# A vector-form hybrid particle-element method for modeling and nonlinear shell analysis of thin membranes exhibiting wrinkling

**Citation:** Yao-zhi Luo, Chao Yang, 2014. A vector-form hybrid particle-element method for modeling and nonlinear shell analysis of thin membranes exhibiting wrinkling. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 15(5):331-350. [doi:10.1631/jzus.A1300248]

JZUSA

# Main Goal

- Propose a recently-developed numerical method-VHPEM for investigating the wrinkling phenomena of flat thin membranes.
- Improve the wrinkling simulation technology based on the bifurcation buckling theory of shells.
- Acquire the deformed geometry of the wrinkled membranes in detail for the structures with high precision requirement of shapes.

JZUSA

# Main Approach and Strategies

- Construct a 3-node triangular shell element with the non-zero bending stiffness taken into account on the basis of an appropriate kinematical description of the particles in 3D thin membranes involving large rigid body motion.

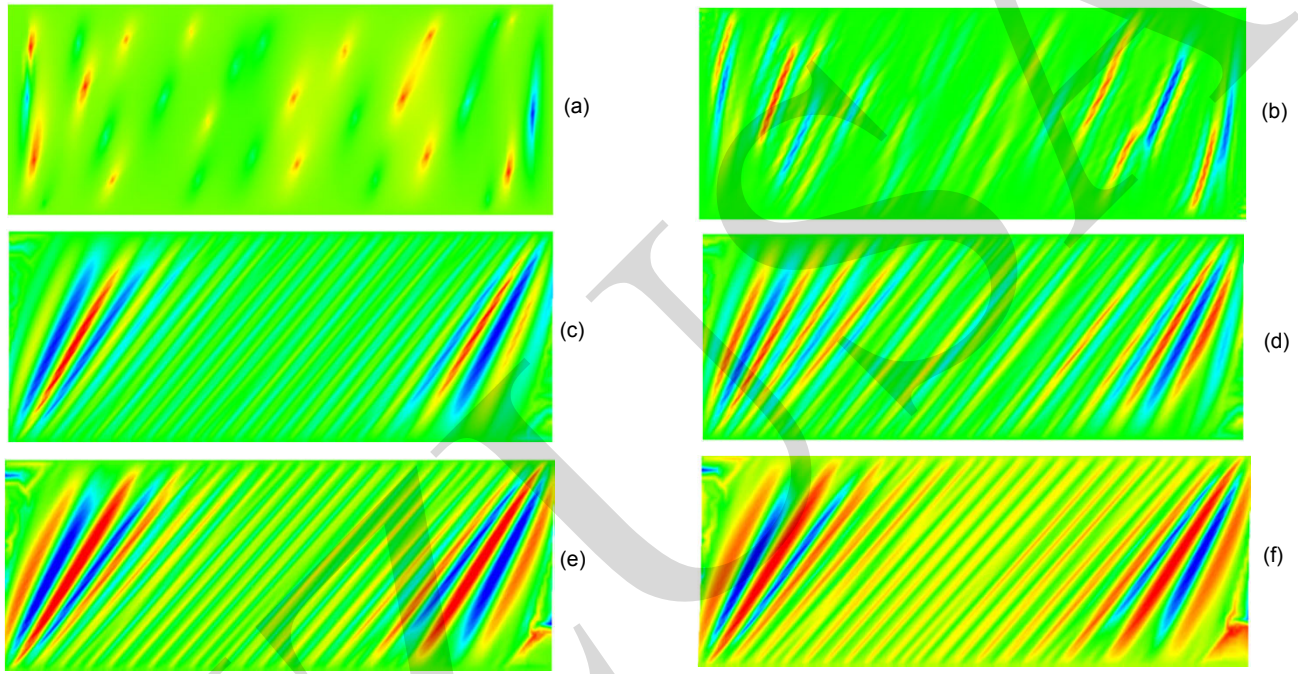
- A pseudo bifurcation analysis incorporated into the VHPEM is performed to initiate the out-of-plane wrinkling deformation for the perfect flat membranes are only subjected to in-plane loading.

- To overcome the numerical difficulties associated with wrinkles, a pseudo-dynamic scheme using the explicit time integration is introduced

JZUSA

# Computation Models and Results

## ■ Rectangular thin-film membrane subject to in-plane shear loading



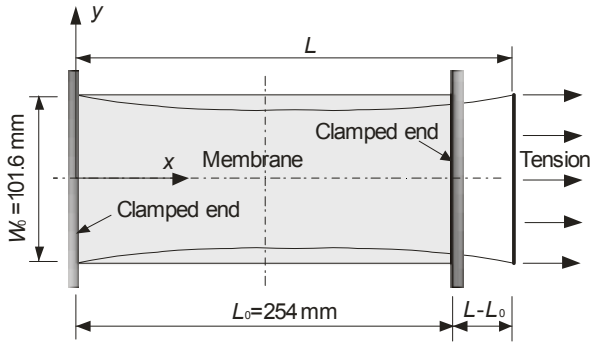

**Contour maps of out-of-plane deformation $w$ (mm) for the development of wrinkles under the desired shear displacements $\delta_x$ (mm)**

(a) $\delta_x$=0.085 and $\delta_y$=0.025, $w$ (max./min.)=0.063/−0.085; (b) $\delta_x$=0.095 and $\delta_y$=0.025, $w$ (max./min.) =0.078/−0.098; (c) $\delta_x$=0.115 and $\delta_y$=0.025, $w$ (max./min.)=0.102/−0.113; (d) $\delta_x$=0.15 and $\delta_y$=0.025, $w$ (max./min.)=0.374/−0.368; (e) $\delta_x$=0.17 and $\delta_y$=0.025, $w$ (max./min.)=0.441/−0.436; (f) $\delta_x$=3.0 and $\delta_y$=0.025, $w$ (max./min.)=1.190/−1.139

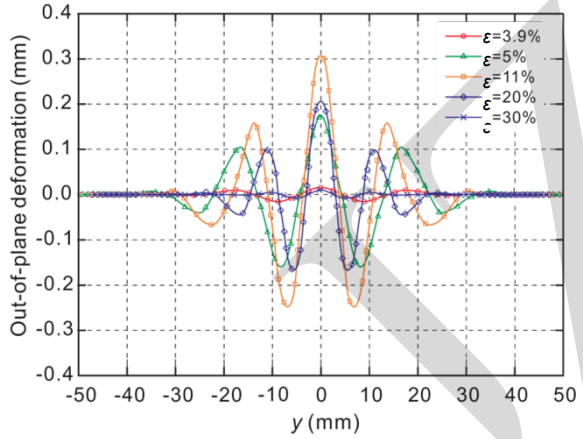
ZJUSA

# Three Representative Activities

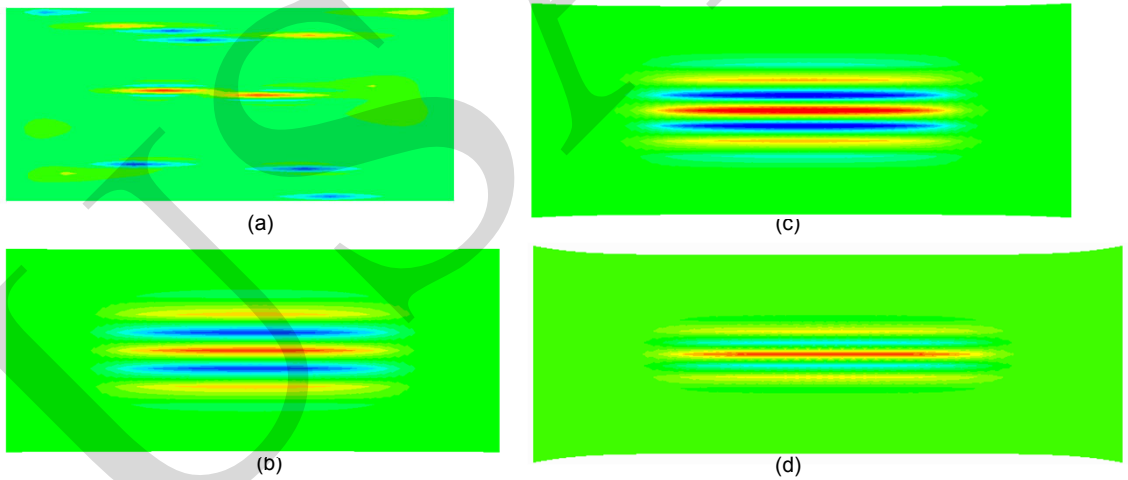
## Rectangular thin-film membrane loaded in uniaxial tension




**Problem setting of an end-clamped rectangular thin membrane loaded in uniaxial tension**




**Profiles along the transverse mid-section of the membrane (at $x$=127 mm) at desired strain levels**




**Contour maps of out-of-plane deformation for the evolution of wrinkles at desired strain levels**

(a) $\varepsilon$=1.5%, $w$ (max./min.)=0.00725/−0.0044; (b) $\varepsilon$=3.9%, $w$(max./min.)=0.0155/−0.0143; (c) $\varepsilon$=11.0%, $w$ (max./min.) =0.3128/−0.2484; (d) $\varepsilon$=30.0%, $w$ (max./min.)=0.0105/ −0.0.0102

ZJUSA