Seismic Response Control for Parallel Building Structures Using MR Damper

Shinya Soma and Takashi Tanaka and Toru Watanabe Kazuto Seto

Nihon University, Tokyo, Japan 101-8308

This research aims to develop a seismic response control method for dual high-rise buildings arranged in parallel. The connected control mechanism is utilized, and semi-active control method using variable damper is applied. As a variable damper, magnetorheological (MR) damper with biased hybrid magnet is introduced. Semi-active controller is designed by two method: LQ-feedback controller based mapping design, and genetic algorithm (GA) feedback controller based mapping design. Obtained controllers are investigated through computer simulation and control experiments. The results demonstrated the capability of presented control system design.

1. Introduction

With advance in architectural technology, buildings are getting higher; therefore their natural frequencies are getting lower. Since Buildings vibrate easily by disturbances of strong winds and earthquakes, the livability of buildings is getting worse. Therefore various studies of vibration control for buildings have been researched. Vibration control method for buildings is classified to the passive control system as typified by tuned mass damper (TMD), the active control system by active mass damper (AMD), the semi-active control system combine the features of both passive and active control systems and so on. It is difficult to control large vibrations like earthquakes using passive control systems such as TMD, because they don’t have large damping force. The active control must require a large energy to control large vibration. So it is difficult to control large vibrations like large earthquakes using active control systems such as AMD. However, semi-active control systems combined the features of passive systems with active ones have large control force with lower energy than energy required in active control system. So it is believed that semi-active control systems is hit to control large vibration such as large earthquakes.

The purpose of research is in semi-active vibration controls for seismic response control using the connected building control (CBC) method. The CBC method is a vibration control one using the interaction of the multiple buildings by installing the control equipment between the these buildings. A large control force can be gotten at low frequency vibrations, because the CBC utilizes interactive force between parallel buildings. In addition, this method does not need additional mass required in the TMD. Moreover, this method can reduce a number of vibration control devices against a number of control objects. Furthermore, this method can make working space effective, because the inside of control equipment is used as a passageway to connect buildings.

In this research, the MR (magnetorheological) damper is used as the control device. This paper proposes the sponge type MR damper that utilizes both electric and permanent magnets. To include a MR fluid in sponges, a little MR fluid is required, moreover magnetic particles do not deposit. The MR fluid is included in sponges, because permanent magnet applies a magnetic field to the MR fluid constantly. Even when unexpected loss of supply, this damper serves as passive damper. An electric magnet changes strength of magnetic field; therefore a damping force is controlled. If electric magnet negates magnetic field of permanent magnet, a damping force can be close to 0 N.

In this research, The state feedback control system must be expanded into the semi-active control system, because a sponge type MR damper has the non-linearity by the friction. Then, an optimal solution may be in an instable area, which is unable to be searched with LQ theory while GA can search both stable and instable area. The semi-active system assures stability, because the semi-active control device cannot generate control force by itself. On semi-active control, the effective method for finding the optimum solution has not yet been established. Therefore, this research proposes design method of an optimal output feedback gain using GA due to considering non-linearity of MR damper. It is shown that GA is effective by comparing with this method and LQ theory. This paper, the EL Centro earthquake was used for the ground input as a disturbance. We report that the semi-active control system used in this study is effective.
2. Controlled object

The control object is shown in Fig. 1. These controlled objects assume twin-building structures. The natural frequencies of the 1\textsuperscript{st} and 2\textsuperscript{nd} mode of structure 1 are located in 8.16, 25.2 Hz, respectively. The natural frequencies of the structure 2 are 5.76, 18.32 Hz, respectively. These objects are controlled to the first two bending modes. The control structures with a distributed parameter are reduced to two mass points using the reduced-order modeling method. Two DOF reduce order model and parameters are shown in Fig. 2 and Table.1 Comparisons between the frequency responses of reduce order model and the experimental result are shown in Fig. 3. The transfer function from ground to mass point m1 is shown in Fig. 3a. The transfer function from ground to mass point m3 is shown in Fig. 3b. Simulation and experimental results are compared in order to verify the effectiveness of this modeling method.
3. Sponge type MR damper

The schematic diagram of the sponge type MR damper we constructed is shown in Fig. 4. A sponge type MR damper contains MR fluid as the working fluid in sponges. Therefore, damping force is generated by shear stress of the MR fluid. To include a MR fluid in sponges, a little MR fluid is possible, magnetic particles do not deposit, and sealing is not need, because it is included in sponges. The sponge type MR damper has biased hybrid magnet. The magnetic field of permanent magnet affects the MR fluid constantly; therefore, the MR fluid is included in the sponges. Even when unexpected loss of electric power supply in this damper, it serves as passive damper because permanent magnet applies a magnetic field to MR fluid constantly. When supplying power by the electric magnet in this damper, strength of magnetic field is adjusted. Therefore the damping force is changed because the shear stress is changed. The magnetic field is made stronger by a positive current, moreover weaken by a negative current. Therefore, the damping force of the MR damper can be controlled. Damping force of the sponge type MR damper due to impression electric current is shown the figure 5.

4. Semi active control

4.1 Control system design based on the optimum control rule

Control system for semi-active control is based on state feedback system. It then expands to the semi-active vibration control system. First, a control force is defined as the required control force. Next, the required control force and the damping force which can be generated with the MR damper, are compared. The actually generated control force is decided as follows.

\[
F_u = \begin{cases} 
F_{\text{max}} & \text{if } u > 0 \\
0 & \text{if } |u| < F_{\text{max}} \\
-F_{\text{max}} & \text{if } u < 0 \\
F_{\text{max}} & \text{if } u \leq 0
\end{cases} \quad \text{Case 1, 2, 3, 4}
\]

Where

- \( F_{\text{max}} = 40 \text{[N]} \)
- \( F_{\text{min}} = 20 \text{[N]} \)
- \( F_u \) : Actually generated control force
- \( u \) : Required control force
Case 1: When the required control force is too large to be reproduced by the semi-active control device. In this case, a semi-active control device outputs maximum damping force of this devise.

Case 2: When the semi-active control device can output the required force completely. In this case, required damping force output by changing damping force of the semi-active control device moment by moment.

Case 3: When the required control force is too small to be reproduced by a semi-active control device. In this case, the sponge type MR damper outputs minimum damping force of this devise.

Case 4: The semi-active control device cannot reproduce the control force because the relative velocity occurs in the opposite direction to the required force. In this case, the sponge type MR damper outputs minimum damping force of this devise.

The block diagram of the semi-active control system is shown in Fig. 7.

4.2. Genetic algorithm

In semi-active control it is needless to consider the stability of system, because the semi-active control device is a kind of passive damping device that assures stability by itself. A genetic algorithm (GA) is available for determining the optimum solution and to search a broader region, when only evaluation of the solution is clarified. GA provides an alternative to traditional search techniques by considering mechanisms found in genetics.

A simple GA considers a population of n strings and in order to create the next generation, applies the operators: Reproduction (or Selection), Crossover, and Mutation.

Reproduction is a process in which strings are copied according to their fitness function. Crossover is a process by which the newly reproduced strings are mated at random and each pair of strings partially exchanges information. Mutation is the occasional random alternation of the value of one of the bits in a string. The most common application of GA is for design optimization or problems.

5. Simulation result

The effectiveness of the semi-active vibration control system with the MR damper is evaluated with a benchmark earthquake, the El Centro. The resonance frequencies of the earthquakes are adjusted in the vicinity of 6 Hz (the middle of 1st mode resonance frequencies of controlled objects) so that the most dangerous earthquakes for controlled objects are reappeared. Simulation results of top floor are shown in Fig. 9, Fig. 10, Fig. 11 and Fig. 12. Fig. 9 shows time response of structure 1. Fig. 10 shows time response of structure 2. Fig. 11 shows frequency response of structure 1. Fig. 12 shows frequency response of structure 2.
From these results, the semi-active controlled using GA and the semi-active controlled using LQ theory are more effective than no controlled. From Fig. 11, the semi-active control both using GA and using LQ theory more effective than no controlled, reducing by 10 dB for the first mode and about 10 dB for the second mode. From Fig. 12, the semi-active control both using GA and using LQ theory more effective than no controlled, reducing by 15 dB for the first mode and about 15 dB for the second mode.

6. Experimental equipment

The experimental equipments consist of: the sponge type MR damper as a semi-active control device, controlled objects, a shake table, acceleration sensors to measure responses of controlled objects, a displacement sensors to measure response of the shake table, an A/D board to change sensor signals from analog to digital, PC to calculate control signal, a D/A board to change control signal from digital to analog and PWM amplifier. The experimental equipments are shown in Fig. 13.
7. Experimental result

Experimental results of top floor are shown in Fig. 14, Fig. 15, Fig. 16 and Fig. 17. Fig. 14 shows time response of structure 1. Fig. 15 shows time response of structure 2. Fig. 16 shows frequency response of structure 1. Fig. 17 shows frequency response of structure 2. The disturbance is the same previously mentioned.

Fig. 14 Time response measured of mass point 1

Fig. 15 Time response measured of mass point 3

Fig. 16 Frequency response measured of mass point 1

Fig. 17 Frequency response measured of mass point 3

From these results, the semi-active control using GA and the semi-active control using LQ theory are more effective than no control. It is important that only one MR damper suppresses two vibration modes of twin building structures. In addition, comparing the simulation and experimental results, both results are agreed well.

8. Verification of semi active control effectiveness

In this research, semi-active vibration control effects based on LQ-feedback theory and GA are equivalent because the variable damping range is too small to control vibration well. However the simulation result is credible, because the simulation and experimental results are the similar. Consequently, we simulate an expanded range of variable damping. In this time, a range of variable damping force is 3 ~ 100N. Simulation results of top floor are shown in Fig. 18 and Fig. 19. Fig. 18 shows frequency response of structure 1. Fig. 19 shows frequency response of structure 2. The disturbance is the same previously mentioned.
From Fig. 18, the semi-active control using GA is more effective than the semi-active control using LQ theory, reducing by 5 dB for the first mode and about 3 dB for the second mode. From Fig. 19, the semi-active control using GA is more effective than the semi-active control using LQ theory, reducing by 3 dB for the first mode and about 3 dB for the second mode. From these results, the effectiveness of the semi-active control using GA was shown.

9. Conclusions

Simulation results and experimental ones are agree well. Therefore, it was demonstrated that the modeling of proposed damper is effective.

From the results of frequency response, it was demonstrated that only one MR damper controls two vibration modes of twin-building structures.

It was demonstrated that the semi-active vibration control system using GA was effective for seismic response control.

10. References

[1] Kazuto Seto, and Yukito Matumoto, Vibration Control of Multiple Connected Buildings using Active Controlled Bridges, Proceeding of The 3rd World Conference on Structural Control, pp.253-261