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Emergent lengthscales in the quenched stresses and elastic response of soft particle packings near jamming

Karimi, Kamran; Roy, Arka; Maloney, Craig, CMU, United States

ABSTRACT

We study stress correlations and elastic response in large-scale computer simulations of two-dimensional particle packings near jamming. We show that there are characteristic lengths in both the stresses and elastic response that diverge in similar ways as the confining pressure approaches zero from above. For the case of the stress field, we show that the power spectrum of the hydrostatic pressure and shear stress agrees with a field-theoretic framework proposed by Henkes and Chakraborty at short to intermediate wavelengths (where the power is flat in Fourier space), but contains significant excess power at wavelengths larger than ~ 50-100 particle diameters, with the specific crossover point going to larger wavelength at decreasing pressure, consistent with a divergence at $p = 0$. For the case of the elastic response, we probe the system in three ways: (i) point forcing; (ii) "constrained" homogeneous deformation where the system is driven with no-slip boundary conditions; and (iii) "free periodic" homogeneous deformation. For the point force, we see distinct characteristic lengths for longitudinal and transverse modes each of which diverges in a different way with decreasing pressure with $\xi T \sim P^{-0.25}$ and $\xi L \sim P^{-0.4}$ respectively. For the constrained homogeneous deformation we see a scaling of the local shear modulus with the size of the probing region consistent with $\xi \sim P^{-0.5}$ similar to the $\xi L \sim P^{-0.4}$ observed in the longitudinal component of the point-response and in perfect agreement with the rigidity length discussed in recently proposed scenarios for jamming. Finally, we show that the transverse and longitudinal contributions to the strain field in response to unconstrained deformation (either volumetric or shear) have markedly different behavior. The transverse contribution is surprisingly invariant with respect to p with localized shear transformations dominating the response down to surprisingly small pressures. The longitudinal contribution develops a feature at small wavelength that intensifies with decreasing p but does not show any appreciable change in length. We interpret this pressure-invariant length as the characteristic shear zone size.