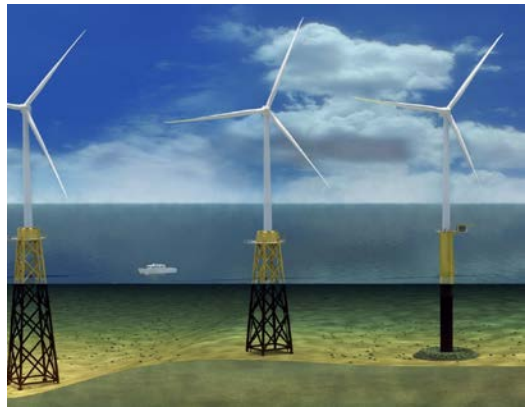
SITE-SPECIFIC LOADS
COST AND BENEFITS OF MONITORING

Ursula Smolka
SUPERGEN Wind Hub, Cranfield, 23 November 2016

RAMBØLL

RAMBOLL WIND ENERGY
STRONG FOOTPRINT IN OFFSHORE WIND ENGINEERING

- Close to 12,300 experts across 35 countries and close to 300 offices.
- Established 1945 and owned by the Ramboll foundation
- Onshore since 1986, Offshore since 1989.
- More than two third of the world's offshore wind turbines rise from foundations designed by Ramboll.
- Close to 200 employees work full time in wind.
- Large draw on multidisciplinary resources.



FOUNDATION DESIGN

65-75% market share

5 OFFICES

Copenhagen, DK
Esbjerg, DK
Aarhus, DK
London, UK
Hamburg, DE

AGENDA

1. Introduction
2. The Asset Management Perspective
3. Achieving the Target Safety Level
4. Impact of Low Cost Monitoring Solutions
5. Outlook


The Telegraph
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Business
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Business
New record for cheapest offshore wind farm


RENEWABLE ENERGY WORLD
How DONG Energy Bid Offshore Wind at Just 8 Cents
September 14, 2016

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THE ASSET MANAGEMENT PERSPECTIVE

Asset …

"…is an item, thing or entity that has potential or actual value to an organization" (ISO 55000:2014(E), p.13).

Asset Management …

"… is the coordinated activity of an organization to realize value from assets" (ISO 55000:2014(E), p.14).

Risk …

"…is the effect of uncertainty on objectives" (ISO 31000:2009(E), p. 1).

Risk-Informed Decision Making …

"…is a deliberative process that uses a set of performance measures, together with other considerations, to "inform" decision-making" (Dezfuli et al. 2010, p. 12).

STUDY ON MATURITY OF ASSET MANAGEMENT (06/2016)
GAP ANALYSIS

Proposed Best Practice Criteria	Smaller Operators	Larger Operators	Operator with Offshore O&G experience
Asset Management Definition			
Scope of Asset Management			
Asset Management Set-Up			
Asset Management Responsibility			
Alignment of Asset Management Objectives with Corporate Objectives			
Continuous Alignment with Asset Management Objectives			
Interconnectivity between Lifecycle Phases			
Incorporation of Risk			
Feedback Processes on all Levels			
Asset Management Maturity (IAM Scale)	0 - 2	1 - 4	2 - 4

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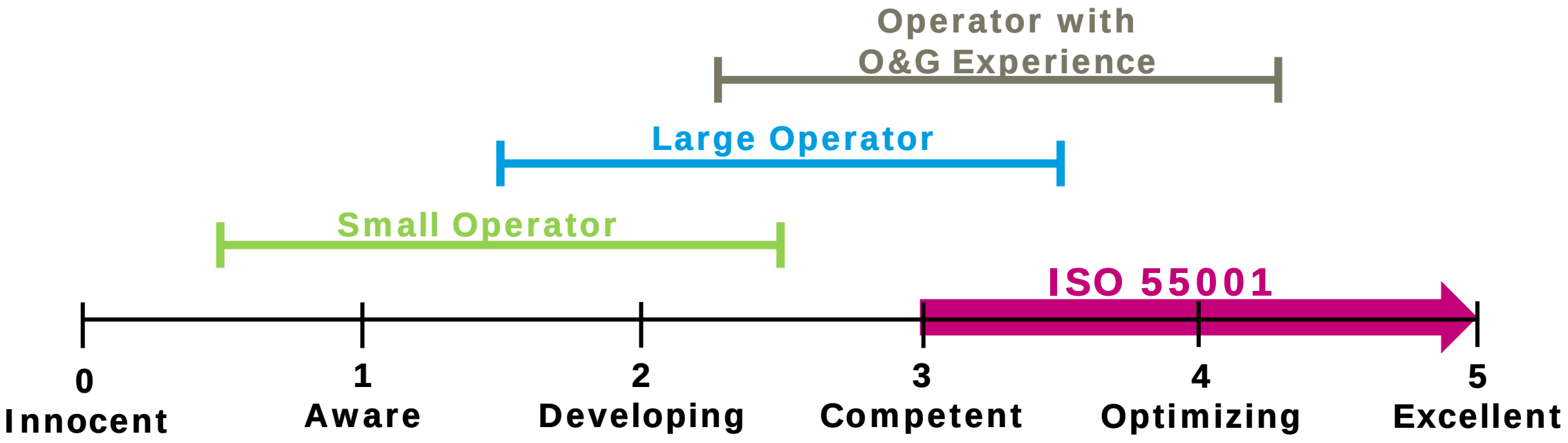
Not fulfilled | Slightly fulfilled | Partly fulfilled | Fulfilled

STUDY ON MATURITY OF ASSET MANAGEMENT (06/2016)



(Institute of Asset Management 2015, p. 8)

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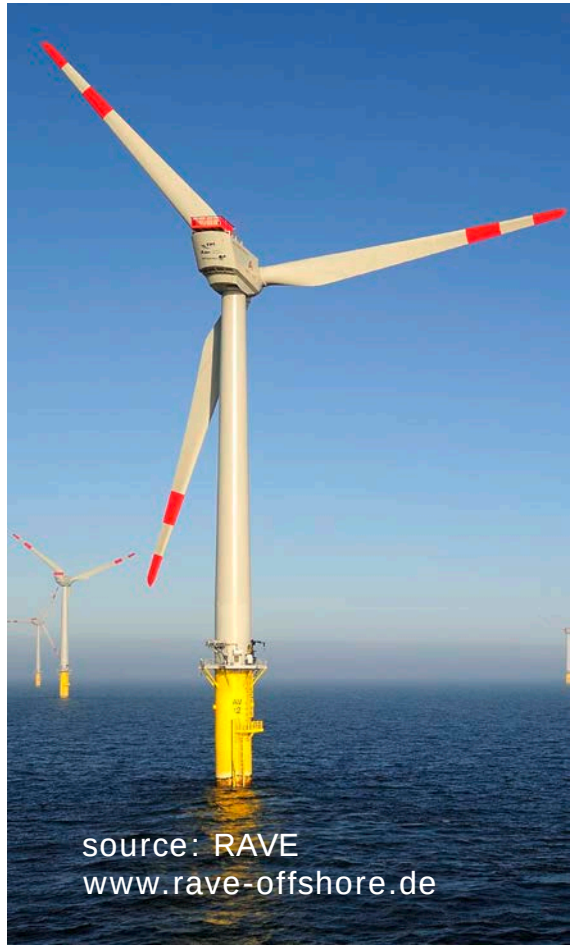
EXTENSIVE MONITORING FOR R&D

- **Example:**



Instrumentation at alpha-ventus AV7

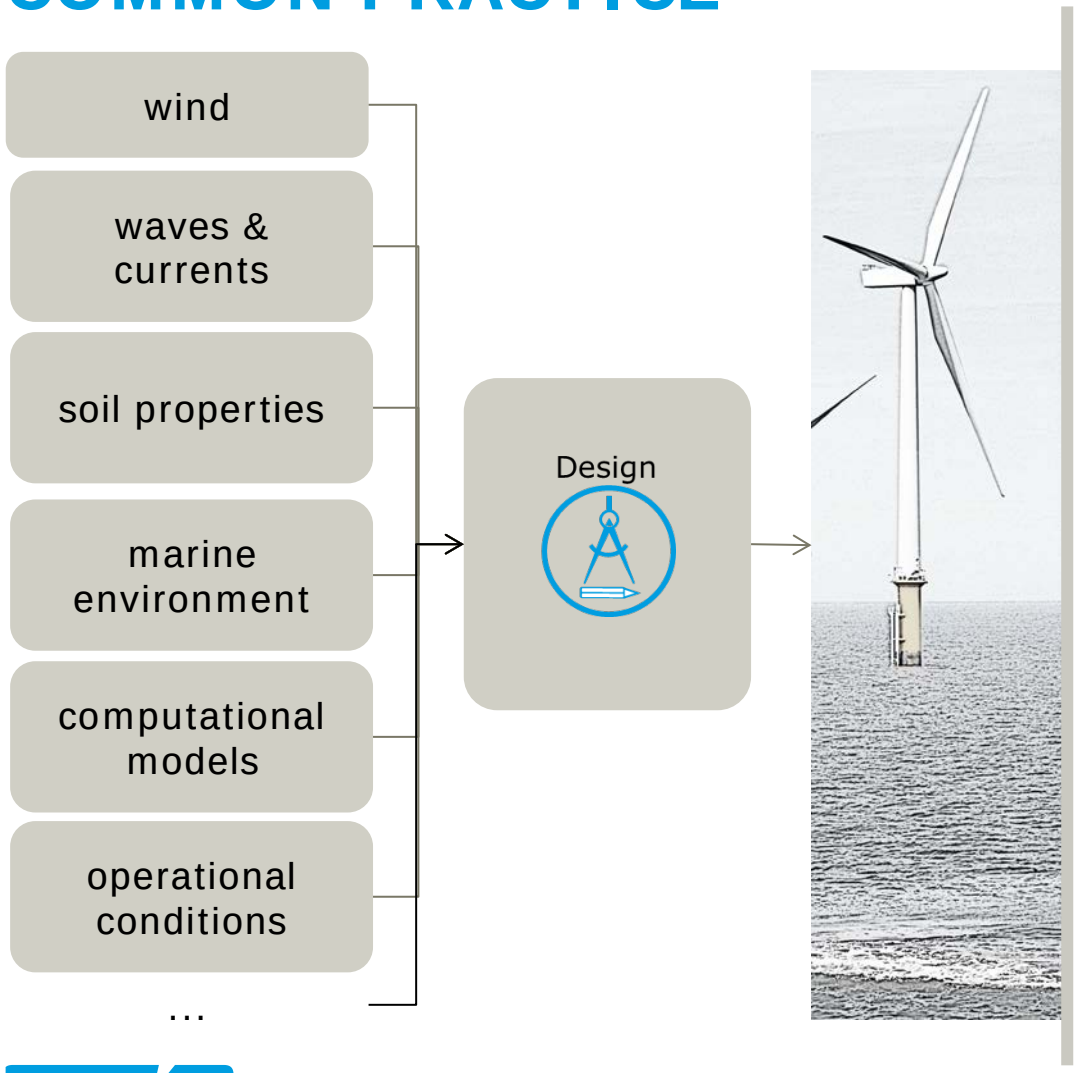
- strain gauges (>160) from blade tip to driven pile
- accelerometer (>40) in tripod, main column and nacelle
- inclination sensors in main column
- relative movement of driven pile
- ADCP (acoustic Doppler current profiler)
- water pressure sensors (30) in three depths
- echo sounders
- temperature and humidity

Data Summary
~500 data channels
50Hz measurement frequency (mostly)
(~6.3TB / Year)

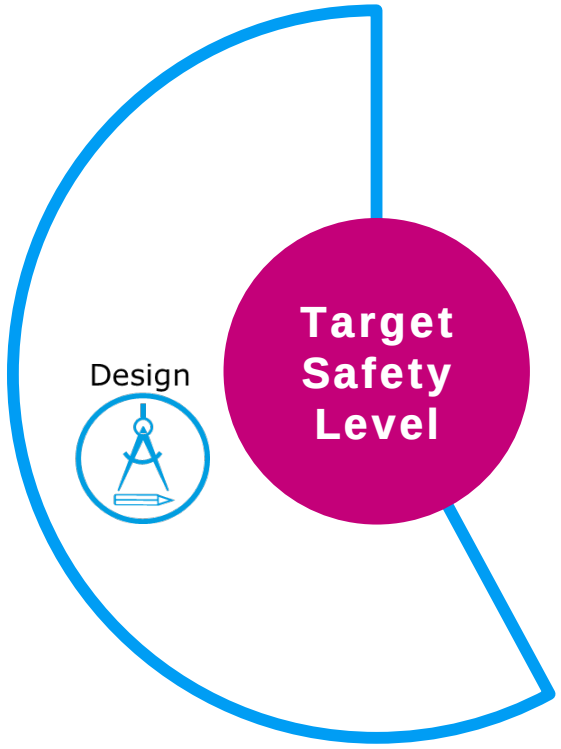
STATUS OF FOUNDATION MONITORING

- Monitoring concepts focus on authority requirements that give little guidance.
- Typically, few wind turbines selected for measurements of local physical quantity (acceleration at tower top, indicators for corrosive environment, inclination)
- Data recorded is typically not evaluated and not implemented for daily O&M
- Instead focus on conservative design and periodic inspection
- Reactive on detected failures

ACHIEVING THE TARGET SAFETY LEVEL
COMMON PRACTICE



ACHIEVING THE TARGET SAFETY LEVEL
COMMON PRACTICE



designed for fatigue life of 20-25 years

- with ultimate loads not to exceed ULS
- and fatigue loads not to exceed FLS

at any hotspot

Translated into operational phase

- maximum allowed scour
- maximum allowed corrosion
- no cracks
- no damage to protective measures.
- …

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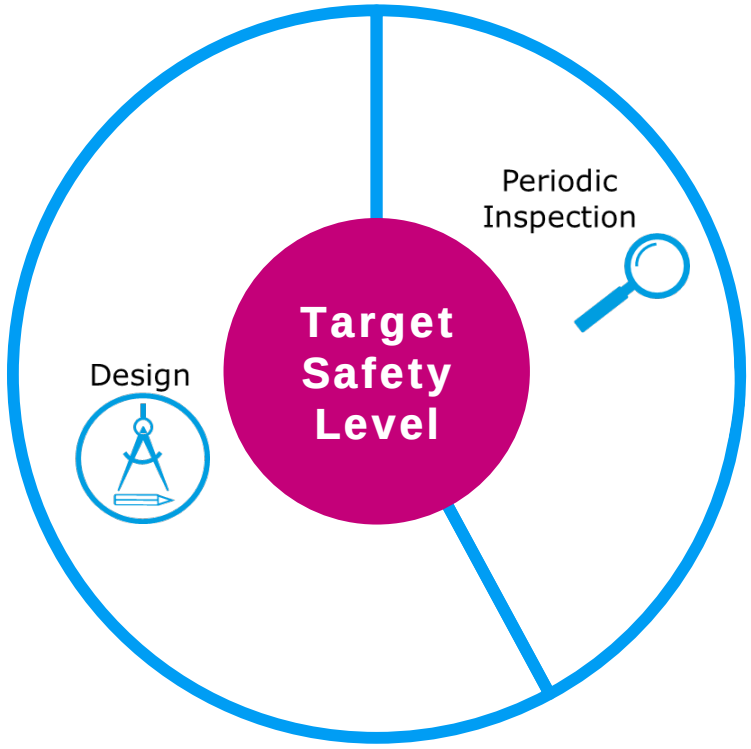
ACHIEVING THE TARGET SAFETY LEVEL
COMMON PRACTICE



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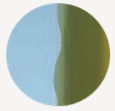
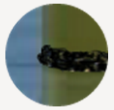
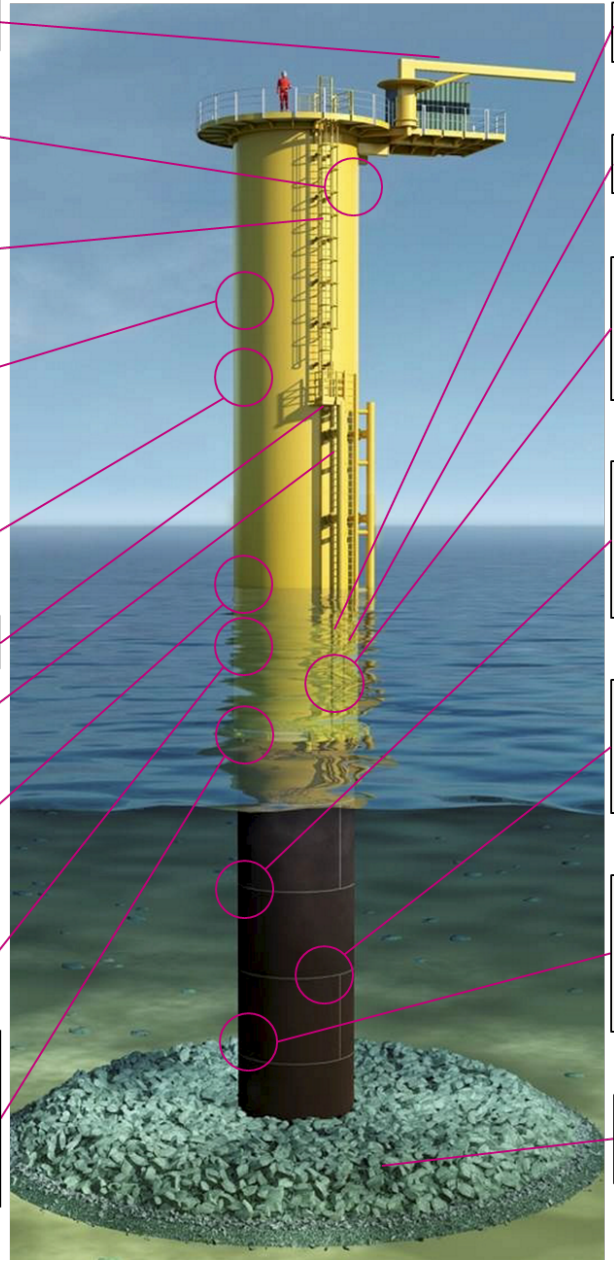
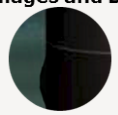
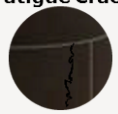
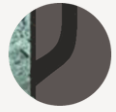
PERIODIC INSPECTIONS (DNVGL 04/2016)

Check for damages.	Inspection Interval: < 1 year	**Lifting appliances**
Check for damages.	Inspection Interval: < 1 year	**Upper part of J-Tubes** 
Check for damages.	Inspection Interval: < 1 year	**Upper part of Ladders**
Inspection Interval = Calculated fatigue life * DFF/3.0 Reliable inspection (eddy current or magnetic particle inspection) has to be carried out.	Inspection Interval: Depends on design fatigue factor (DFF)	**Fatigue Cracks** 
Inspection should clarify the structural condition above water.	Inspection Interval: < 1 year	**Dents and Deformations** 
Check for damages.	Inspection Interval: < 1 year	**Access Platforms**
Check for damages.	Inspection Interval: < 1 year	**Upper part of Fenders**
Is there marine growth that has to be removed to comply with the design assumptions?	Inspection Interval: < 1 year	**Marine Growth** 
Check for damages at bolted connections. Check bolt pre-tension.	Inspection Interval: < 1 year	**Bolt pre-tension** 
Inspect grout seal for cracks and loss of grout (top and bottom of connections). Usually sufficient to inspect limited number of structures (as long as inspected behaviour is similar).	Inspection Interval: < 1 year	**Grouted Connections/ Grout Seal** 



Lower part of Fenders	Inspection Interval: < 5 years	(more frequent inspection during first five years)
Lower part of Ladders	Inspection Interval: < 5 years	(more frequent inspection during first five years)
Corrosion Protection 	Inspection Interval: < 1 year (above water) < 5 years (below water)	Anodes and coating have to be checked. Visual inspection below water may be carried out by ROV
Dents, Deformations, Damages and Debris 	Inspection Interval: < 5 years	Inspection should clarify the structural condition below water. Visual inspection may be carried out by ROV
Fatigue Cracks 	Inspection Interval: Depends on material factor (γ_m)	Inspection Interval = Calculated fatigue life * $\gamma_m^5/1.25^5$ Reliable inspection has to be carried out.
Lower part of J-Tubes 	Inspection Interval: < 5 years	Check for damages. (more frequent inspection during first five years)
Scour and Scour Protection	Inspection Interval: < 5 years	Check scour protection and possible scour development. (more frequent inspection during first five years)

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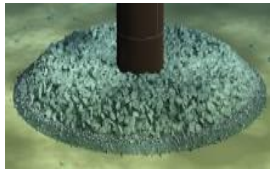
ACHIEVING THE TARGET SAFETY LEVEL
COMMON PRACTICE

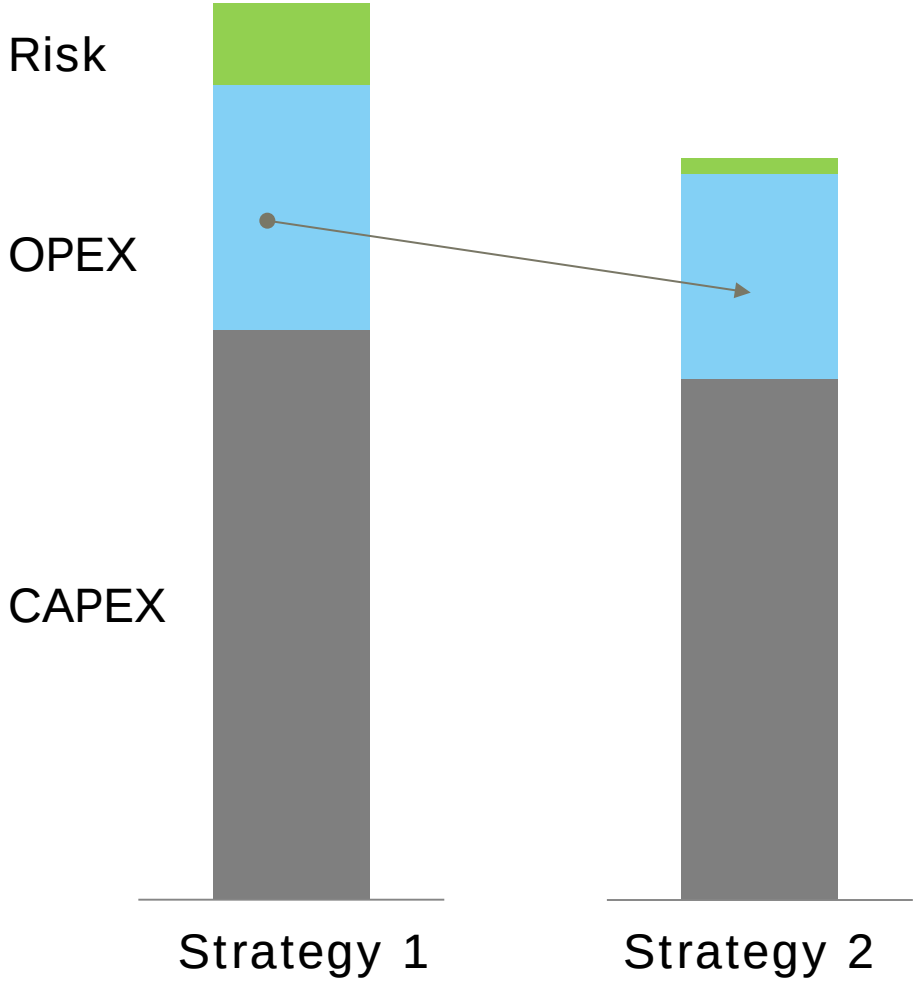
“lost” information:

- design assumptions
- design calculations
- definition of safety levels

Low-cost monitoring integrates this knowledge into daily operation!



ACHIEVING THE TARGET SAFETY LEVEL
LOW-COST MONITORING AS GAME CHANGER?



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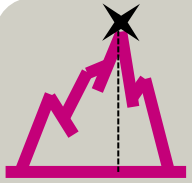
DESIGN KNOWLEDGE TO EXPLOIT

- load model
- structural model
- dynamic model

exploit this knowledge with low-cost monitoring relying on real life tuned models



overloading at hot spots

remaining fatigue life at hot spots

damage detection and localization

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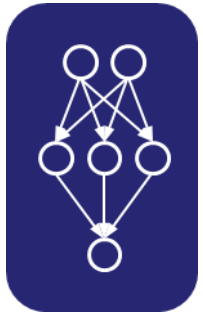
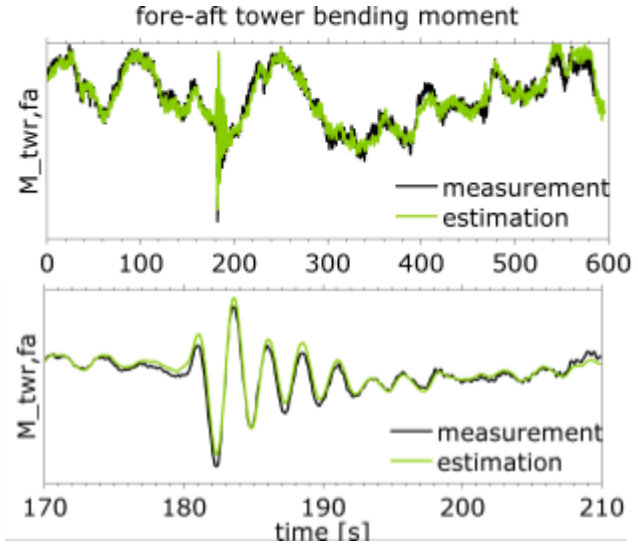
RAMBOLL'S MONITORING EXPERTISE STEMS FROM LATEST DEVELOPMENT PROJECTS

1: Machine Learning example fom RAVE



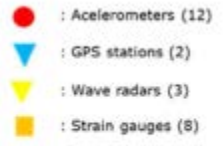
www.rave-offshore.de

2: stochastic Kalman Filter Horns Rev I V80 Turbine



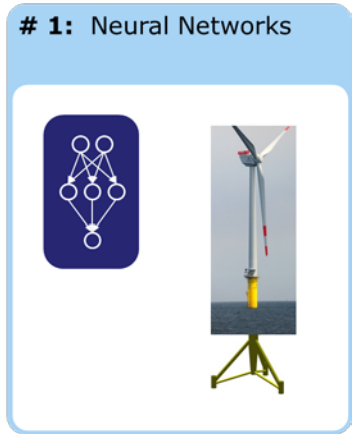
courtesy of VATTENFALL

3: deterministic FEM based Valdemar Offshore Platform



courtesy of MAERSK OIL

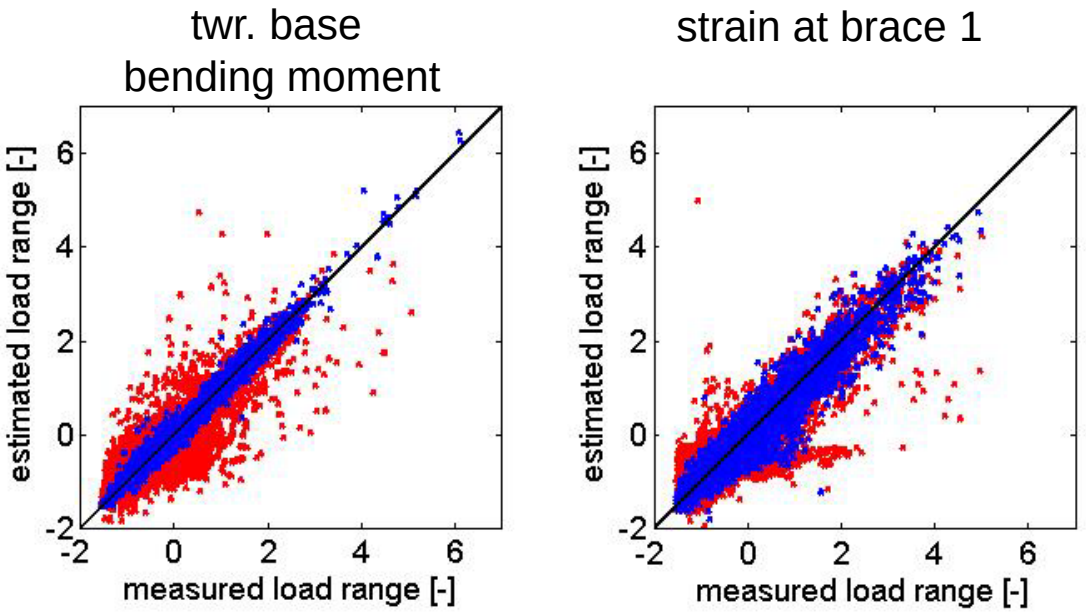
RAMBOLL'S MONITORING EXPERTISE
#1 MACHINE LEARNING



Required:

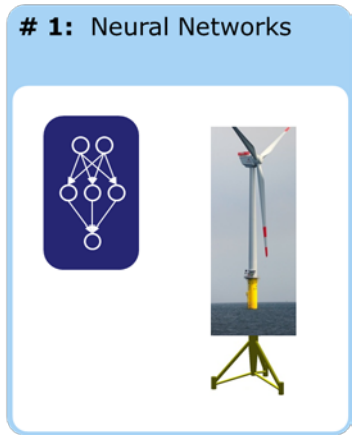
- 10 min SCADA data statistics
- monitoring campaign with strain gauges of at least a year
- strain gauge data required from all hot spots of interest
- update of models in case of any change in operational regime

-



Smolka, U., Kaufer, D. and Cheng, P.W. (2012). "Are sea state measurements required for fatigue load monitoring offshore wind turbines?" in Proceedings of The Science of Making Torque from Wind, Oldenburg, Germany.

RAMBOLL'S MONITORING EXPERTISE
#1 MACHINE LEARNING



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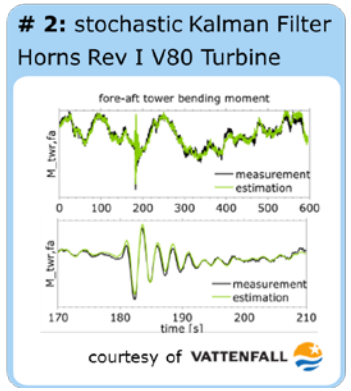
no direct extrapolation possible, strongly depends on training data

only for selected hot spots

localization and detection of damage not possible

RAMBOLL'S MONITORING EXPERTISE # 2: STOCHASTIC KALMAN FILTER



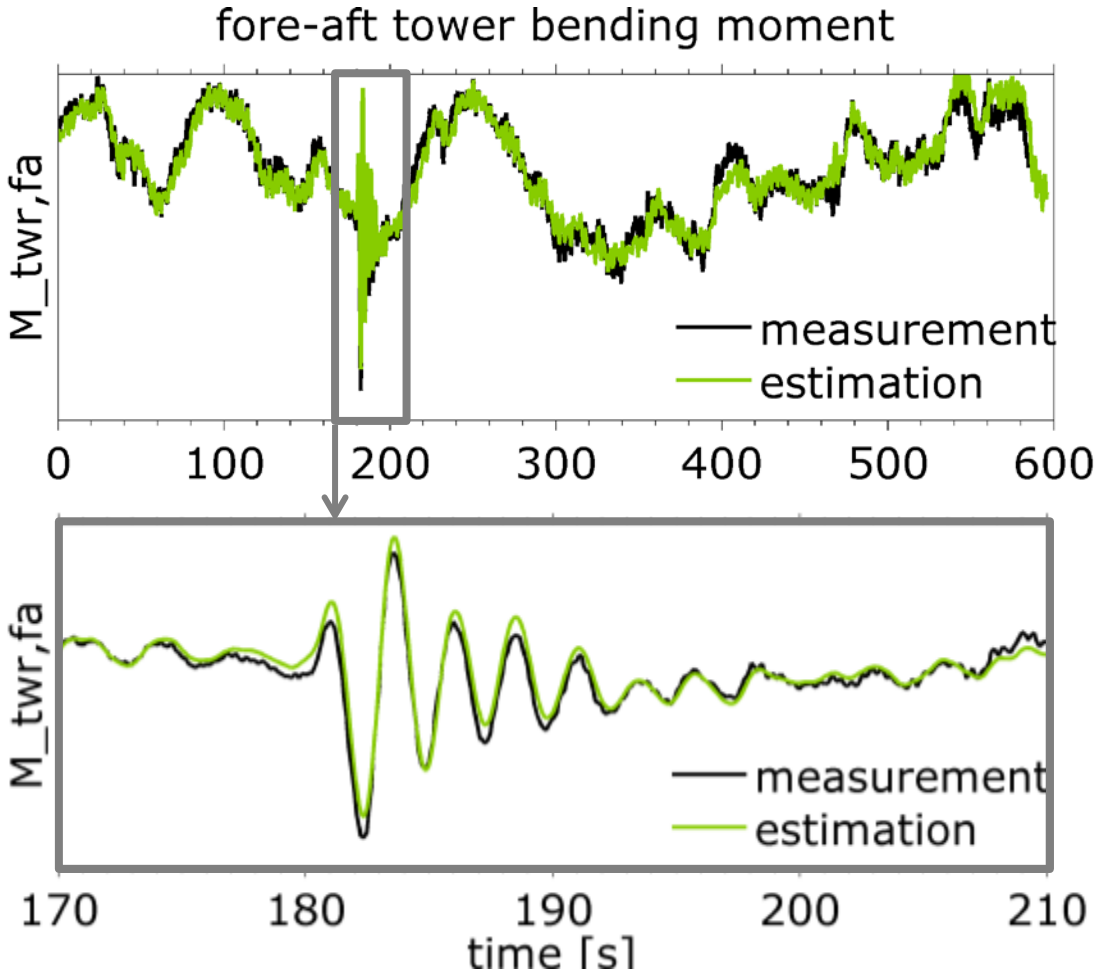
Required:

- 1-20Hz SCADA data
- 3-4 DOF mathematical model
- monitoring campaign with strain gauges of a few weeks
- strain gauge data required from all hot spots of interest
- update of models in case of any change in operational regime

VALIDATION STUDY AT HORNS REV I FOR RAMBOLL'S LOAD OBSERVER TOOL

- Validation of load monitoring with sensor installations and measurements at five V80-2.0MW at Horns Rev I
- Comparison against resistive strain gauge measurements.
- An average accuracy of 97-98% in estimating high resolution time series achieved.

Full replacement of strain measurements validated!



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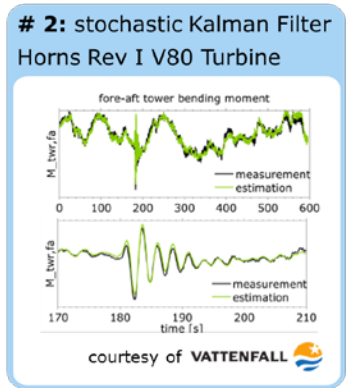
WHAT
SUPERGEN

RAMBOLL'S MONITORING EXPERTISE
2: STOCHASTIC KALMAN FILTER



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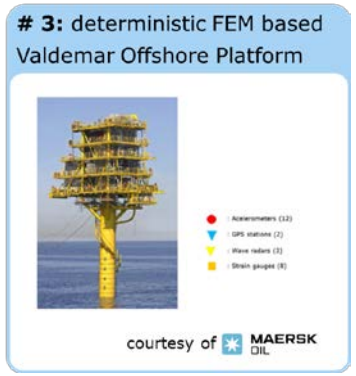
only for selected hot spots,
no access to below mudline hot spots

only for selected hot spots,
no access to below mudline hot spots

localization not possible
damage detection based on change of residual estimation error

RAMBOLL'S MONITORING EXPERTISE STEMS FROM LATEST DEVELOPMENT PROJECTS

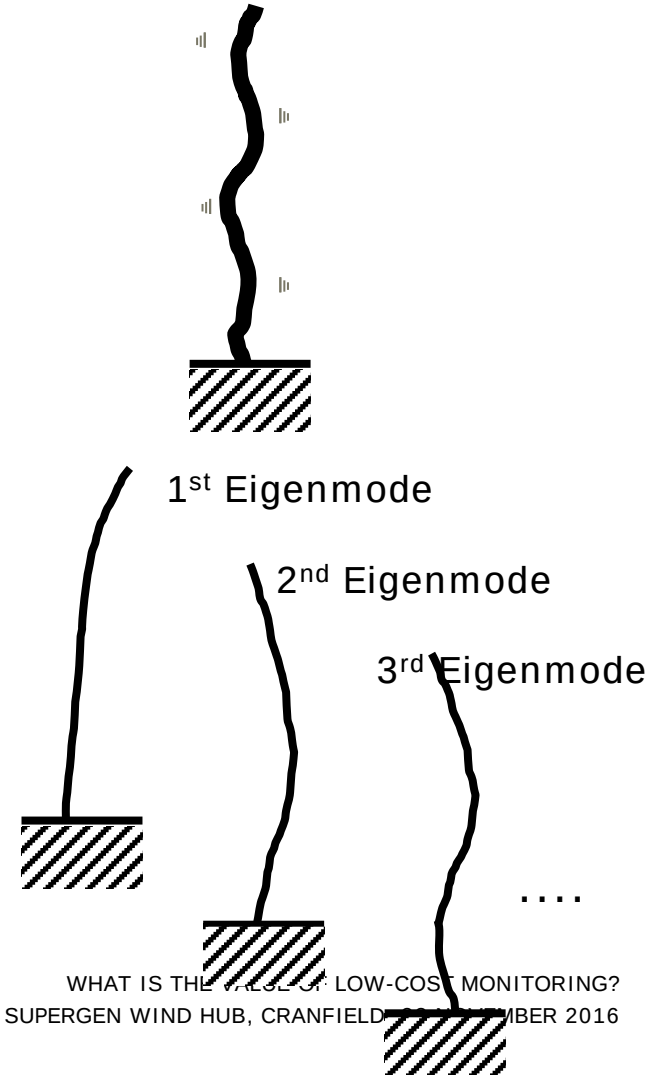


Required:

- 10 min SCADA data
- distributed accelerometer at specific locations
- FE (design) model
- reference strain gauge data of a few days
- high resolution wave radar for hydrodynamic loads

optimal sensor placement

modal decompo-sition

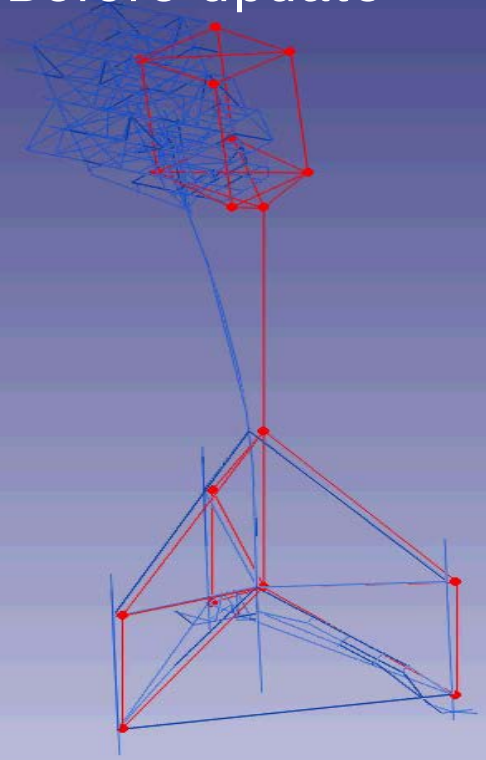


LIFETIME EXTENSION OF AN OIL & GAS PLATFORM, DENMARK

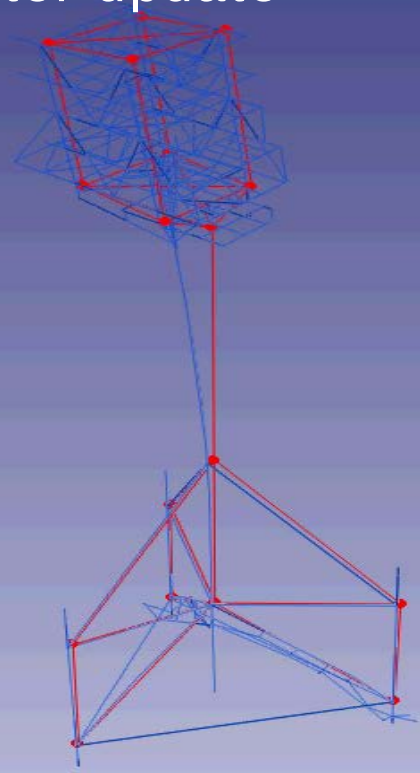
Valdemar Offshore Platform (2011-2014)

courtesy of MAERSK OIL

Before update

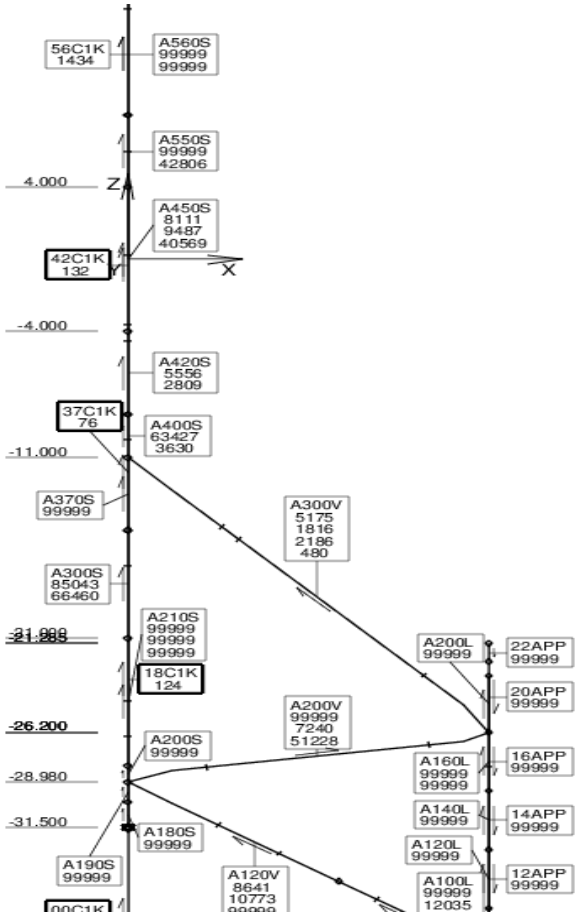


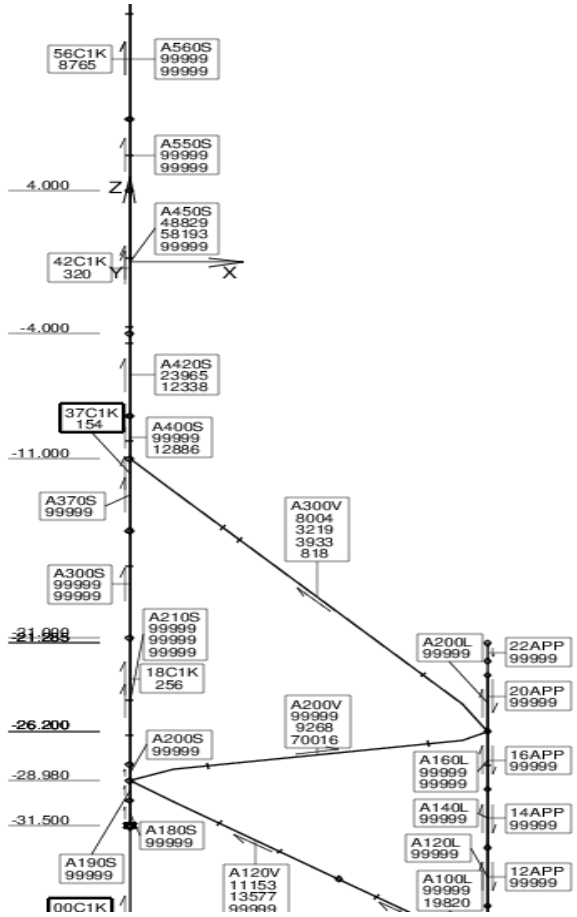
After update



Nevena Perisic and Ulf T. Tygesen, “Cost-effective Load Monitoring Methods for Fatigue Life Estimation of Offshore Platform”, ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, USA

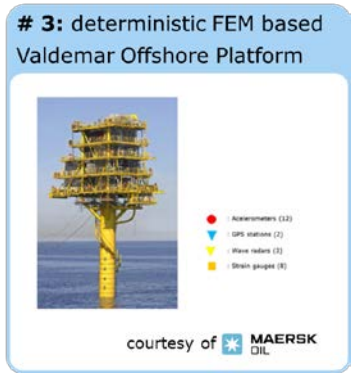
LIFETIME EXTENSION OF AN OIL & GAS PLATFORM, DENMARK





Increase a factor of 2.0 on fatigue life

RAMBOLL'S MONITORING EXPERTISE STEMS FROM LATEST DEVELOPMENT PROJECTS



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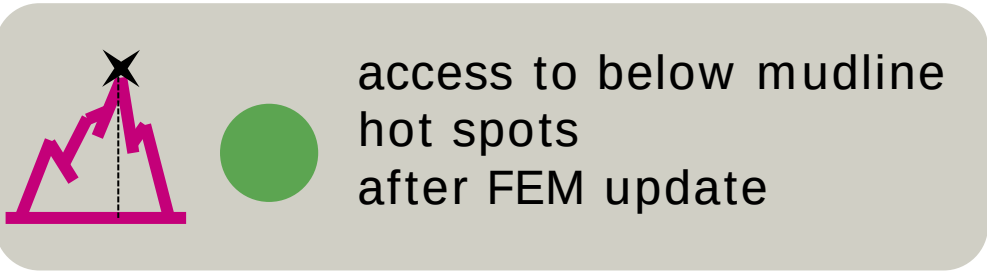
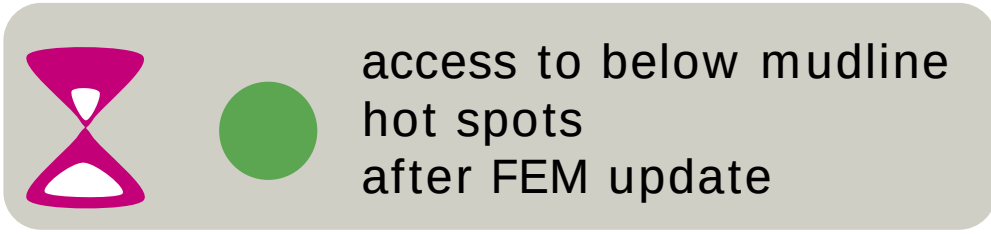
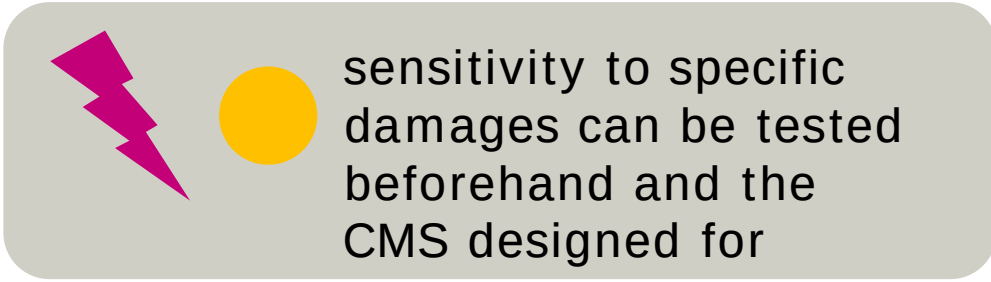


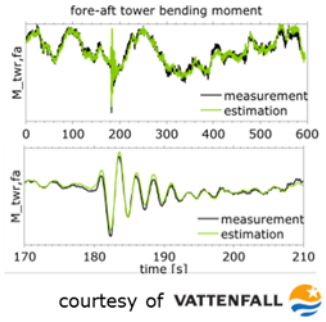




OVERVIEW – FINAL ASSESSMENT

 # 1: Neural Networks

 # 2: stochastic Kalman Filter
Horns Rev I V80 Turbine



courtesy of VATTENFALL

 # 3: deterministic FEM based
Valdemar Offshore Platform

courtesy of MAERSK OIL

Robustness, applicability to entire wind farm

Certainty on structural health

Expenses for installation

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MONITORING
FOR REDUCTION COST OF ENERGY

LIFE–CYCLE VIEW
from early stage on

1

STRUCTURAL RESERVES
know and exploit them

2

HUMAN OFFSHORE TIME
reduce by risk based inspection

3

FORCED OUTAGES
shift from forced to scheduled

4

RAMBOLL

THANKS

Ursula Smolka

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———————————————

Ramboll Wind
Hamburg, Germany
www.ramboll.com/wind