Analysis of Sandwich Panels Under Several Load Cases with Consideration of Core Compression

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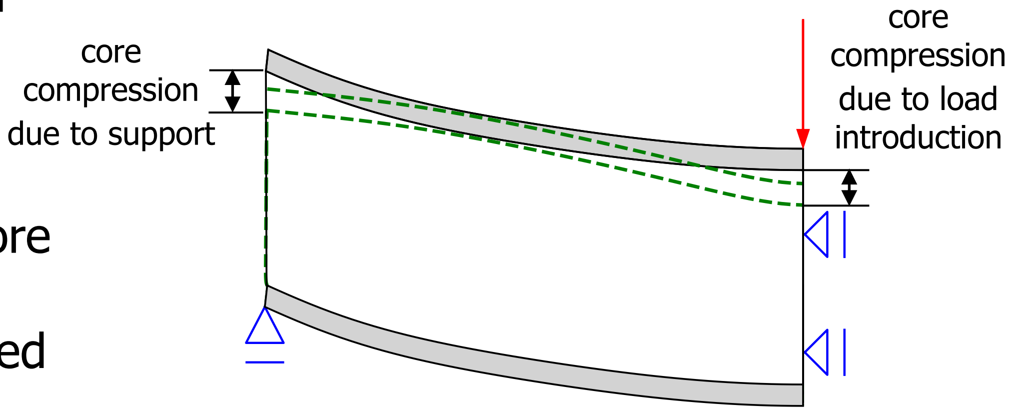
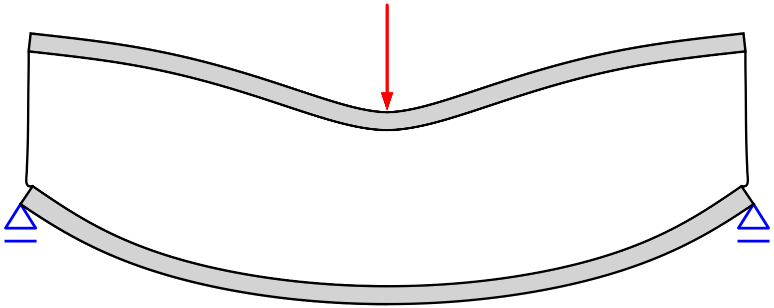
Sandwich Panels Under Localized Loads

- Core failure: one of the dominated failure modes in sandwich panels
- Transverse normal stresses and core indentation induced by concentrated loads not predictable by common sandwich theories



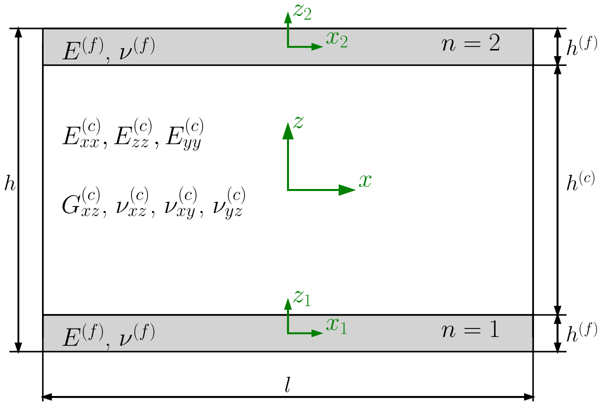
Agenda

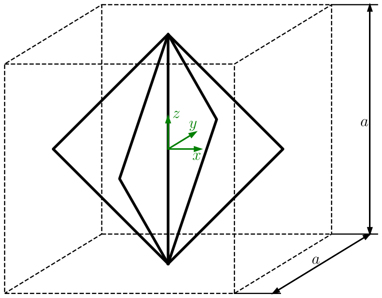
1. Sandwich model
2. Higher-order displacement representations
3. Load cases
4. Results
5. Conclusion and outlook



Sandwich Model

- 2D Sandwich model (plane-strain state)
- Isotropic face sheets
- Orthotropic core material:
  - Effective properties of a lattice structure
- Prediction of core stresses





Georges et al. (2023): European Journal of Mechanics A/Solids

Modeling Approach

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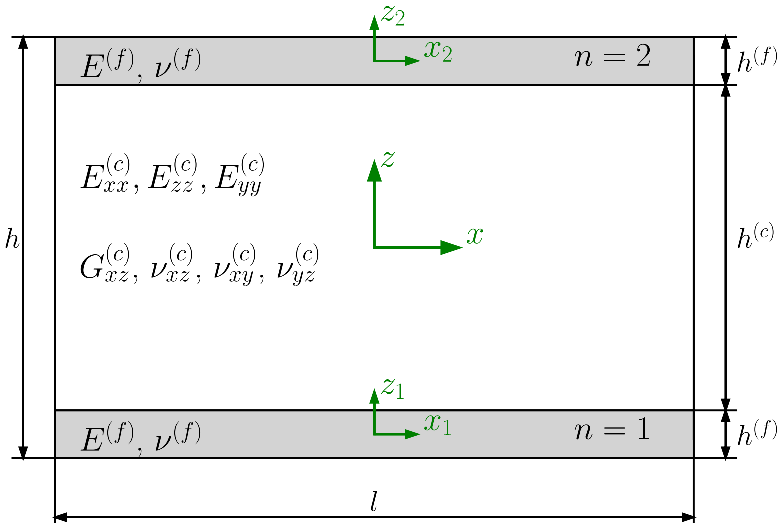
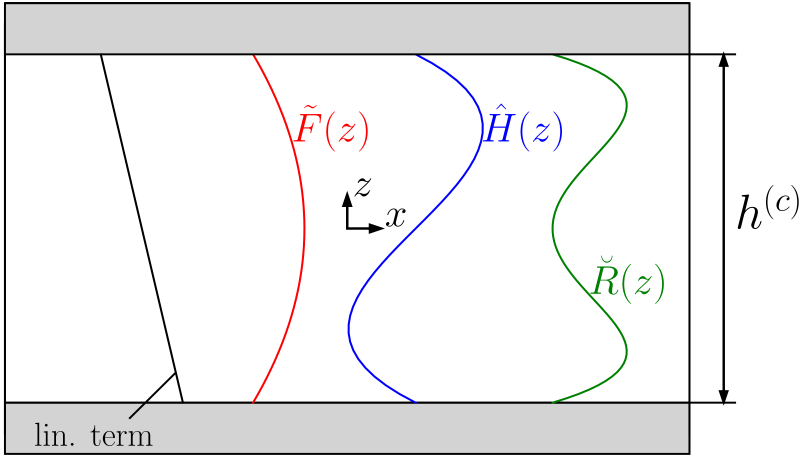
- $u^{(n)} = u_0^{(n)} + z\psi^{(n)}, \qquad w^{(n)} = w_0$
- $\varepsilon_{xx}^{(n)} = \frac{\partial u^{(n)}}{\partial x}, \qquad \gamma_{xz}^{(n)} = \frac{\partial w^{(n)}}{\partial x} + \frac{\partial u^{(n)}}{\partial z}$
- $\sigma_{xx}^{(n)} = \frac{E^{(f)}}{1-\nu^{(f)2}} \varepsilon_{xx}^{(n)} \qquad \tau_{xz}^{(n)} = G^{(f)} \gamma_{xz}^{(n)}$
- $\Pi_{\mathrm{i}}^{(n)} = \frac{1}{2} \int_{-l/2}^{l/2} \int_{-h^{(f)}/2}^{h^{(f)}/2} \left(\sigma_{xx}^{(n)} \varepsilon_{xx}^{(n)} + \tau_{xz}^{(n)} \gamma_{xz}^{(n)}\right) \mathrm{d}z \, \mathrm{d}x$



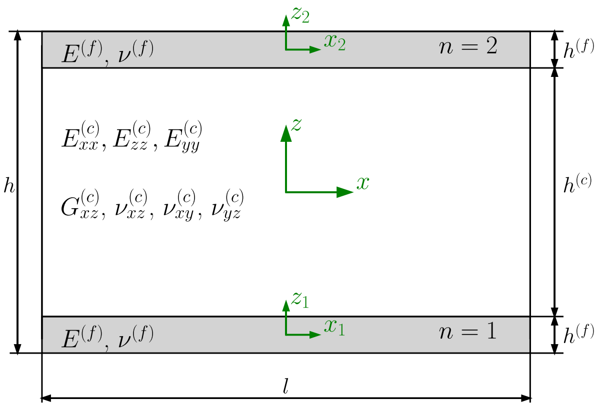
Higher-Order Displacement Representations

- $u^{(c)} = \frac{u_0^{(1)}+u_0^{(2)}+\frac{h^{(f)}}{2}\psi^{(1)}-\frac{h^{(f)}}{2}\psi^{(2)}}{2} + \frac{-u_0^{(1)}+u_0^{(2)}-\frac{h^{(f)}}{2}\psi^{(1)}-\frac{h^{(f)}}{2}\psi^{(2)}}{h^{(c)}} z + \tilde{u}\tilde{F} + \hat{u}\hat{H} + \breve{u}\breve{R}$
- $w^{(c)} = \frac{w_0^{(1)}+w_0^{(2)}}{2} + \frac{w_0^{(2)}-w_0^{(1)}}{h^{(c)}} z + \tilde{w}\tilde{F} + \hat{w}\hat{H} + \breve{w}\breve{R}$
- $\varepsilon_{xx}^{(c)} = \frac{\partial u^{(c)}}{\partial x}, \quad \varepsilon_{zz}^{(c)} = \frac{\partial w^{(c)}}{\partial z}, \quad \gamma_{xz}^{(c)} = \frac{\partial w^{(c)}}{\partial x} + \frac{\partial u^{(c)}}{\partial z}$
- $\tilde{F}(z) = \left(1 - \frac{4z^2}{h^{(c)2}}\right)$
- $\hat{H}(z) = \tilde{F}(z)\, z$
- $\breve{R}(z) = \tilde{F}(z)\, z^2$

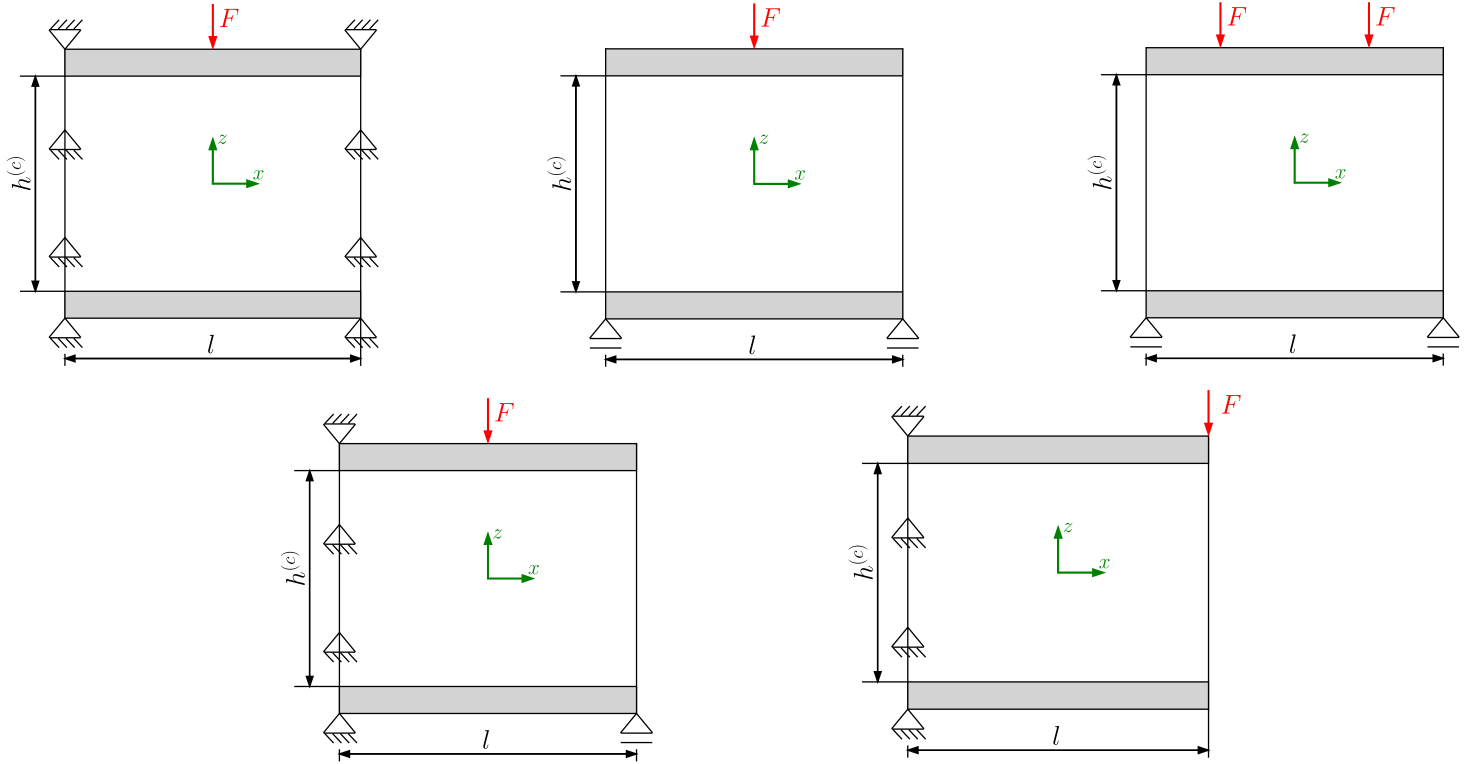


Core‘s Potential Energy

- $\Pi_\mathrm{i}^{(c)} = \frac{1}{2} \int_{-l/2}^{l/2} \int_{-h^{(c)}/2}^{h^{(c)}/2} \left(\sigma_{xx}^{(c)} \varepsilon_{xx}^{(c)} + \sigma_{zz}^{(c)} \varepsilon_{zz}^{(c)} + \tau_{xz}^{(c)} \gamma_{xz}^{(c)}\right) \mathrm{d}z\, \mathrm{d}x$
- $\Pi = \Pi_\mathrm{i}^{(1)} + \Pi_\mathrm{i}^{(2)} + \Pi_\mathrm{i}^{(c)} + \Pi_\mathrm{e}$
- $\delta\Pi = 0$ → 12 coupled second-order differential equations
- $\underline{\dot{\Phi}} = \underline{\underline{E}}\, \underline{\Phi}$, with $\underline{\Phi} = \begin{bmatrix} \underline{\Psi} \\ \underline{\dot{\Psi}} \end{bmatrix}$, and $\underline{\Psi} = \begin{bmatrix} u_0^{(1)} & u_0^{(2)} & \dots \end{bmatrix}^T$
- General solution: $\underline{\Phi}_h = \sum_{m=1}^{24} K_m \underline{v}_m\, e^{\lambda_m x}$

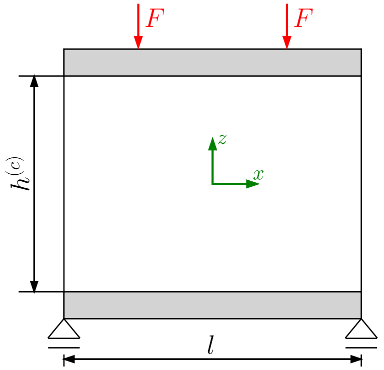


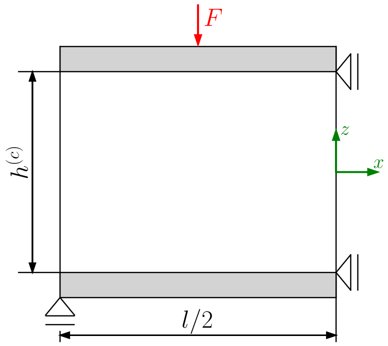
Load cases



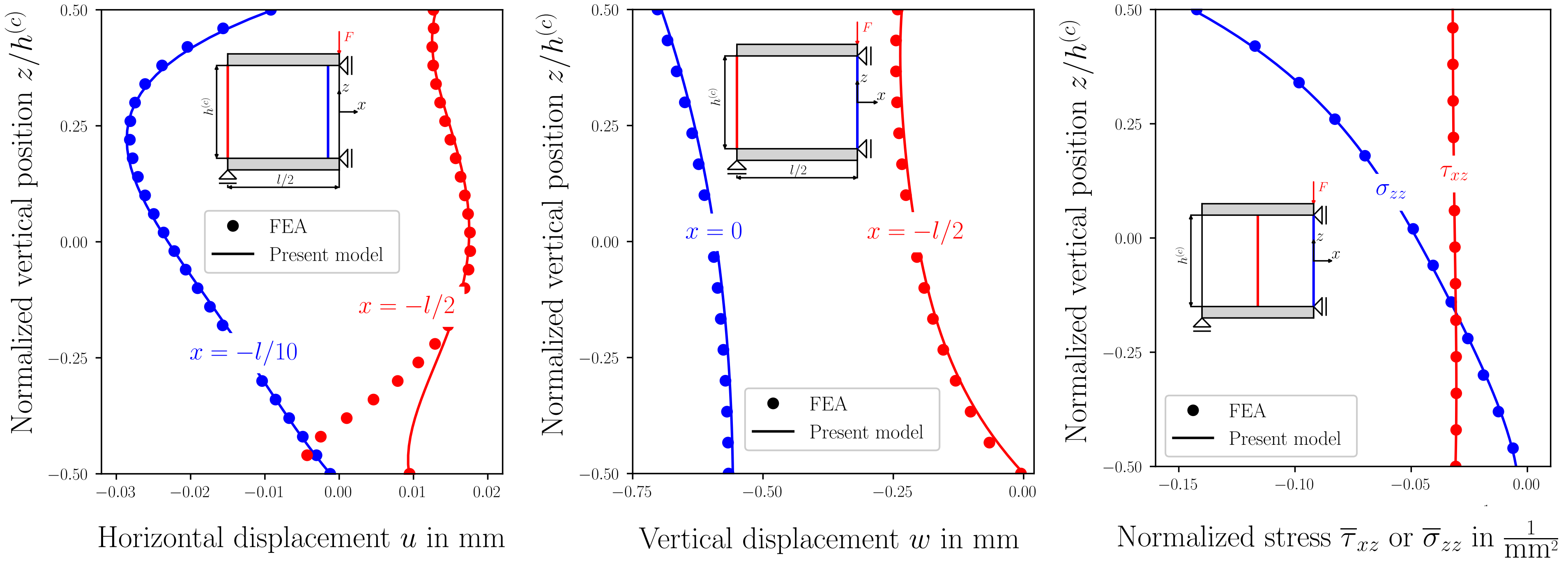
FE Model

- 2D analysis using Abaqus
- Plane strain quadratic solid elements
- $E^{(f)}$=70000 MPa , $\nu^{(f)}$=0.35
- Thin face sheets: $\frac{h^{(c)}}{h^{(f)}} = 15$
- Thick sandwich: $\frac{l}{h^{(c)}} = 4$

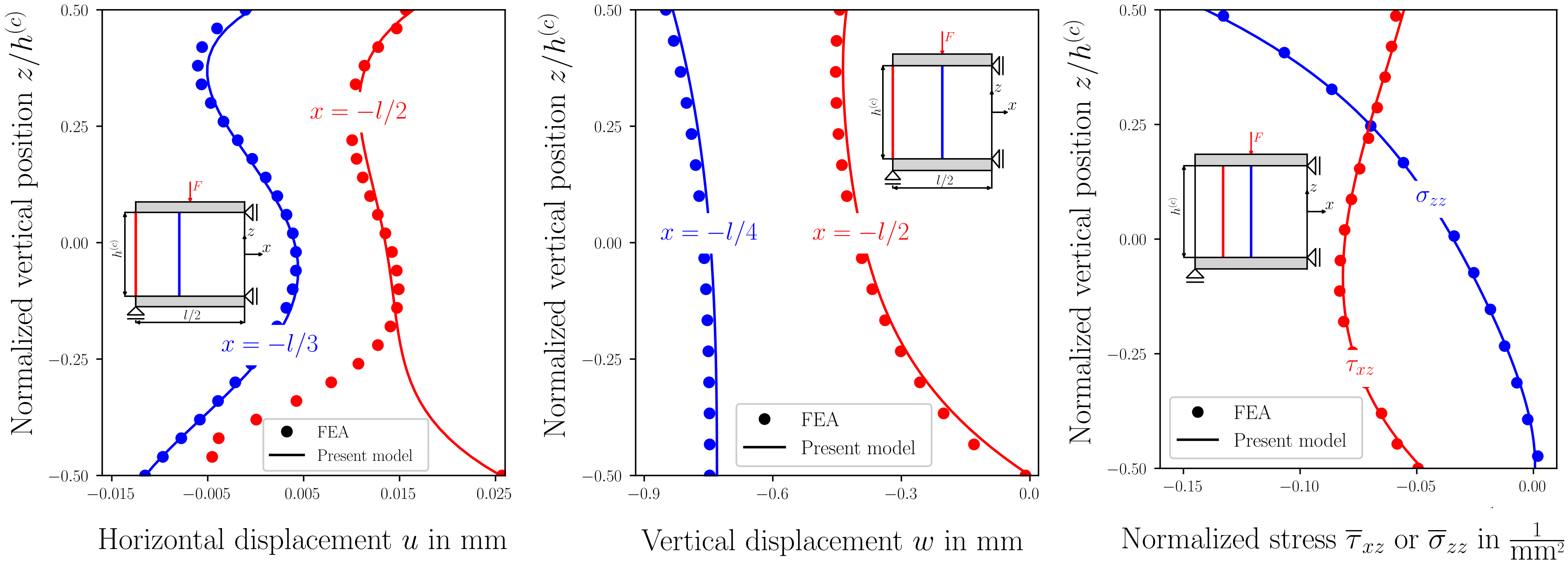




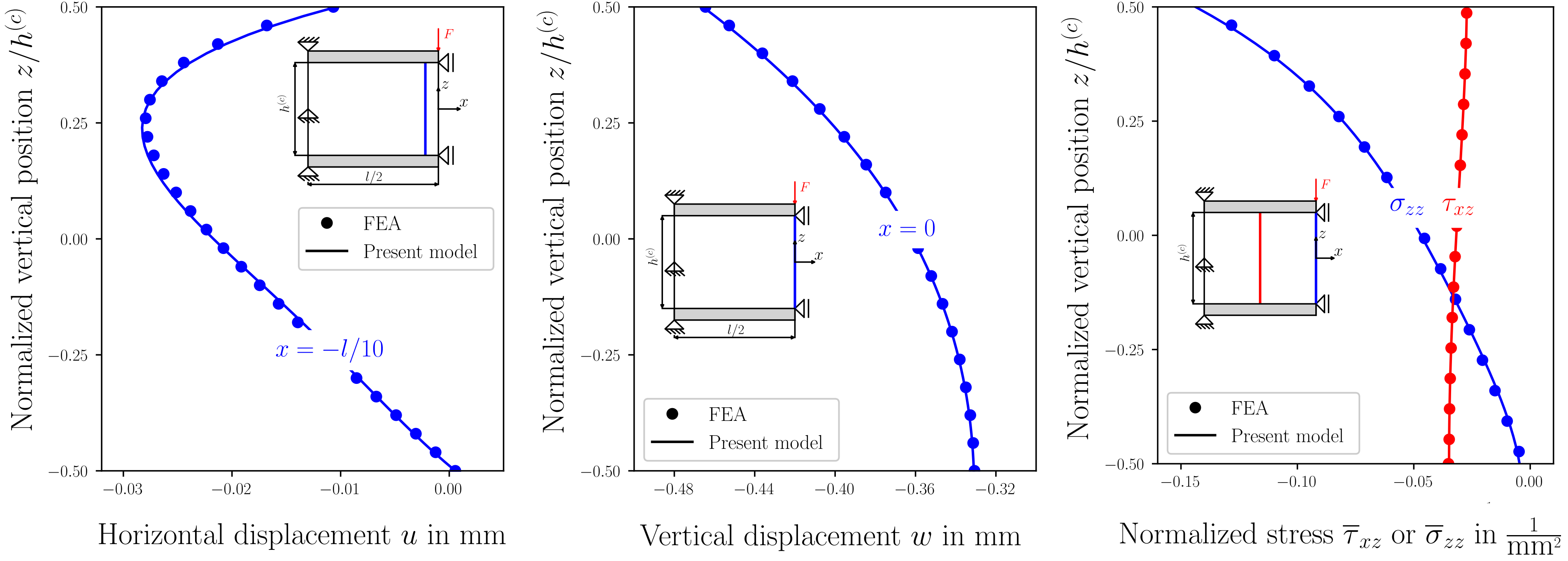
3-Point Bending



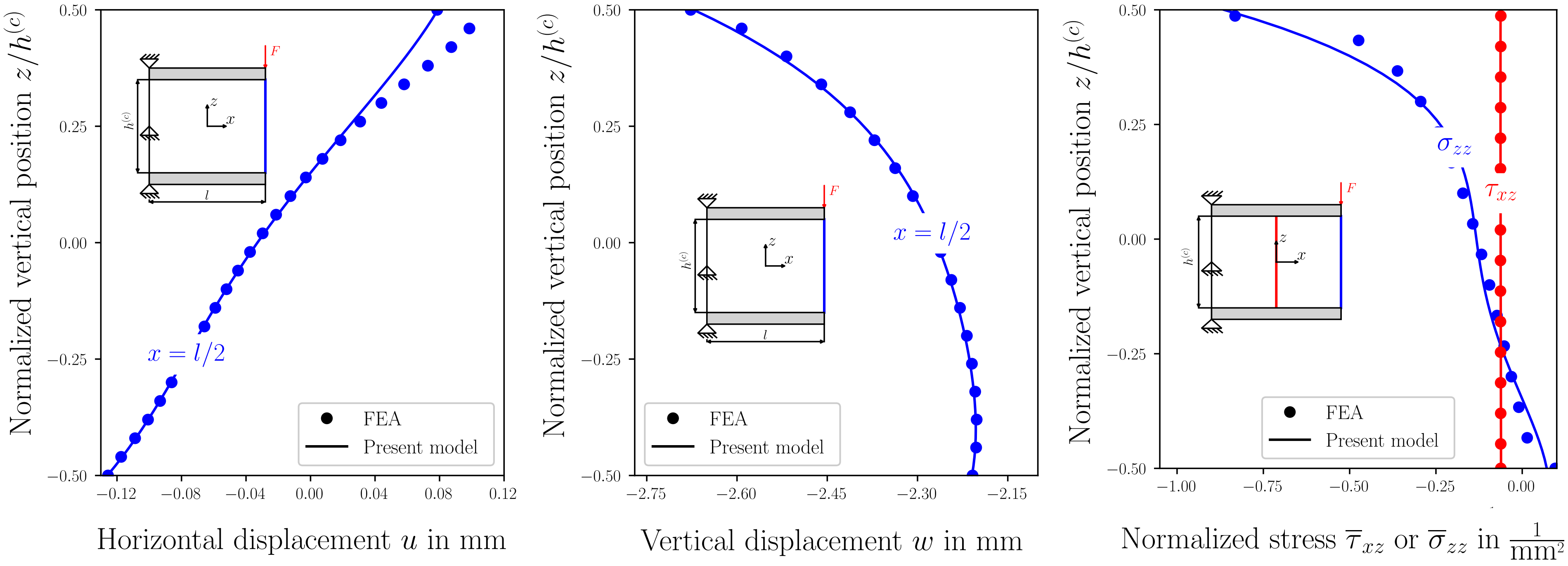
4-Point Bending



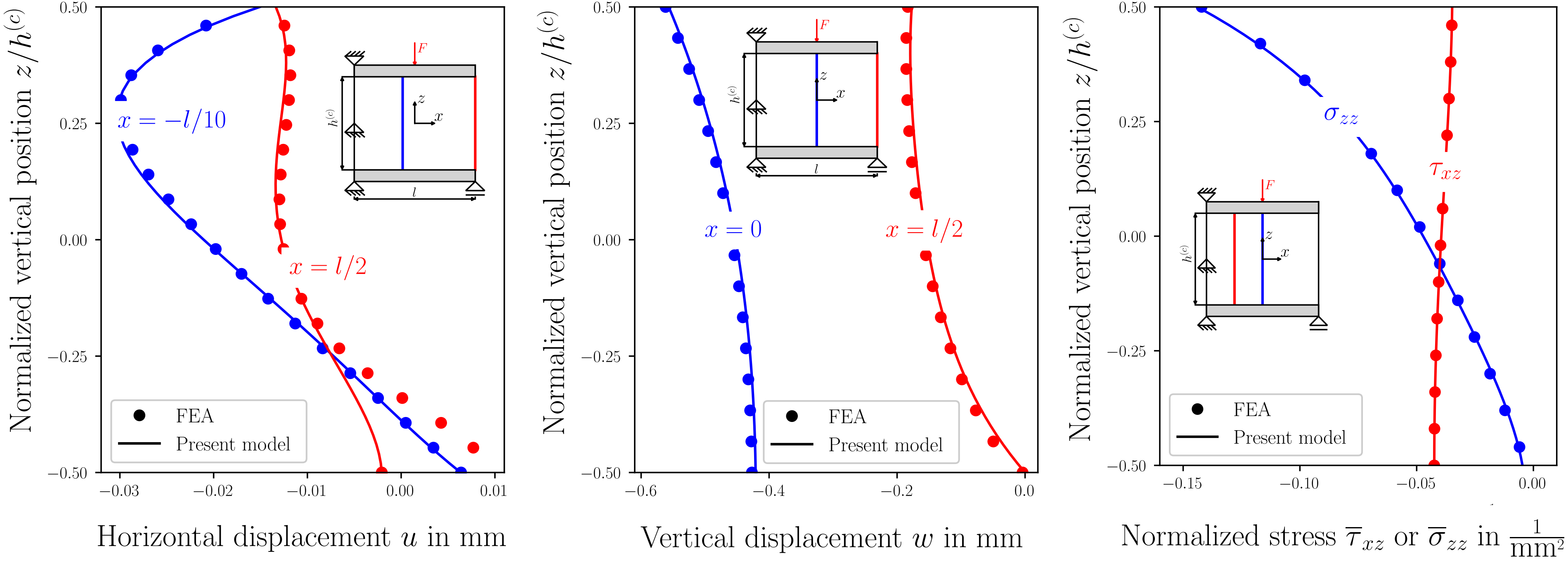
Fixed-End Sandwich Beam



Cantilever Sandwich Beam

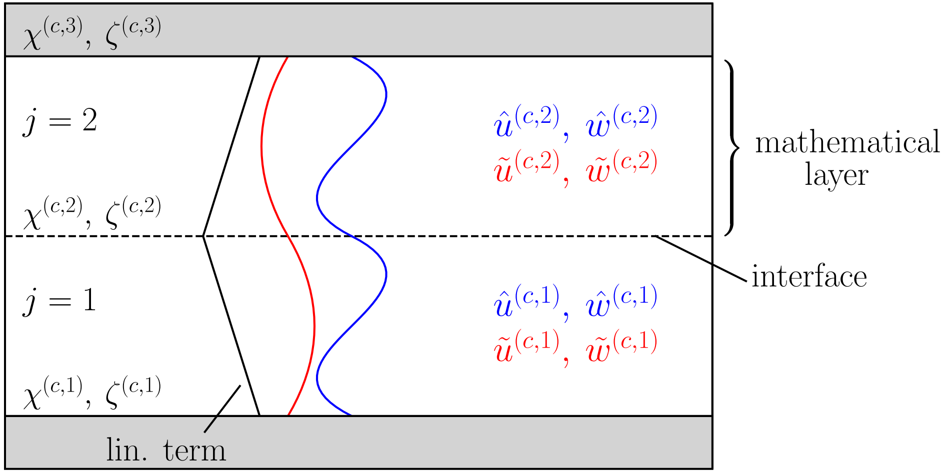


Restrained Sandwich Beam



Introducing Mathematical Sublayers

- $u^{(c,j)} = \chi^{(c,2)} + 2\,\frac{\chi^{(c,j+1)}-\chi^{(c,j)}}{h^{(c)}}\,z + \tilde{u}^{(c,j)}\tilde{F}^{(c,j)} + \hat{u}^{(c,j)}\hat{H}^{(c,j)}$
- $w^{(c,j)} = \zeta^{(c,2)} + 2\,\frac{\zeta^{(c,j+1)}-\zeta^{(c,j)}}{h^{(c)}}\,z + \tilde{w}^{(c,j)}\tilde{F}^{(c,j)} + \hat{w}^{(c,j)}\hat{H}^{(c,j)}$
- $\tilde{F}^{(c,j)}(z) = \frac{8(3-2j)}{h^{(c)}}\,z - \left(\frac{4}{h^{(c)}}\,z\right)^2$
- $\hat{H}^{(c,j)}(z) = \tilde{F}^{(c,j)}(z)\,z$



Localized Deformation on Edges

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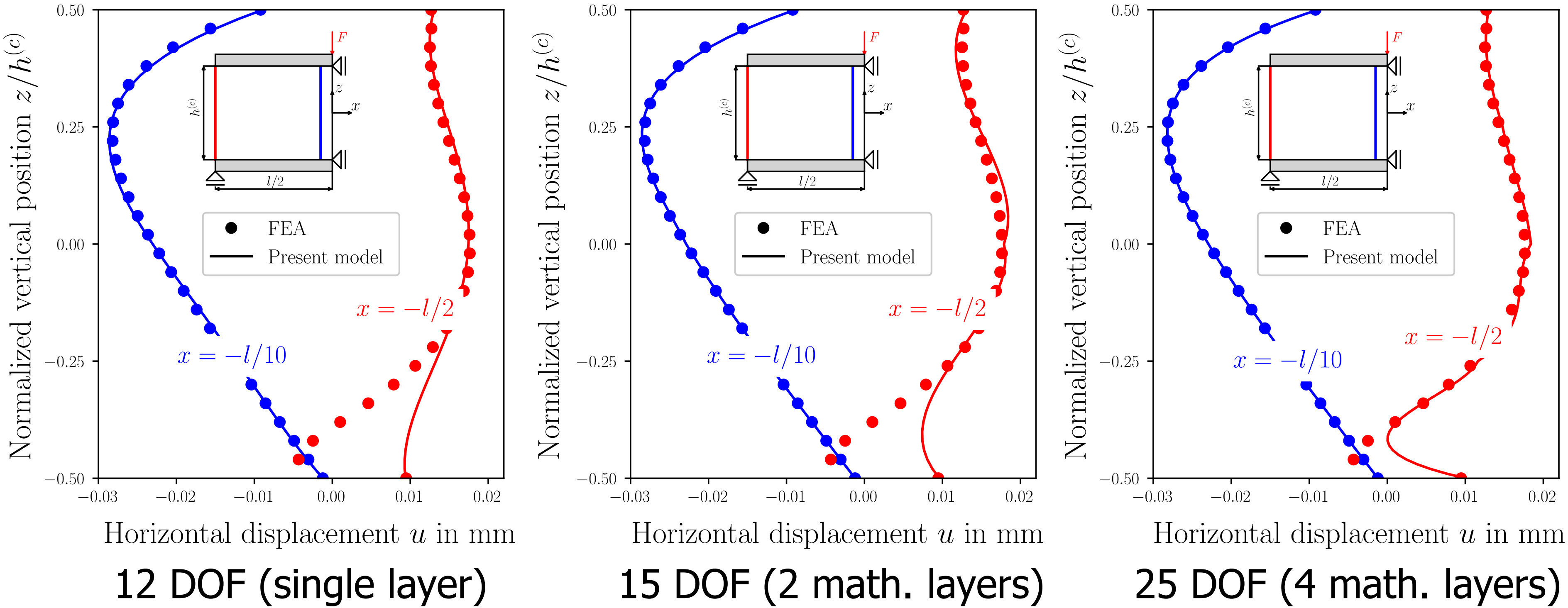

Conclusion

- Efficient determination of core compression in several load cases
- Sufficient prediction of critical core stresses induced by concentrated loads
- Capturing of localized free-edge deformation by introducing mathematical layers
- Outlook:
  - Grading the core material and optimizing the core weight

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