The 2016 World Congress on
The 2016 Structures Congress (Structures16)
Jeju Island, Korea, August 28-September 1, 2016

To Control Vibration of Cable-stayed Bridges by Semi-active Damper and Lyapunov Control Algorithm

Gwang-Hee Heo[1)], Seung-Gon Jeon[2)], Chung-Gil Kim[3)], Chin-Ok Lee[4)], Sang-Gu Seo[5)], Byung-Jik Son[6)] and *Joon-Ryong Jeon[7)]

[1), 6), 7)] *Department of Civil Engineering, Konyang University, Nonsan 32992, South Korea*
[2), 3), 4)] *Department of Civil Engineering, Chungnam National University, Daejeon 34134, South Korea*
[5)] *Department of Civil Engineering and Informatics, Chungnam State University, Cheongyang 33303, South Korea*

[7)] *Corresponding author: jrjeon@konyang.ac.kr*

ABSTRACT

This study experimentally explores into a way in which vibration is controlled when wind load is afflicted to cable-stayed bridge with a semi-active damper and Lyapunov control algorithm. For this study, a cable-stayed bridge model (Seohae Grand Bridge downscaled) was manufactured, and the wind load value obtained from the real bridge was applied considering the size of the model bridge. A control device used for semi-control was equipped with a shear-type MR damper manufactured by our research team, while Lyapunov control algorithm was applied. The effect of vibration control was analyzed by taking quantitative inspection of displacement made in the middle of bridge and of amount of power consumed by shear-type MR damper (according to the given control type). As a result, it was found that semi-active vibration control system utilizing Lyapunov control algorithm is effective for controlling the vibration generated by wind load in the cable-stayed bridge. And its effectiveness and economic advantage was verified by reduced amount of power supplied into shear-type MR damper.

1. INTRODUCTION

Semi-active vibration control technology was introduced in the construction field as Carlson (1996) in American Company (Lord) had invented MR Fluid. Then, many

---

1) Professor
2) Graduate Student
3) Graduate Student
4) Professor
5) Professor
6) Professor
7) Research Professor

researchers, including Spencer (1997) and Dyke (1998), conducted various researches regarding control methods utilizing MR Fluid. Especially, Spencer (1997) and Dyke (1998) in America developed and suggested dynamic models (to copy MR damper's hysteresis utilizing MR Fluid) and semi-active control algorithms (to activate MR damper). Numerical verification and experimental research were followed. As found in such preceding researches, for application of MR damper based on MR Fluid to vibration control, proper control algorithm is required. Amid active analytic/experimental researches on semi-active vibration control for bridges in U.S.A and Japan, the research conducted in Korea has been only about development of MR control device and control algorithm verification phase (Moon 2004). Besides, those researches tend to focus on building structure (Yoon, 2008). When it comes to vibration control problem in bride structure, only numerical analysis types of research have been dominant(Park 2002).

In this study, an experimental research to control harmful vibration caused by wind load was conducted specially for cable-stayed bridges having relatively flexible structure than some other bridges. As for control device, a shear-type MR damper was manufactured by our research team, while Lyapunov control algorithm was used for its algorithm. The effect of vibration control was analyzed by taking quantitative inspection of displacement made in the middle of bridge and also of the amount of power consumed by the shear-type MR damper (according to the given control type).

2. Fabrication of Shear-type MR Damper

In general, MR Fluid is subject to magnetic field generated by the strength of current. So, if a current of particular level is input, MR Fluid control force is expected to increase [17]. In this study, Hydrocarbon Type MRF-132DG provided by Lord (American company) was used to design the shear-type MR damper. And, electromagnet Yoke and shear plate of MR shear-type MR damper were made of low carbon steel (S15C~S20C). Also, the shear plate connecting rod and the magnetic external cover were made of aluminum (having no magnetic impact) in order for magnetic field to be concentrated on the shear plate. The shear-type MR damper is as in figure 1.

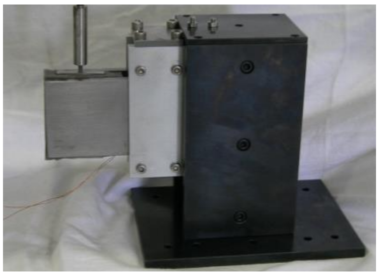


Figure 1 Production of the Prototype Shear Type of MR Damper

For the shear-type MR damper, electromagnet was manufactured by winding enamel coils (with 0.4mm diameter) around the Yoke 2,000 times. Meanwhile, a gap between the Yoke and the wear plate was set to 6mm (left and right side are the same).

Also, MRF-132DG-impregnated sponge was located between the shear plate and the wear plate, while Current Driver RD-3002-03 (provided by Lord, American Company) was used in order to secure stable supply of current.

3. Building a Model Cable-stayed Bridge

For the purpose of experiment, a model of cable-stayed bridge was designed and manufactured. To build it, its moment of inertia was reduced as much as possible for its upper plate to be sensitive to vibration generated by external force, and it was made of steel for convenience in FE modelling. Cable tension was evenly distributed to the all sections of the bridge, based only on the load of upper structure. For quantitative tension value, Force Gauge was utilized, and cable tension was introduced by allocating approximately 18N for each cable. The bridge model for vibration control is shown as in Fig.2.

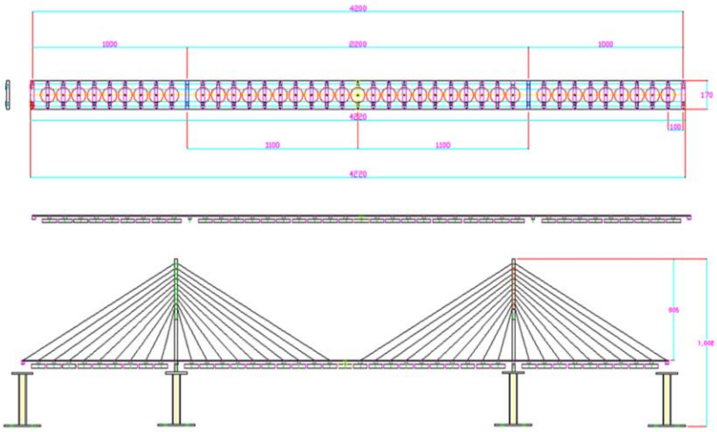


Figure 2 Bridge Model for Vibration Control

4. Control Method of Lyapunov’s Stability Principle

Lyapunov, A. M (Russia, 1983) presented a general principle on system's stability. His theory has been used as one of the most popular methods by which stability of all systems can be measured until today. As a result, for a feedback controller for structure vibration, Lyapunov principle was used [101]. Leitmann [102] utilized Lyapunov's direct access method for semi-active controller. And its control law is described below as in the formula (1).

$$V_i = V_{\max} H((-\mathbf{z}^{\mathbf{T}})\mathbf{PB}_i f_i) \tag{1}$$

In this formula, $H()$ is a function of Heaviside step to limit the level of voltage applied to MR Damper, semi-active controller, from 0 to $V_{\max}$. And i is an expression to consider the number of controller when multiple controllers are used. V_i is a controlled voltage to be applied to each controller in the current phase, while $\mathbf{B}_i$ is i th row of $\mathbf{B}$ matrix which has a same row with the number of controller expressed in initial state equation. f_i is a controlling force generated and measured from i th controller in previous step. Lastly, $V_{\max}$ is a maximum voltage to be applied to controller according to its given condition.

5. Semi-active Control Experiment Setup

In this study, for real-time vibration control experiment, structural response was obtained from the model in real-time. And an integrated control system for processing control signal output was established as in Fig.3

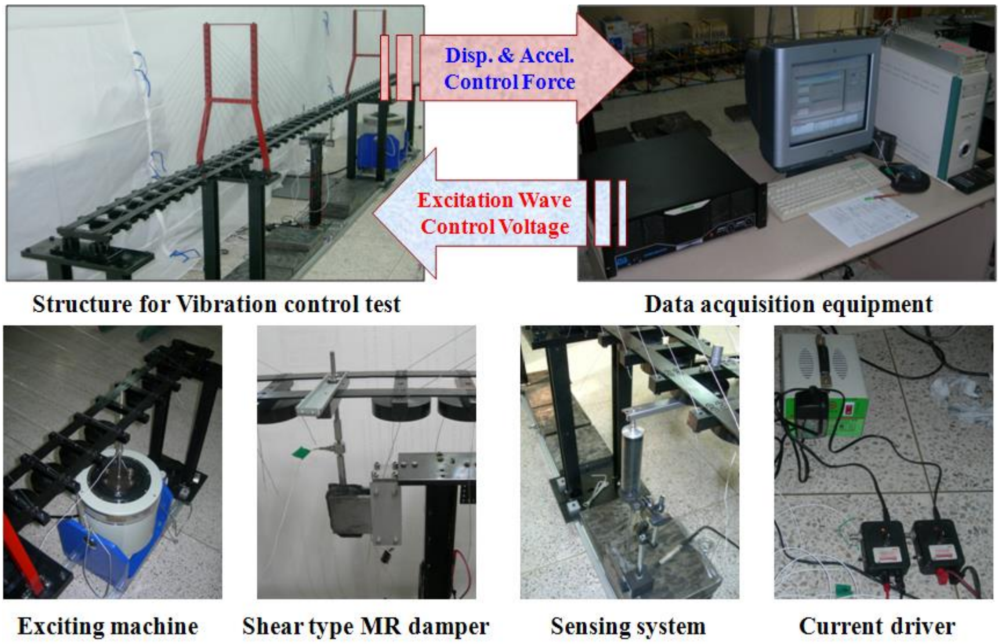
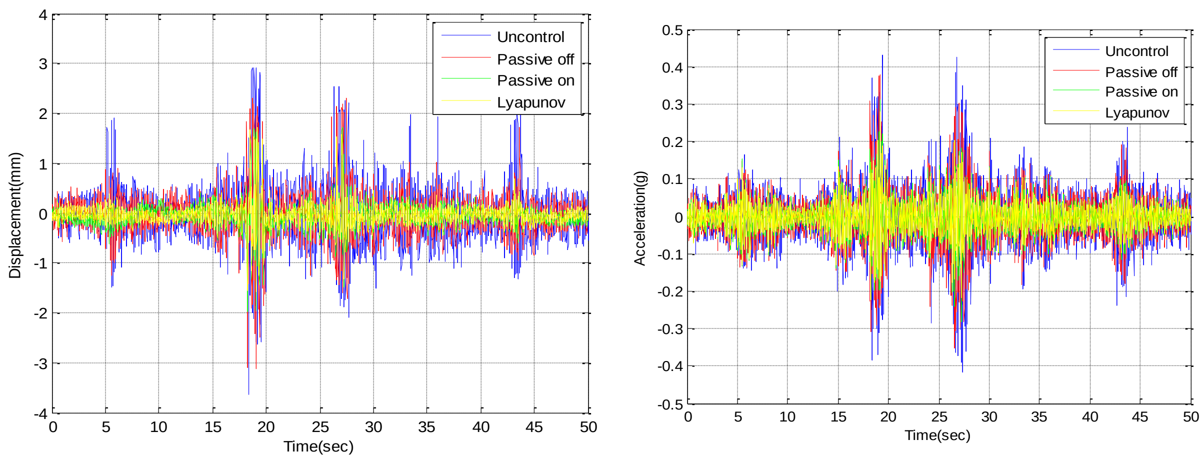


Figure 3 Setup of Semi-active Vibration Control Test

For this experiment, several sensors including acceleration sensor (Dytran 3134D), displacement sensor (Tokyo Sokki CDP-50) and Force sensor (1051V5) were utilized. Acceleration data were obtained and used for reference to evaluate a status of structure, and displacement data was used also for reference with which to determine the effect of control along with acceleration data obtained from a location where control device was installed. And force data were obtained and used to estimate control output by measuring real-time controlling force of control device. Vibration of constant level was applied on structure by installing Modal Exciter (Famtech ED S50-120) on the middle point of the left span of bridge. When it comes to excitation wave pattern, acceleration response of vertical direction (occurred due to unexpected wind load), detected in stiffened girder of Seohaedaegyo Bridge's main span (on 27 Feb 2011, PM 11:20~11:30) by measuring the response for 50 seconds, was reproduced for its utilization. Lastly, aforementioned H/W is equipped with dSPACE CP1103 (real-time guarantee type I/O board) in order to connect HW and PC operated in user's environment.

6. Result of semi-active vibration control experiment

The result of Lyapunov control based on displacement and acceleration responses obtained from the middle point of the upper plate of the model is shown in Figure 4. When it comes to displacement and acceleration responses in Figure 4, it is found that the control effect becomes enhanced in Manual-Off control, Manual-On control and Lyapunov control (in order) in comparison to non-control. Also, Figure 5 shows each distribution of consumed amount of applied voltage per each semi-active control method. With this figure, a significant reduction in control voltage during vibration control for 50 seconds can be checked.



(a) Displacement of Lyapunov Control   (b) Acceleration of Lyapunov Control

Figure 4 Disp. & Accel. of Lyapunov Control

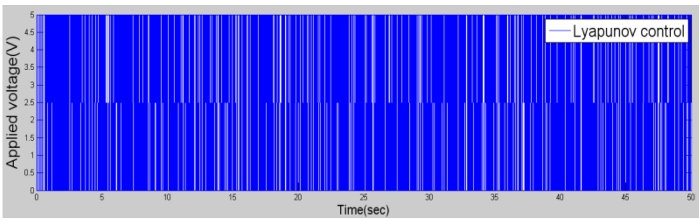


Figure 5 Input Voltage of Lyapunov

6. CONCLUSIONS

In this study, an experiment utilizing a model cable-stayed bridge was conducted to control harmful vibration when wind load was inflicted. And the result is as follows:

1. Considering the effect of vibration control (in comparison to non-control status) under random vibration of vertical direction, Lyapunov control was more effective in reducing displacement and acceleration than Manual On/Off control does. Especially, given the comparison of Lyapunov control with Manual-On control (to check control performance against consumed applied voltage), it was found that semi-control method was much more superior to manual control method since the amount of consumed applied voltage was reduced by 50%.

2. Based on status response of structure, the vibration control method utilizing semi-active control algorithm was found to be applicable to real-time vibration control effectively. It is also found that the result of experiment conducted for this study provides a foundational basis for future experimental research on real-time semi-active vibration control for bridge.

REFERENCES

Dyke, S. J., Spencer, Jr. B. F., Sain, M. K. and Carlson, J. D.(1998), "An Experimental Study of MR Dampers for Seismic Protection", *Smart Materials and Structures: Special Issue on Large Civil Structures*., Vol.7, pp.693-703.

Carlson, J. D. and Spencer, Jr. B. F.(1996), "Magneto-rheological Fluid Dampers for Semi-active Seismic Control", *Proc, 3rd International Conference on Motion and Vibration Control, Chiba, Japan*, Vol.3, pp.35-40.

Spencer, Jr. B. F., Dyke, S. J., Sain, M. K. and Carlson, J. D.(1997), "Phenomenological Model of a Magnetorheological Damper", *Journal of Engineering Mechanics., ASCE,* Vol.123, No.3, pp.230-238.

Moon, S. J., Kim, B. H. and Jeong, J. A.(2004), "An Experimental Study on the Structural Vibration Control Using Semi-Active Orificed Fluid Dampers", *Journal of the Earthquake Engineering Society of Korea*, Vol.8, No.2, pp.55-62.

Youn, K. J., Park, E. C., Lee, H. J., Moon, S. J., Min, K. W., Jung, H. J. and Lee, S. H.(2008), "Performance Evaluation of Decentralized Control Algorithm of a Full-scale 5-story Structure Installed with Semi-active MR Damper Excited by Seismic Load", *Transactions of the Korean Society for Noise Vibration Engineering*, Vol.18, No.2, pp.255-262.

Park, K. S., Jung, H. J., Lee, J. H. and Lee, I. W.(2002), "Hybrid Control Strategy for Seismic Protection of Benchmark Cable-Stayed Bridge", *Journal of the Korean Society of Civil Engineers*. A., Vol.22, No.3-A, pp.573-585.

Acknowledgments

This research was supported by National Research Foundation of Korea through funding from the Ministry of Education (Project No: NRF-2013R1A2A1A01016192 and NRF-2013R1A1A2059914). Many appreciation and acknowledgements go to the National Research Foundation who made this research possible.