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Rigidity of Dry Granular Solids

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Solids are distinguished from fluids by their ability to resist shear. In traditional solids, the resistance to shear come as an energy cost of straining, which works to distort density modulations that exists in both crystalline or amorphous structures. In our recent work,we focus on the emergence of shear-rigidity in a special class of solids: dry (non-cohesive) granular materials which have no energetically preferred density modulations. In contrast to traditional solids, the emergence of mechanical rigidity in these marginal granular solids is a collective process, which is controlled solely by boundary forces, the constraints of force and torque balance, and the positivity of the contact forces. We develop a theoretical framework based on these constraints, and show that these solids can be characterized by topological invariants and that, in two dimensions, they have internal patterns that are most naturally represented in the space of gauge field of the stress. Broken translational invariance in this gauge space is a necessary condition for rigidity in granular solids. We apply our theory to experimentally shear-jammed states as well as numerically generated jammed force networks to show that the statistics of stress fluctuations, and the ability of jammed configurations to resist deformations can be understood within this theoretical framework.