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Hierarchical one-dimensional model for global/local buckling of thin-walled I-section beams

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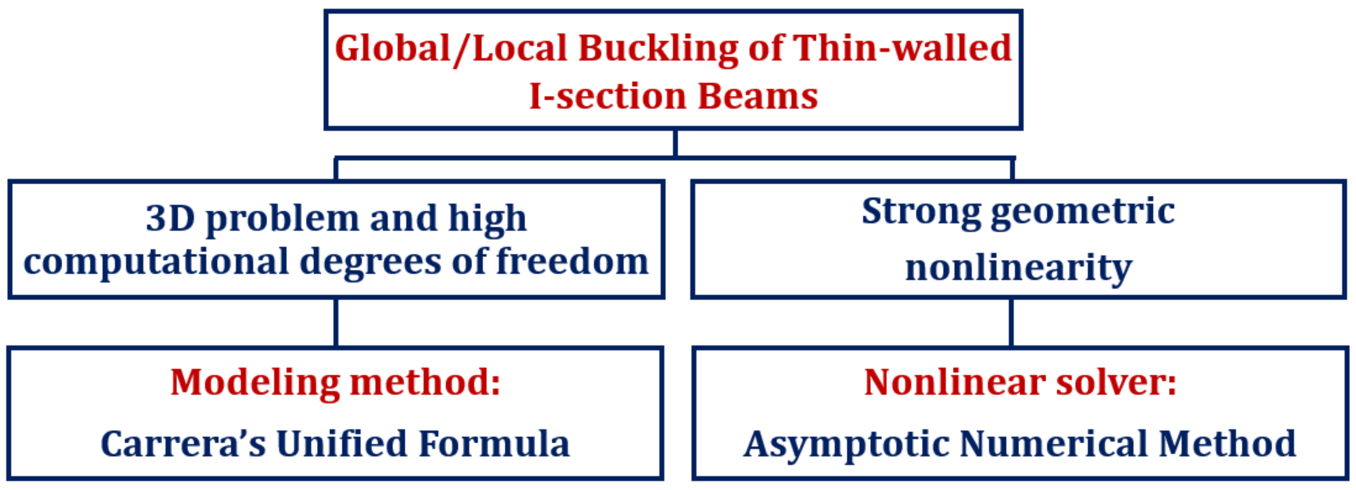
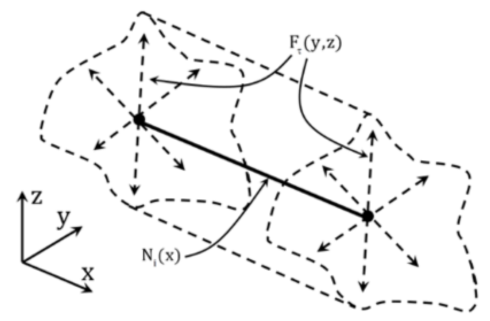
Abstract

As a typical thin-walled structure, I-section beam tends to have severe instability phenomena such as buckling, local buckling and global-local coupled buckling due to its large slenderness ratio and narrow cross-section features. This work proposes a numerical model based on a hierarchical one-dimensional unified formulation for the analysis of global/local buckling phenomena in the thin-walled I-section beams. Within the framework of Carrera's Unified Formulation (CUF) [1], a model is built by using Lagrange polynomials to describe the three-dimensional displacement field as an arbitrary order approximation by displacement variables over the beam cross-section. Due to its high efficiency and step length adaptability, the Asymptotic Numerical Method (ANM) [2] is adopted to solve the nonlinear governing equations. Several typical buckling problems in I-section beams, including global buckling, local buckling and global-local coupled buckling, are investigated. The numerical results demonstrate the validity and efficiency of the proposed model.

Methodology and context



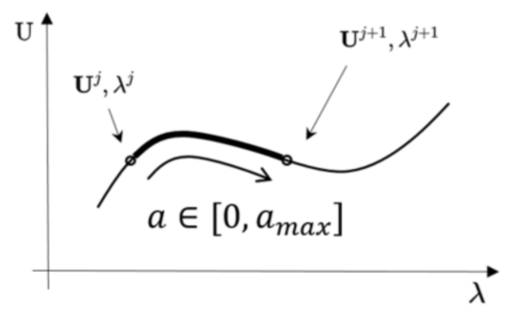


The beam model is separated as the axial approximation and the expansion over the cross-section:

$$u(x,y,z) = F_\tau(y,z)N_i(x)q_{\tau i}$$

Lagrange shape functions; Expansion functions; Displacement variable

- Uniform derivation format
- Efficient: Reducing computational degrees of freedom and Gauss points



Expanding the unknown variables with power series:

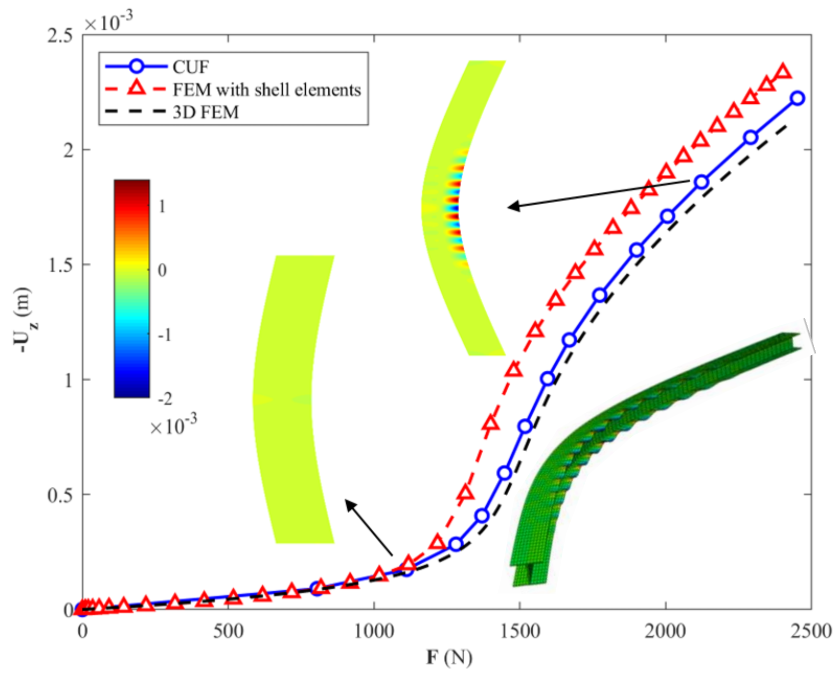
$$\mathbf{U} = \mathbf{U}^j + \sum_{p=1}^{Norder} a^p \mathbf{U}_p = \mathbf{U}^j + a\mathbf{U}_1 + a^2\mathbf{U}_2 + \ldots$$

$$\lambda = \lambda^j + \sum_{p=1}^{Norder} a^p \lambda_p = \lambda^j + a\lambda_1 + a^2\lambda_2 + \ldots$$

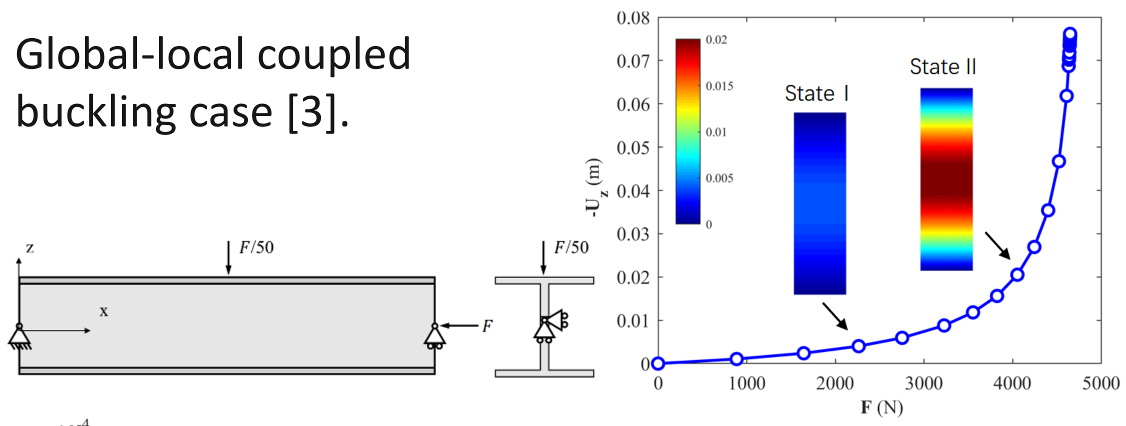
- Each step has only one inversion of stiffness matrix
- The step length is self-adaptive

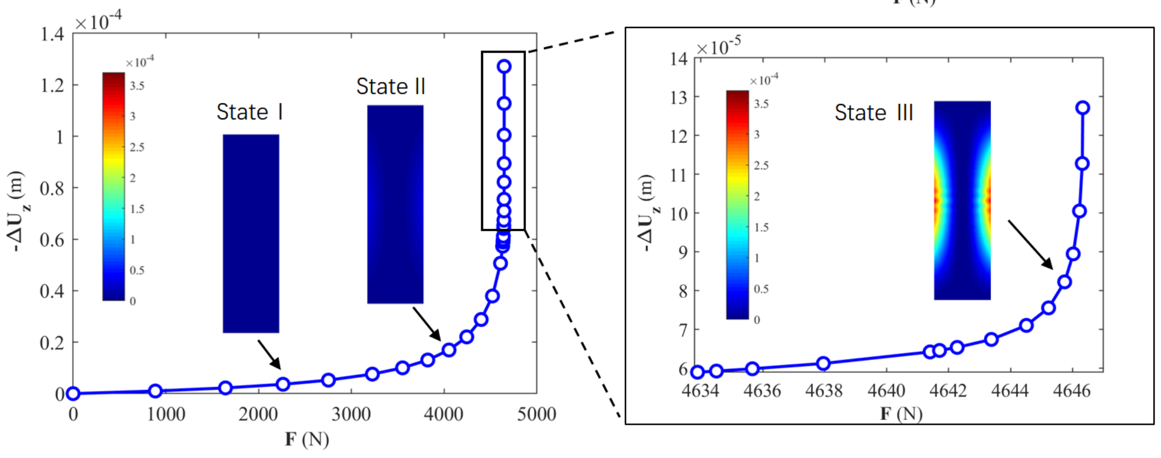
Results

Local buckling analysis of a simply supported beam [3].



Global-local coupled buckling case [3].





Conclusion and perspectives

This work establishes a numerical model for the global/local buckling analysis of I-section beams within the frame work of CUF and ANM. The results are compared with the three-dimensional finite element solution. The proposed model improves the computational efficiency on the premise of ensuring accuracy. In addition, because of the generality in selecting the expansion function of the beam cross-section and significant reduction for integration points, CUF has potential advantages to be applied in data-driven computational mechanics.

References

[1] Carrera E., Theories and finite elements for multilayered plates and shells: a unified compact formulation with numerical assessment and benchmarking. *Arch Comput Methods Eng* 10, 215-96 (2003).

[2] Damil N., Potier-Ferry M., et al. A new method to compute perturbed bifurcations: application to the buckling of imperfect elastic structures. *Int J Eng Sci* 28, 943–57 (1990).

[3] Yang Y., Hui Y., et al. Global/local buckling analysis of thin-walled I-section beams via hierarchical one-dimensional finite elements. *Eng Struct* 280, 115705 (2023).