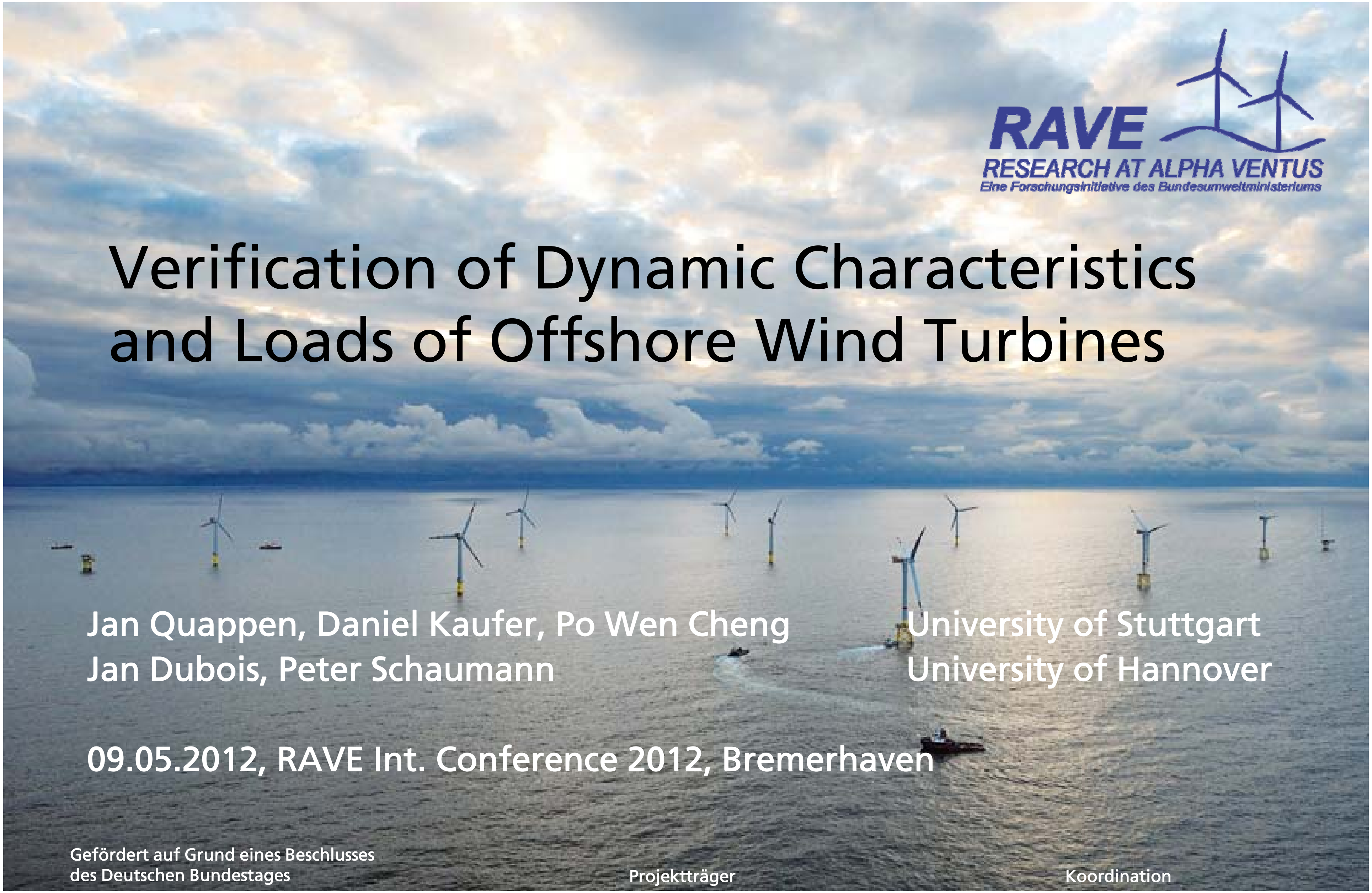

RAVE
RESEARCH AT ALPHA VENTUS
Eine Forschungsinitiative des Bundesumweltministeriums

Verification of Dynamic Characteristics and Loads of Offshore Wind Turbines

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09.05.2012, RAVE Int. Conference 2012, Bremerhaven

Gefördert auf Grund eines Beschlusses des Deutschen Bundestages

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

Projektträger

PtJ Projektträger Jülich Forschungszentrum Jülich

Koordination

Fraunhofer IWES

Introduction to the Rave – OWEA Project

The OWEA project deals with verification and validation of offshore wind turbines,

- Verification of meteorological aspects,
- Verification of aerodynamic simulations,
- Load monitoring aspects
- Validation of measured and simulated loads and dynamics of offshore wind turbines

Project started in 2008

Motivation and Aims

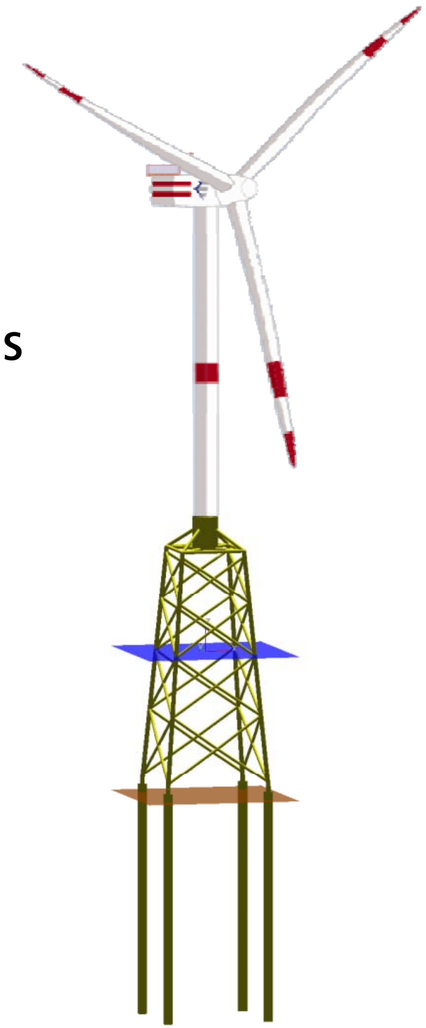
- Improvement of design tools and methods, demanded by industry
- The intention is to optimize future wind turbine concepts and components → increase reliability and reduction of costs

Process steps have been defined:

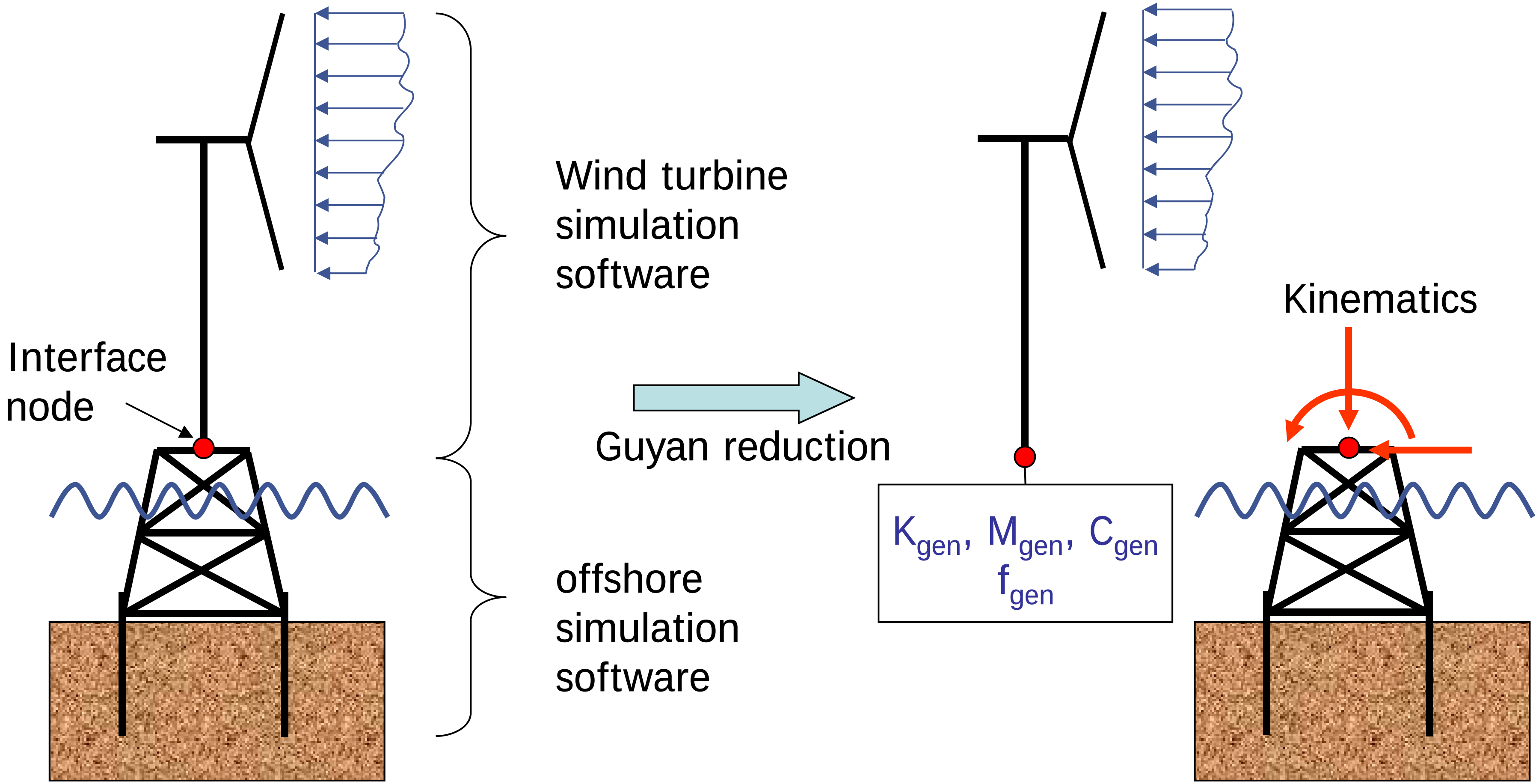
- Development and improvement of design tools
- Dynamic characterization of offshore wind turbines (with fixed bottom mounted structures in medium water depth)
- Measurement data analyses
- Validation of simulation tools with measurements

Development of Simulation Tools I

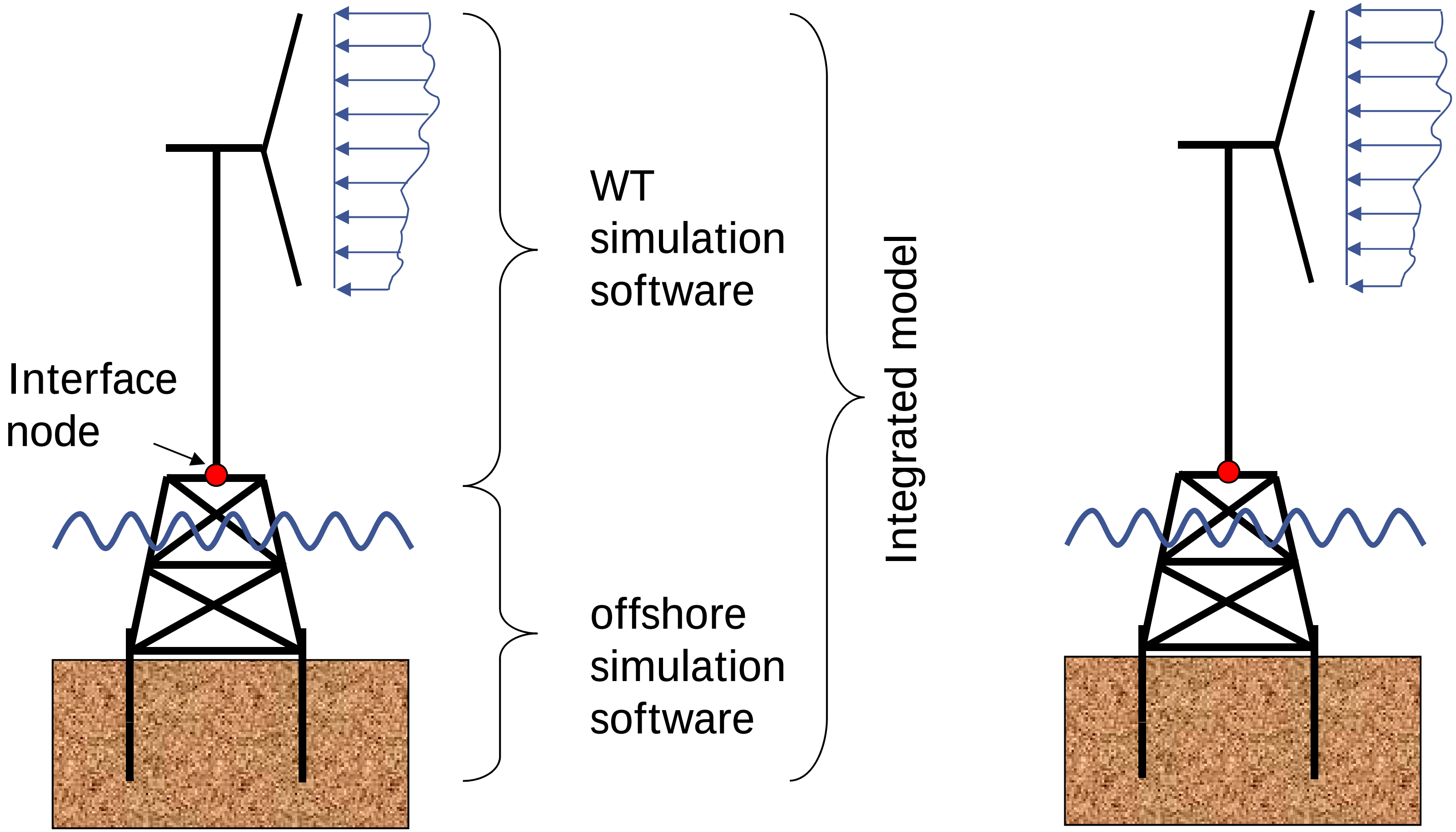
- New support structure types are used in alpha ventus
- The industry demand advanced simulation solutions to handle the following statements:
  - Allow the simulation of complex support structures (such as Tripod & Jacket)
  - Integrated load analysis of wind turbine and complex support structure instead of separation or reduction methods
  - Include non-linear foundation and hydrodynamics



Coupling – Sequential Approach



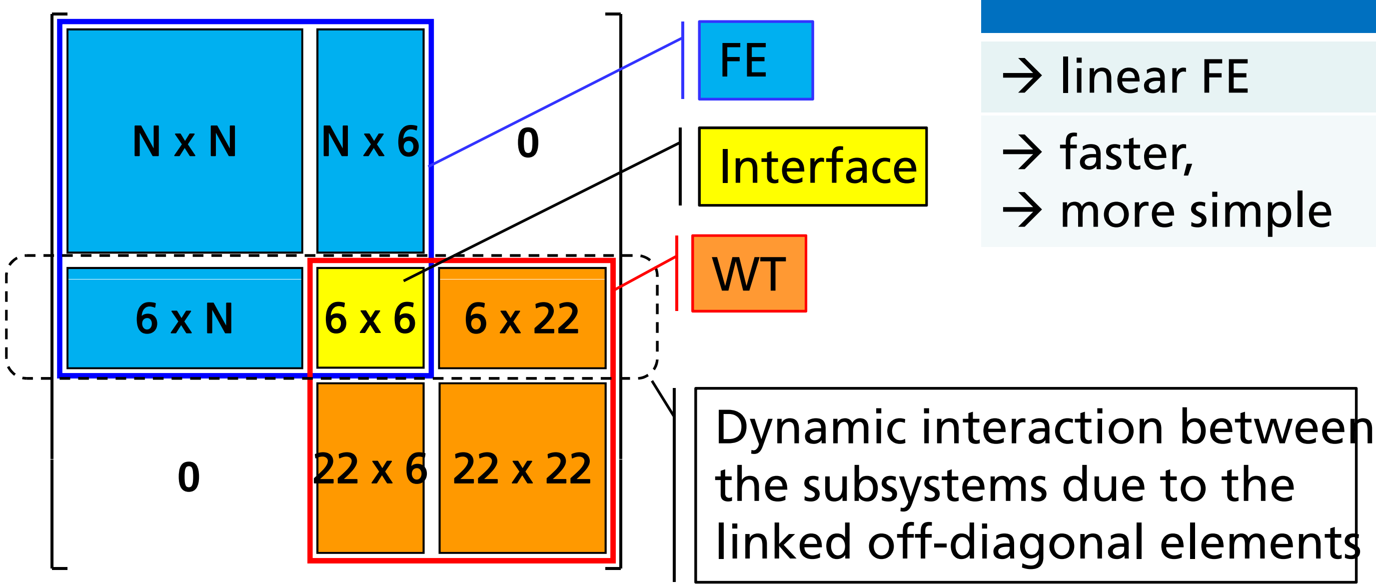
Integrated Coupling Approach



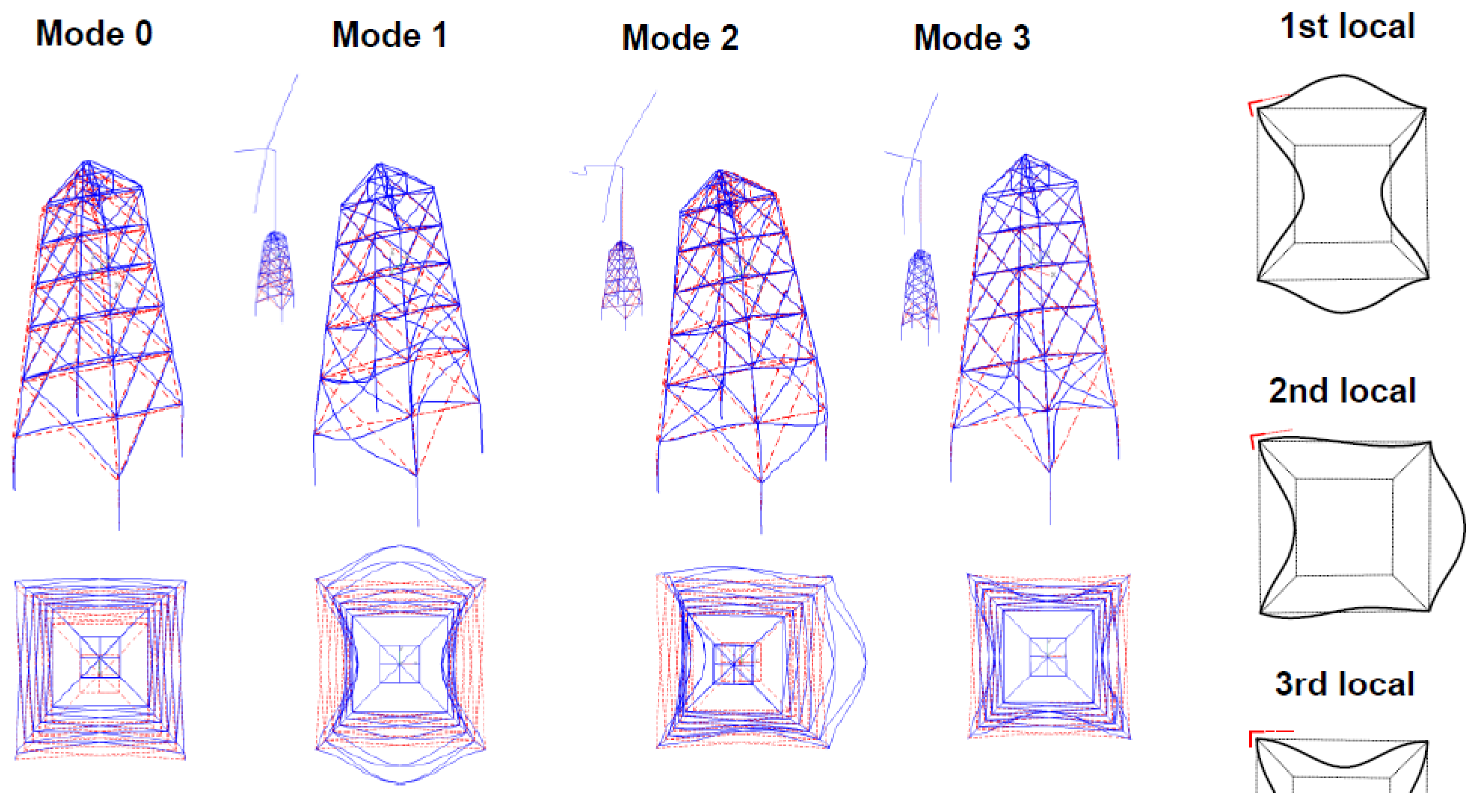
Development of Simulation Tools II

- The idea is to couple sophisticated simulation tools of two worlds: wind turbine (WT) simulation & offshore support structure code
- Coupling is based on the combination of the equations of motion

Flex5 - Poseidon	Flex5 - ANSYS ASAS (NL)
→ linear FE	→ non-linear FE
→ faster, → more simple	→ slower → more complex



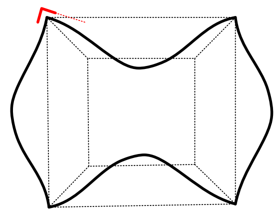
Advantage: Coupled Modes Shapes



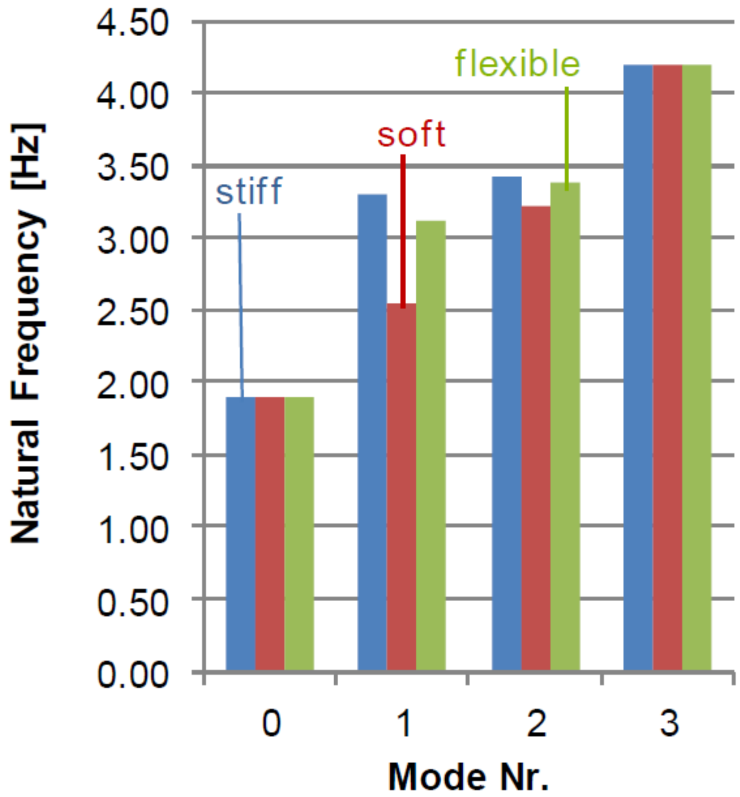
2nd global mode side-to-side with minor local contribution	1st local mode coupled with blade modes	3rd global fore-aft with sign. contribution of 2nd local	3rd global mode with sign. contribution of 3rd local

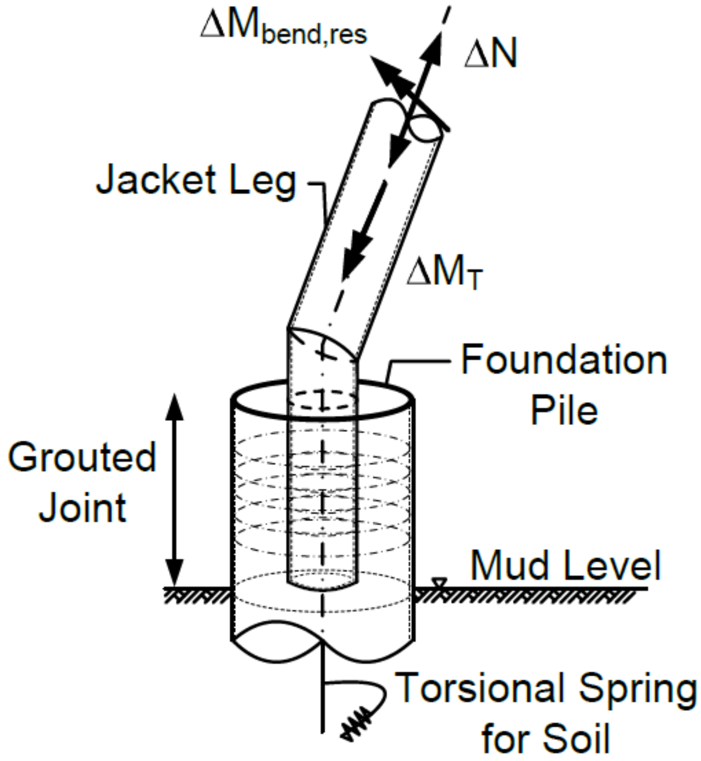
Integrated Coupling
Influence of Rotational Pile Stiffness

1st local



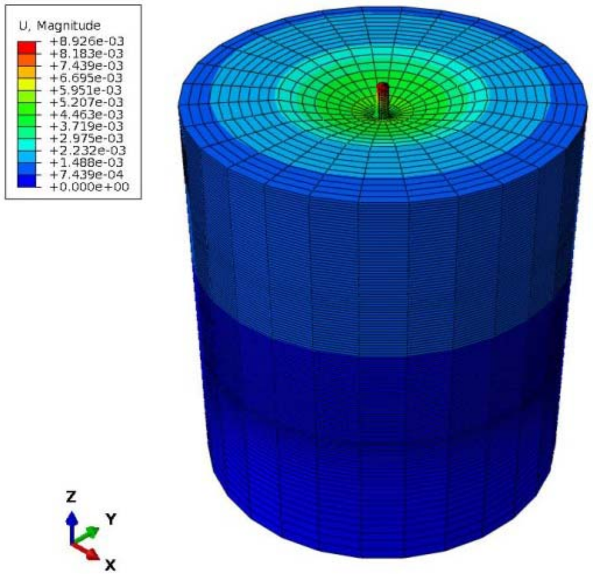
- Major influence on 1st local mode

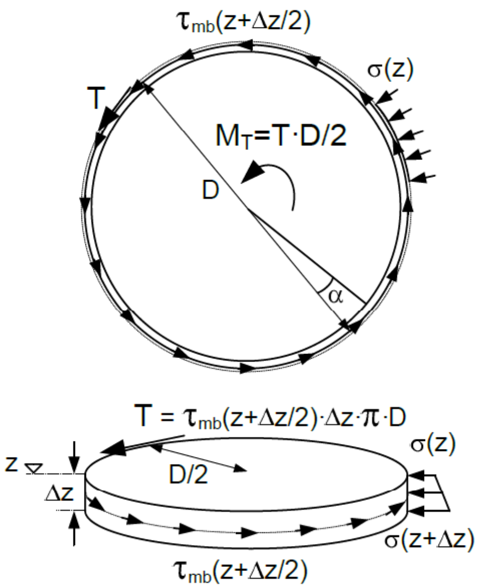




Rotational Pile Stiffness under Multi-Axial Loading

- Sophisticated FEM model vs. engineering approach





q3

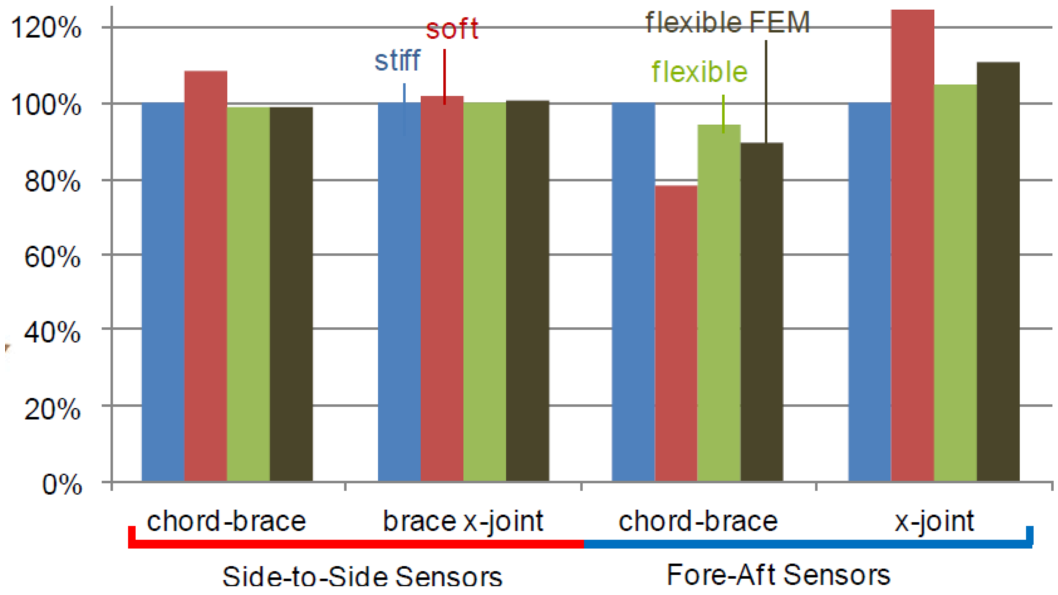
➔ Use of engineering approach leads to minor overestimation of rotational pile stiffness

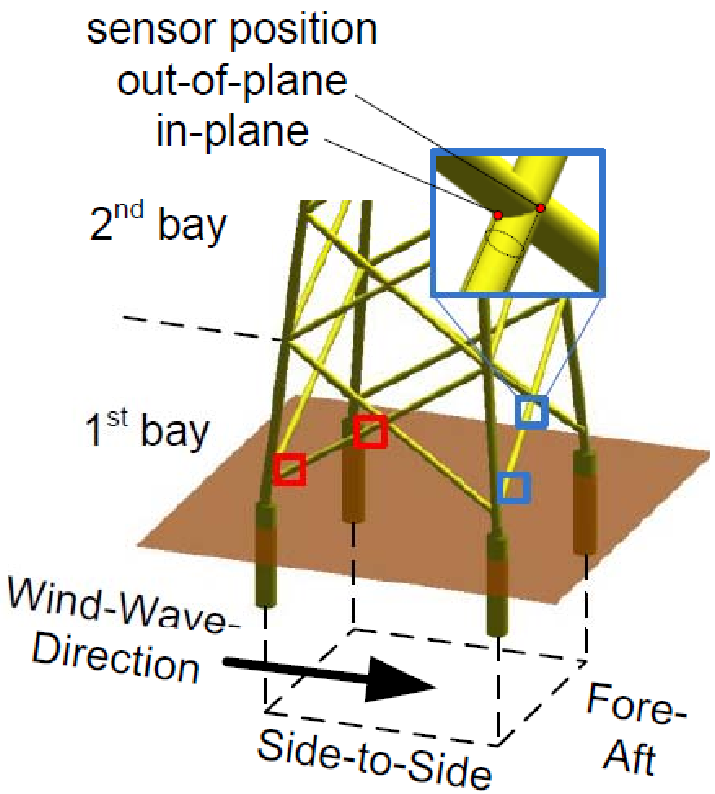
q3 quelle

quappen; 16.04.2012

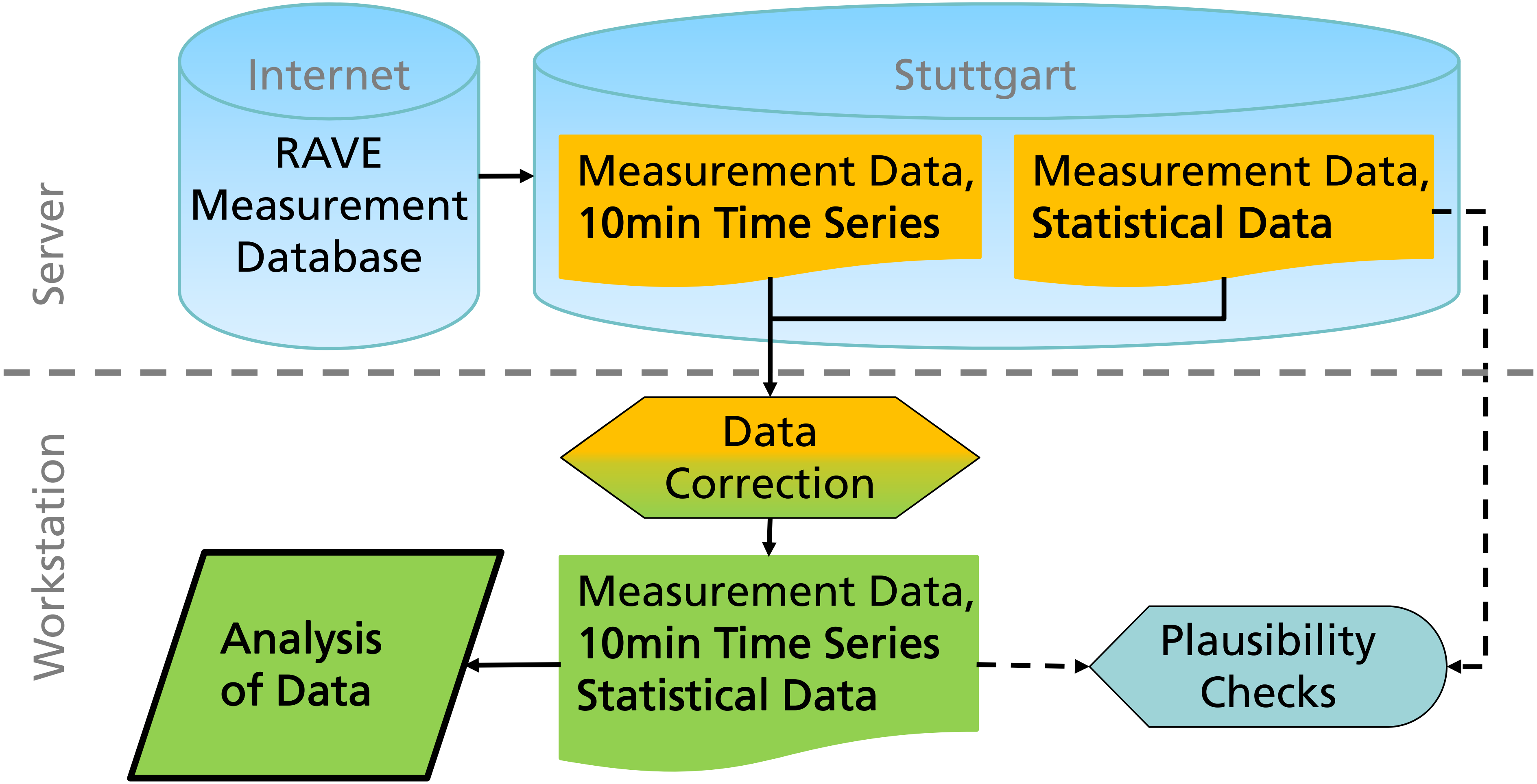
Influence of Local Vibrations on Fatigue

- Soft model conservative
- Stiff model „neglects" additonal fatigue
- Realistic assumption of pile stiffness leads to a few percent additional fatigue in braces





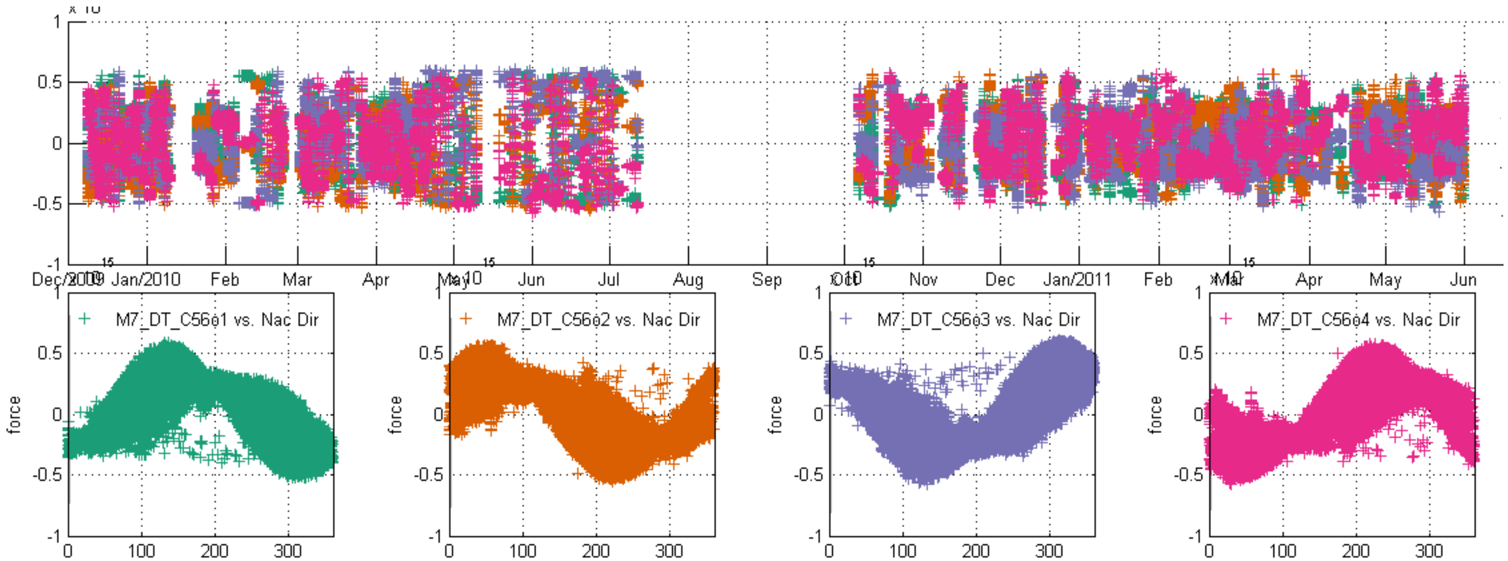
Measurement Data Storage @ University Stuttgart



Analysis of Measurement Data I

- Analysis of measurement data are more challenging than expected
- Data not gained from the lab, but from the field → irreproducible
- Measured quantities needs adjustment and calibration

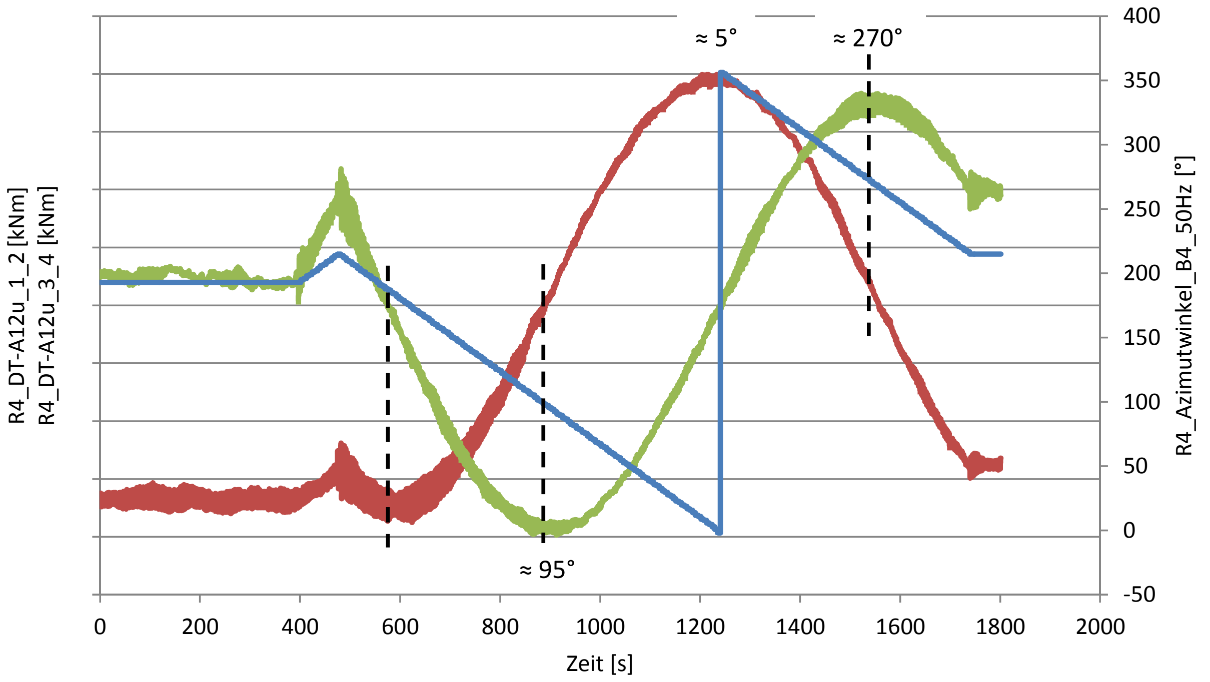
Normalized mean strain sensors at the tower top:

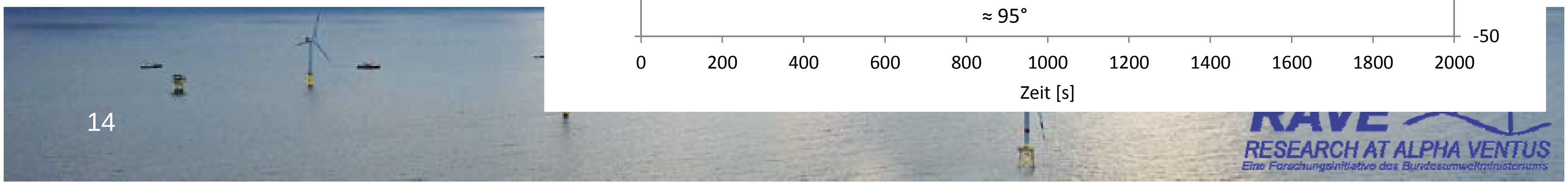


Analysis of Measurement Data II

- A steered nacelle revolution is a very basic plausibility check
  → rotor mass imbalance provides quasi-constant loading
  → tower and blade loads can be estimated by hand
  → support structure loads are sinusoidal
  → calm weather required

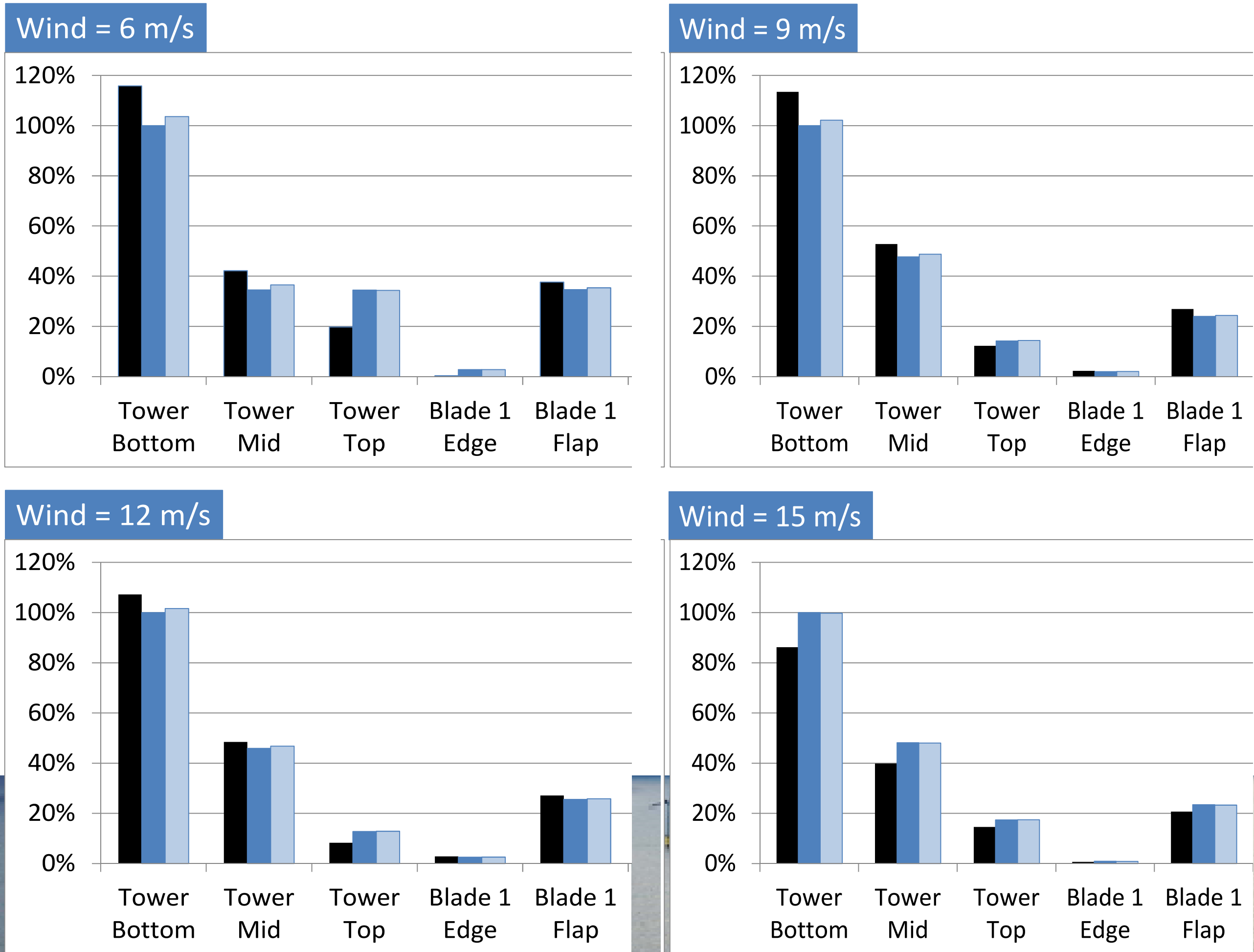
- Example of the towe
  bending moment at
  the wind turbine R4





Measurement vs. Simulation I

- Example: load analyses according to wind speed of 6, 9, 12, 15m/s
  → R4 measurement data are re-simulated as close as possible



Comparison of mean bending moments at
→ tower base
→ tower mid
→ tower top
→ blade 1 edge
→ Blade 1 flap

Measurements

Simualtion according to weather situation

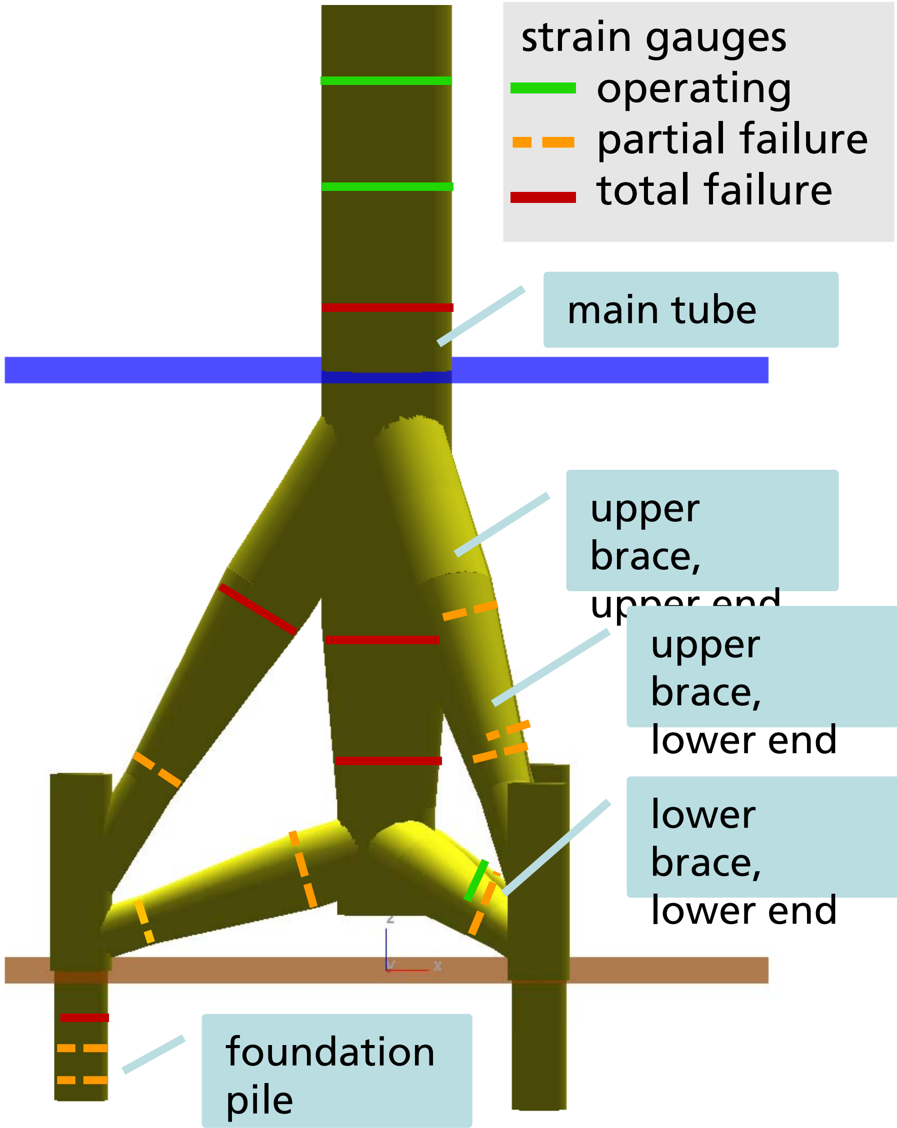
Simulation with 20% increased turbulence

Tripod Strain Gauges, M7

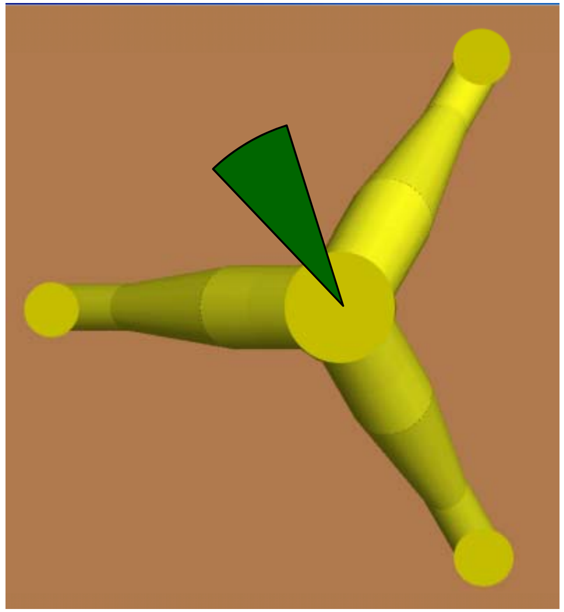
- Measurements started in Jan. 2010

- Sensors initially working / installed:
  - tower: 12 / 12
  - tripod: 25 / 40
  - pile: 08 / 40

- Several of the sensors at tripod and pile failed during the campaign



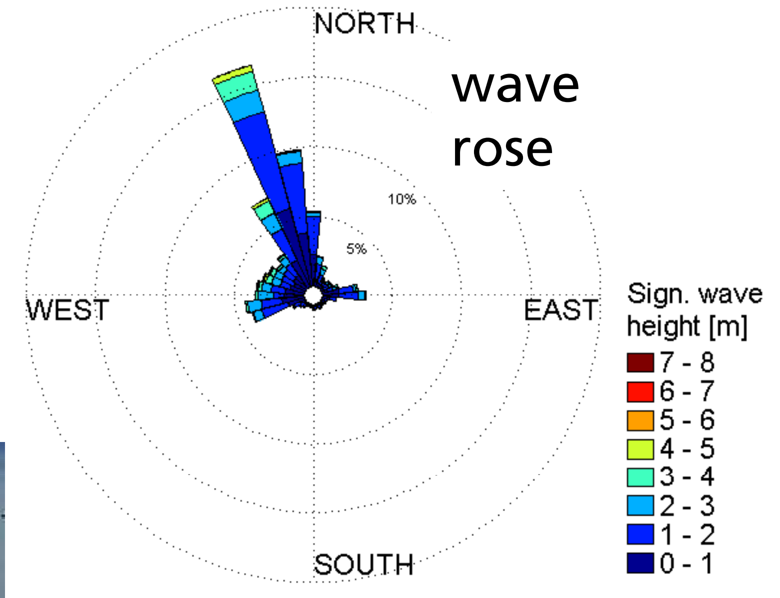
Example of Validation Test Case

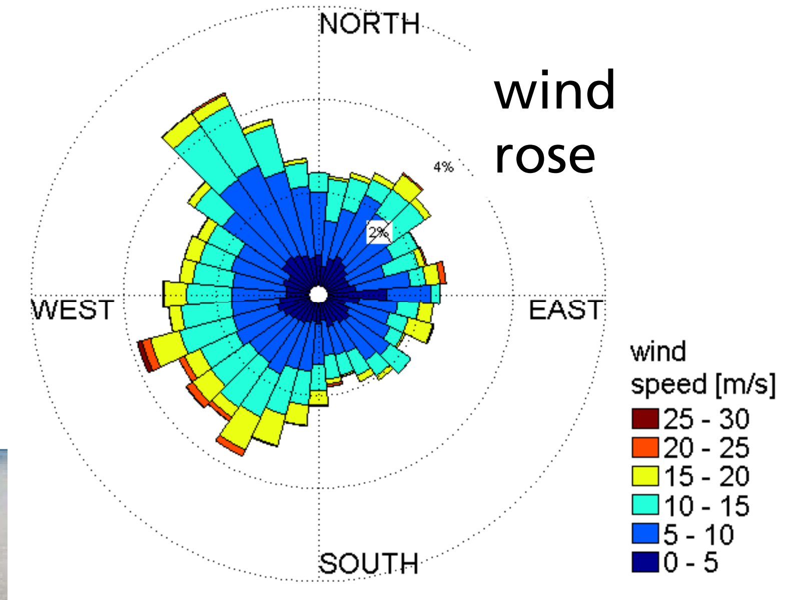


Simulation test case:

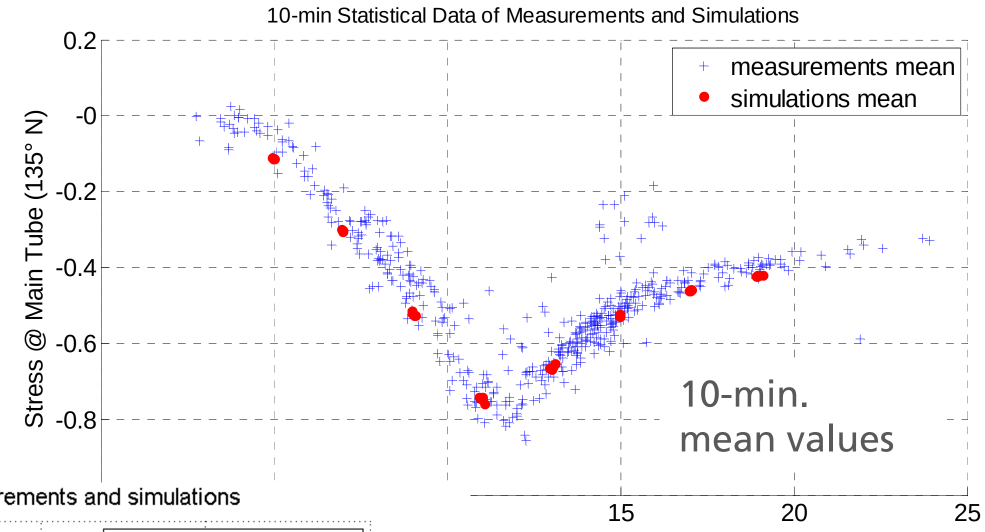
- Tripod loads highly depend on the yaw angle
- As little wind wave misalignment as possible
- Tripod brace should be aligned with wind and wave direction

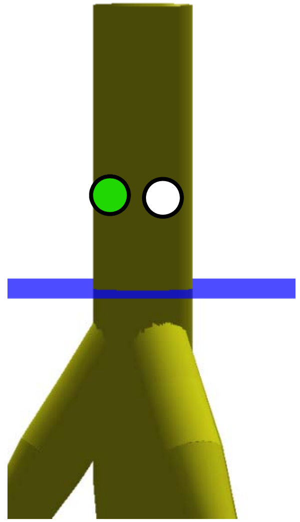
→ wind and wave sector from 315° to 345°

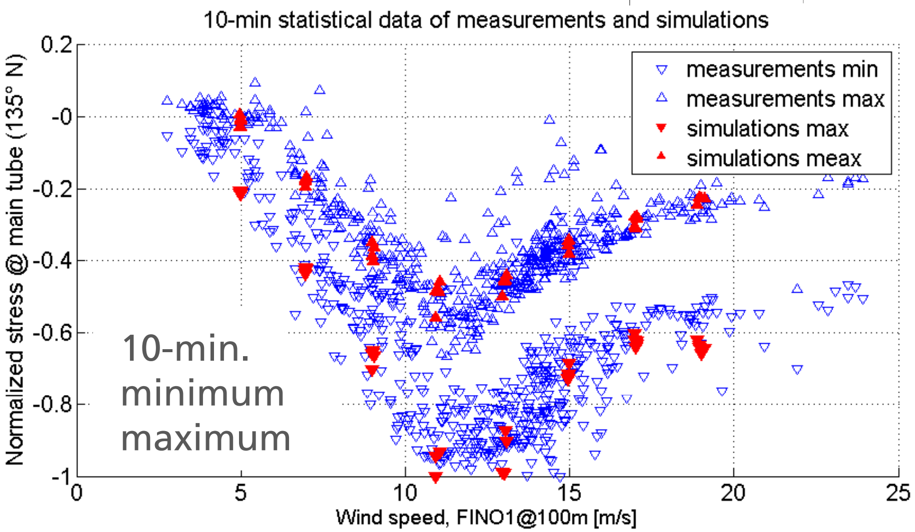




Measurement vs. Simulation II



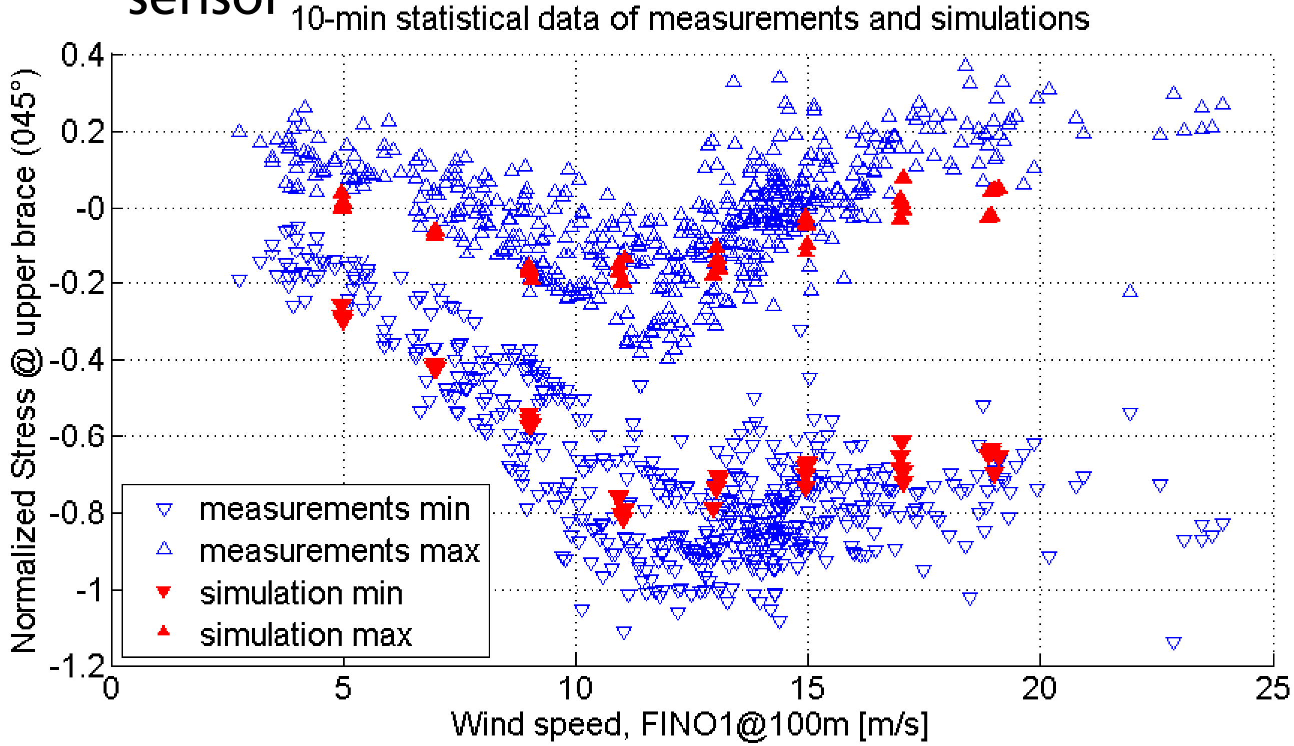


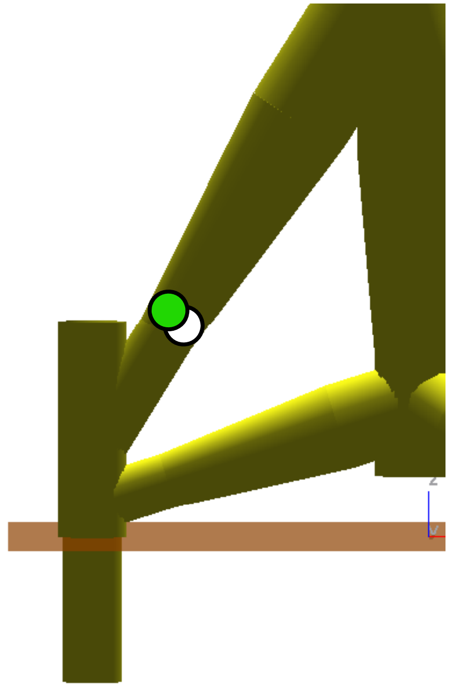


- At the main tube, simulated and measured stress quantities fit quite well for the test load case

Measurement vs. Simulation III

- Small underestimation of stresses in the simulation at the upper braces sensor





Conclusions

1. The implemented coupling approach works well
   - Tool development is successful
   - Interaction of turbine and support structure can be handled

2. Measurement Data Management System established
   - Allowing plausibility checks and data correction
   - Enables general data analyses of validated data

3. Validation of simulations with measurement data
   - Comparison of global component loads and
   - Analyses of strain gauges at the support structures
   - Quality of precise simulation input data is the key