Nonlinear Normal Modes For Damage Detection: Theoretical Concepts And Preliminary Experimental Validation.

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The exploitation of nonlinearities in the field of damage detection is a promising direction for the establishment of robust and reliable monitoring systems in several engineering applications. In this perspective, the concept of nonlinear normal mode (NNM) is the natural candidate for extending the knowledge already established in the linear framework and for developing new approaches. The nonlinear dynamic response sensitivity with respect to damage is herein investigated by considering a significant case study representative of a wide class of real-world structures. A simply supported beam with reductions of the cross-sectional area localized in small segments of the span is considered in the present study. In the first stage, the problem is analytically tackled with the method of multiple scales for computing the NNMs and the backbones curves. The latter describe the trends of the resonance frequencies as a function of the oscillation amplitude and are regulated by the so-called effective nonlinearity coefficient associated to each mode. This coefficient is shown to exhibit a higher sensitivity to damage with respect to the linear natural frequencies, whereas the backbones associated to each mode reveal an interesting dependency on the stiffness reduction and damage site. A strategy to identify the damage position without employing information of the undamaged beam is proposed by computing the discontinuities in the second derivatives of the NNMs, which correspond to the first order estimate of the bending curvatures. Using a finite set of sampled beam deflections associated to each individual NNMs, the discontinuities are evaluated by means of the high-order derivatives of the Nadaraya-Watson kernel estimator. The results show that the damage-induced discontinuities have a higher influence on the second derivatives of the NNMs with respect to linear modal curvatures. The robustness of the approach against noise is also investigated. In the second stage, an experimental campaign is carried out on a set of simply supported beams with different levels of area reduction localized in a few segments along the beam span. The beams are base excited via an electromechanical shaker while the linear resonances frequencies, modes and associated damping ratios are estimated by performing Experimental Modal Analysis by means of the Polytec PSV-500-3D vibrometer system and the PolyWave software. The LMS-Siemens-TestLab system is employed to acquire the backbone curves, which are obtained by carrying out sweep tests for increasing excitation levels in the ranges of the resonance frequencies. The experimental results corroborate refined finite element predictions obtained by Abaqus. The theoretical concepts developed in the first analytical phase are validated by the outcomes of the experimental campaign, thereby confirming the usefulness of the nonlinear dynamic response in the context of structural health monitoring.