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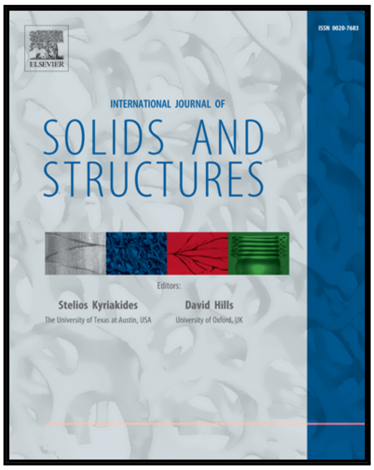

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Modeling longitudinal wave propagation in nonlinear viscoelastic solids with softening

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Abstract

A model for longitudinal wave propagation in rocks and concrete is presented. Such materials are known to soften under a dynamic loading, i.e. the speed of sound diminishes with forcing amplitudes. Also known as slow dynamics, the softening of the material is not instantaneous. Based on continuum mechanics with internal variables of state, a new formulation is proposed, which accounts for nonlinear Zener viscoelasticity and softening. A finite-volume method using Roe linearization is developed for the system of partial differential equations so-obtained. The method is used to carry out resonance simulations, and its performance is assessed in the linear viscoelastic case. Qualitative agreement with experimental results of nonlinear ultrasound spectroscopy (NRUS) and dynamic acousto-elastic testing (DAET) is obtained.

Keywords: Nonlinear acoustics, softening, viscoelasticity, numerical methods
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1. Introduction

Longitudinal vibrations of rocks and concrete highlight features which cannot be reproduced by standard elastodynamics [1]. First, in nonlinear resonance ultrasound spectroscopy (NRUS), a frequency-shift of the resonance peaks with the amplitude of forcing is observed [2, 3]. This feature reveals the highly nonlinear behavior of such material. Second, in dynamic acousto-elastic testing (DAET) [4, 5], a decrease of the sound speed over a time scale larger than the period of the dynamic loading is observed (*softening*), which highlights the phenomenon of *slow dynamics*. When the excitation is stopped, the sound speed recovers gradually its initial value (*recovery*). Third and last, hysteresis curves are obtained when the speed of sound is represented with respect to the axial strain. All these phenomena are accentuated when the forcing amplitude is increased.

Several models can be found in the literature to describe these phenomena (see e.g. [6–8]). The approach proposed by Vakhnenko et al. in their *soft-ratchet* model [9, 10] consists in adding a variable g to describe the softening of the material. Also, an evolution equation for g is provided, and a relaxation time is included. A similar model with refinements was proposed by

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