Welcome

WIND . ASSURING CONFIDENCE THROUGH COMPETENCE

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Fraunhofer IWES

Investigation of Degradation Processes in Large-scale Experimental Tests by Structural Health Monitoring Techniques and Numerical Simulations

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Outline

1. Introduction
2. Motivation & Experimental Set-up
3. Experimental Results
4. Simulation and Validation
5. Summary & Outlook

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1. Introduction

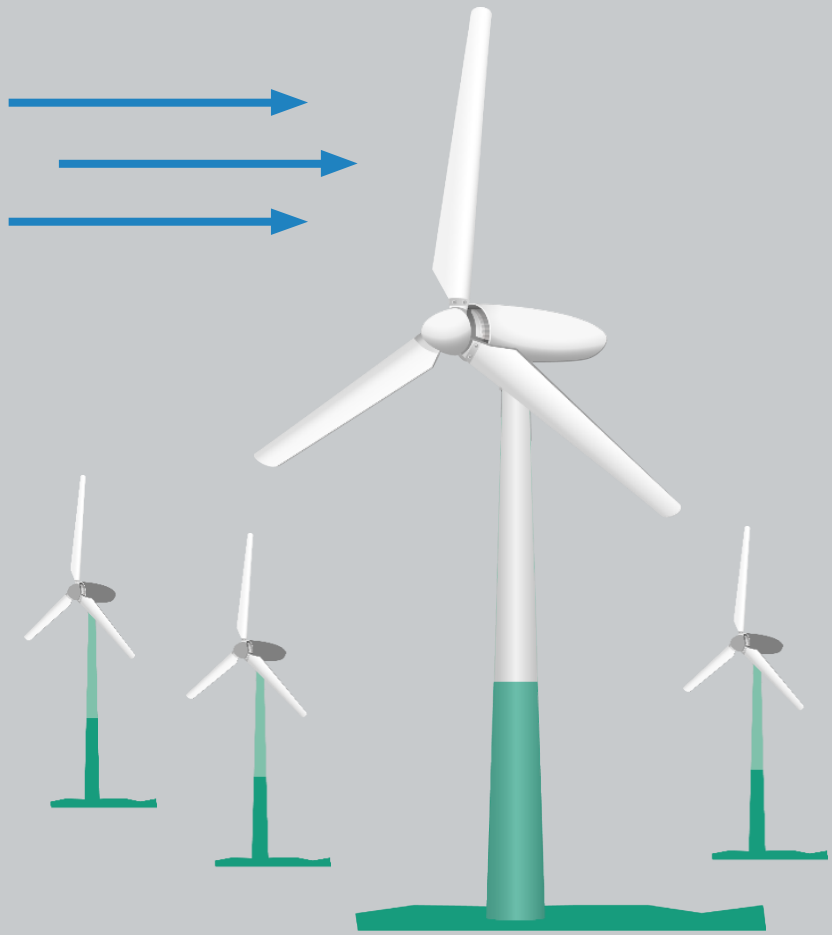
Research with added value

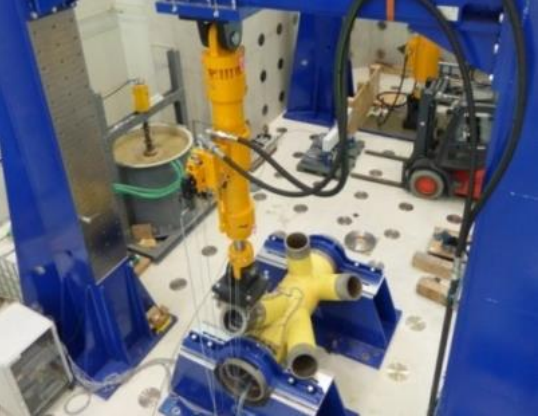
Field measurements, computational fluid dynamics and wind farm simulation

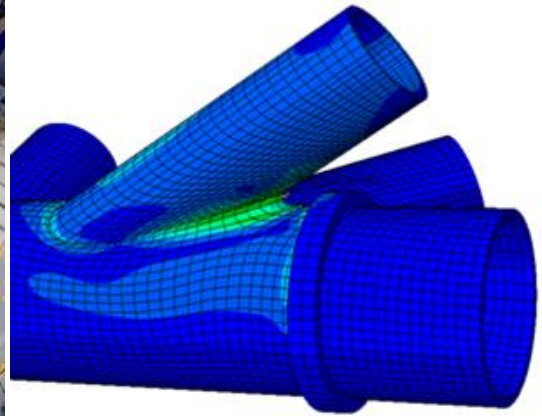
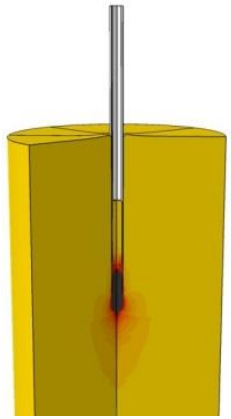
Rotor

Drive train and grid connection

Support structures, foundations and assessment of soil conditions





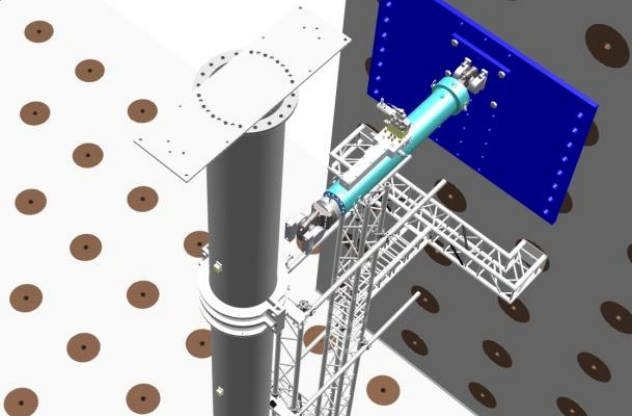
Support structures & foundations

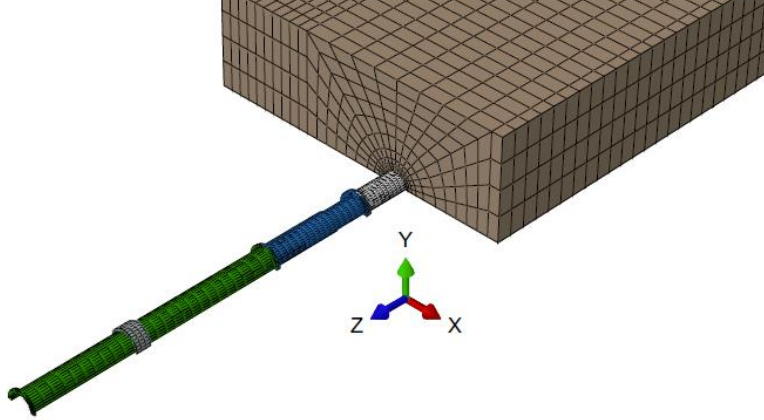
Experimental tests in large scale

- Experimental model testing on foundation elements and substructures
- Numerical calculation and simulations
- Development and testing of environmentally friendly construction methods
- Simulation of the structure's dynamic and fatigue behavior under the long-term cyclic influence in "time lapse"

Validation of design approaches and monitoring methods

⇒ Foundation installation techniques
⇒ Foundation load-bearing behavior
⇒ Structural Health Monitoring (SHM) systems





Support structures & foundations

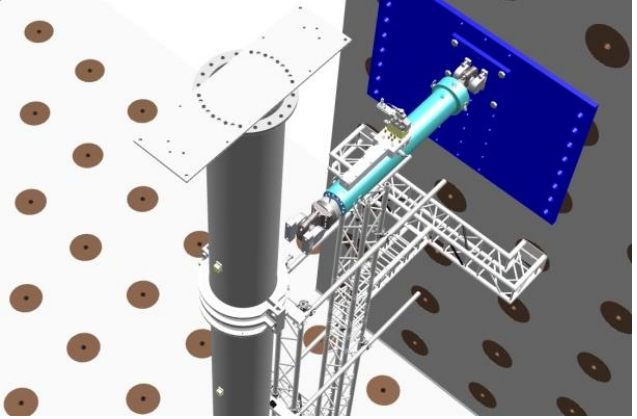
Numerical modeling approach (Virtual Test Bench)

- Application of Python and Abaqus Scripting Interface
- Object oriented program for numerical model set-up
  - Parameterization (geometry, material or mesh properties)
  - Realization of different modeling strategies

Virtual Test Bench is providing faster insight into tests strategies and results

⇒ Adaptation of the model during design phase based on computer aided design (CAD)
⇒ Sensitivity studies w.r.t. mesh refinement, model scales or material properties
⇒ Basis for validation of test strategies and numerical modeling
⇒ Documentation in terms of quality management

2. Motivation & Experimental Set-up



Joint Research Project: Quality Assurance and SHM of Grouted Connections of Underwater Support Structures for Offshore Wind Turbines - **QS-M Grout**

Wölfel

Fraunhofer IWES

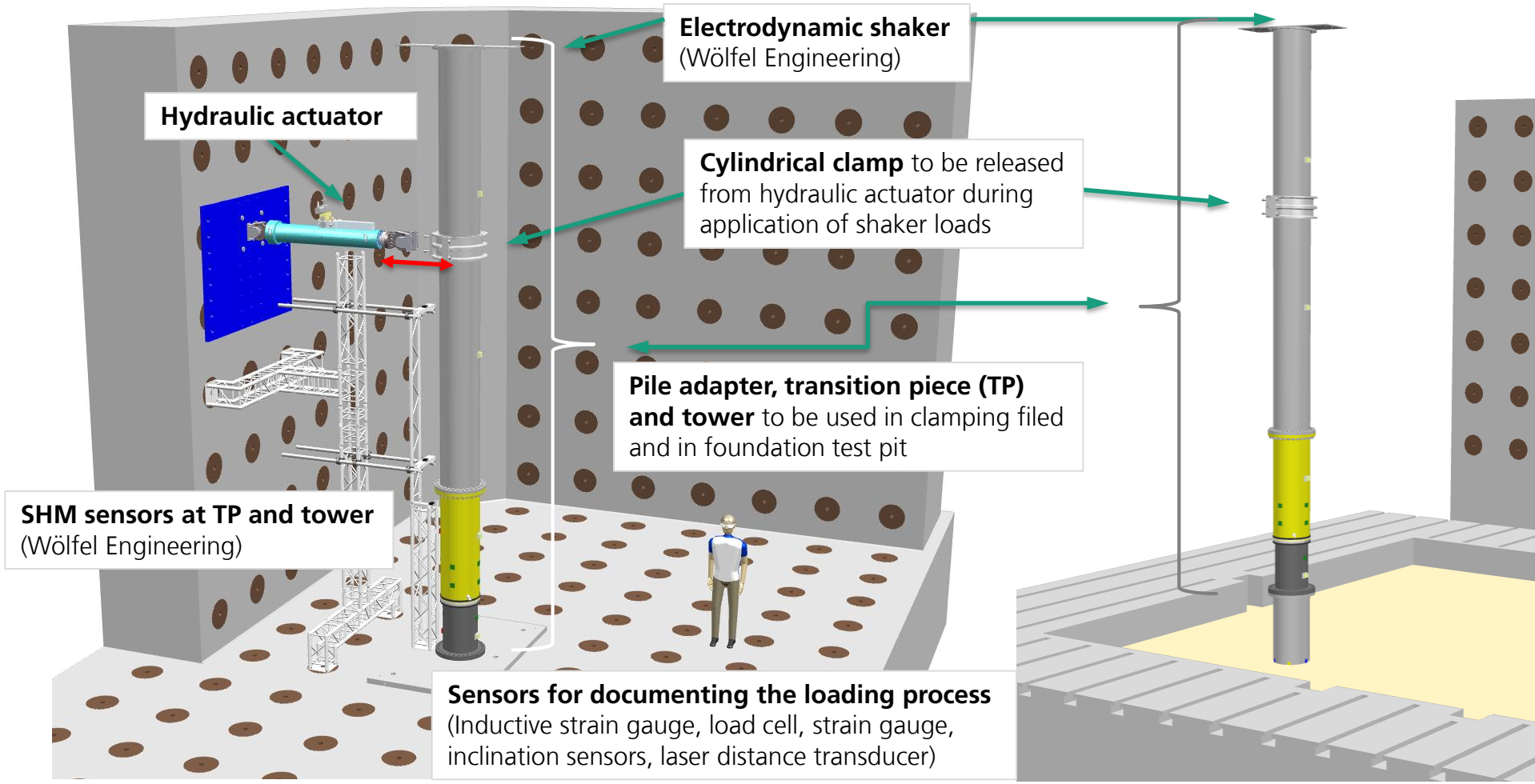
BALTIC ROSTOCK TB Taucherei- und Bergungsbetrieb GmbH

Fraunhofer IKTS

WindMW

Sub project at Fraunhofer IWES: *„Assessment of Grouted Connections by Experimental and Numerical Investigations“*

Experimental test set-up

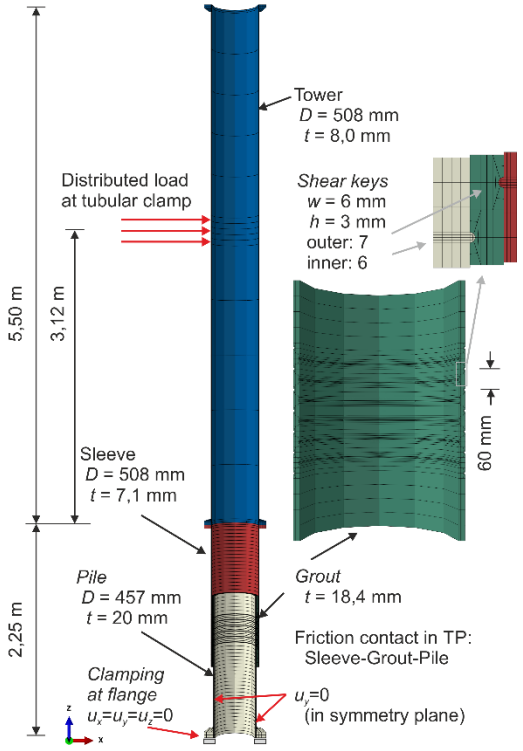


Grout damaging and monitoring in the clamping field

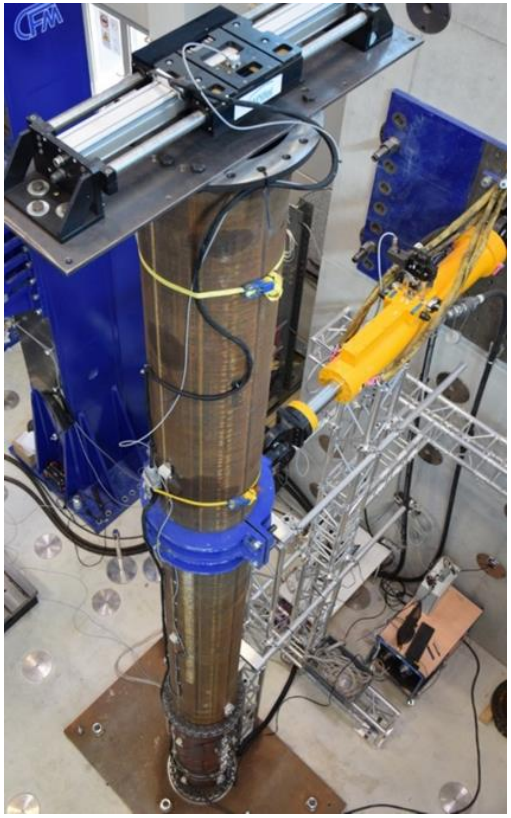
Assessment of SHM methods in foundation test pit

Assessment of structural health monitoring (SHM) systems

Numerical modeling, testing & degradation



Numerical modeling of the damage process in grouted connections for design purpose and for validation against measurement data



Experimental test set-up for damaging a grouted connection

Assessment of SHM systems

Experimental test set-up in the test pit

Strategies

- Test set-up based on computer aided design and numerical predictions
- Large-scale model tests under realistic offshore conditions

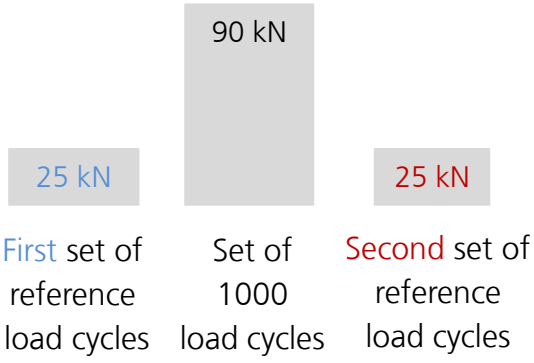
Objective

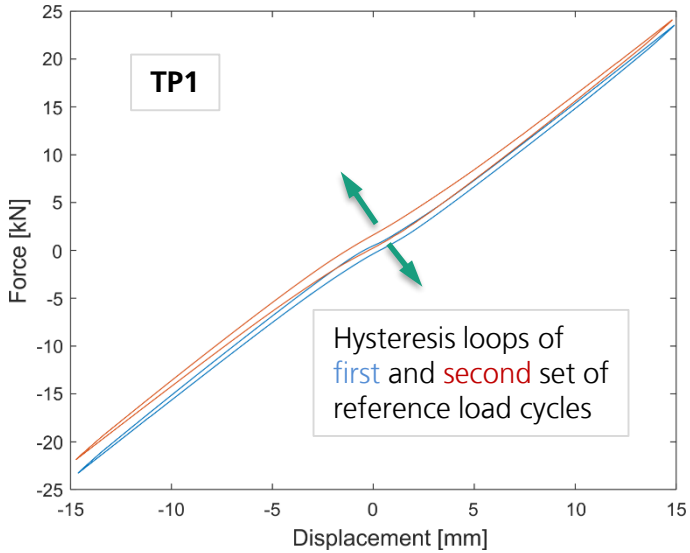
⇒ Assessment of SHM systems regarding a specific damaging process and a realistic soil-structure interaction

3. Experimental Results

Specific grout damaging with hydraulic actuator – damaging approach

Exemplary evaluation
Load-displacement curves at transition piece 1 (TP1)





Hysteresis loops before and after load step 90 kN (1000 load cycles)

Grout damage test at 90 kN load (March 6, 2017)

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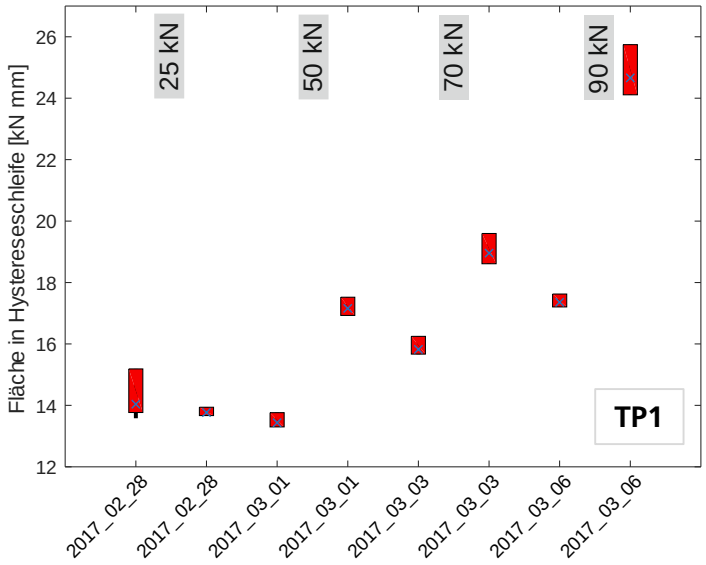
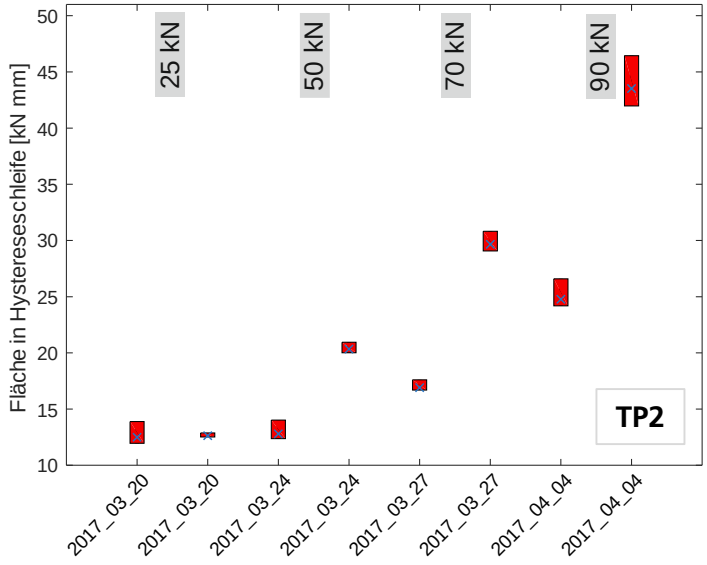
Specific grout damaging with hydraulic actuator – load-displacement analysis

Incremental development of inner area of 25 kN reference hysteresis before and after load steps of 25 kN, 50 kN, 70 kN and 90 kN for transition piece TP 1 (left) and TP 2 (right)





10 kN / 25 kN load

- No significant detection of damage in view of nonlinear load-displacement relation
- No acoustic emission

50 kN / 70 kN / 90 kN load

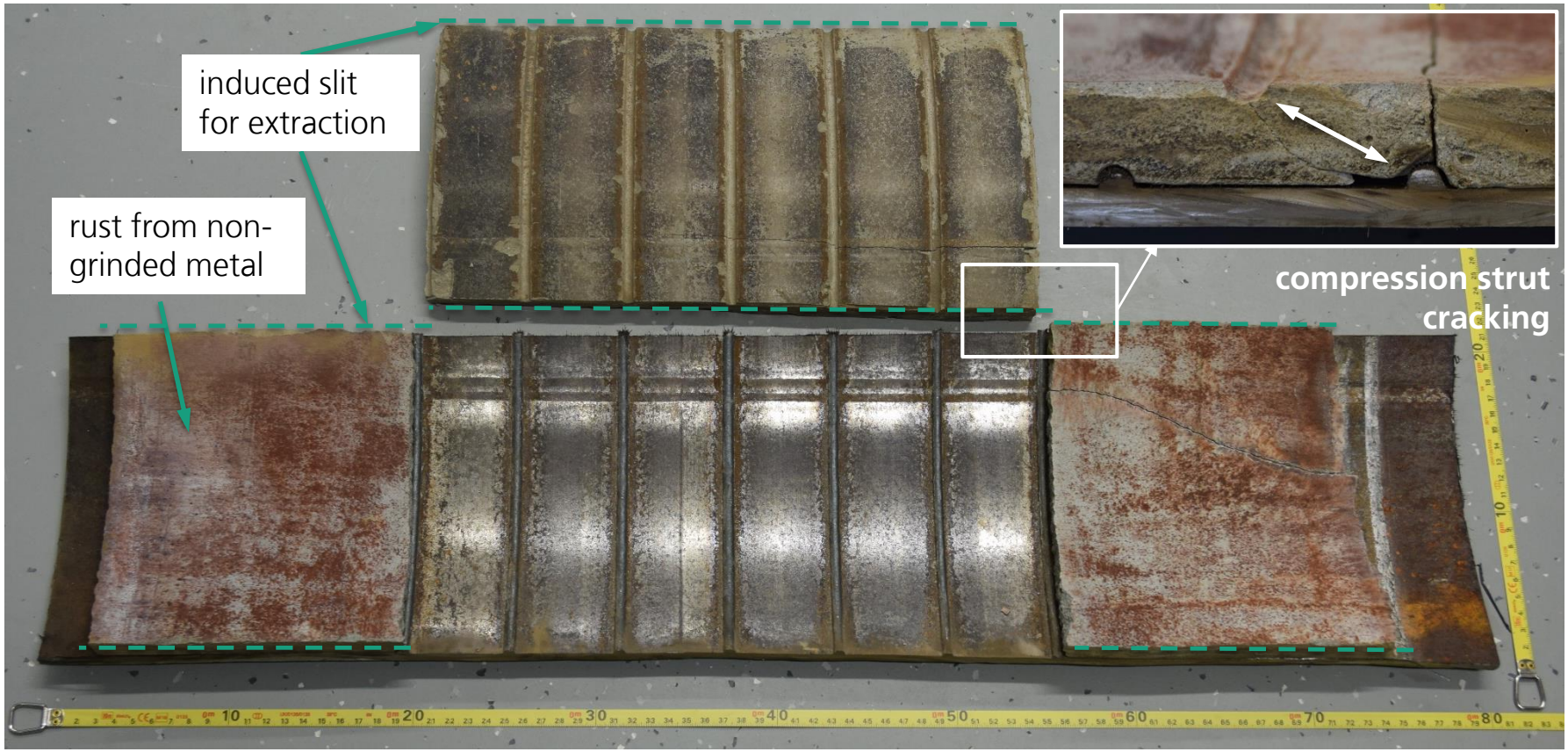
- Grout damage with distinct acoustic emissions during each cycle especially at the beginning of a higher loading step

90 kN load

- Beginning of grout disruption at the upper end

Visual inspection of TP1 (after loading of 90 kN)

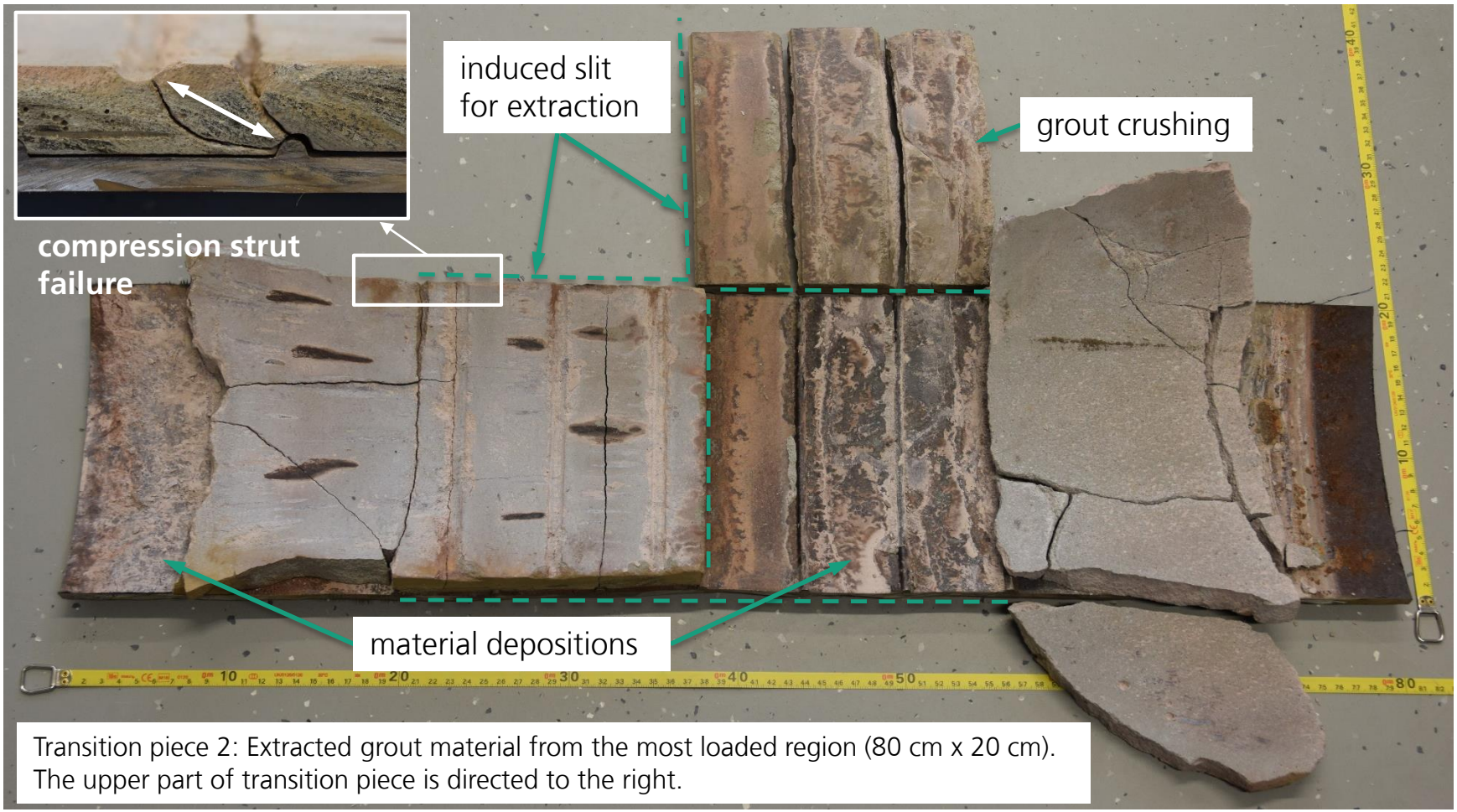
Extracted parts of grout material after grout opening



Transition piece 1: Extracted grout material from the most loaded region (80 cm x 20 cm). The upper part of transition piece is directed to the right.

Visual inspection of TP2 (after loading of 100 kN, Phase 2)

Extracted parts of grout material after grout opening

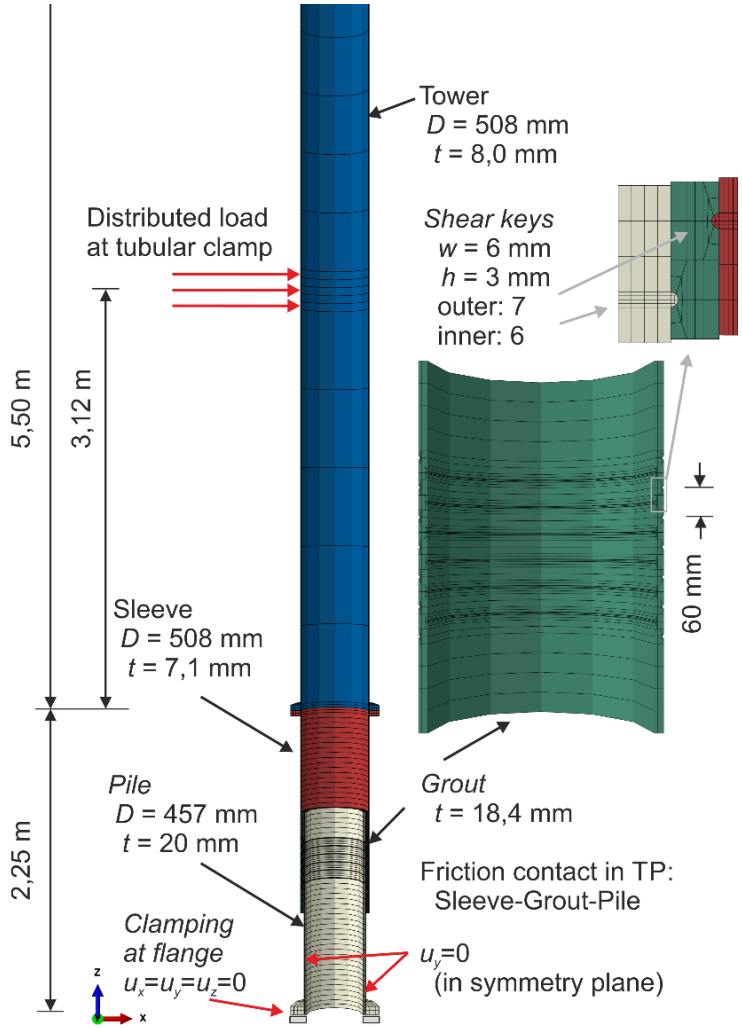


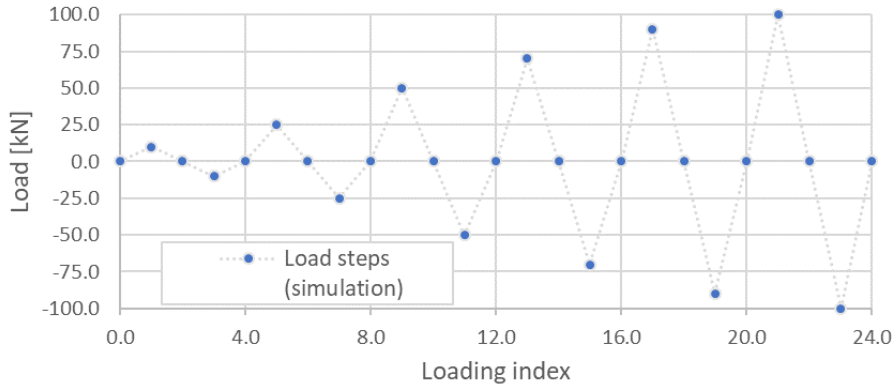
Transition piece 2: Extracted grout material from the most loaded region (80 cm x 20 cm).
The upper part of transition piece is directed to the right.

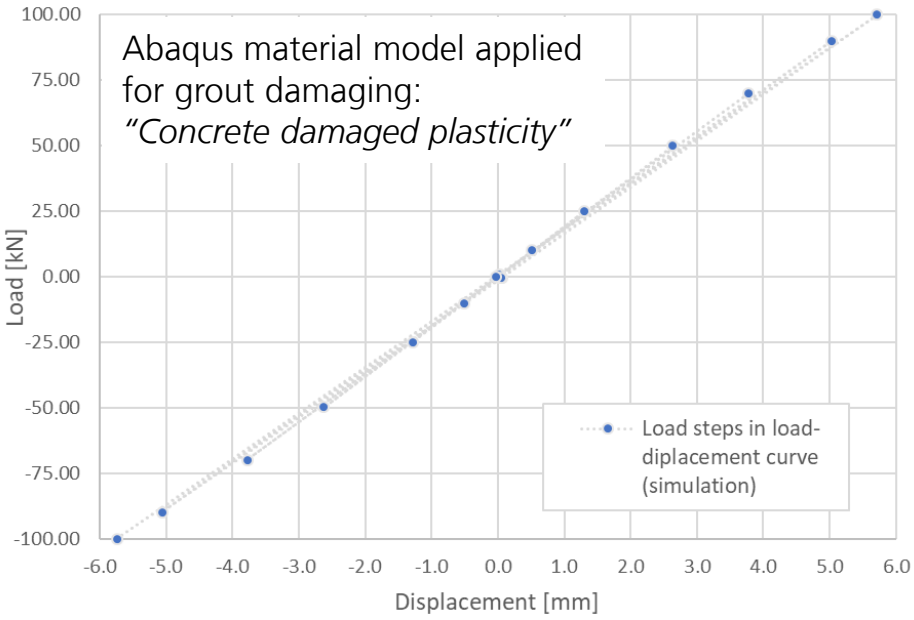
4. Simulation & Validation

Damaging process of the grout at the clamping field

Numerical model set-up, load series and results of grout damage modeling







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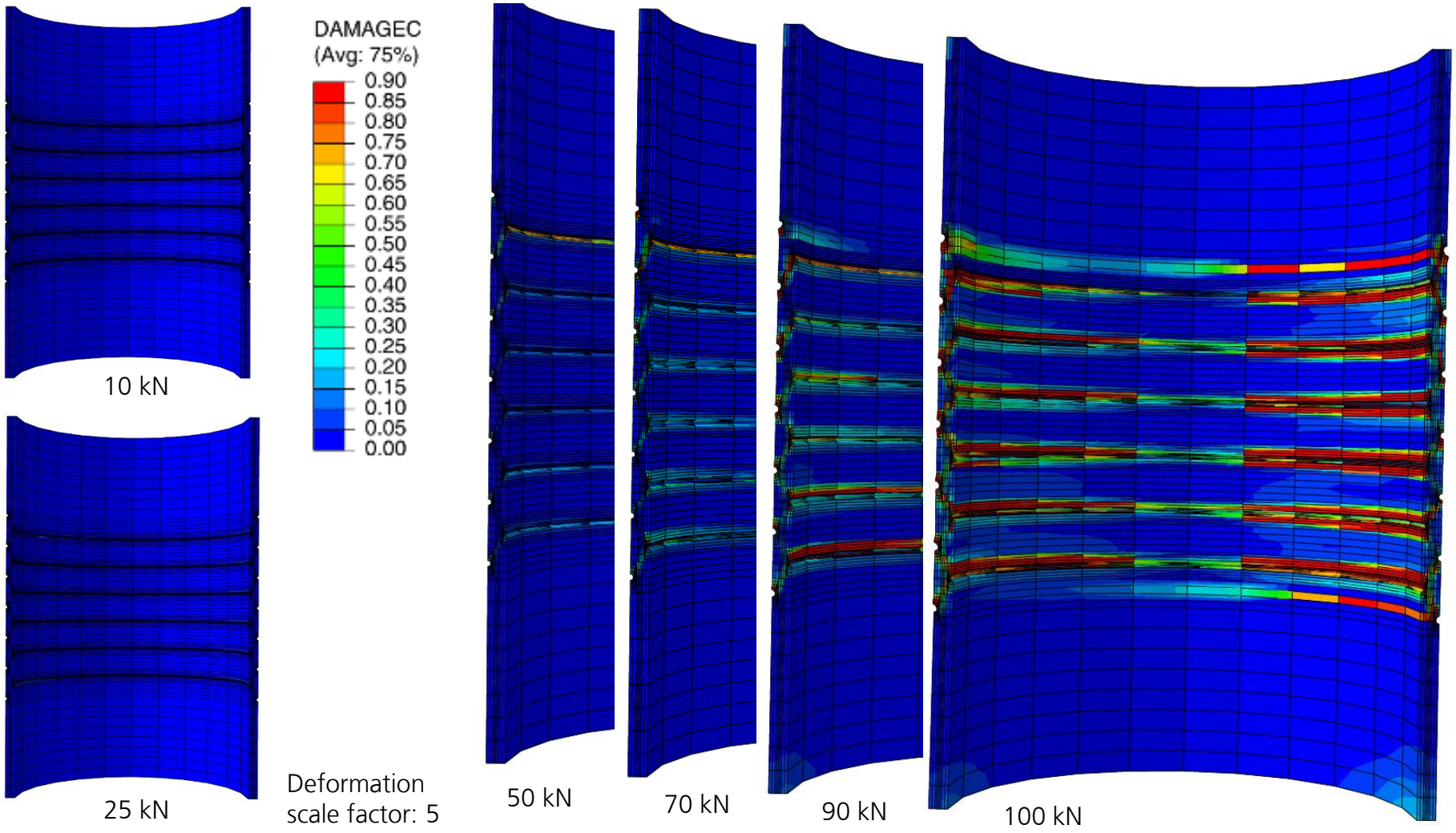
Damaging process of the grout at the clamping field

Compressive damage (crushing) using *concrete damaged plasticity model*



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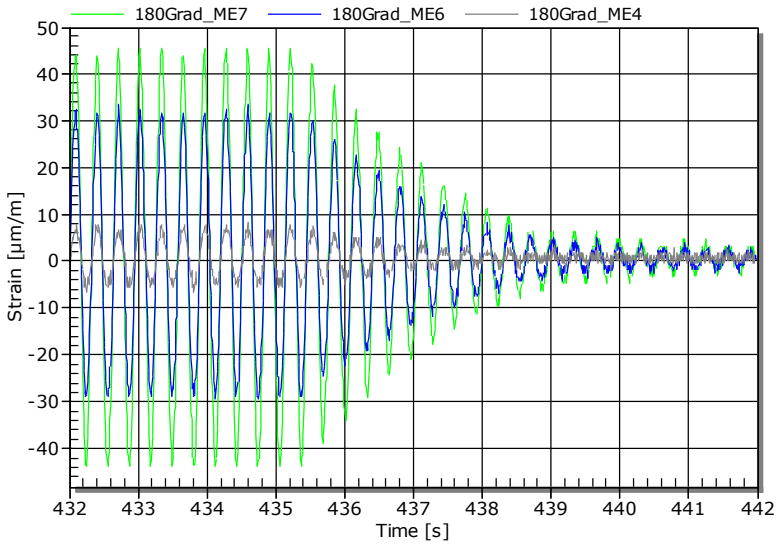
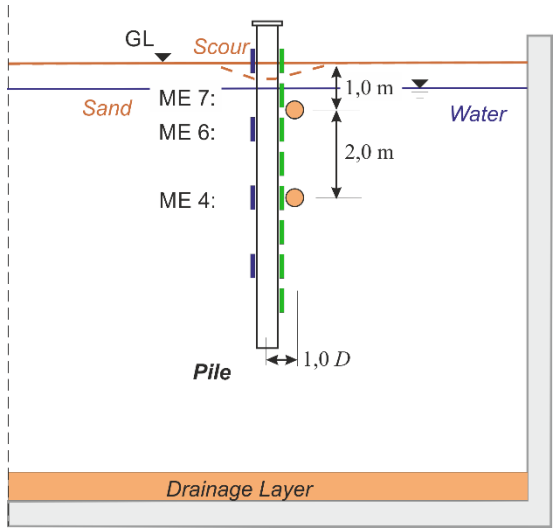
Strain gauge measurements and structural dynamics

Evaluation of fiber optical strain gauge measurements at the pile shaft at different depths

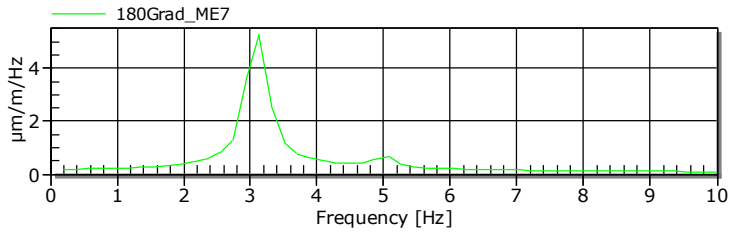
- Structural dynamic behavior
- Test with excitation of constant frequency



Time series of strains at measuring depth ME7, ME6 und ME4



Strain gauges (green and blue) at the pile shaft



Representation of strain values in frequency domain

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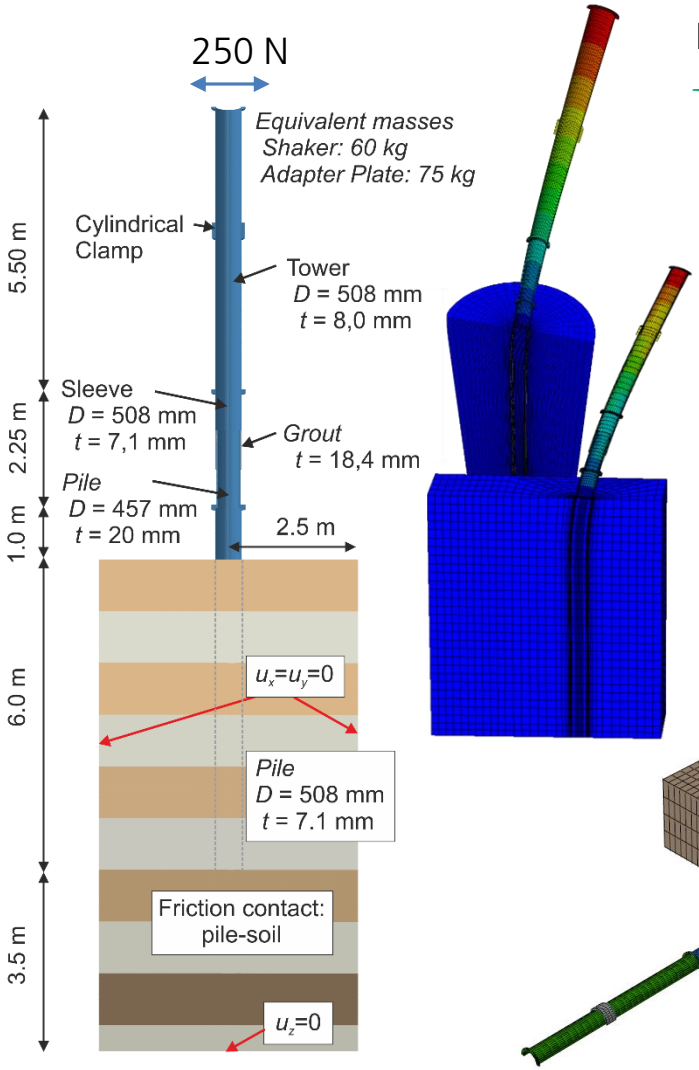
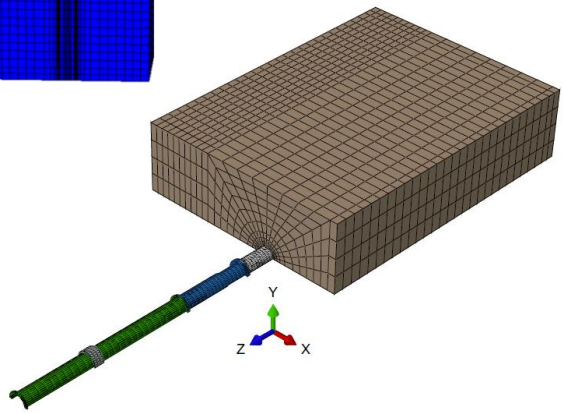
Simulation of structural dynamics in the test pit





Design approach

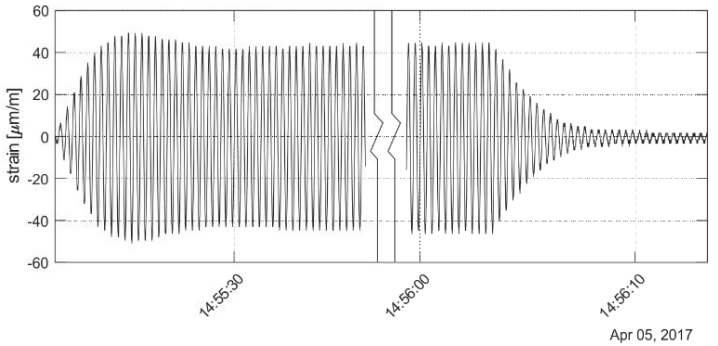
- For estimation of natural frequencies (3.11 Hz first bending mode)

Validation approach

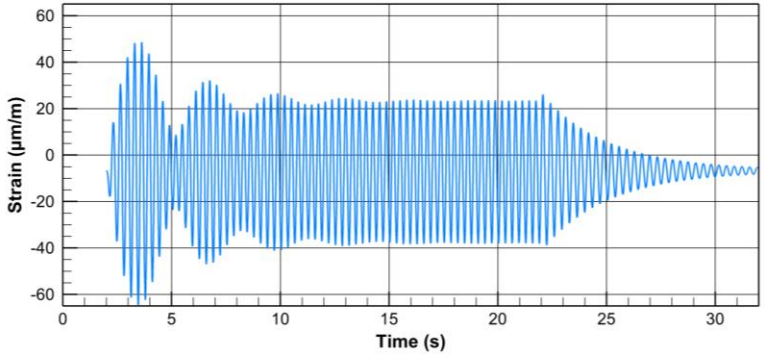
- Investigation of modal characteristics (3.09 Hz first bending mode)
- Investigation of the damping behavior

Dynamic excitation at tower top

- Validation of strain gauge values
- Experimental investigation of damping behavior



- Numerical investigation of structural dynamics and damping



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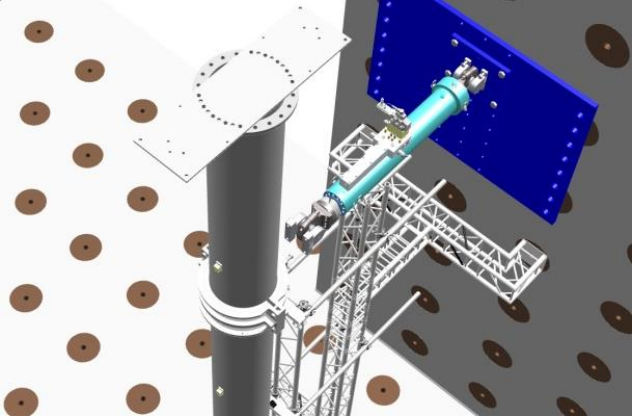
5. Summary & Outlook



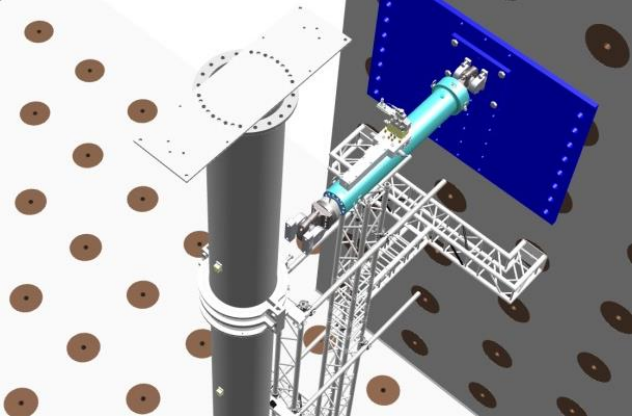
Summary

SHM at model scale

- Experimental model tests at large scale (1:10) seem to be meaningful for SHM assessment
- Specific changes in offshore environmental conditions can be reproduced in the model

Virtual Test Bench approach

- Analyses of measured changes in the structural behavior during loading phases correspond to estimations of the monitoring system
- Setting-up variations of numerical models is very convenient for design or sensitivity studies



Outlook

Reduction of O&M costs

- Structural health monitoring is an important basis for cost reduction
- Monitoring systems may reduce number of periodic inspections
- Optimization of sensor applicability and reliability

Improving the knowledge on offshore wind turbine behavior

- Investigation of the wind turbine's as-built characteristics
- Development of degradation models for long term prediction
- Validation of numerical models for offshore wind turbine modeling

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- Senator of Economy, Labor and Ports
- Senator of Science, Health and Consumer Protection
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Federal State of Lower Saxony

Free and Hanseatic City of Hamburg

Thank You for Your Attention

Any questions?

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