Damping of Wind Turbine Tower Vibrations by a stroke amplifying brace concept

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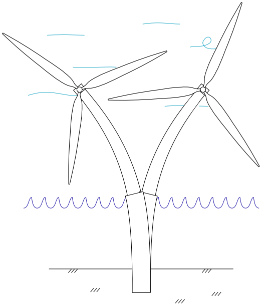
EERA Deepwind
January 22-24 2014

Outline

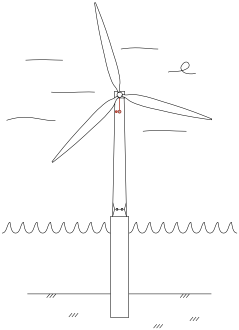
Offshore wind turbine tower vibrations

- Wind-wave misalignment
  - Larger wind turbine and deeper waters



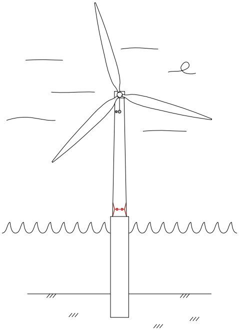
Offshore wind turbine tower vibrations

- Wind-wave misalignment
  - Larger wind turbine and deeper waters
- Resonant dampers



Offshore wind turbine tower vibrations

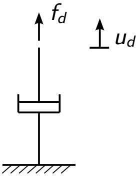
- Wind-wave misalignment
  - Larger wind turbine and deeper waters
- Resonant dampers
- Dampers inside the tower



Criteria for effective damping

- Damper stroke
  - Activation of damper
  - Damper force

$$E_d = \dot{u}_d f_d$$



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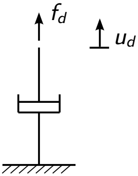
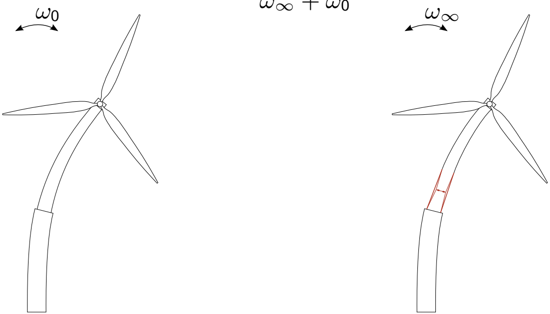


- Attainable damping
  - Given by the change in frequency

$$\zeta_{max} \simeq \frac{\omega_\infty - \omega_0}{\omega_\infty + \omega_0}$$



Criteria for effective damping

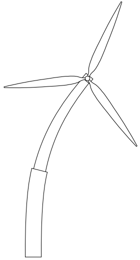
- Tuning of dampers
  - Viscous dampers with damping parameter c

$$f_d = c\dot{u}_d$$

  - Tuning for maximum damping

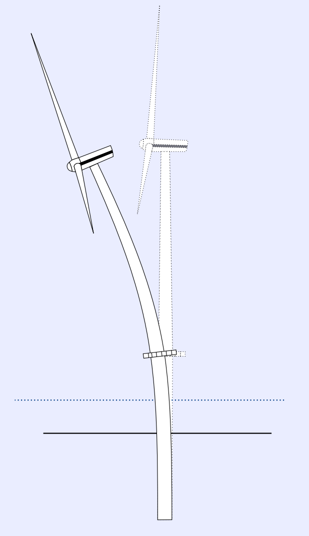
$$c_{opt} \simeq 2\frac{\omega_\infty - \omega_0}{\sum_k^N \gamma_k^2}$$

γ is the damper stroke with respect to mode $\mathbf{u}_0$ for unit modal mass $\mathbf{u}_0^T\mathbf{M}\mathbf{u}_0 = 1$

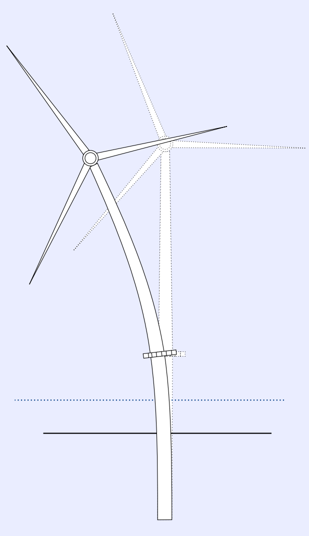


$\mathbf{u}_0$

Tower modes

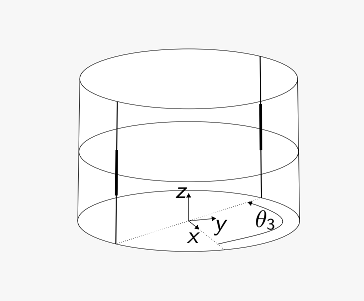


For-aft mode



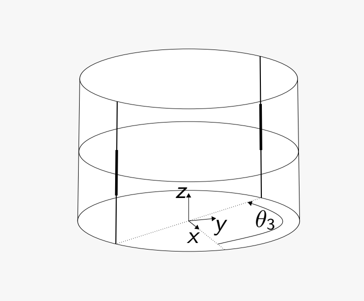
Side-to-side mode

Brace concepts



Curvature-brace

Brace concepts



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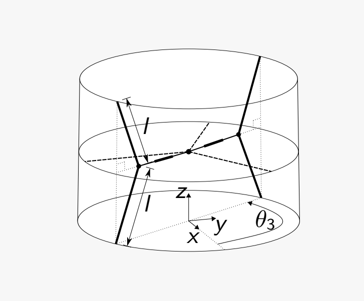
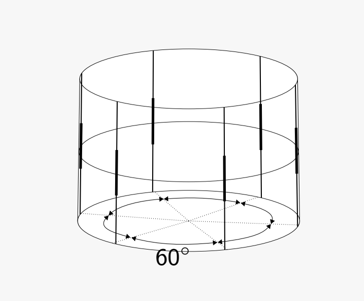
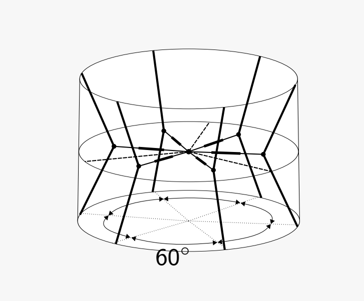


Curvature-toggle-brace

Brace concepts





Curvature-brace

Curvature-toggle-brace

Numerical models

- Linear beam model
  - Wind turbine at standstill
  - Linear Winkler type spring model
  - Lumped inertia
  - Stiffness matrix derived from complementary energy

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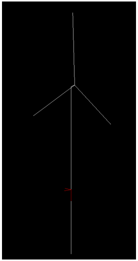
  - Blade element momentum theory
  - Multi-body formulation
  - Control via Dynamic Link Library (dll) interface
  - External system



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  - Control via Dynamic Link Library (dll) interface
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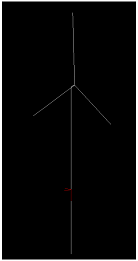
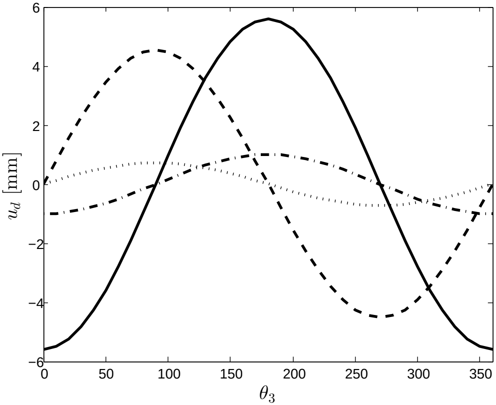
- Offshore Code Comparison Collaboration
  - NREL reference turbine + monopile in 20 m water

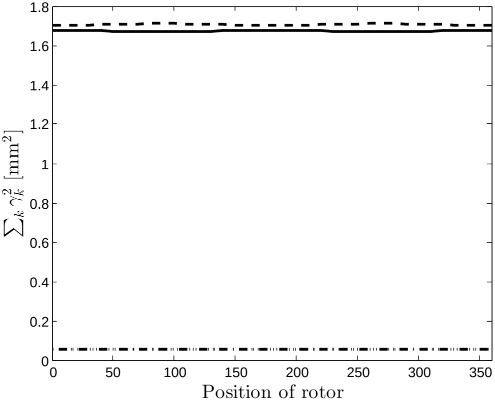


Displacement of damper



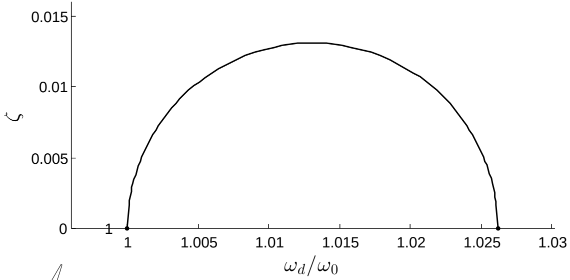
u_d for the curvature brace with respect to the fore-aft mode (dotted) and the side-to-side mode (dash-dotted) and u_d for the curvature-toggle-brace with respect to the fore-aft mode (dashed) and the side-to-side mode (solid)

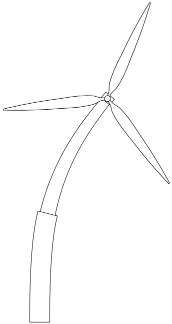
Displacement of damper



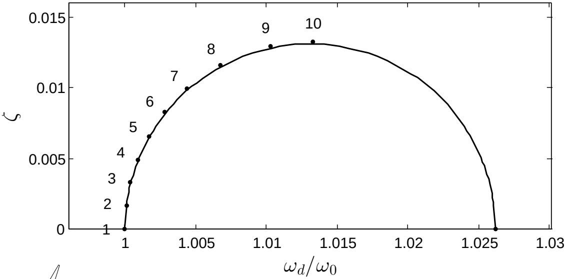
γ^2 for the curvature brace with respect to the fore-aft mode (dotted) and the side-to-side mode (dash-dotted) and γ^2 for the curvature-toggle-brace with respect to the fore-aft mode (dashed) and the side-to-side mode (solid)

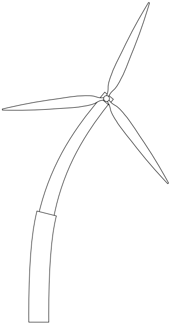
Attainable damping



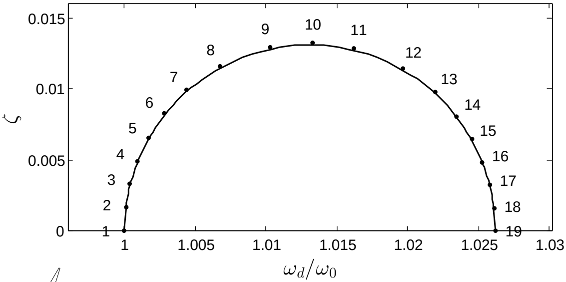


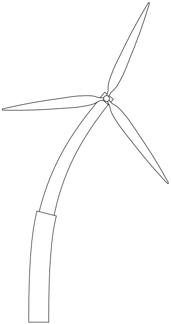
Attainable damping

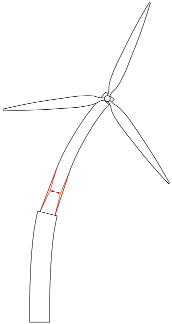




Attainable damping

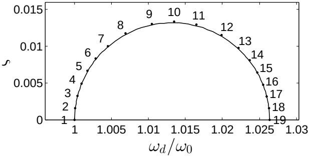




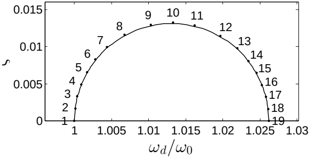


Attainable damping

Curvature-brace

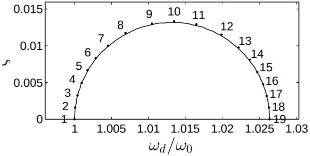


Fore-aft mode



Side-to-side mode

Curvature-toogle-brace



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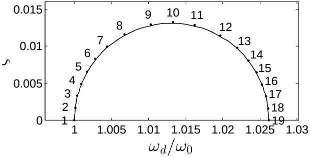
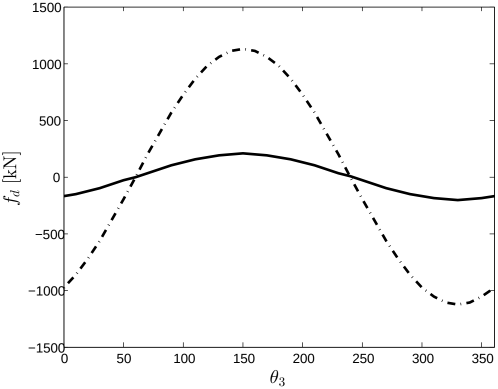


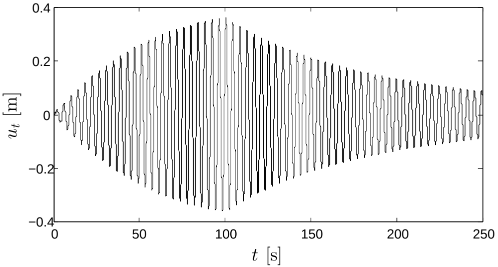
Side-to-side mode

Damper force



f_d for the curvature brace (dash-dotted)
and f_d for the curvature-toggle-brace (solid)

Free decay



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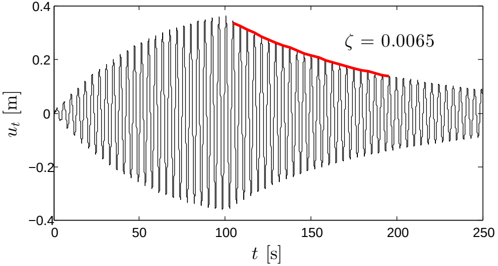

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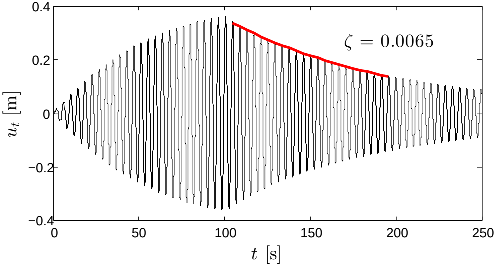
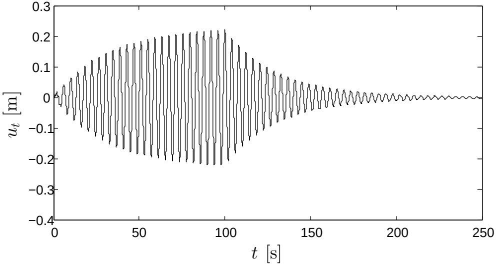
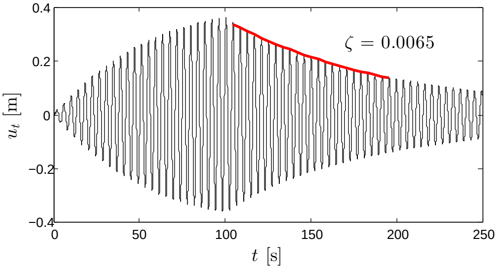


$\zeta = 0.0065$
0.4
0.2
0
−0.2
−0.4
0
50
100
150
200
250
u_t [m]
t [s]



0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
0
50
100
150
200
250
u_t [m]
t [s]

Free decay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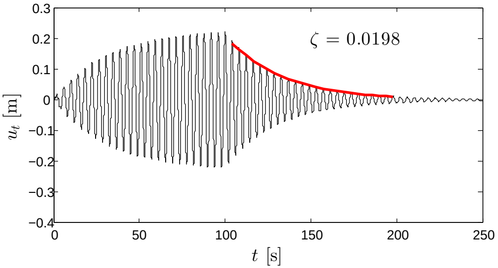
0.4
0.2
0
−0.2
−0.4
u_t [m]
0
50
100
150
200
250
t [s]


$\zeta = 0.0198$
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
u_t [m]
0
50
100
150
200
250
t [s]

Outlook

Summary

- Maximize attainable damping and damper stroke
  - Installation at the bottom of the tower
  - Stroke amplifying toggle brace
  - Attainable damping: 1.3 % critical
  - Optimum tuning independent of the orientation of the rotor
  - The same tuning can be used for both critical modes

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Ongoing work

- Physical implementation
- Experimental validation