Acoustic monitoring and triggering of shearing instability in granular media

Laboratory studies of granular friction have emerged as a powerful tool for investigating dynamics of seismic faults [1], such as local static and remote dynamic triggering of earthquakes [2]. However, the physical origin of dynamic triggering still remains a challenging issue due to small strain amplitude of impinging seismic waves ($\sim 10^{-4}$) [3]. Advances in granular physics and acoustics have paved the way for a better understanding of how seismic waves may trigger fault slips. Unlike ordinary solids and liquids, static and dynamic properties of dense granular media are determined by the inhomogeneous contact force network exhibiting multiple metastable configurations; they may undergo a transition from jammed solid to flowing liquid states when the external driving such as shearing or shaking is beyond a certain threshold [4]. The emerging view is that dynamic perturbation of sheared gouge materials causes a material failure and fault slip that can be characterized as an unjamming transition induced by the acoustic fluidization [5].

**Acoustic probing of the shear banding**

Here we intend to investigate the granular shear instability (earthquake nucleation) in finite-thickness granular media by acoustic probing (Fig. 1A). Decrease of the shear wave velocity and development of the fabric anisotropy will be measured prior to failure (Figs. 1B & 1C). We will use the correlation function of the multiply scattered coda waves to monitor the stick-slip-like rearrangement of granular network during shear banding (Figs. 1B and 1D) [6]. We will also study the acoustic emission (passive probing) resulting from the contact network rearrangement and/or the particle motion during the shear banding, similarly to Acoustic Emission (AE) monitoring of fracture propagation [7]. We will examine the possibility to identify the major rearrangement or fracture during shear from AE signals and seek to localise the AE sources, likely inside the shear band, by acoustic time reversal.

**Seismic wave triggering of the shear failure**

We will study the effect of impinging elastic waves on their nucleation by nonlinear acoustic pumping. Two regimes of fast nonlinear dynamics were already identified with the material softening (Fig. 1E-a). In the irreversible regime of the sound-matter interaction, the wave velocity and correspondingly elastic modulus remains weakened after the wave transient and the force network is strongly modified even in the absence of visible grain motion (Fig. 1E-b) [5]. We will particularly study the onset of sliding triggered far below the static threshold by nonlinear sound waves via the acoustic lubrication of the stuck contact area between solid particles [8]. Here the finite amplitude of vibration basically reduces the coefficient of solid friction rather than inducing the geometric rearrangement, i.e., dilatancy [1].

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![Figure 1](image)

**Figure 1** (A) Shear apparatus (B) Evolution of the shear with slip (in blue) and the cross-correlation of Coda waves shown inset (in green) (C) Monitoring of the decrease of the shear wave speed (D) Zoom into Fig. B. (E) Sound-induced fluidization in granular media.

**References**