Nonlinear dynamic response of a Negative Stiffness-Shape Memory Alloy isolation system

Andrea Salvatore*, Biagio Carboni* and Walter Lacarbonara*
**Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Rome, Italy*

Abstract. The negative stiffness exhibited by bi-stable mechanisms together with tunable hysteresis in the context of vibration isolation devices can enhance the dynamic resilience of a structure [1, 2]. The effects of negative stiffness and shape memory alloy (SMA) damping in base-isolated structures are here explored via pathfollowing, bifurcation analysis, and time integration [3]. The frequency-response curves of the isolated structure, with and without the negative stiffness contribution, are numerically obtained for different excitation amplitudes to construct the acceleration and displacement transmissibility curves. The key advantages of negative stiffness, damping augmentation and reduced transmissibility together with the existence of rich bifurcation scenarios leading to quasi-periodicity and synchronization, are extensively illustrated.

Introduction

In the present work, the dynamic response of a classical seismic isolation system made up of elastomeric bearings working in parallel with a negative stiffness mechanism and SMA wires is explored. The SMA wires are used in order to realize an initial gap and, at the same time, provide hysteretic damping to the system while the negative stiffness contribution is used to achieve a zero dynamic stiffness away from the equilibrium position. For a careful investigation of the nonlinear periodic response of a SDOF representing the isolated structure controlled with a negative stiffness-SMA (NS-SMA) damping mechanism, both the restoring force of the bearing devices and that of the super-elastic response of SMA wires are modelled employing suitable hysteretic constitutive laws.

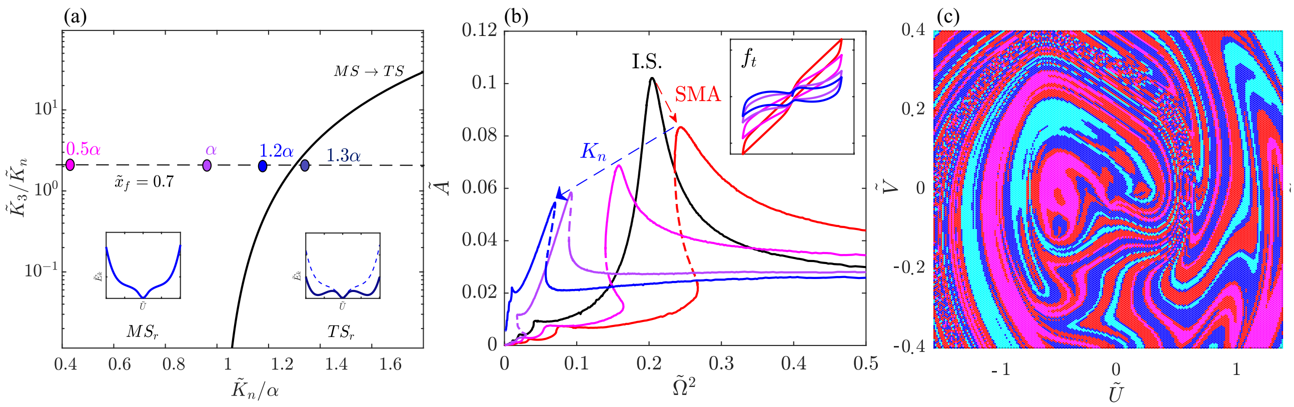

Figure 1: a) Bounding curves between mono-stability and tri-stability regions in the parameters space of the negative stiffness mechanism ($\tilde{K}_n, \tilde{K}_3$). b) Accelerations FRCs for the baseline isolation system (black line), for the system plus SMA damper alone (red line) and for the system with SMA damper and different levels of negative stiffness (magenta, violet and blue lines). c) Basins of attraction of the tri-stable configuration exhibiting four distinct quasi-periodic attractors.

Results and discussion

The novel vibration isolation system is investigated parametrically for different levels of negative stiffness, SMA hysteretic damping ratio and yielding force and the optimum ranges of the design parameters are identified. The study of the nonlinear dynamic response and its bifurcations has unfolded very rich bifurcation scenarios with detached resonances and surprising interactions between the primary resonance and superharmonic resonances, or between superharmonic resonances of various orders, featuring multiplicity of coexisiting attractors, secondary Hopf bifurcations leading to quasi-periodicity, synchronization, symmetry breaking and period-doubling cascades. The detached resonance curves and bifurcations are numerically explored to assess the consequences on the isolation performance. Moreover, the interesting quasi-periodicity of the response of the tri-stable configuration obtained for higher levels of negative stiffness and the subsequent dynamic amplification, are discussed.

References

[1] Taylor D, Nagarajaiah S, Reinhorn AM, et al, Adaptive negative stiffness: A new structural modification approach for seismic protection, Journal of Structural Engineering (139), 2013.

[2] Platus DL. Negative stiffness mechanism vibration isolation systems, Proceedings Volume 1619, Vibration Control in Microelectronics, Optics, and Metrology, 1992.

[3] Lacarbonara W, Vestroni F, and Capecchi D, Poincarè map-based continuation of periodic orbits in dynamic discontinuous and hysteretic systems, 17th Biennial ASME Conference on Mechanical Vibration and Noise, 1999