

Damage Detection of Prestressed Concrete Girder Bridges Through Nonlinear Modal Damping Identification

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Recent attention has been drawn to damping-based damage detection techniques due to their superior sensitivity in portraying even small damage. Most studies utilizing damping as a damage indicator rely on the traditional viscous damping model, assuming a constant damping mechanism. However, damage-induced damping demonstrates nonlinear characteristics, where the location of damage notably influences modal damping, particularly when the damage occurs near the antinode of a vibrating mode. Based on this fact, this research proposes a novel methodology for detecting and localizing damage by identifying the nonlinearities in modal damping behavior. Two laboratory-scale experimental setups were used to characterize the damping behavior with and without damage. The first involved simply supported reinforced concrete (RC) beam with varying degrees of flexural cracks at mid-span to study quadratic type of damping. The second setup featured a steel cantilever beam to simulate damage with frictional damping. The challenge of decomposing the measured vibration signal into distinct modal responses was addressed using the Variational Mode Decomposition (VMD) technique. The decaying amplitudes of the decomposed modal responses are then used to extract the instantaneous damping behavior of each mode. Experiments with RC beams showed that at undamaged conditions, modal damping behavior remains constant across all active modes. However, when the damage occurred at mid-span, the damping behavior of the first flexural mode in which the antinode is at midspan becomes nonlinear. In contrast, the second flexural mode in which mid-span is the node point continued to exhibit constant damping. Increasing the degree of flexural damage increased the nonlinearity in damping of the first mode. The experiment of cantilever beam with varying degree of friction damping demonstrated that increasing the degree of friction resistance increased the nonlinearity in damping. Gradual change of location of friction force towards the antinode intensified the nonlinearity in damping of respective mode. These experimental findings indicated that the presence of damage results in nonlinear damping behavior. The location of the damage dictates the presence of nonlinearity in damping of each mode, while the severity of the damage intensifies this nonlinearity in modal damping. Then, the proposed method was used to assess the condition of a single spanned pre-stressed concrete (PC) girder bridge. Free vibration responses extracted from ambient response measurements of the selected bridge were analyzed using the proposed method and revealed that the modal damping behavior is constant for all active modes reflecting no damage as per the laboratory-scaled tested hypothesis.

Keywords: PC Bridges, Vibration-Based Damage Detection, Nonlinear Damping Identification, Variational Mode Decomposition