THE GAP-THERMO-MECHANICAL EFFECT OF THE FLUID VISCOUS DAMPER

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Extended Abstract

Fluid viscous dampers (FVDs) have been widely implemented in bridge and building structures because of their high energy dissipation capacity and reliability in mitigating structural vibrations. However, during long-term service, the performance of FVDs may deteriorate due to several physical mechanisms. Among them, the gap effect caused by connection clearances or fluid leakage and the thermo-mechanical effect associated with temperature-dependent fluid viscosity are two dominant factors that can significantly influence the actual damping performance. The gap effect occurs when the piston motion reverses and the damping force temporarily disappears due to connection clearances or insufficient fluid volume inside the damper chamber. This phenomenon results in a force-free stage in the hysteresis loop, leading to a significant reduction in energy dissipation and vibration mitigation performance. To reproduce this behavior in structural analyses, three numerical models are proposed: the Gap model, the Equivalence model, and the Stiffness degradation model. To validate these models, shake table tests are conducted on a single-degree-of-freedom structural system equipped with an imperfect FVD. The experimental results clearly demonstrate that the presence of gaps leads to incomplete hysteresis loops and intermittent damping force

generation. Consequently, the vibration control performance of the damper is significantly weakened compared with that of an ideal device. Comparisons between numerical simulations and experimental observations confirm that the proposed models can effectively reproduce the dynamic behavior of FVDs affected by the gap effect under both harmonic and seismic excitations.

In addition to mechanical imperfections, the performance of FVDs is also influenced by the temperature-dependent viscosity of the damping fluid. To investigate this effect, a series of material-level and device-level experiments are carried out. First, rheological tests of silicone oil are performed under various temperatures and shear rates to establish the temperature–viscosity relationship. The results indicate that the viscosity of the fluid decreases significantly with increasing temperature, which directly leads to a reduction in the damping force generated by the damper. Subsequently, cyclic loading tests are conducted on the FVD under different operating temperatures to quantify the temperature dependence of the damper parameters. The experimental results show that the damping coefficient decreases exponentially with increasing temperature, while the velocity exponent remains nearly constant. Furthermore, the self-heating effect of the damper during cyclic loading is examined. A linear relationship between the temperature rise and the dissipated energy is observed, indicating that continuous operation may further reduce the damping performance due to internal heat accumulation.

To incorporate the above findings into structural design, a stochastic vibration-based design framework for FVDs is proposed for long-span suspension bridges. A simplified beam–spring–mass (BSM) model is introduced to efficiently represent the longitudinal dynamic interaction between the bridge girder and pylons. Within this framework, stochastic vibration theory and the energy equivalence principle are combined to evaluate the influence of damper degradation on structural response. A three-factor modification strategy for the damping coefficient is proposed to account for the effects of operating temperature, self-heating, and gap size. Through seismic

response analyses under both stationary and non-stationary excitations, the influence of these degradation factors on vibration mitigation performance is systematically evaluated. The results reveal that the gap effect has the most significant influence on the damping performance, followed by the operating temperature and the self-heating effect. By applying the proposed parameter modification strategy, dampers with degraded performance can still achieve vibration mitigation performance comparable to that of ideally designed devices, thereby ensuring the safety and reliability of the bridge system.

Keywords: *Fluid viscous damper; Oil leakage; Temperature variations; Self-heating; Damping evolution model*