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## **Semi-Analytical Finite Element Modeling of Nonlinear Nanoshells**

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The nonlinear response of shell structures is highly sensitive to geometry, loading and imperfections. These effects are even more pronounced passing at micro- and nano-scale, where size-dependent phenomena also play an important role on the mechanical response. Capturing the combined effects of nonlinearity and nonlocality remains a major modeling challenge, requiring specialized and sophisticated computational tools.

To address this need, the present work introduces a new nonlinear finite element formulation for nanoshells which is capable of accounting for both geometric nonlinearities and nonlocal scale effects. The framework is implemented within the Kirchhoff–Love shell theory where geometric nonlinearities are introduced through the von Kármán hypothesis. Size dependency is incorporated via the second-order strain gradient constitutive model, leading to a final set of nonlinear partial differential equations of order six.

The solution of these equations is achieved through a combination of finite elements and perturbation approach. In this solution strategy, the generalized displacements of the shell are interpolated using a novel hierarchical Hermite polynomial space which satisfies the high continuity requirements of the nonlocal shell model. Subsequently, the finite element coefficients are expanded into an asymptotic series, leading to a semi-analytical solution of the nonlinear governing equations. This combination enables efficient and accurate prediction of postbuckling and nonlinear vibration responses of nanoshells.

Numerical results demonstrate the capability of the proposed framework to accurately capture the coupled effects of nonlinearity and nonlocality. Our results show significant deviations from classical models and highlight the importance of incorporating size-dependent effects in nonlinear nanoscale shell analysis.