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Cyber-physical system applications for FPSOs
Today, Tomorrow and the day after Tomorrow

Development of Hi-tech Systems for Integrity Assessment of FPSOs

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November 9, 2021, Delft

Structural integrity assessment

Conventional non-destructive evaluation

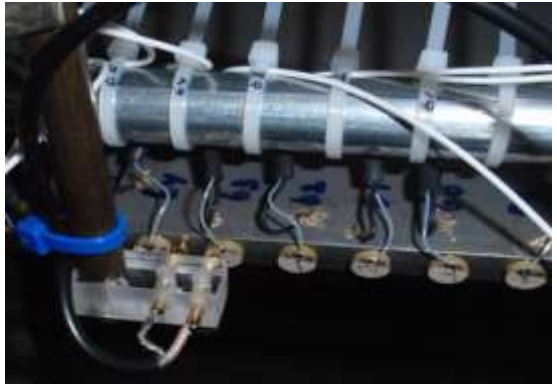
Measurement unit is independent from the structure

Development trajectories

Automated/robotic inspection

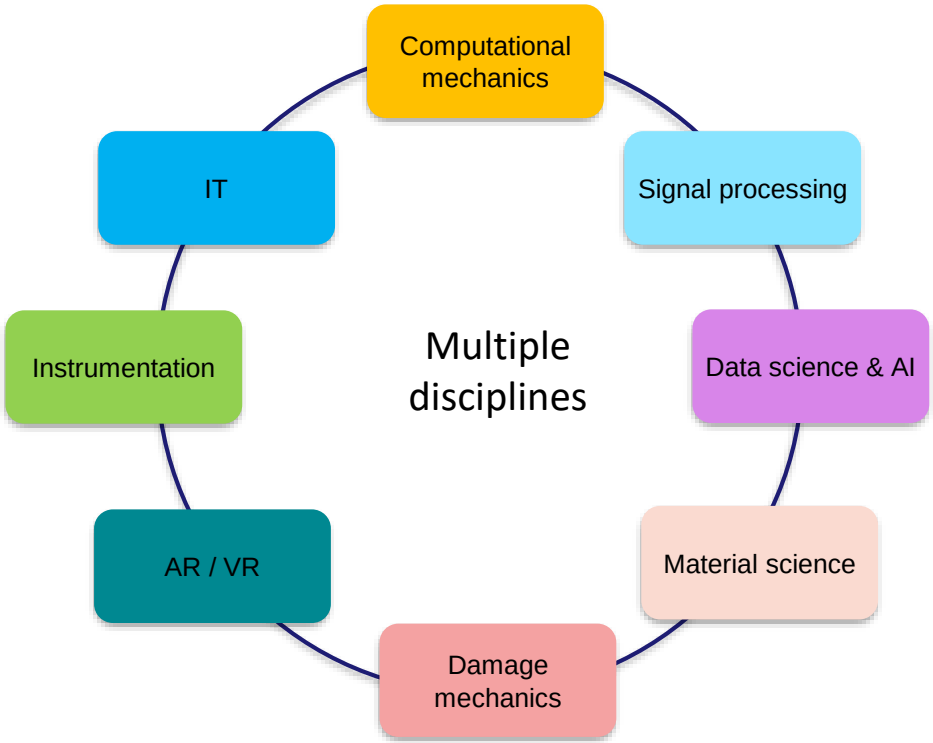
Measurement unit is independent from the structure

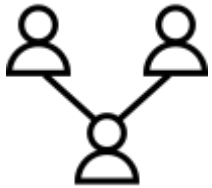
Structural health monitoring



Measurement unit is an integrated part of the system

Cyber-physical systems for structural integrity monitoring





Outline

- **HiTeAM JIP** developments for turret bearings
- **Donut JIP** developments for mooring systems
- Intelligent **cyber-physical structures** of tomorrow

Low-speed heavily-load bearings

Objective: development of a monitoring methodology for quantitative condition monitoring of heavy-loaded low-speed roller bearings

Courtesy of SBM Offshore

Courtesy of Shaeffler

Courtesy of Heerema Marine Contractors

Researchers
Bart Scheeren
Filippo Riccioli
Nitesh Thakoerdajal

Passive ultrasound monitoring

(Acoustic Emission)

Recorded signal

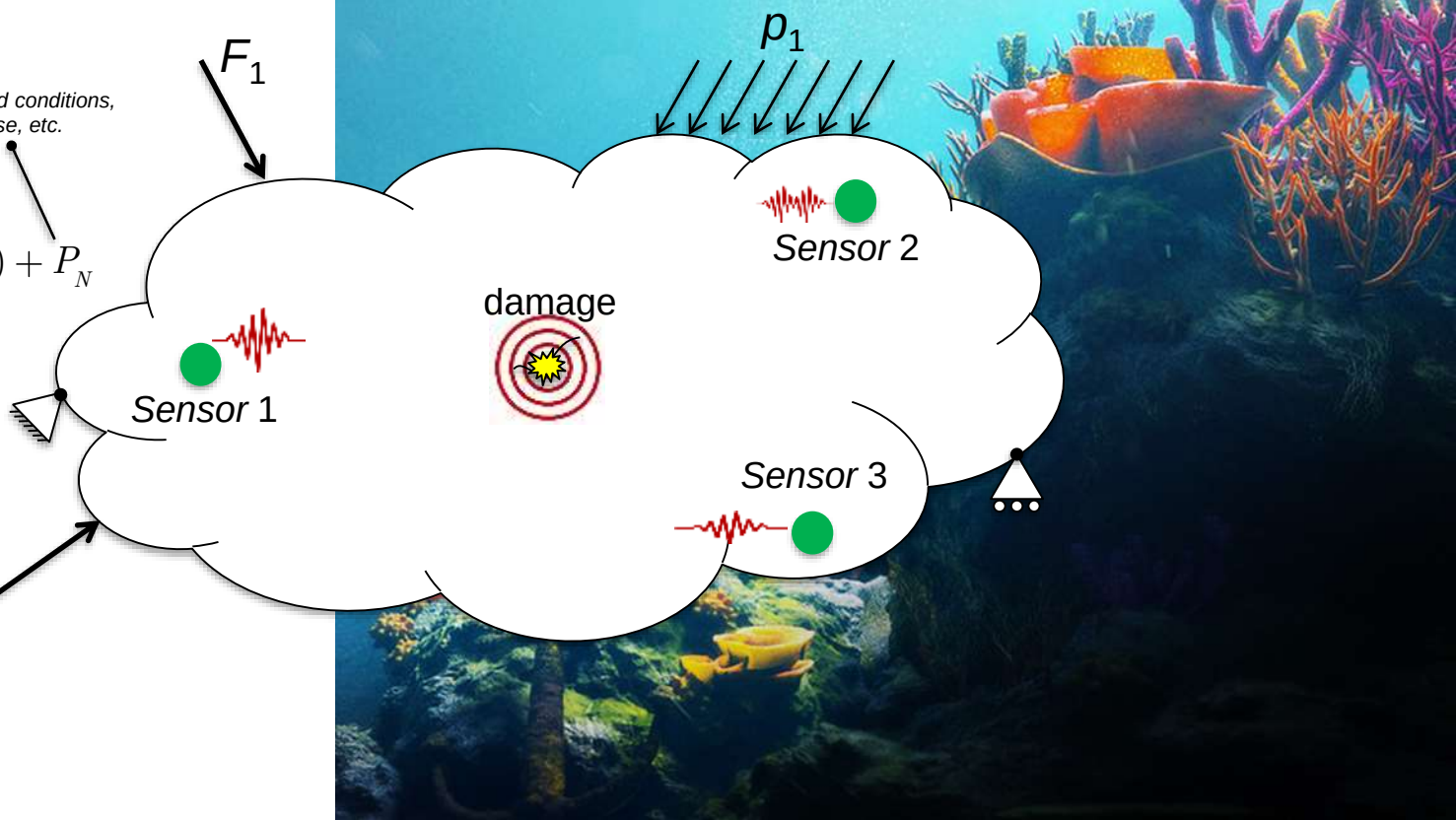
Governed by background conditions, e.g. vibrations, noise, etc.

$$P_1(\mathbf{x}_1, \mathbf{x}_O, \omega) = D_1(\omega) W(\mathbf{x}_1, \mathbf{x}_O, F, \omega) S_O(\omega) + P_N$$

Governed by elastodynamic equations

Governed by damage mechanism

Governed by piezoelectricity equations, coupling conditions, and DAQ system



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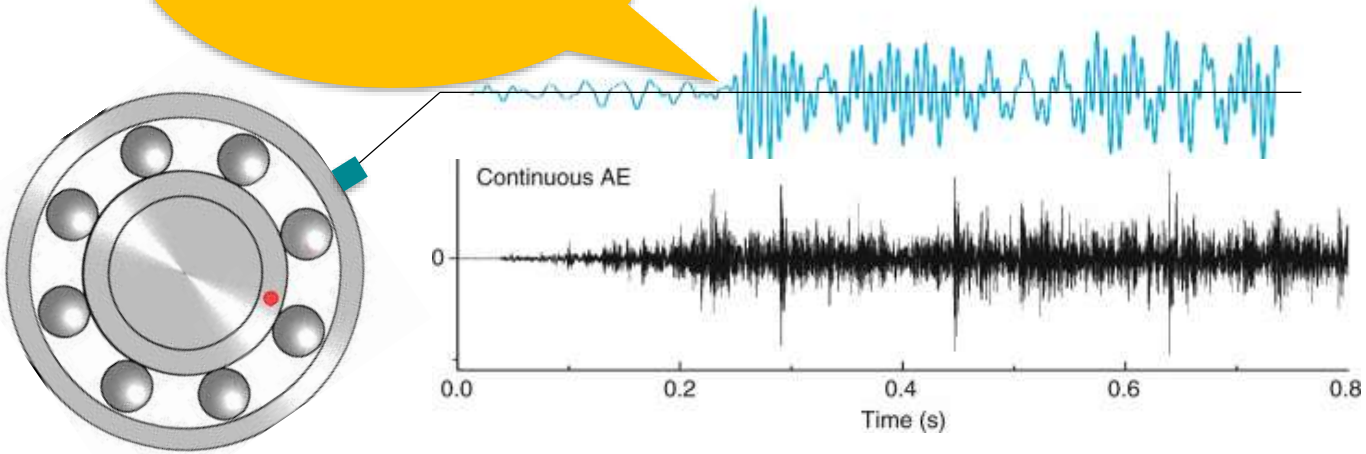
Acoustic Emission

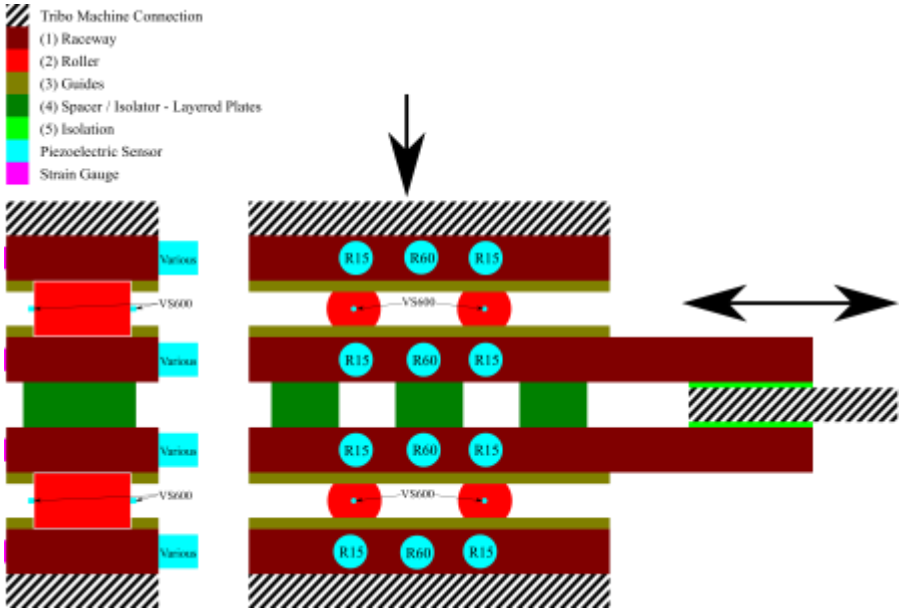
How these damage signals look like?
Can they be measured?



"The class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material" - ASTM E1316

How do the damage signals look like?

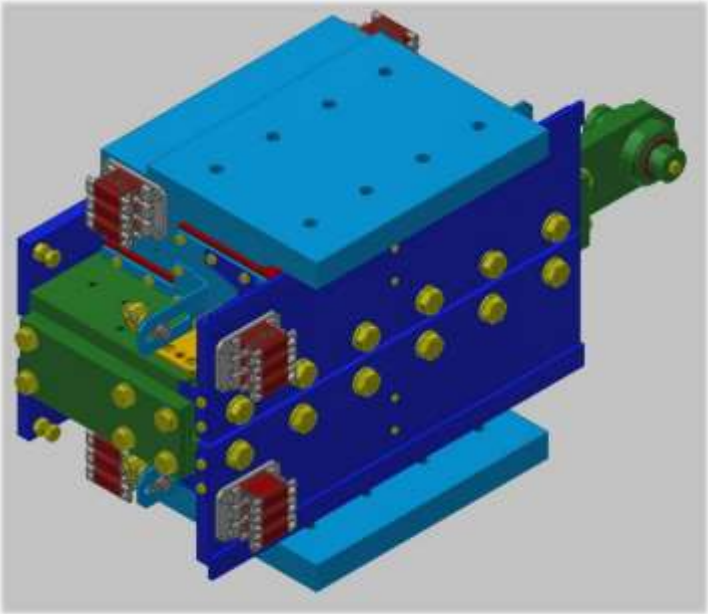
- Obtaining ultrasonic signatures of relevant defect types
  - Crack in raceways
  - Crack in rollers
  - Corrosion
  - Lubrication contamination
  - Lubrication starvation
  - Brinelling
  - Electric pass



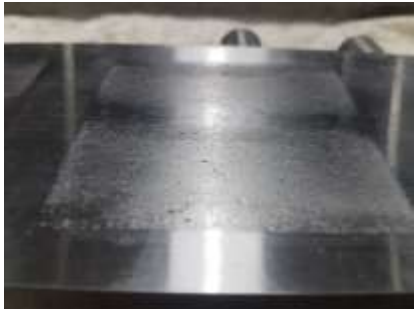
Test setup design

Purpose-built representative-scale turret bearing segment

bluewater sofec TU Delft Huisman

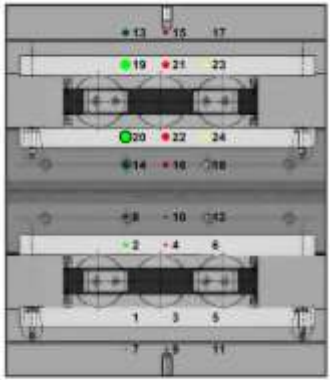


Different damage types

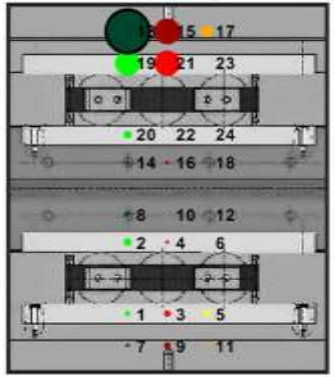


Example of results – towards a digital twin

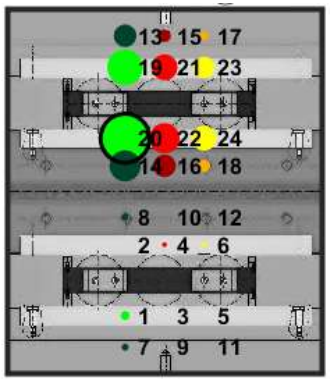
Baseline

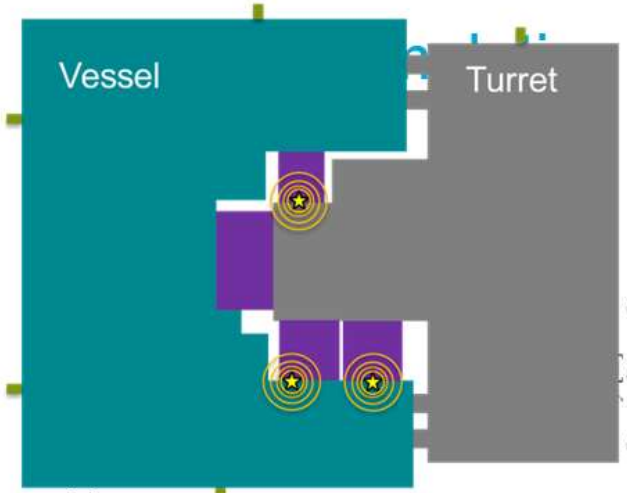


Roller damage

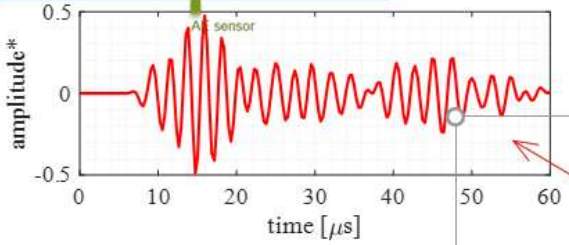


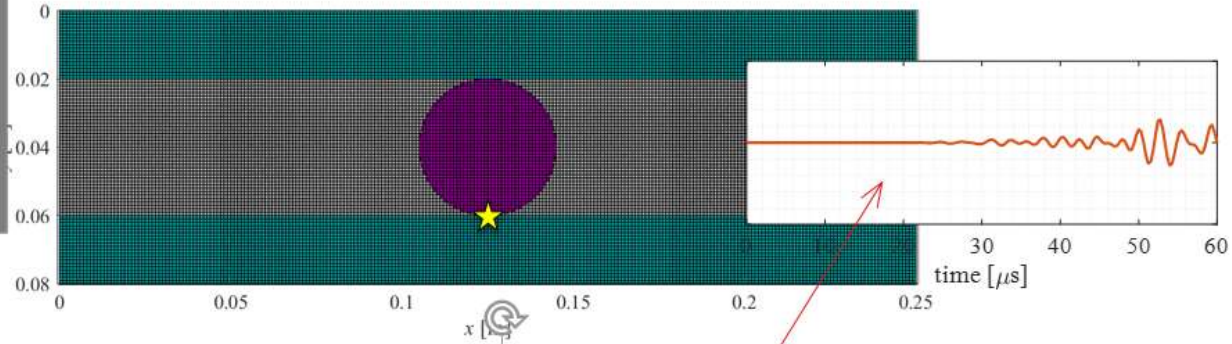
Lubrication starvation

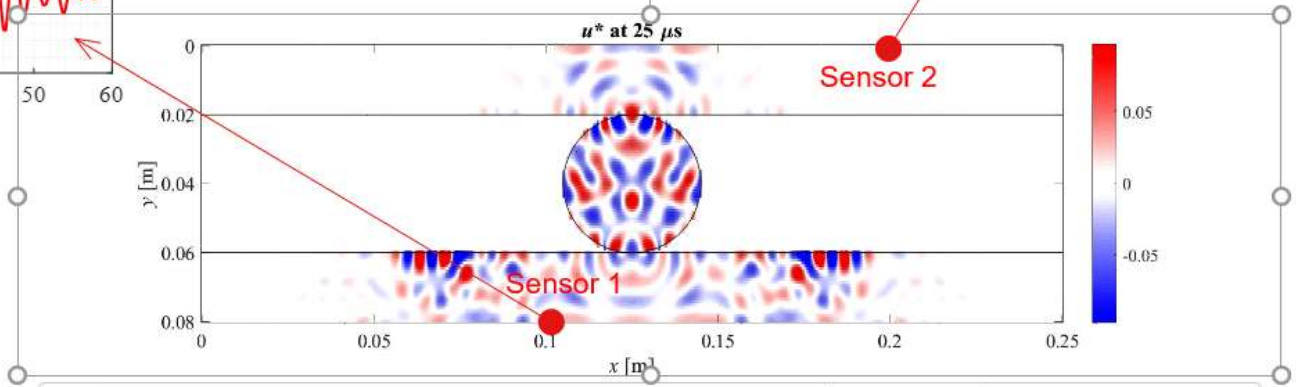




Higher-order spectral FEM analysis







HiTeAM next steps

- Full-scale lab validation on different bearings
- Field demonstrations
- Development of utilization roadmap

Assessment of corrosion-induced damage under marine growth

A non-intrusive technology

Integrity assessment & marine growth

Source: molasubsea

Source: Wikimedia.org

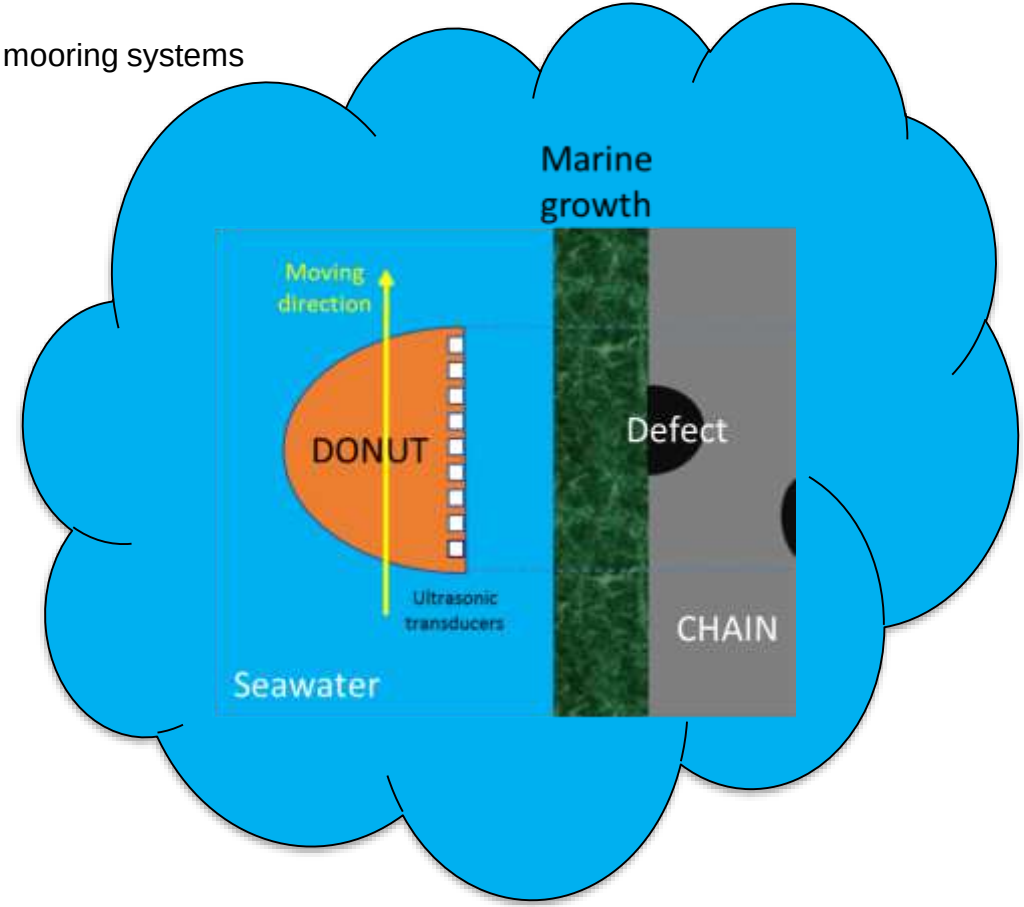
Currently the surface has to be **cleaned** before inspection

Technically, economically, and environmentally undesirable ☹

Enabling inspection under marine growth

Objective: Digital twin of mooring systems

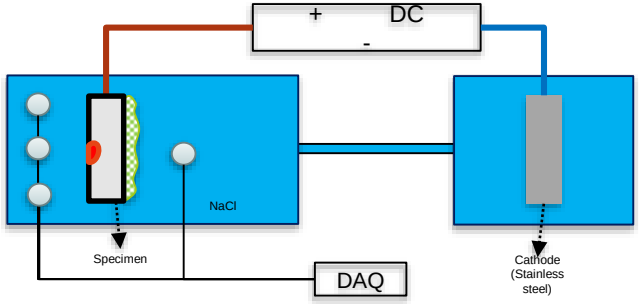
- No cleaning of the chain
- Damage diagnosis
- Damage prognosis
- Deployable on ROV



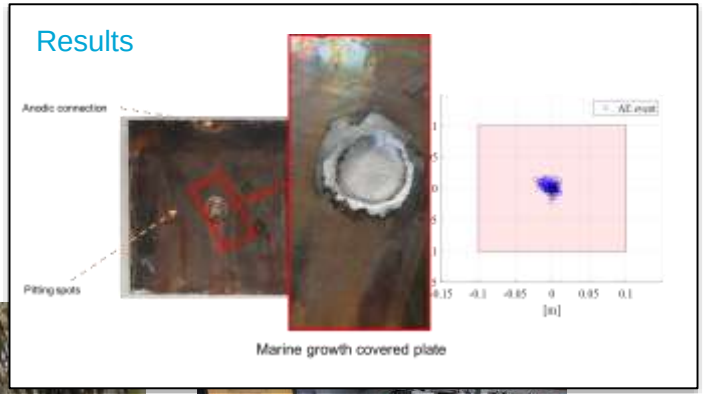
Researchers
Sarjoon Alkhateeb
Filippo Riccioli

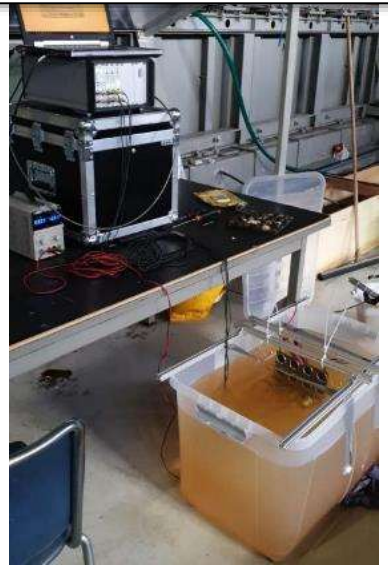
Accelerated corrosion setup

- Electrochemical cell
- Impressed anodic current on the specimen
- Specimens with and without marine growth
- Three weeks duration for each test

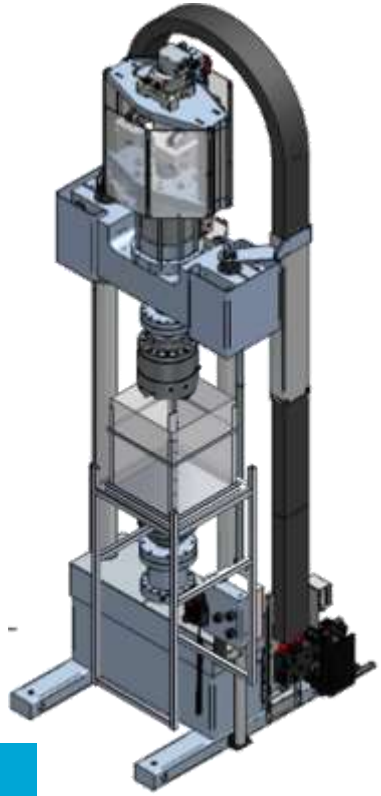


Schematic overview of accelerated corrosion experiment





Corrosion-fatigue experiments



Composites with embedded sensor networks

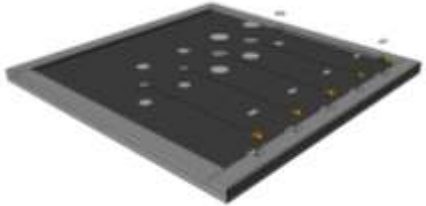
Cyber-physical structures of tomorrow

Composites with embedded sensor networks

- Continuous load and damage monitoring

Preparation of the sensors

Preparation of host plies



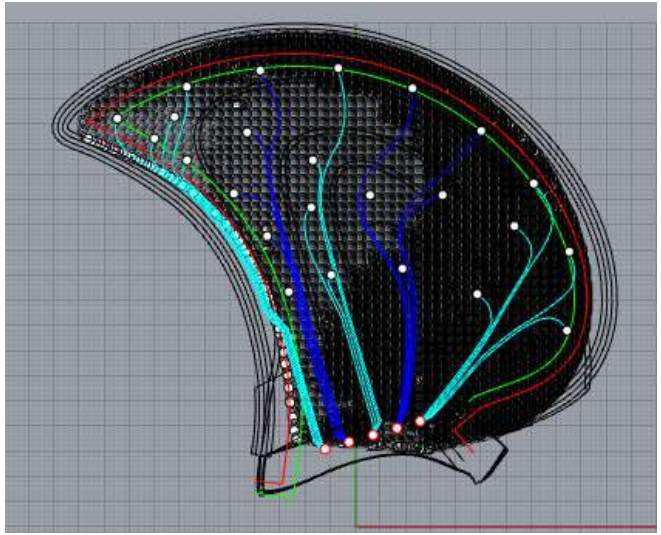
Autoclave

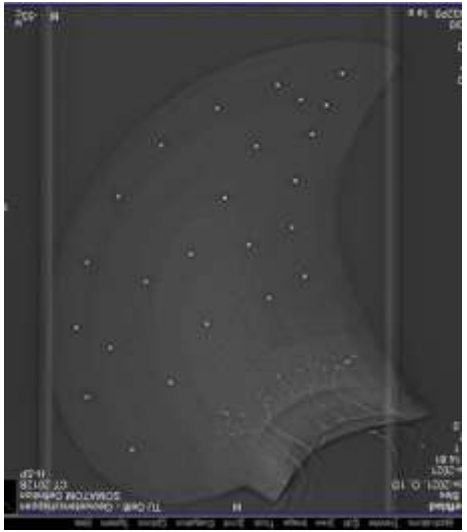
4p bending tests

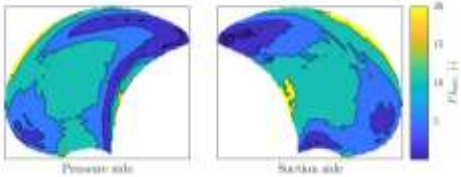
Researcher
Arno Huijer

Composite propellers with embedded sensors

ECoProp







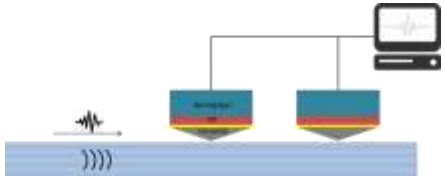
- Continuous load and damage monitoring
- Remaining lifetime prediction

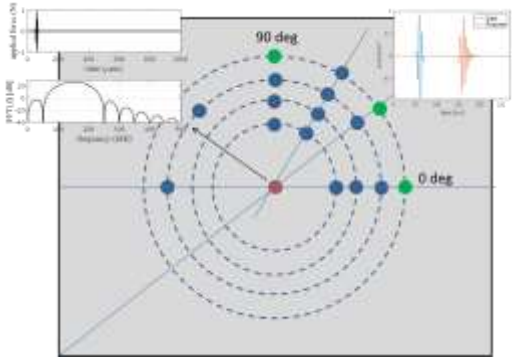
<u>Researchers</u>
Arno Huijer
Wouter de Bles
Xiaobo Zhang

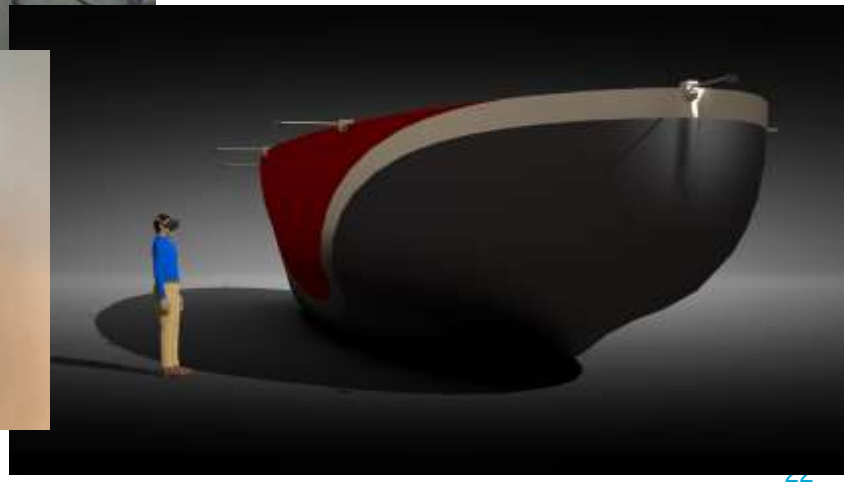
TU Delft MARIN oceAnco JVS ENGINEERS SOLICO WÄRTSILÄ NWO

In-situ non-intrusive assessment of FRCs

- Using multi-modality and dispersion of ultrasonic guided waves

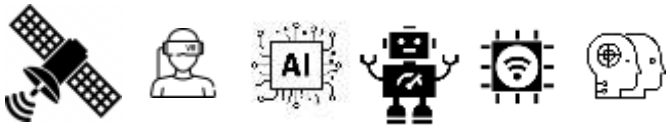


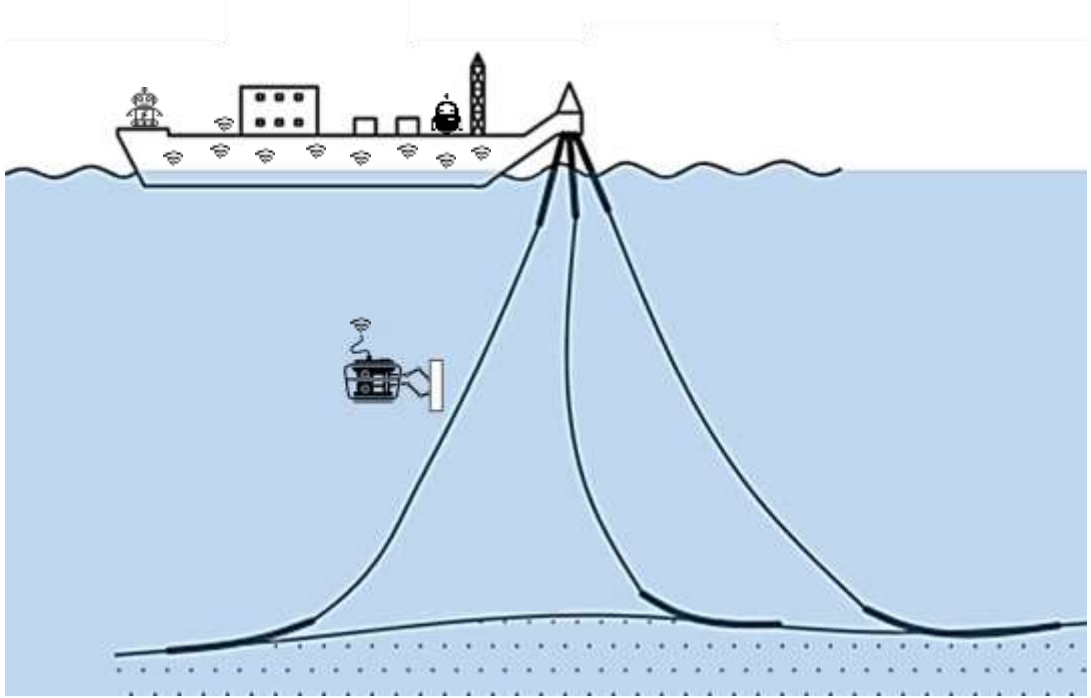




<u>Researchers</u>
Maarten Adams
Arno Huijer
Henri Norden

FPSO’s of tomorrow





Concluding remarks

- We need a holistic view during the technology development phase as well
- We need to work together closely and effectively combine different disciplines
- We need to train students with multidisciplinary skills for the developments of tomorrow

Acknowledgement

MARINE CONTRACTORS
sofec
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WÄRTSILÄ
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BUREAU VERITAS
TOTAL
CORROSION
MARIN
THI Maritiem
Nederland Maritiem Land
NWO
Netherlands Organisation for Scientific Research
SOLICO
SOLUTIONS IN COMPOSITES

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