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Selection of hexagonal buckling patterns by the elastic Rayleigh-Taylor instability

Aditi Chakrabarti[a,b], Serge Mora [1a], Franck Richard[a], Ty Phou[c], Jean-Marc Fromental[c], Yves Pomeau[d], Basile Audoly[e,f]

[a]*Laboratoire de Mécanique et de Génie Civil, Université de Montpellier and CNRS 163 rue Auguste Broussonnet, F-34090 Montpellier, France.*
[b]*Department of Chemical and Biomolecular Engineering, Lehigh University, Bethlehem, Pennsylvania 18015, USA.*
[c]*Laboratoire Charles Coulomb, Université de Montpellier and CNRS 163 rue Auguste Broussonnet, F-34090 Montpellier, France.*
[d]*Department of Mathematics, University of Arizona, Tucson, Arizona 85721, USA.*
[e]*Laboratoire de Mécanique des Solides, École Polytechnique and CNRS, F-91128 Palaiseau, France.*
[f]*Division of Applied Science and Engineering, California Institute of Technology, Pasadena, California, USA.*

Abstract

We investigate the non-linear buckling patterns produced by the elastic Rayleigh-Taylor instability in a hyper-elastic slab hanging below a rigid horizontal plane, using a combination of experiments, weakly non-linear expansions and numerical simulations. Our experiments reveal the formation of hexagonal patterns through a discontinuous transition. As the unbuckled state is transversely isotropic, a continuum of linear modes become critical at the first bifurcation load: the critical wavevectors form a circle contained in a horizontal plane. Using a weakly non-linear post-bifurcation expansion, we investigate how these linear modes cooperate to produce buckling patterns: by a mechanism documented in other transversely isotropic structures, three-modes coupling make the unbuckled configuration unstable with respect to hexagonal patterns by a transcritical bifurcation. Stripe and square patterns are solutions of the post-bifurcation expansion as well but they are unstable near the threshold. These analytical results are confirmed and complemented by numerical simulations.

Keywords: A. Buckling, B. Elastic material, B. Finite strain, B. Plates, C. Stability and bifurcation

1. Introduction

Elastic buckling phenomena have been classically investigated in thin or slender structures such as shells, plates and rods, that are effectively compliant at large scale owing to their thin or slender geometry. More recently, the attention has been extended to buckling instabilities arising in elastic solids made of soft materials, such as gels or soft polymers. Soft elastic solids are attractive for applications as they can be actuated by forces that are otherwise too weak to induce significant elastic strains such as their own weight (Mora et al., 2014), electric forces (Arun et al., 2006; Wang et al., 2011; Huang et al., 2012; Bense et al., 2017), magnetic forces (Danas and Triantafyllidis, 2014), adhesive forces (Ghatak et al., 2000; Mönch and Herminghaus, 2001), or even the capillary forces present at a curved solid-fluid interface (Mora et al., 2010, 2013). As they undergo large strains, soft elastic solids display a non-linear response and are prone to a variety of buckling instabilities (Biot, 1963; Tanaka et al., 1987; Mora et al., 2011; Ciarletta et al., 2013; Lagrange et al., 2016); some of these instabilities are discontinuous and are therefore difficult to approach analytically: this is the case of the creasing instability for example (Hong et al., 2009; Cao and Hutchinson, 2011; Hohlfeld and Mahadevan, 2012; Ciarletta and Fu, 2015).

This is also the case of the *elastic* Rayleigh-Taylor instability, which we investigate in this paper. This instability is obtained when a thick slab of elastic material is hung below a rigid plane, see figure 1. A competition takes place between the elasticity of the slab (which tends to keep the slab undeformed) and its weight (which acts as a destabilizing force). When elasticity wins, the slab remains undeformed and its lower