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Linear and non linear acoustic waves in macroscopically inhomogeneous unconsolidated granular crystals

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Ordered unconsolidated structure of spherical beads in the absence of external loading except the gravity field constitutes a macroscopically inhomogeneous and strongly nonlinear phononic crystal. We report the experimental and theoretical investigation of linear and nonlinear acoustic phenomena in these granular crystals of finite thickness along the gravity direction. In particular the dependence of the resonance frequencies on the thickness of the crystal (the number of layers) is evaluated. The linear transmission of acoustic waves from the bottom to the free surface of the granular crystal exhibits complicated features. It is compared to the linear transmission through the same structure but with a macroscopically homogeneous static stress. Some frequency regions of the acoustic response function are shown to be insensitive to the transition from an inhomogeneous static stress (gravity induced) to a homogeneous one (additional external load). The nonlinear acoustic phenomena of resonance frequency shift and resonance curve broadening with increasing amplitude of acoustic oscillations are observed. It allows to measure the nonlinear parameters of the crystal for different amounts of layers, accounting for the absolute particle velocity amplitude detected at the free surface with a laser vibrometer. Corresponding theoretical models describing the acoustic eigenmodes in macroscopically homogeneous and inhomogeneous granular crystals are developed.