JIP Moorlife - Objectives

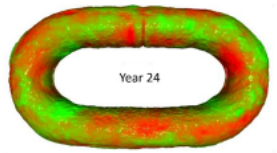
Fatigue Assessment of corroded chain links – JIP Moorlife planned advancements

JIP MoorLife

A framework for corrosion and fatigue life monitoring of mooring chains

JIP MoorLife objectives (phase 1)

- Establish an objective corrosion grading tool that is highly correlated with remaining fatigue life.
- Provide a model for the entire crack life development at the critical cross section for real-world corroded links.
- Investigate the effects of real-world load sequences on damage accumulation in chain links.



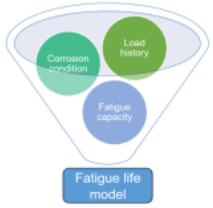
Project background (LifeMoor 2018-2022)

Inspections of used mooring chains often reveal non-uniform corrosion loss and corrosion pitting after years in service (which is not properly accounting for in Industry standards). This can decrease fatigue capacity dramatically and should be closely monitored, understood and taken into account during design and life extension assessment.

An approach to monitoring mooring chain condition with reliability updates was proposed in the research project LifeMoor supported by the Research Council of Norway and an industrial consortium.

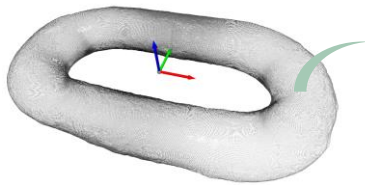
A framework was therefore established by the research partners SINTEF and NTNU, to link in-service load monitoring, inspection data and reliable fatigue models, developed and calibrated from fatigue laboratory testing data.

This framework has been further refined and built upon in four subsequent projects: Hywind (FOWT load history), Objocorr (corrosion assessment tool), Eddy.C (crack detection) and SeeMoor (chain cleaning and assessment).



LifeMoor achievements

- Material behavior and fatigue parameters for R4 steel were characterized. [1][2]
- Residual stresses in mooring chains were measured before and after years of service. [1]
- FE Fatigue models accounting for the effect of residual stresses and local mean loads on the lifetime at critical hot spots.
  i. Energy-based damage approach for fatigue crack initiation at corrosion pits. [1]
  ii. Fracture mechanics approach for fatigue crack growth (mode I). [3]
- An algorithm using 3D scans was created for accurate and fast corrosion grade assessment (corrosion loss and pitting) of chain links, suitable for onshore and underwater inspections. [4]
- A neural network processing for rapid stress calculations due to pitting. [5]
- A database with over 200 fatigue tests and 500 3D scans was established.
- Empirical SN-curve formulations were developed to include mean load and corrosion pitting effects on fatigue. [6]
- 62 years of metocean data were analyzed for mooring line tension histories in case studies. A fatigue reliability damage mode (Miner's rule) showed fatigue life dependency on mooring line position of a semi-submersible. [7]



Level 4 _ Hybrid tool for design & digital twin

- AI-based corrosion grade prediction
- FEA-informed hybrid S–N models
- 3D scan-based corrosion evolution forecasting

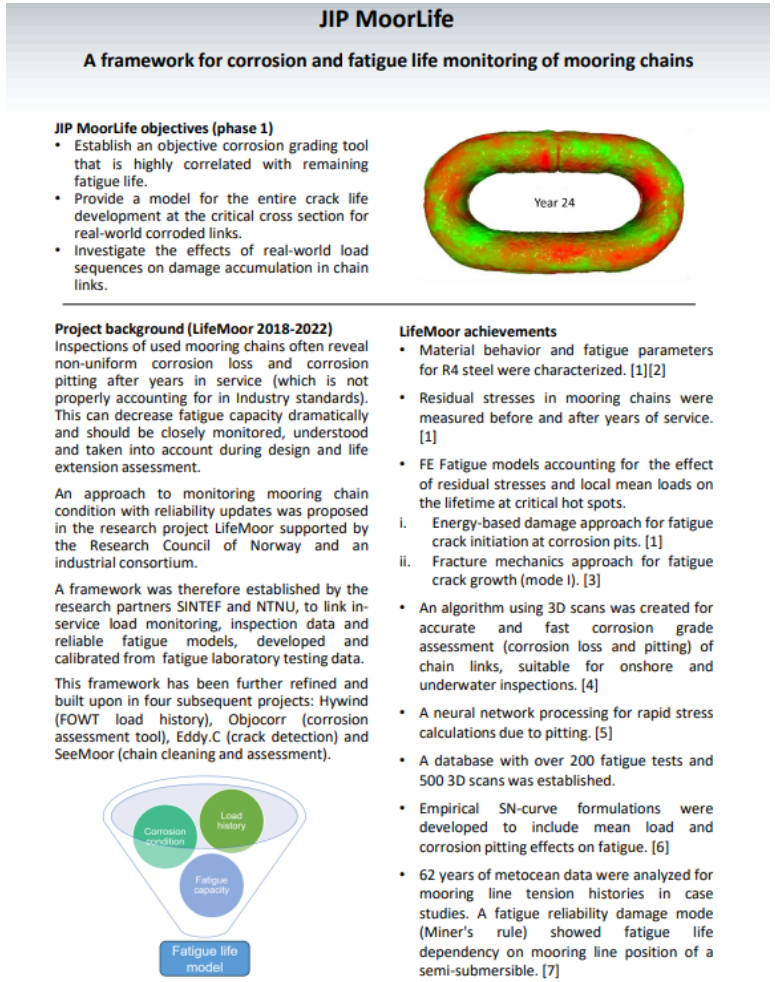
Level 3+ _ Advanced FEA

- Real corroded geometry with surface pitting
- Residual stress evolution after proof loading
- Detailed SCFs and local stress/strain at hotspots for S–N, crack initiation/propagation models

Level 2+ _ Corrosion Grade S–N Models

- Automatic corrosion classification (incl. pitting corrosion, cross section variation and defect's location)

JIP Moorlife – Consortium and funding



JIP MoorLife

A framework for corrosion and fatigue life monitoring of mooring chains

JIP MoorLife objectives (phase 1)

- Establish an objective corrosion grading tool that is highly correlated with remaining fatigue life.
- Provide a model for the entire crack life development at the critical cross section for real-world corroded links.
- Investigate the effects of real-world load sequences on damage accumulation in chain links.

Project background (LifeMoor 2018-2022)

Inspections of used mooring chains often reveal non-uniform corrosion loss and corrosion pitting after years in service (which is not properly accounting for in Industry standards). This can decrease fatigue capacity dramatically and should be closely monitored, understood and taken into account during design and life extension assessment.

An approach to monitoring mooring chain condition with reliability updates was proposed in the research project LifeMoor supported by the Research Council of Norway and an industrial consortium.

A framework was therefore established by the research partners SINTEF and NTNU, to link in-service load monitoring, inspection data and reliable fatigue models, developed and calibrated from fatigue laboratory testing data.

This framework has been further refined and built upon in four subsequent projects: Hywind (FOWT load history), Objocorr (corrosion assessment tool), Eddy.C (crack detection) and SeeMoor (chain cleaning and assessment).

LifeMoor achievements

- Material behavior and fatigue parameters for R4 steel were characterized. [1][2]
- Residual stresses in mooring chains were measured before and after years of service. [1]
- FE Fatigue models accounting for the effect of residual stresses and local mean loads on the lifetime at critical hot spots.
  i. Energy-based damage approach for fatigue crack initiation at corrosion pits. [1]
  ii. Fracture mechanics approach for fatigue crack growth (mode I). [3]
- An algorithm using 3D scans was created for accurate and fast corrosion grade assessment (corrosion loss and pitting) of chain links, suitable for onshore and underwater inspections. [4]
- A neural network processing for rapid stress calculations due to pitting. [5]
- A database with over 200 fatigue tests and 500 3D scans was established.
- Empirical SN-curve formulations were developed to include mean load and corrosion pitting effects on fatigue. [6]
- 62 years of metocean data were analyzed for mooring line tension histories in case studies. A fatigue reliability damage mode (Miner's rule) showed fatigue life dependency on mooring line position of a semi-submersible. [7]

2 years project (2025 – 2027) **JIP phase 1**

Project manager : SINTEF

Industry consortium :

equinor, TotalEnergies, SOFEC, AkerBP, Shell, Statens vegvesen

*Finalizing contractual agreements with three additional industrial partners.

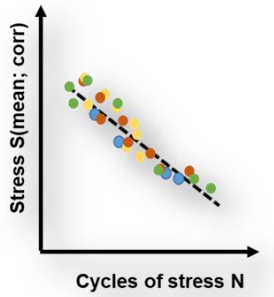
Sponsor fees per participant:

- 600 kNOK per year for Energy companies
- 200 kNOK per year for Contractors/Suppliers
- 150 kNOK per year for Engineering companies
- In-kind contribution from the classification society

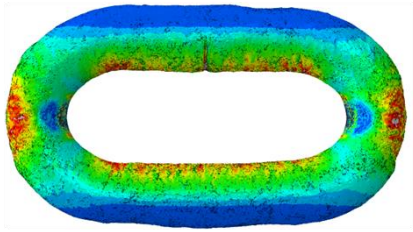
JIP Moorlife – WPs activities

WP1: Objective corrosion grading of chain links

WP3: New insights for SN-based model



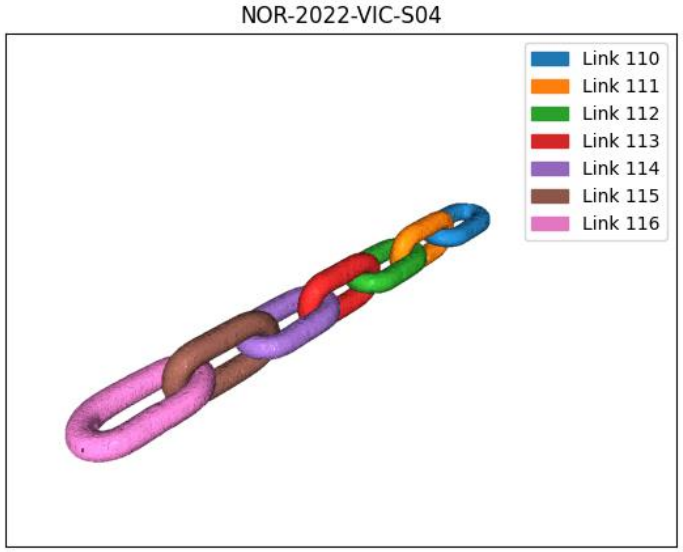
WP2: Fatigue crack initiation and crack growth at hot spots



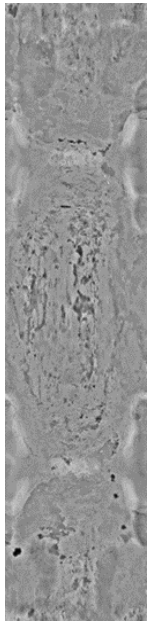
WP1 Objective corrosion grading of chain links: Task 1.1 New corrosion grades

- New corrosion grades considering pits, material loss and position on the chain link

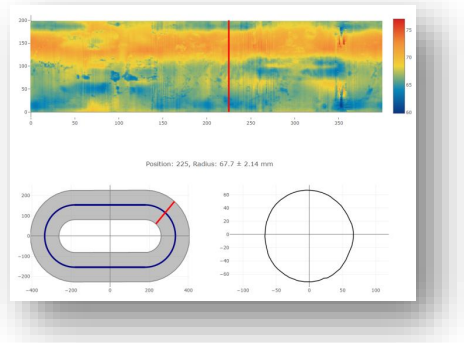
3D scan of corroded Chain links (Point clouds)



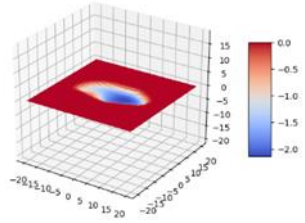
Texture unwrapping



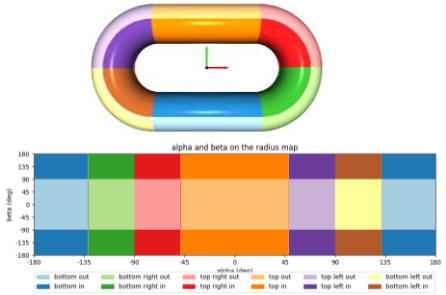
Corrosion loss (cross section profile variation analyses)



Surface pitting (pits distribution, size morphology analyses



Area discretization of the link for analyzing location influence



Input to define and calibrate corrosion criteria function of:

- pits criticality (e.i. sharpness, volume, depth, density, location…)
- actual minimum cross-section

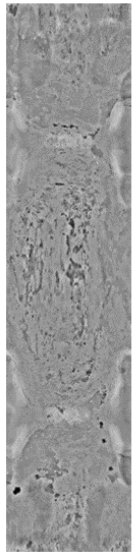
Level 1: based solely on geometric/topological criteria

WP1 Objective corrosion grading of chain links: Task 1.1 New corrosion grades

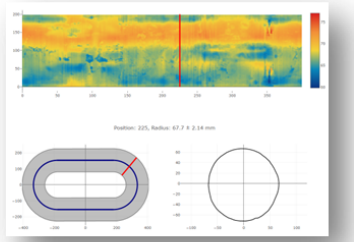
- New corrosion grades considering pits, material loss and position on the chain link: Hybrid (FEM) based corrosion criteria

3D scans

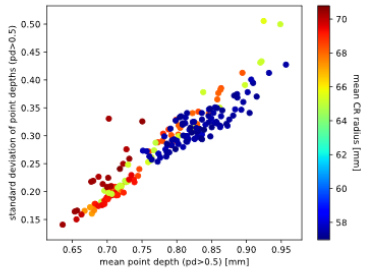
Texture unwrapping



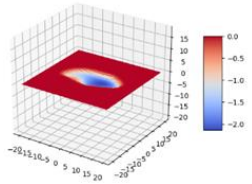
Corrosion loss (cross section profile)

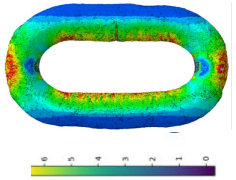


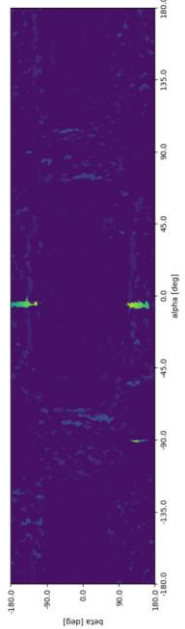
pits depth distribution



Single pit morphology







FEM based pit criticality (stress maps)

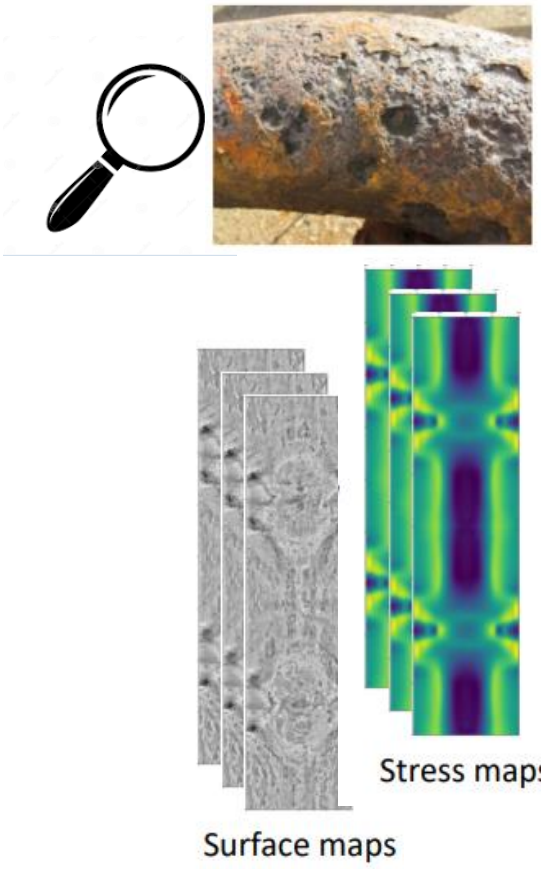
New objective Corrosion indicator(s)

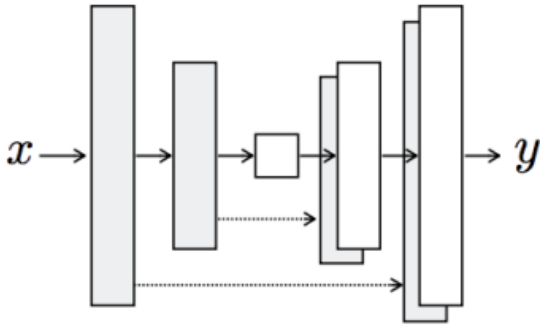
Level 2: Hybrid (FEA based) criteria

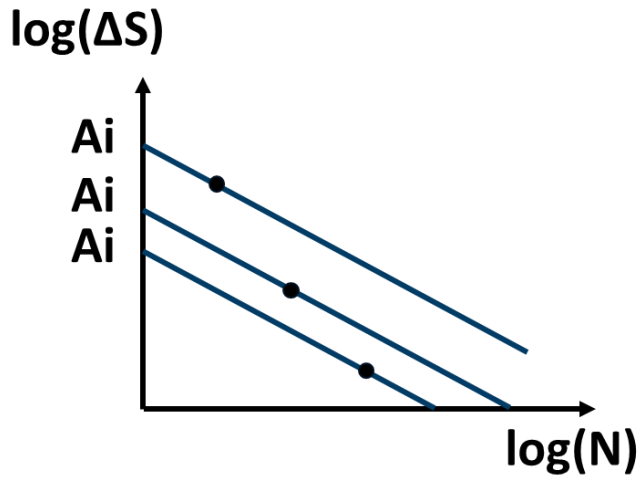
WP1 Objective corrosion grading of chain links: Task 1.1 New corrosion grades

- Pipeline for automatic stress map prediction with FEM and AI-accelerated FEM.

➢ **Hybrid corrosion assessment tool for design & digital twin**

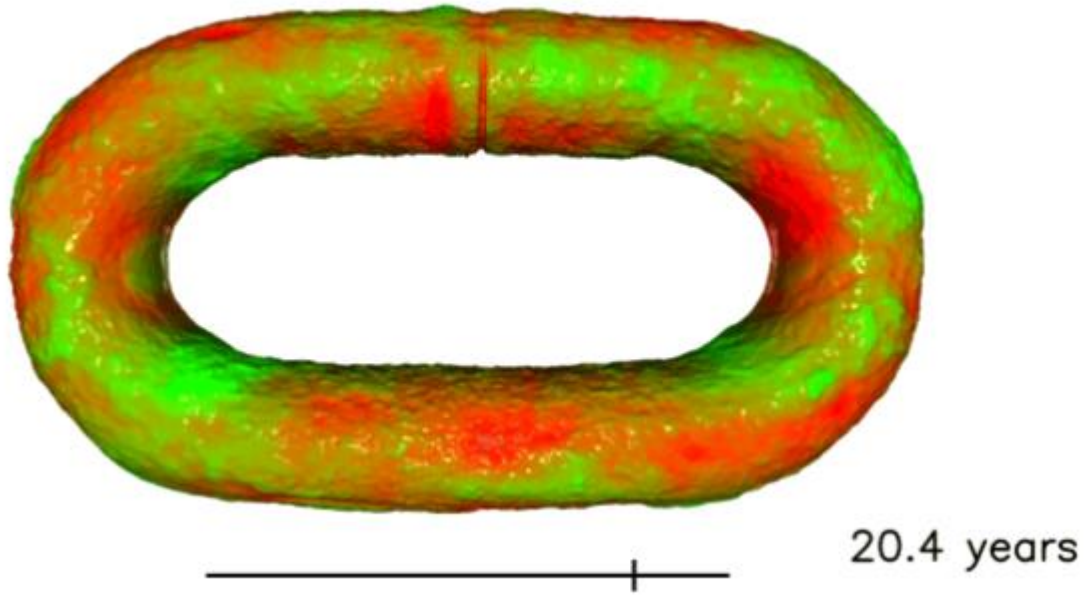






WP1 Objective corrosion grading of chain links: **Task 1.2 Model corrosion evolution from 3D scans**

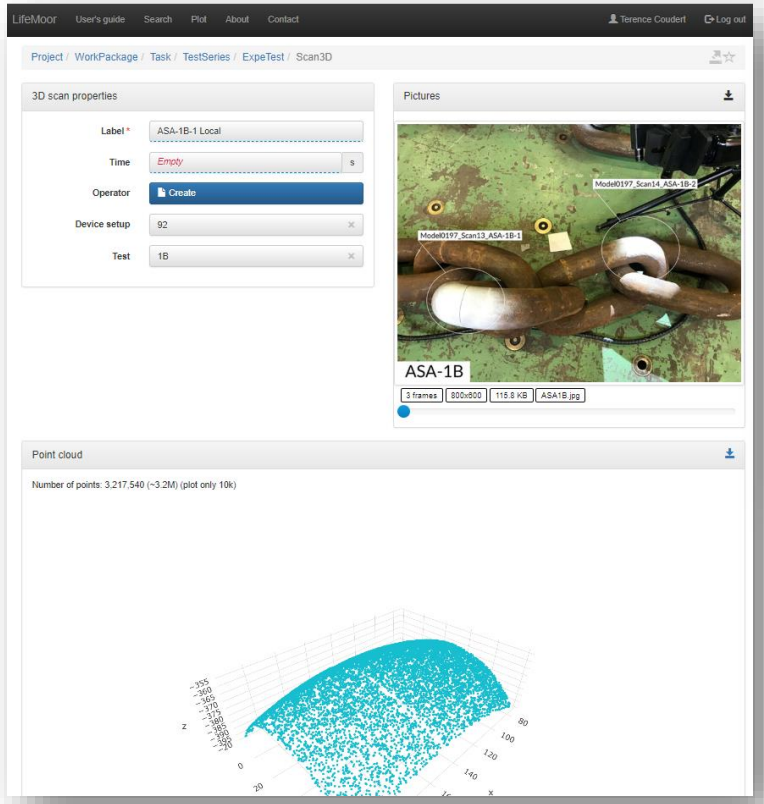
- Use 3D scan data to enable interpolation of corrosion patterns between chain links with varying years of corrosion (but similar production batches and service conditions).

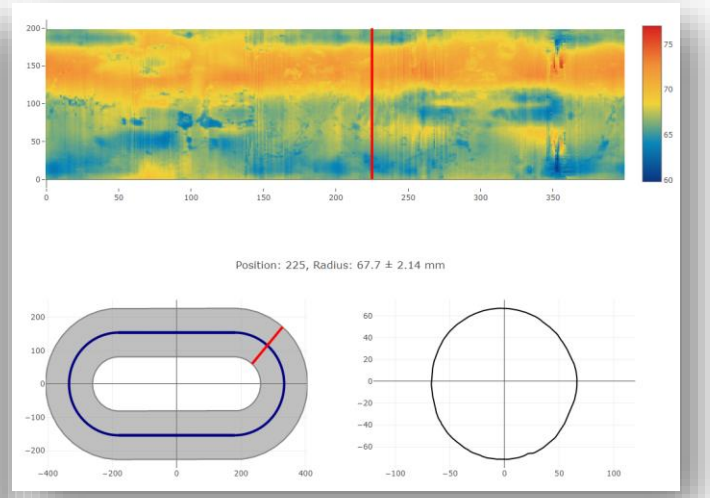


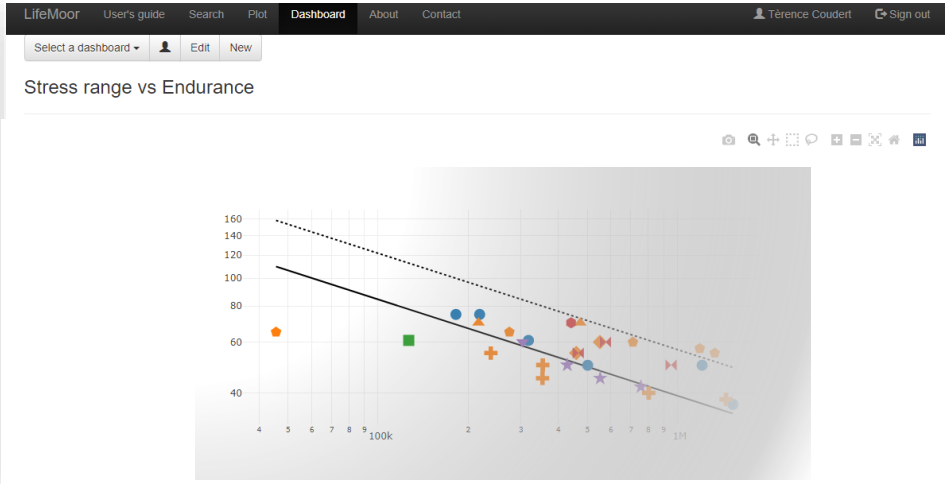
Ex: Corrosion evolution deduced from post-processing of 3D scans of chain links

WP1 Objective corrosion grading of chain links: **Task 1.3 Industrial use and feedback**

- Industry partners will be granted access to Objocorr during the project, allowing them to upload and process their own scan data, as well as providing feedback.
- Documentation, including a User Guide, will be made available.
- Access to the database will be managed according to data ownership.







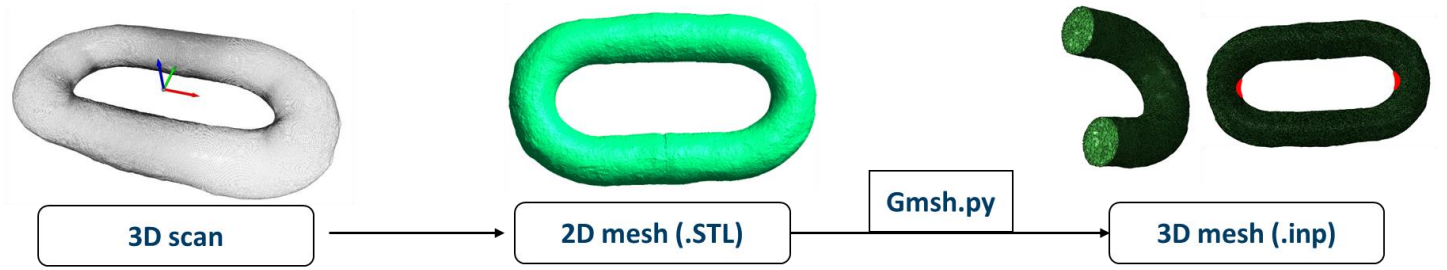
WP2 FEA Stresses concentration, Fatigue crack initiation and crack growth at hot spots:

Task 2.1 Pipeline for automatic stress map prediction with FEM

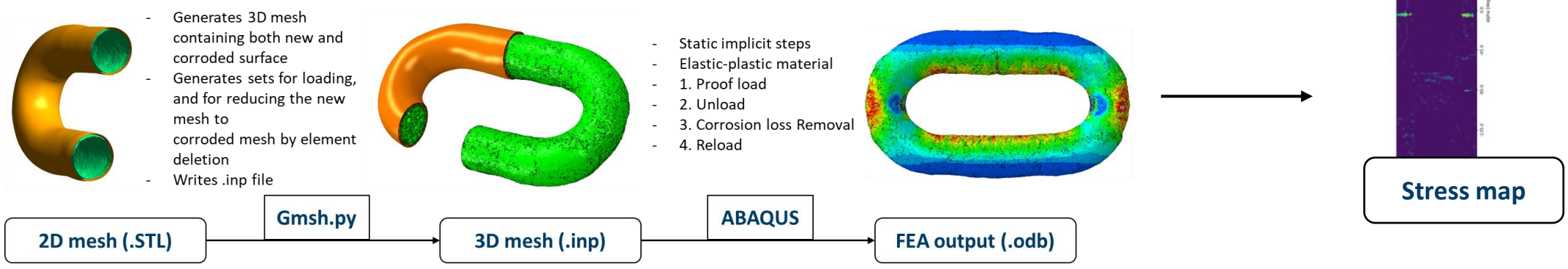
Task 2.2 Quantify numerically corrosion loss effect on initial residual stresses field change

Task 2.3 Establish stresses field maps

Pipeline for 3D mesh generation



Pipeline for FE simulations (with actual corroded geometry and actual RS)



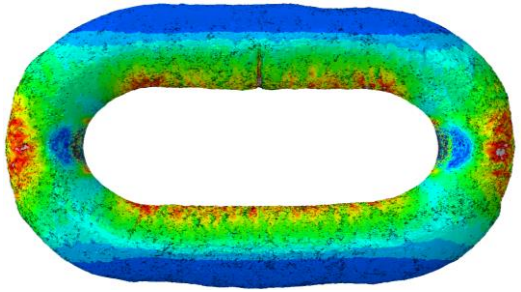
WP2 Fatigue crack initiation and crack growth at hot spots:

Task 2.4 Study the impact of local stresses on fatigue capacity at hot spots.

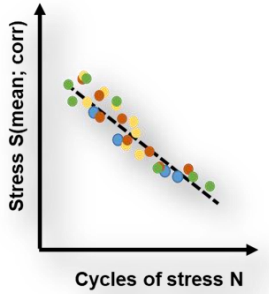
- Remaining life assessment for corroded chain geometry, including residual stresses
- Critical locations in tension/tension
- Consider fatigue damage (crack initiation), and crack growth models that account for mean stress and RS.

➢ **Parametric FEA studies, key influencing parameters**

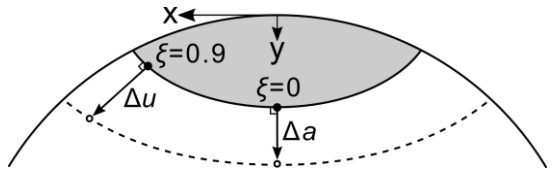
FEM with actual chain links geometry and actual RS



SCF investigation, input to Wp1 for corrosion grade in S-N model



3D local stress distribution and defect geometry as input to crack initiation and crack growth models.



$$\frac{da}{dN} = C(\Delta K_{th})^m$$

WP3: New insights for SN-based model

- Understand Residual Stress (RS) Effects on Fatigue:
- Improve corrosion-grade S-N fatigue models by quantifying:
- Quantify crack initiation vs. crack growth contributions

Cases studies are defined based on partners new input data to expand the assessment:

Under discussions:

- Case study 1 : heavy corrosion & Crowns and PWC failures
- Case study 2 : PWC & very heavy corrosion
- Case study 3 : interlink wear & low corrosion
- Case study 4 : very heavy corrosion incl. mega pits
- ..

For more information, please contact

Email: alexandre.kane@sintef.no