On the vibration attenuation properties of metamaterial design using negative stiffness elements

Kyriakos Alexandros Chondrogiannis*, Vasilis Dertimanis*, Boris Jeremic** and Eleni Chatzi*
*Institute of Structural Engineering, ETH Zürich, Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland
**Department of Civil and Environmental Engineering, University of California, Davis, CA 95616, U.S.A

Abstract. In recent years, the promising concept of metamaterials has entered the field of civil engineering. These type of configurations are characterized by extraordinary properties regarding prevention or guidance of wave propagation. In order to increase the potential frequency band in which such structures are efficient, nonlinearities are utilized. In the current study, negative stiffness elements are studied and arranged in an array of multiple identical cells, in order to study the resulting wave screening properties. The outcome results indicate the ability of the system to mitigate vibration within a wide range of frequencies.

Introduction

A very important aspect in the design of civil structures is their behaviour under dynamic excitation. Mitigation of vibrations has been frequently treated via use of passive devices ; with a primary candidate lying in use of tuned mass dampers [1]. New novel designs, within the framework of metamaterials, have been recently proposed for structural protection applications [2]. These type of configurations are characterized by extraordinary properties regarding prevention of wave propagation within a specific frequency range, the so called band-gap, or guidance of propagating waves [3]. A challenge that arises when considering seismic excitation is related to the large amount of seismic energy that needs to be treated and also to the frequency content of the seismic input. Seismic motions are usually composed by low frequency content, which lies well outside the most common applications of metamaterials, which were initially studied for electromagnetic waves, therefore high frequency spectra. There is high research activity towards creating meta-structures, which are able to inhibit low frequency wave propagation [4], also relating to seismic excitation. In the current work, geometric nonlinearities are utilized as a basis for metamaterial development. Geometrically nonlinear behaviour is produced with the use of a triangular shallow arch that is undergoing large displacements and that can, under specific conditions, trigger negative stiffness effects [5]. The equilibrium path of this configuration can be calculated analytically and is incorporated in the equations of motion of the system. The system under investigation consists of multiple, identical and elastically interconnected unit cells, that form a lattice (Figure 1). Each cell is composed of a rigid support, connected to the nonlinear element. One end of the configuration is connected to the ground and the other to a primary mass, subjected to protection from incoming vibration. Moreover, the system is excited by a harmonic input ground motion.

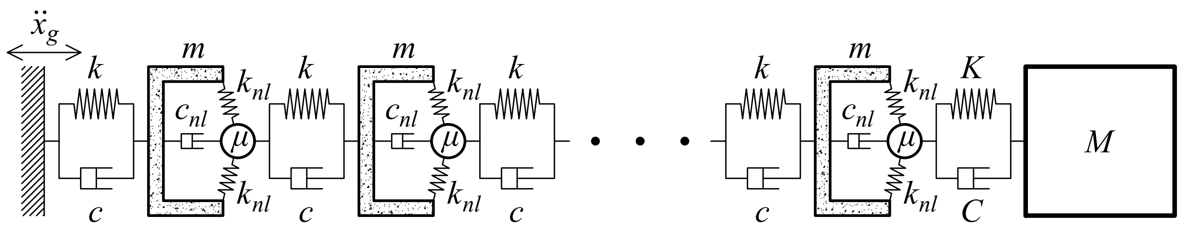

Figure 1: Nonlinear metamaterial lattice

Results and discussion

The system's performance is calculated by the solution of the differential equations of motion for various parameters of the system. Of particular interest are the geometric properties of the triangular arch. The sharper the arch angle at rest, the more significant negative stiffness effects are observed. The results clearly indicate the ability of the configuration to absorb vibration within a wide range of frequencies. Moreover, the benefit of multiple unit cells is evident, as an increasing number of such cells results into more favourable results in terms of accelerations at the protected mass, thus improving the filtering capabilities of the configuration.

References

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