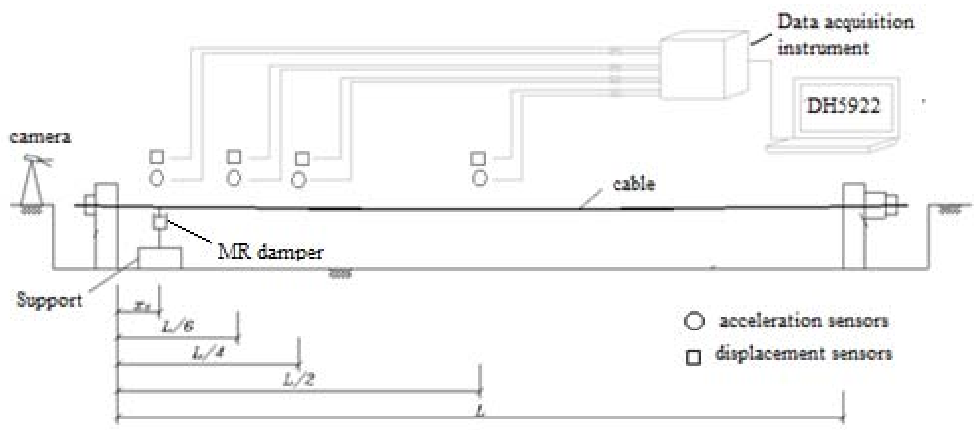

Figure 3: Set-up of cable test

3. SEMI-ACTIVE CONTROL ALGORITHM

The semi-active control algorithm proposed in Huang et al (2012) was applied in the cable test, which can be described by the flow chart shown in Figure 4.

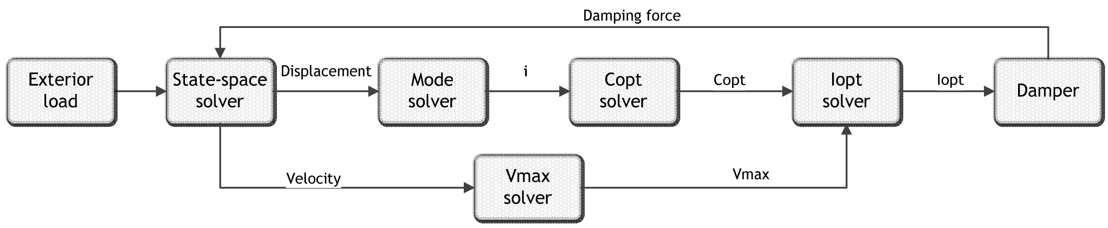

Figure 4: Flow chart of semi-active control algorithm

The closed loop semi-active control was realized using Quanser® active control system which consists of data acquisition card (DAC) and matched computer, and the control algorithm was written using the softwares of Qua-RC and MATLAB/Simulink.

4. TEST RESULTS

Both free vibrations and forced vibrations of the cable were generated in the full-scale test, however, due to space limitation only the results of first mode free vibration will be presented in this paper, where four different scenarios were considered as: (1) No damper (without installation of MR damper); (2) Passive-off (with installation of MR damper whose input current is 0A); (3) Passive-on (with installation of MR damper whose input current is the maximum of 2A); and (4) Semi-active (with installation of MR damper whose input current is calculated by the semi-active control algorithm).

Displacement responses at the mid-span of the cable for different test scenarios are shown in the left columns of Figures 5-8 and the corresponding power spectrum density (PSD) are plotted in the right columns of the same Figures. The logarithmic decrement ratio of the displacement time-history was also obtained for each test case, presented in Table 3. It can be seen from Figures 5-8 and Table 3 that the effectiveness of the MR damper on suppressing cable vibration was similar when it was in the semi-active state or in the Passive-on state, and was much better than when it was in the Passive-off state. However, as the input current of the semi-active MR damper changes along with the cable vibration (Figure 9), the required energy input is much more reduced than when it is always tuned to its maximum working current (Passive-on state). Therefore, the overall performance of the MR damper is much better when it is working as a semi-active control device.

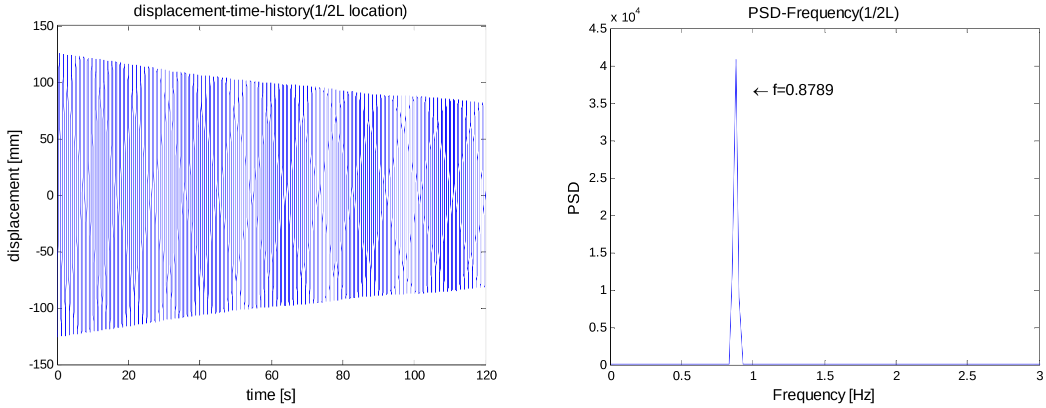

Figure 5: Displacement time-history and PSD (no damper）

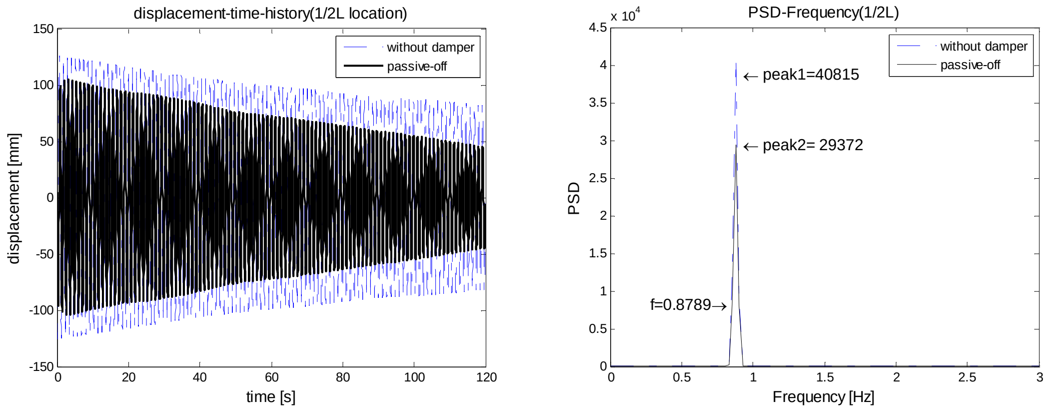

Figure 6: Displacement time-history and PSD (Passive-off)

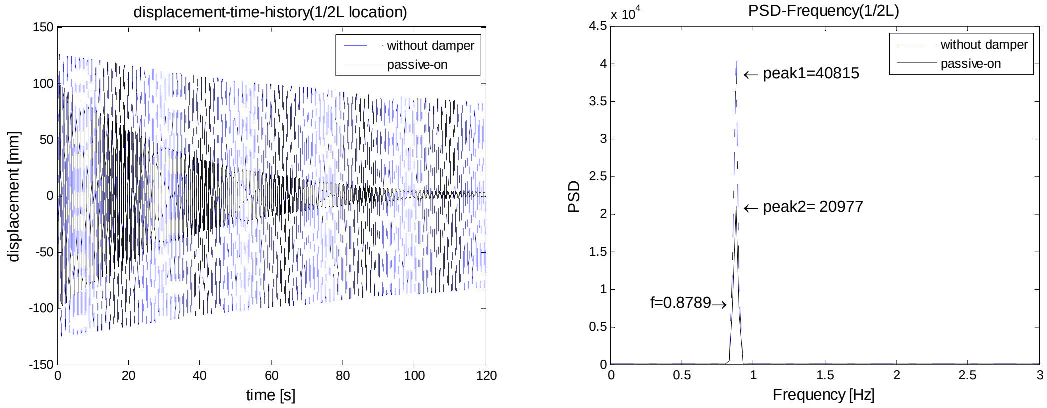

Figure 7: Displacement time-history and PSD (Passive-on)

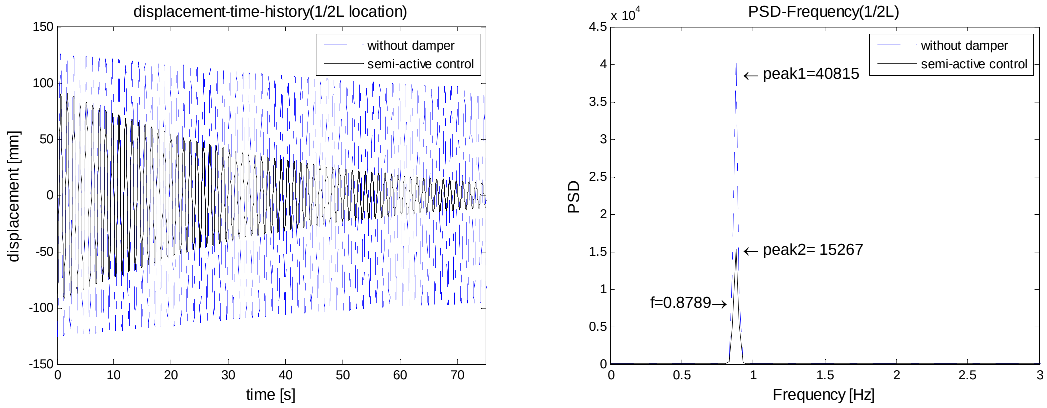

Figure 8: Displacement time-history and PSD (Semi-active)

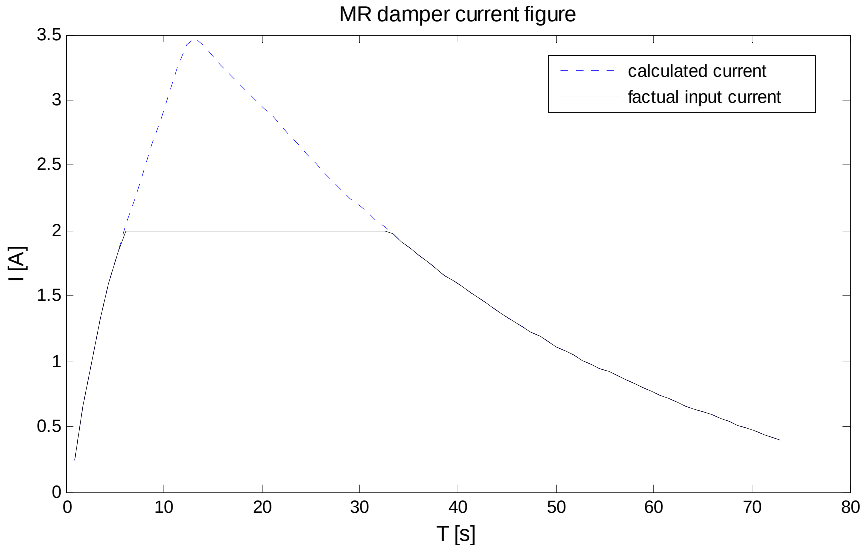

Figure 9: Changes of input current of MR damper (Semi-active)

Table 3 Logarithmic decrement ratio and modal damping of first order vibration

Frequency （HZ）	Condition	δ	ξ	η
0.8789	No damper	0.004037	0.000643	1
	Passive-off	0.007874	0.001254	1.950557
	Passive-on	0.039724	0.006325	9.83998
	Semi-active	0.038539	0.006137	9.546445

Remark: vibration reduction ratio (VRR): $\eta = \delta_i / \delta_{UD}$

5. CONCLUSION

In this paper, a full-scale experimental test was carried out to verify the effectiveness of MR damper for vibration mitigation of stay cable. A long stay cable fabricated for a real bridge was set-up with MR damper installed. The cable was excited under free vibrations. Different test scenarios were considered where the MR damper was tuned as passive-off damper (0 input current), passive-on damper (maximum input current), or semi-active damper (varying input current). The test results showed that the MR damper is capable for controlling the vibration of stay cable and its performance was better when it was used as semi-active device with input current changed according to the proposed semi-active control algorithm. Therefore, MR damper has considerable energy-saving property and is much more suitable for suppressing vibrations of super-long cables.

6. ACKNOWLEDGMENTS

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