SEISMIC-INDUCED BEARING UPLIFT IN LONG-SPAN DECK-TYPE ARCH BRIDGES: ANALYSIS AND MITIGATION

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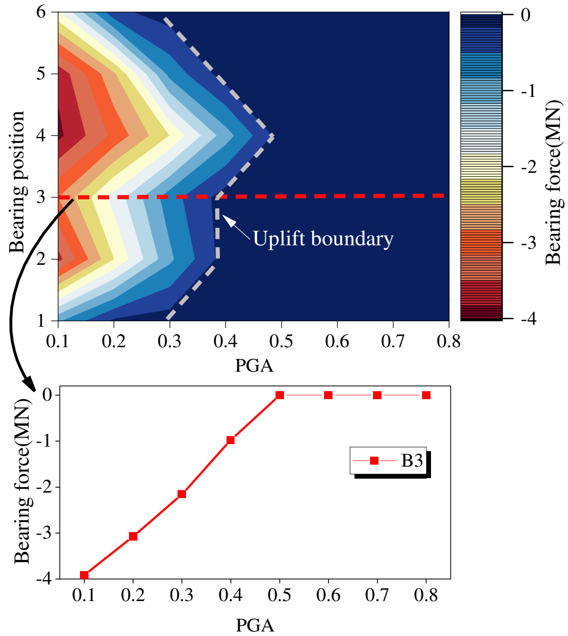
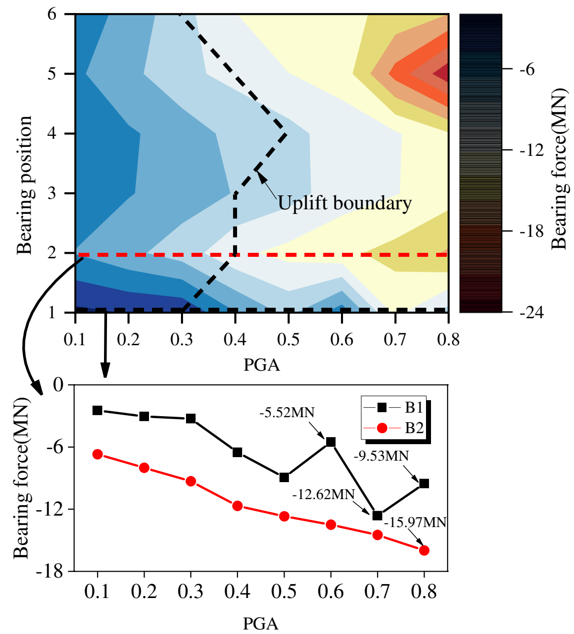
Extended Abstract

Past earthquake damage has shown that bearing uplift is one of the significant causes of bridge structural failure. For long-span deck arch bridges, due to the spatially coupled vibration characteristics of the spandrel structures, the bearing uplift problem is particularly pronounced. This study first conducts nonlinear time-history analyses on a long-span deck arch bridge subjected to near-fault pulse-type ground motions, revealing the dynamic development process of bearing uplift and clarifying its influence on the seismic response of the bridge. On this basis, an enhanced SMA friction self-restoring damper (eSMA-FSRD) is proposed to control bearing uplift in such bridges.

The bearing uplift behavior under seismic excitation exhibits a distinct intensity threshold. Bearings along the bridge from the abutment piers toward the arch crown show a roughly V-shaped distribution of the minimum PGA required to trigger uplift. Bearings at the abutment pier and the arch crown are most susceptible, with thresholds as low as 0.3g, whereas bearings near the quarter-span require higher PGAs (0.4g–0.5g). Once uplift occurs, the maximum bearing force increases sharply and exhibits significant fluctuations. This phenomenon is attributed to the coupled vibration of the long-span deck arch bridge: when the arch ring rebounds upward as the girder descends, it drives the bearings and the girder into more intense collision; conversely, downward vibration of the arch ring mitigates the collision force. These findings highlight the need for a control device that can accommodate vertical deformation while providing reliable energy dissipation and self-restoring capability.



(a) Minimum bearing force



(b) Maximum bearing force

Fig. 1. Influence of different PGA levels on bearing force

The proposed eSMA-FSRD features a modular assembly configuration incorporating a lever amplification mechanism. The damper consists of a transmission block, a movable end plate, a transmission rod, and SMA bolts, all positioned and secured by a base plate and a cover plate. Under external loading, vertical displacement at one end of the transmission rod drives the transmission block into in-plane rotation, converting the vertical displacement into horizontal translation that stretches the SMA bolts. Notably, regardless of whether the damper is subjected to tension or compression, the SMA bolts are always maintained in a tensile state for energy dissipation, fundamentally eliminating the risk of buckling instability that plagues conventional compression members. This mechanism effectively enhances both the deformation and load-carrying capacity of the SMA bolts.

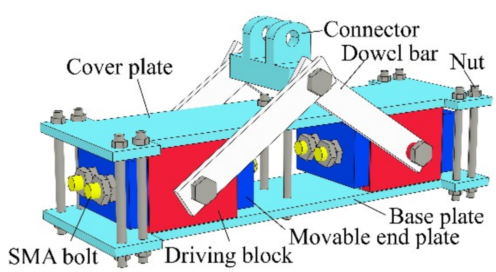


Fig. 2. Configuration of eSMA FSRD

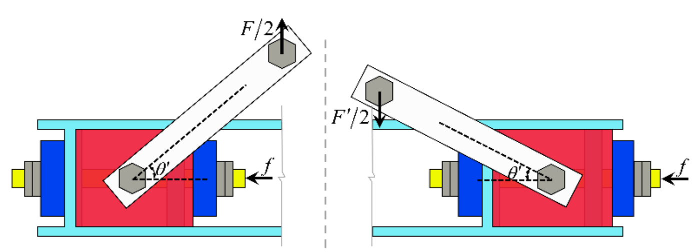
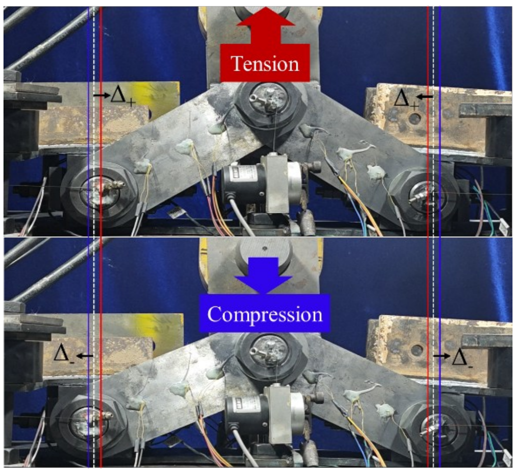


Fig. 3. Working mechanism of eSMA FSRD

Quasi-static loading tests were performed to evaluate the mechanical performance of the eSMA-FSRD. The loading protocol adopted one cycle per 1% tensile strain increment of the SMA bolts, proceeding stepwise to 5% strain. The results show that the damper works as designed under both tension and compression, and upon unloading it returns to its initial position, confirming reliable self-restoring capability. The measured hysteretic curves exhibit a distinct double-flag shape, with high overlap among multiple cycles, reflecting stable working performance. The lever amplification mechanism significantly enhances the performance of the SMA bolts.



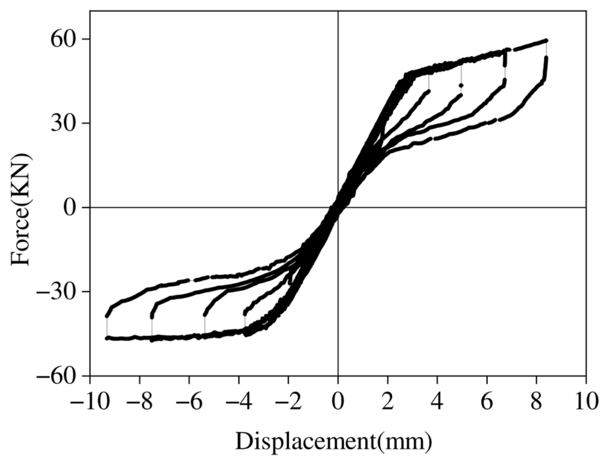


Fig. 4. Tension and compression behavior of eSMA FSRD   Fig. 5. Hysteretic curve

The eSMA-FSRD provides a novel solution for the bearing uplift problem in long-span deck arch bridges. Conventional metallic dampers employing fully rigid control strategies tend to amplify dynamic responses or suffer buckling failure under large negative reactions. In contrast, the eSMA-FSRD capitalizes on the tension-only energy dissipation of SMA bolts and its exceptional self-restoring capability. The study demonstrates that the damper reliably mitigates bearing uplift, manifesting as an effective reduction in both girder uplift displacement and bearing impact force.

Keywords: *Long-span deck arch bridge; bearing uplift; SMA; damper; seismic control.*