ME - PhD Thesis Colloquium

MECHANICAL ENGINEERING
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Studies on modelling the mechanics of slender elastic ribbons

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Offline mode: ME Lecture Hall (50% occupancy & Covid appropriate precautions)

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ABSTRACT

Ribbons are slender structures characterized by three disparate geometric dimensions: length >> width >> thickness. Their buckling-dominated nonlinear deformation behavior, once considered a hindrance, is now routinely exploited in engineering applications related to stretchable electronics and flexible robotics. Such applications demand a systematic understanding of their mechanics using experiments, modeling, and simulations. This thesis is a step in this direction.

Experiments using annulus-shaped ribbons and Moebius strips serve as our point of departure. The critical challenge in these experiments lies in measuring complex three-dimensional deformations. We leverage novel computer vision techniques developed in our lab to faithfully digitize shapes and sample deformation maps of ribbons realized in the experiments. These measurements lead us to the main contributions of this thesis- a detailed examination of the predictive capabilities of commonly used modeling approaches and the formulation of a dedicated one-dimensional ribbon model.

The physical appearance of ribbons motivates modeling them either as thin elastic plates or as elastic rods having a slender cross-section. Surprisingly, comparing finite element simulations of the widely adopted von Karman plate and Kirchhoff rod models with experimental measurements reveals both approaches to be deficient. We find that it is essential to permit large displacements and rotations in ribbon models and that compliance in the direction of the width, though small, plays an important role. Indeed, the experiments with annular ribbons and Moebius strips are designed to highlight these deformation features.

We propose adopting the small-strain Cosserat plate theory instead. The model's generality, along with a robust finite element implementation that addresses issues of numerical locking by adopting high order elements and approximating large rotations using exponential maps, translates to excellent agreement with experimental measurements. The model faithfully reproduces measured shapes, displacement fields and curvature distributions, as well as bifurcations and energy localization phenomena observed in experiments.

We then formulate a dedicated reduced-order one-dimensional ribbon model by systematically incorporating kinematic assumptions in the Cosserat plate theory. The proposed model is effectively a generalized rod theory that requires one additional field to describe lateral curvatures along the width of the ribbon. With mild boundary conditions, the additional field can even be determined in closed form. We examine the model's predictions in the context of varied experiments, including lateral-torsional buckling and three-dimensional rotation-induced snap-through. The model promises to be a valuable tool to develop insights into the mechanics of ribbons, besides being a compelling alternative to the existing Sadowsky and Wunderlich models available in the literature.

ABOUT THE SPEAKER

Arun Kumar is a Ph.D. candidate in the Dept of Mechanical Engineering at IISc. He has a Bachelor's degree from Jawahar Lal Nehru Engineering College, Himachal Pradesh, and a Master's degree from NIT Calicut. When free, he likes to run on campus.