Accepted Manuscript

A robust Riks-like path following method for strain-actuated snap-through phenomena in soft solids

Yin Liu, Shenyang Liang, Qun Huang, Heng Hu, Yonggang Zheng, Hongwu Zhang

PII: S0045-7825(17)30063-4
DOI: http://dx.doi.org/10.1016/j.cma.2017.05.010
Reference: CMA 11445

To appear in: *Comput. Methods Appl. Mech. Engrg.*

Received date : 10 January 2017
Revised date : 7 May 2017
Accepted date : 8 May 2017

A Robust Riks-like Path Following Method for Strain-actuated Snap-through Phenomena in Soft Solids

Yin Liu[a,b], Shenyang Liang[a], Qun Huang[a], Heng Hu[a*], Yonggang Zheng[b], Hongwu Zhang[b]

[a]School of Civil Engineering, Wuhan University, 8 South Road of East Lake, Wuchang, 430072 Wuhan, P. R. China

[b]State Key Laboratory of Structural Analysis for Industrial Equipment, Department of Engineering Mechanics, Faculty of Vehicle Engineering and Mechanics, Dalian University of Technology, Dalian 116024, P. R. China

*Corresponding author: huheng@whu.edu.cn

Abstract: In this paper, a practical and robust Riks-like path following method is developed to automatically trace the nonlinear equilibrium path for initial-finite-strain-induced snap-through phenomena in soft solids. The deformation gradient is decomposed into an elastic part and an initial-strain part, where the initial strain is characterized through a prescribed pattern tensor and an unknown strain factor describing the magnitude. In the non-linear finite element (FE) solution scheme, an equivalent body force proportional to the increment of the strain factor is derived, which varies in each iteration step due to its dependence on deformed configuration and stress. Both the displacement and the strain factor increments are introduced as unknowns in the linearized equation, which permits to predict the critical equilibrium states before and after the snap-through. Several examples with various configurations and strain histories are constructed, including multilayer beams and film-substrate systems, which demonstrate the effectiveness and robustness of the algorithm to capture the strain-induced snap-through phenomena.

Keywords: The Riks method; snap-through; bistability; initial strain; soft matter; multiplicative decomposition

1 Introduction

When applying a concentrated force on the surface of a simply-supported cylindrical shell (or beam), a fast shape transition from one to another stable state can be observed if the force reaches a critical value [1]. Such a phenomenon is called as ‘snap-through’ traditionally accompanied by fast shape transitions between different stable states in a short time scale. Interestingly, some plants have been found to utilize the large magnitude geometric changes in the snap-through instability to achieve specific functions, such as self-protection, intake of nutrients and reproduction [2]. The most well-known example is Venus flytrap, a plant capable to capture the small insects with a very fast speed. It has been widely accepted that the snap-through instability during the closing process of their leaves plays an essential role to achieve such a fast predatory behavior [3]. The strain energy of the leaf keeps increasing at the beginning of the predatory process and then dramatically releases after reaching a critical state, leading to a fast morphological transition of the leaf from convex to concave. Inspired by such intriguing behaviors, various kinds of devices have been fabricated aiming to achieve fast function transitions by introducing the snap-through instability in their actuating systems, including the PDMS-based micro-lens [4], 3D micro-gel actuators [5], photo-responsive azobenzene-functionalized polymers [6] and reversible snapping actuators [7]. Readers can refer to a comprehensive review on the mechanisms and applications for such fast moving behaviors in Guo et al. [2].