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Wave propagation in and stability of geomaterials with negative stiffness inclusions

Maxim Esin (1), Arcady Dyskin (2), and Elena Pasternak (1)

(1) School of Mechanical and Chemical Engineering, The University of Western Australia, Crawley, WA, 6009, Australia (esinmy@gmail.com, elena.pasternak@uwa.edu.au), (2) School of Civil, Environmental and Mining Engineering, The University of Western Australia, Crawley, WA, 6009, Australia (arcady.dyskin@uwa.edu.au)

The effects of negative stiffness are some times observed in the behaviour of geomaterials, for instance, in the form of post-peak softening. Locally the negative stiffness can be caused by rotations of non-spherical blocks, fragments or grains and can be interpreted as negative shear modulus. While the negative stiffness materials are inherently unstable, materials with negative stiffness inclusions can still be stable as long as the concentration of the inclusions does not exceed a critical one. As the concentration of negative stiffness increases and approaching the critical value the effective shear modulus can both increase or decrease compared to the matrix value. Correspondingly the wave velocities can increase or decrease thus providing a monitoring tool to predict the approaching instability stage and possibly failure.

In order to investigate the mechanism of instability in detail we model geomaterials as discrete mass-spring systems with normal, shear and rotating springs between point masses in one-, two- and three-dimensions. By analysing the equations of motion of such a system we established that systems with certain number of negative stiffness inclusions could be stable and permit wave propagation. For example a finite, one-dimensional mass-spring system with normal and shear springs is stable if not more than one normal and one shear springs are of negative stiffness. Furthermore, the presence of negative stiffness springs increases the stiffness of the system and enhances the damping. These findings open a way to construct the discrete models of geomaterials with negative stiffness inclusions that fit the observed peculiarities of the wave propagation.