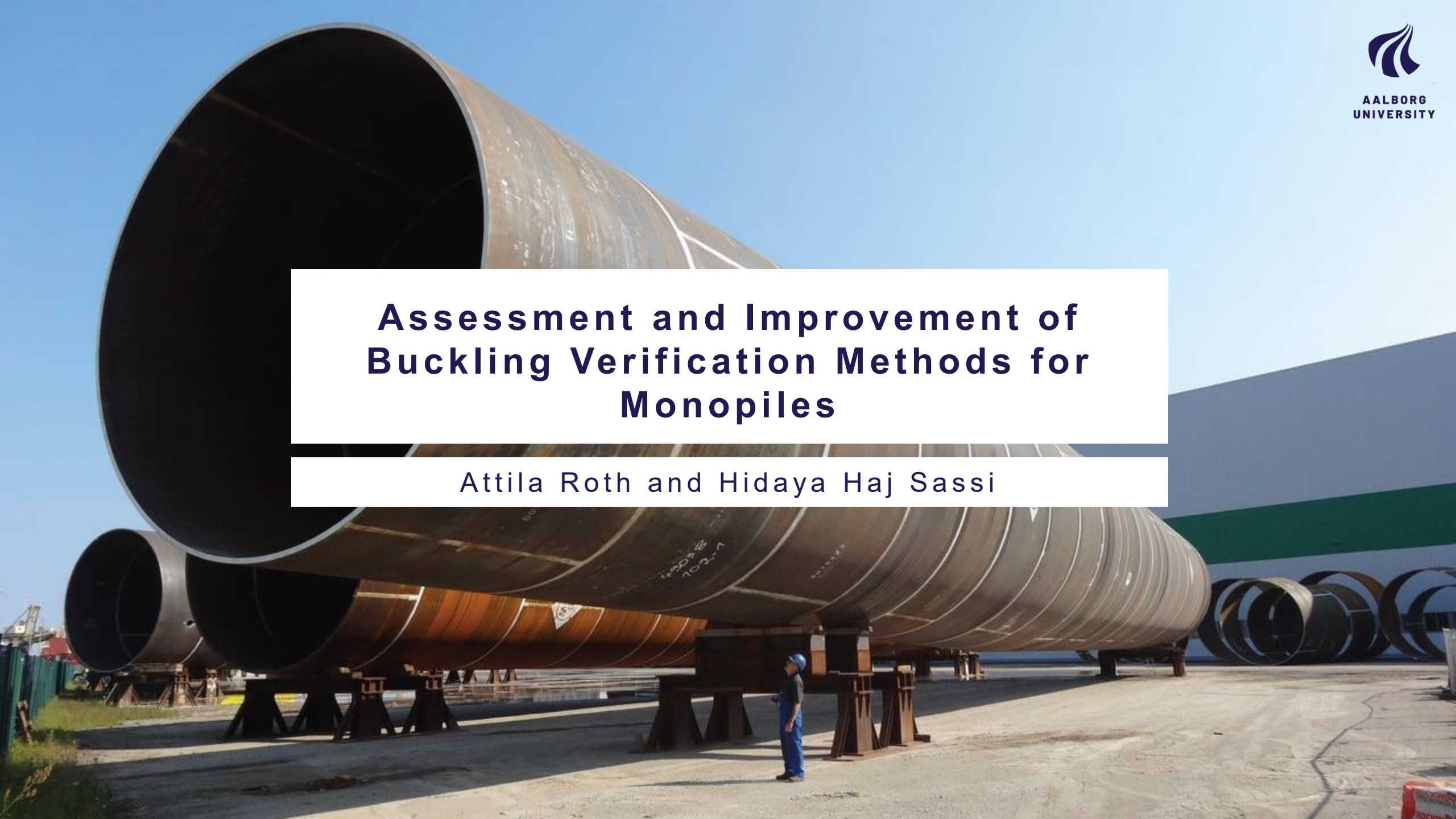**Assessment and Improvement of Buckling Verification Methods for Monopiles**
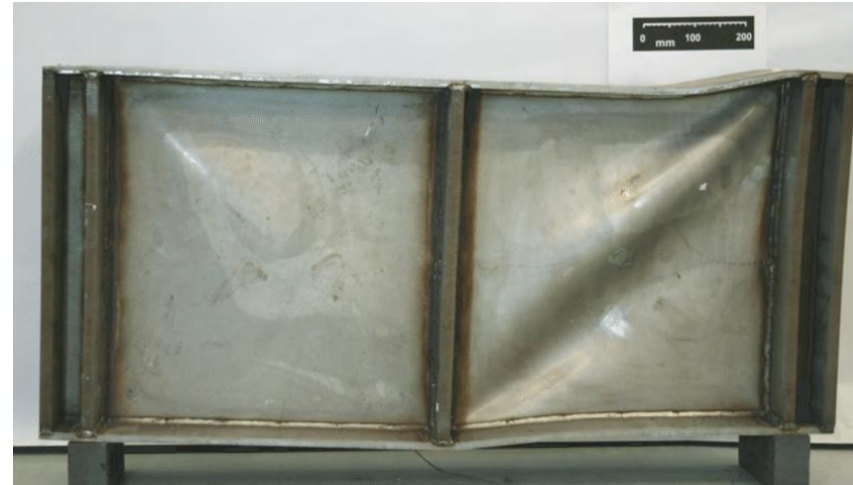
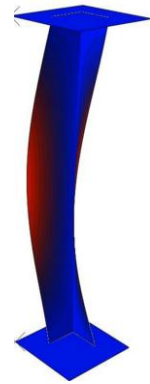Attila Roth and Hidaya Haj Sassi

Buckling
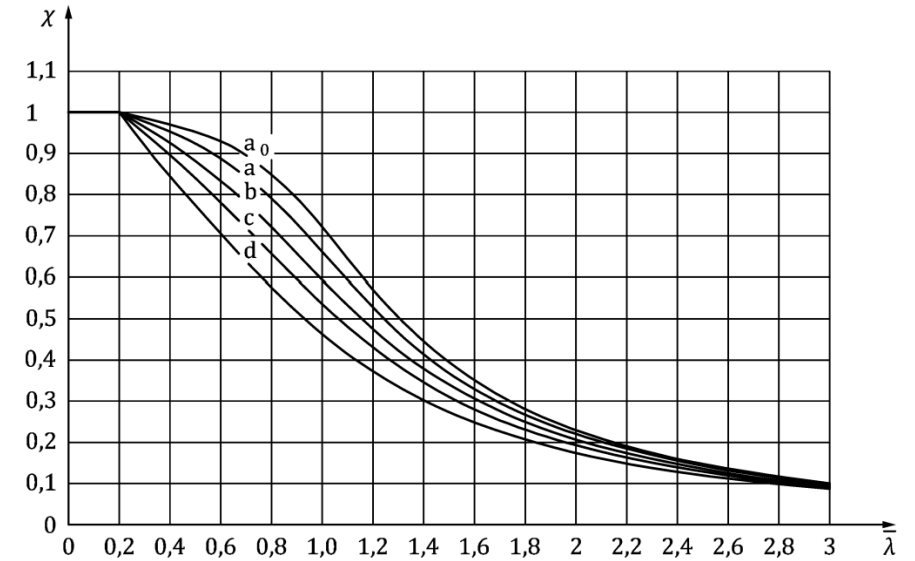
Buckling

Column buckling

$$N_{cr} = \frac{\pi^2 EI}{L^2}$$
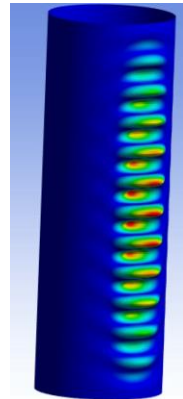
Euler's critical load

$$N_{b,Rd} = \frac{\chi N_{Rk}}{\gamma_{M1}}$$

$$\bar{\lambda} = \sqrt{\frac{N_{Rk}}{N_{cr}}}$$

Shell buckling (bending)

$$M_{cr} = \frac{\pi C_m}{\sqrt{3(1-\nu)^2}} Ert^2$$

$$M_{b,Rd} = \frac{\chi M_{pl,I}}{\gamma_{M1}}$$
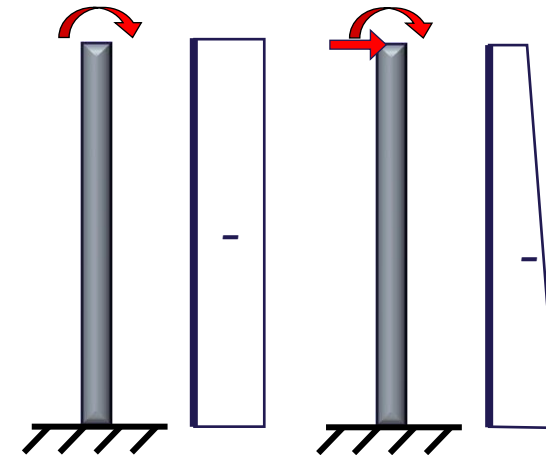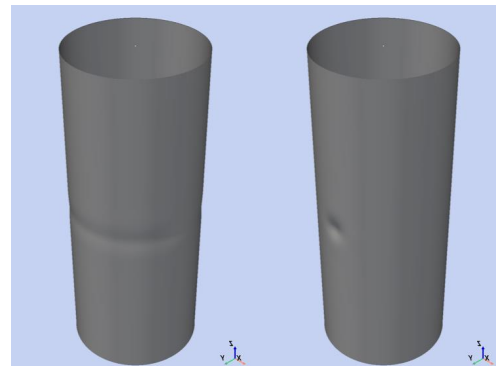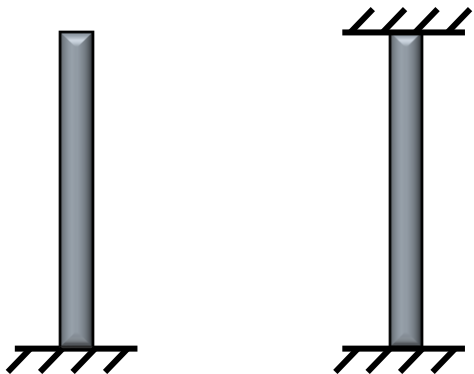
$$\bar{\lambda} = \sqrt{\frac{M_{pl,I}}{M_{cr}}}$$

Eigenmode

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Differences

|	Assumptions in EN 1993-1-6	Conditions in monopile
Static system	Supported at both ends	Cantilever
r/t ratio	Range of validity: 50 – 2000	35 – 65
Imperfection form	Full-circumferential dimple	Dimple of limited size
Moment distribution	Uniform moment	Increasing moment

t
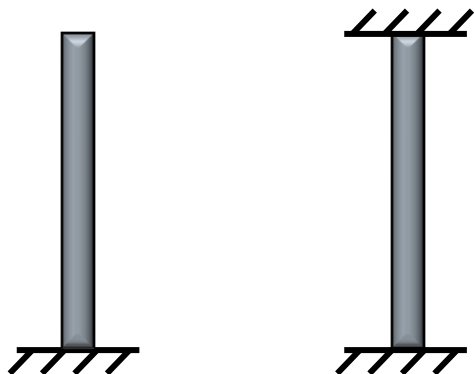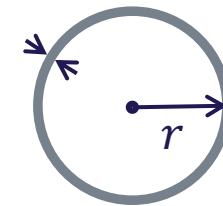
r

Small r/t

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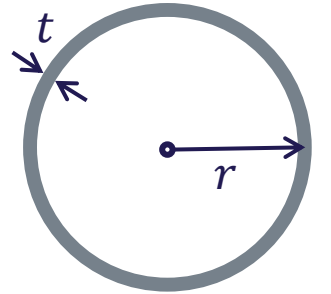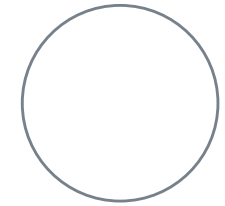
Static system

Based on a brief study

- ❯ Limited effect

- ❯ Small relative difference -2.7% and 2.3%

- ❯ No obvious correlation with geometric parameters
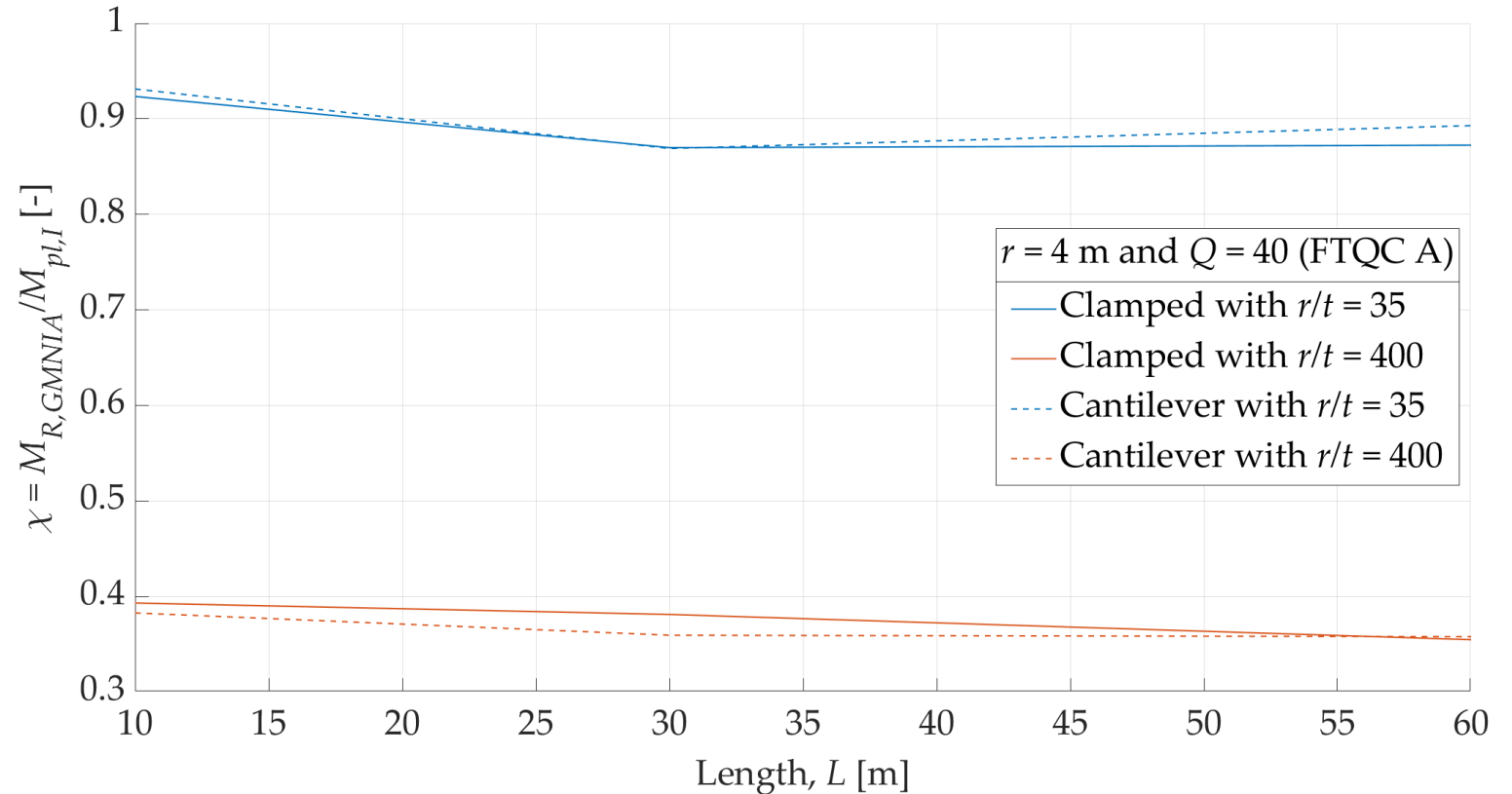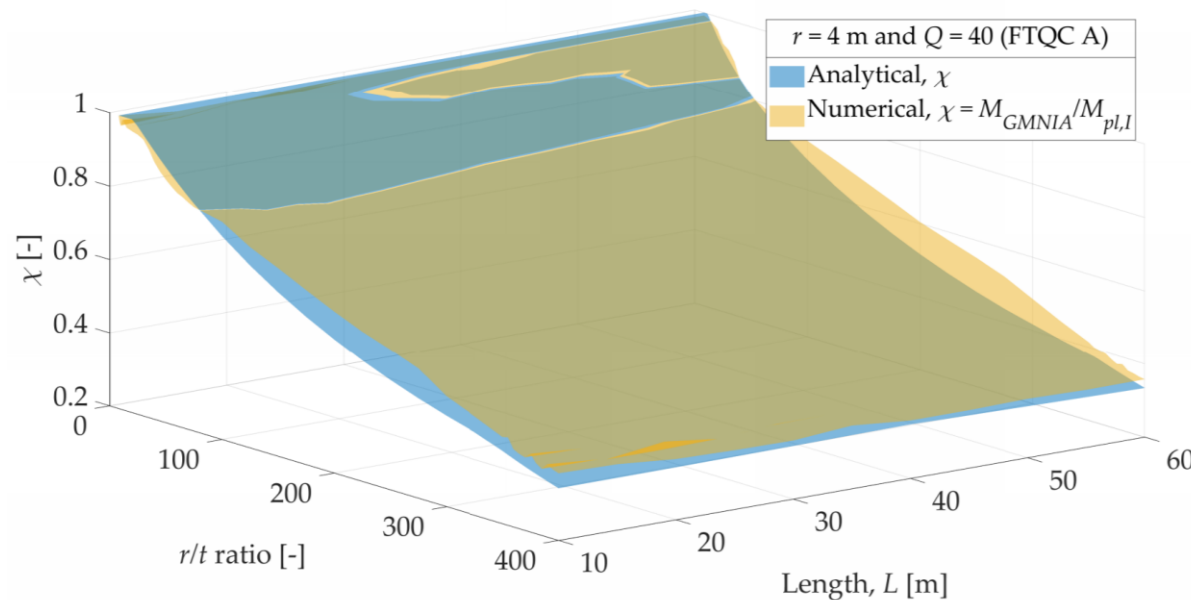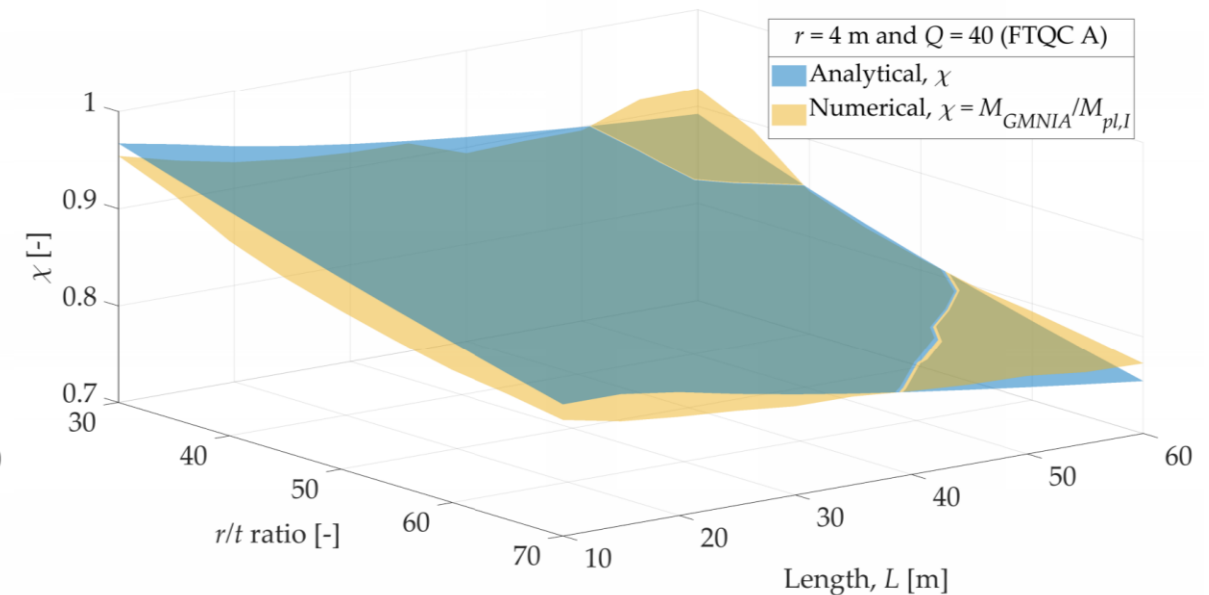
r/t ratio
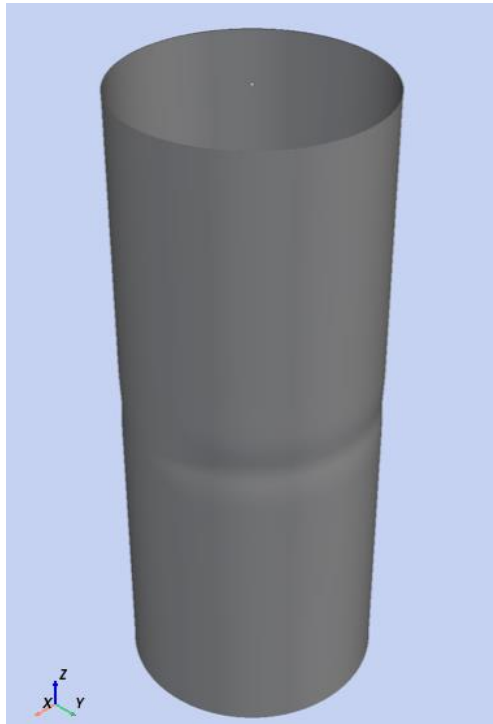
Small r/t   Large r/t

All investigated geometries

Typical monopile geometries

Mostly unconservative analytical results for r/t < 50 and for typical monopile geometries.
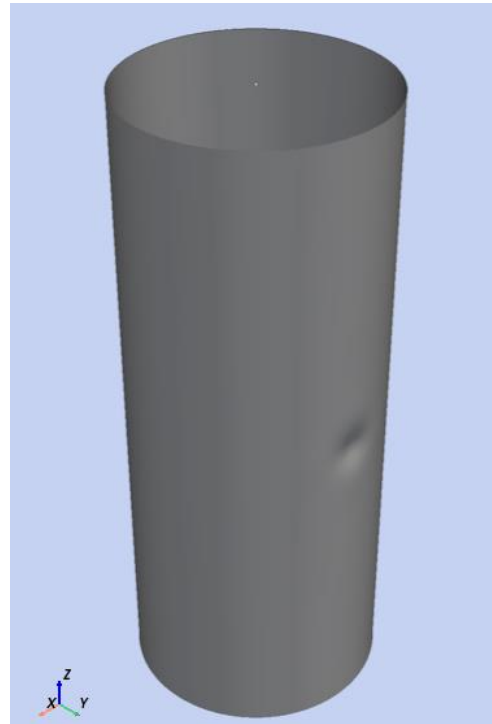
Imperfection form

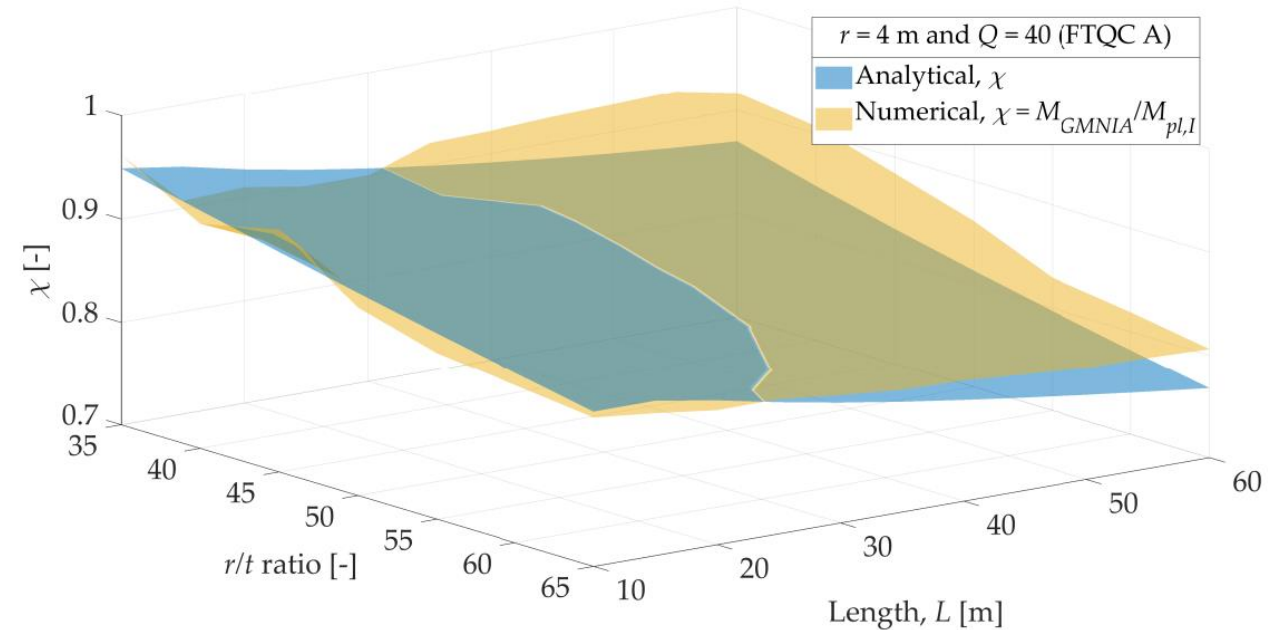**Full-circumferential dimple**

Assumed in analytical methods
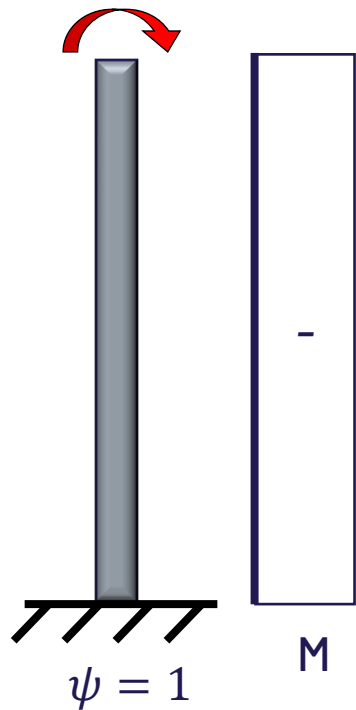
Limited dimple

Allowed in execution standard

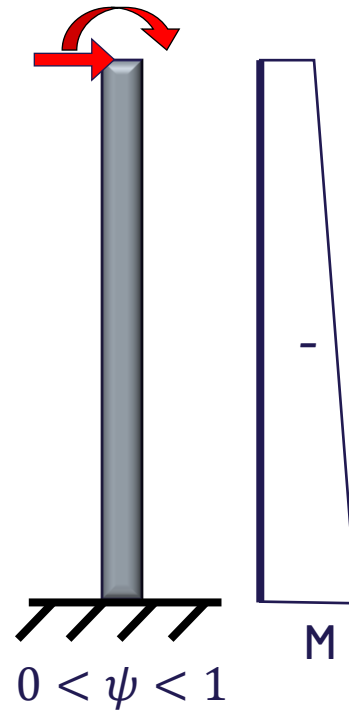**Limited dimple vs. analytical method (with full-circumferential dimple)**

$r = 4$ m and $Q = 40$ (FTQC A)
Analytical, χ
Numerical, $\chi = M_{GMNIA}/M_{pl,I}$

Still some unconservative analytical results for typical monopile geometries.

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Master's Thesis – Assessment and Improvement of Buckling Verification Methods for Monopiles

Moment distribution

Uniform moment

$$\psi = 1$$

Increasing moment

$$0 < \psi < 1$$

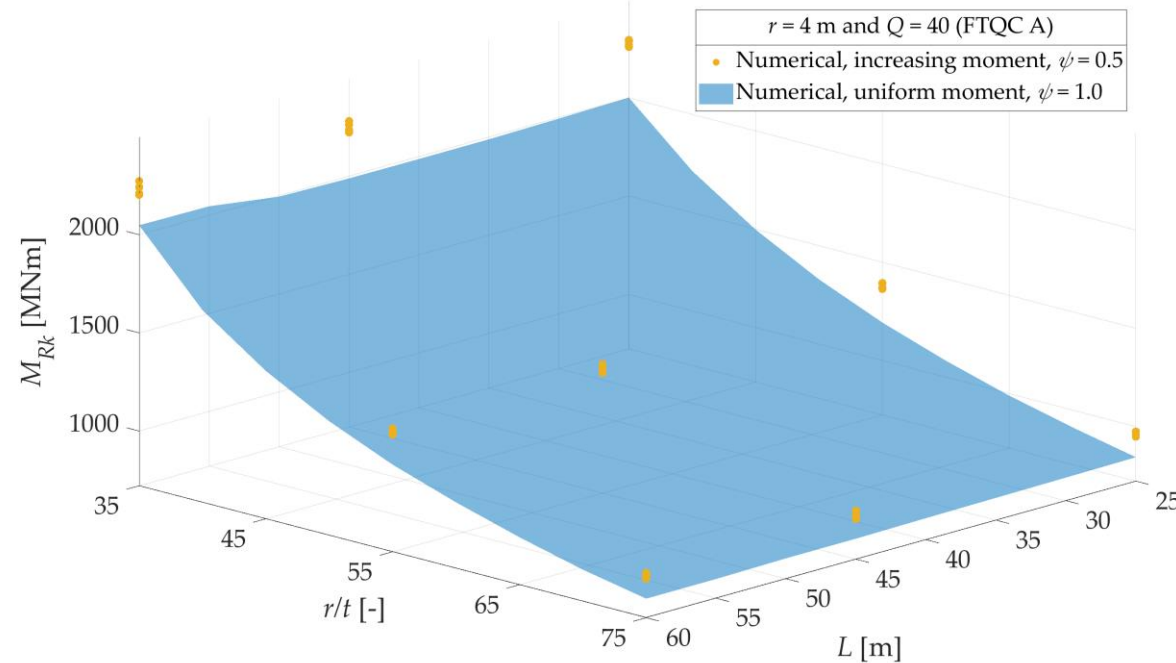**Buckling modes**

$$\psi = 1 \qquad \psi = 0.5$$

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Moment distribution

◈ Uniform moment → linearly increasing moment → min. 7% increase in resistance

Thank you for your attention!