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TEMPERATURE RISE OF FULL-SCALE VISCOUS DAMPER UNDER LONG-PERIOD GROUND MOTIONS

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Long-period ground motions　Temperature increase
Full-scale viscous damper　Energy dissipation

1.INTRODUCTION

Viscous dampers are highly effective in components for dissipating earthquake energy in buildings [1]. The energy dissipated by the dampers is mostly converted into heat, leading to an increase of temperature. Understanding the expected increase of damper temperature is important as it is directly linked to the energy dissipation performance of the damper, as well as the safe operating rang [2-3]. Previous studies have investigated how the viscous dampers perform under harmonic loadings, including the change in damper temperature as in it cycles through various demands [2-4]. However, no studies have looked at how the temperature of the damper changes under realistic demands expected in a building during earthquakes. In particular, the effects of ambient temperature on the expected temperature change of a damper are also unknown. Furthermore, it is also of interest to understand the effect of damper-ambience temperature difference (between the damper cylinder and its surroundings) on the expected temperature rise as the ambient temperature can differ from the damper initial temperature (e.g., in the case of an earthquake aftershock shortly following the main shock as in the Kumamoto earthquake [5]).

In this paper temperature rise due do different long-period ground motions was investigated. The study parameters included the initial damper cylinder temperature and the damper-ambience temperature difference between the damper cylinder and its surroundings.

2. EXPERIMENT INVESTIGATON

Figure 1 shows the full-scale viscous damper used in the experiment. The damper was 4706mm long; the damper cylinder length was 606mm and the area of damper brace (A_b) was 8320mm^2. The damper was installed suspended between two pinned joints, as indicated in Figure1.

Figure 2 shows the locations of displacement sensors, thermocouples and strain gages used on the damper. Since the temperature of the viscous fluid could not be measured directly, the surface temperature of the cylinder was measured instead. A total of 10 thermocouples were utilized. One on the piston rod (θ_1), six on the cylinder(θ_2~θ_7) and one placed on the brace surface 200mm away from the cylinder center(θ_8). Two thermocouples were placed to measure the ambient temperature (θ_{r1}, θ_{r2}). One was placed 100mm from the center of cylinder (θ_{r1}) and the other was placed 2m from the center of cylinder (θ_{r2}).

Four displacement sensors were installed on the piston rod to measure the deformation of damper during loading. The reported damper displacement (u_m) is the average of the four displacement sensors. Twelve strain gages were installed on the damper brace at four gauges each at three cross-sections to calculate the brace force F_b. Since damper cylinder and brace are connected in series, it can be assumed that the damper force F_d is equal to F_b. The reported F_d is the average of the force measured as the three cross-sections.

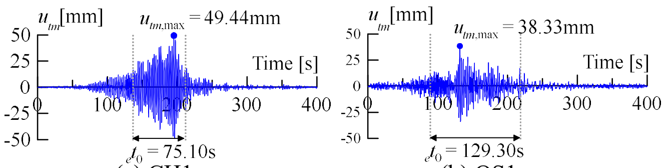
Figure 1 Overview of experiment setup

3. EXPERIMENT OF RANDOM WAVE LOADING

In this section, the random wave loadings CH1 and OS1 are presented. Since dampers are operated in different ambient temperature, the temperature change at ambient temperature 14℃ and 19℃ were discussed.

3.1 Input excitation

Considering the property of the actuator and the performance degradation of the damper, the input excitations used in the loading was the damper displacement response in a 20-story high-rise [6] building with viscous dampers subjected to two long-period ground motion: CH1 and OS1. Figure 2 shows the time-history of the input damper displacement(u_{tm}), obtained from time history analysis of the 20-storey building. The effective loading duration $_et_0$ is defined as duration during that includes 5% ~ 95% of the cumulative squared displacement is indicated in the figure.



(a) CH1　(b) OS1

Figure 2 Input damper displacement

3.2 Loading conditions

Four loading cases were considered in this paper, the details of which are listed in Table 1. The main differences between loading cases were the input excitation, initial damper cylinder temperature (θ_4^0), and the temperature difference ($\Delta\theta_d^0$) between the damper cylinder and its surroundings (hereon "damper-ambience temperature difference"). Case 1R-CH is treated as the base case in which the damper is subjected to the CH1 input exaction. In case 2R-OS, the OS1 input excitation is used. Case 3R-CH considered the effect of an increase of θ_4^0 of 6℃ from the base case. Finally, Case 4R-CH considered the effect of a large damper-ambience temperature difference ($\Delta\theta_d^0$) of 32℃, as could be possible in an aftershock event. To achieve the large initial cylinder temperature, the damper was excited with CH1 input excitation consecutively.

4. EXPERIMENT RESULT

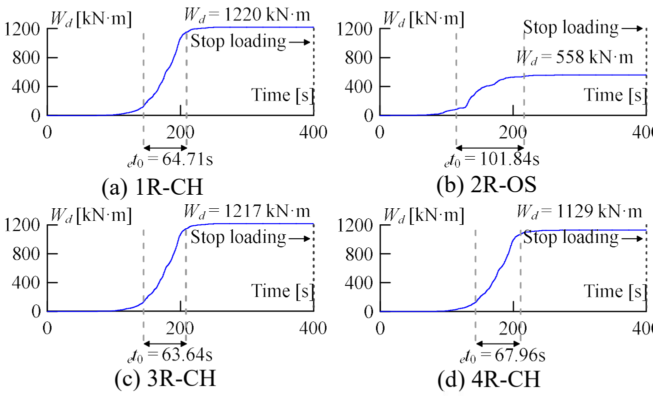
4.1 Energy dissipation

The damper energy dissipation of each case was shown in Figure 3. It can be observed that during the majority of energy dissipation occurred within the effective loading duration $_et_0$, it can be seen that

Table 1 Random wave loading conditions

Loading case	Initial ambient ($\theta_{r2}{}^0$) [℃]	Initial cylider(θ_4^0) [℃]	Temperature difference($\Delta\theta_d^0$) [℃]	Loading objective
1R-CH	14	15	1	Base case
2R-OS	16	17	1	Comparsion earthquake CH1 and OS1
3R-CH	19	21	2	Comparsion initial cylinder temperature θ_4^0
4R-CH	14	47	33	Comparsion damper-ambience temperature difference $\Delta\theta_d^0$

the energy dissipation during the OS1 excitation (Figure 3b) is approximately half of that for CH1 (Figure 3a), as mentioned in [3]. From a comparison of 1R-CH and 3R-CH, it can be seen that despite the initial damper cylinder temperature θ_4^0 of 6°C (Table 1), the energy dissipation is almost the same (within 1%). This result suggests that small changes in the initial damper cylinder temperature have no significant effect on the change in the total energy dissipation of the viscous damper. Finally, the results show that a large temperature difference between the cylinder and surroundings $\Delta\theta_d^0$ (1R-CH vs. 4R-CH), also did not have a significant influence on the energy dissipation (within 8%).



(a) 1R-CH (b) 2R-OS

(c) 3R-CH (d) 4R-CH

Figure 3 Energy dissipation of each case

4.2 Temperature rise

Figure 4 shows the measured temperature along various parts of the damper $t = 0$s, $t = 400$s and $t = 800$s of case 1R-CH. It can be seen that the highest temperature of the damper occurs in the cylinder portion, with little to no heat transfer occurring in the piston rod or the damper brace. Due to temperature of cylinder is the highest near the center, the temperature recorder at the cylinder center θ_4 will be used as the representative cylinder temperature in the next section.

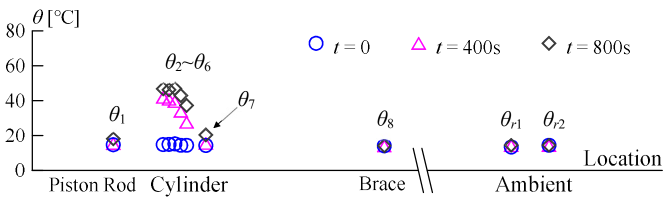
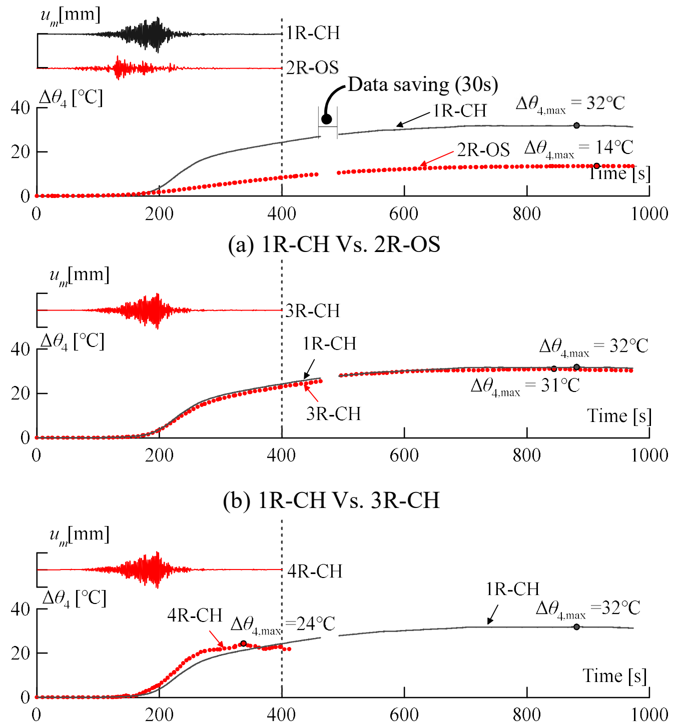


Figure 4 Measured initial and maximum temperature during 1R-CH

The temperature increase of the damper cylinder θ_4 for each loading is presented in Figure 5(a)~(c). It is noted that gaps in the data around the 450s mark correspond the period of date saving. The comparison of the temperature rise of 1R-CH and 2R-OS is shown in Figure 5(a). As expected, the temperature rise of the cylinder during 1R-CH (32°C) is considerably higher than 2R-OS (14°C) due to higher amount of energy dissipated (Figure 3a and 3b). Figure 5(b) presents the temperature rise of 1R-CH and 3R-CH. The initial damper cylinder temperature θ_4^0 of 3R-CH is 6°C higher than 1R-CH, while the damper-ambience temperature difference is almost the same. Similar to energy dissipation results, despite the difference between 1R-CH and 3R-CH, the recorded temperature rise is essentially identical (31~32°C). Thus, small variation (6°C) of the initial damper cylinder temperature has no effective on the temperature rise expected during excitation. This finding is useful to minimize the amount of quality control testing needed to characterize damper performance under various temperature condition. Figure 5(c) shows the temperature rise of 1R-CH and 4R-CH. It can be seen that a larger damper-ambience temperature difference for case 4R-CH ($\Delta\theta_d^0$=33°C) resulted in smaller temperature rise compared to 1R-CH ($\Delta\theta_d^0$=1°C). Therefore, the damper cylinder temperature expected in an aftershock (i.e., a larger $\Delta\theta_d^0$) can be conservatively evaluated assuming consecutive main shock events.



(a) 1R-CH Vs. 2R-OS

(b) 1R-CH Vs. 3R-CH

(c) 1R-CH Vs. 4R-CH

Figure 5 History of temperature rise θ_4

5. CONCLUSIONS

In this paper temperature the effect of different long-period ground motions and initial temperature conditions on the increase of viscous damper cylinder temperature was investigated. The result shows that: (1) The initial damper cylinder temperature (θ_4^0) was not found to influence the temperature increase experienced during excitation, within a small range (6°C). (2) A large difference between the damper cylinder temperature and initial ambient temperature ($\Delta\theta_d^0$) resulted in smaller damper cylinder temperature increase for the same exaction. Based on this, the increase in damper cylinder temperature expected in an aftershock can be conservatively evaluated using temperature increase data for $\Delta\theta_d^0$=0°C conditions.

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