TOWARDS IMPROVED FATIGUE CRACK GROWTH MODELS: OVERVIEW OF THE FELOSEFI PROJECT

TNO offshore wind research on fatigue | Ir. Sjoerd van der Putten

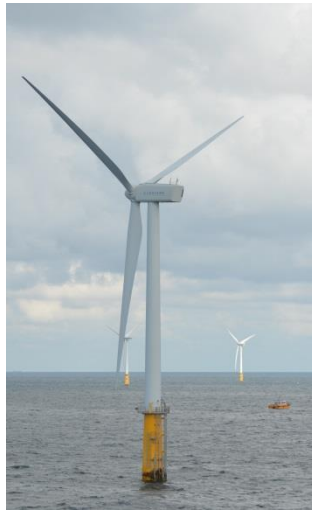
TNO innovation for life

PRESENTATION OUTLINE

- Introduction TNO - Offshore wind R&D
- Outline FeLoSeFI project
- Preliminary results FeLoSeFI
- Conclusions

INTRODUCTION TNO – R&D ON STRUCTURES

- Structural Dynamics and Structural Reliability: 120 experts
  - Core Technologies
    - Structural reliability
    - Structural dynamics
    - Material performance
  - Products and services
    - Modelling and simulation studies
    - On-site and offshore measurements
    - Laboratory experiments: fatigue, fracture, shock
    - Via contract research or (joint industry) projects



INTRODUCTION TNO - OFFSHORE (WIND) R&D

- TNO Roadmap Offshore
- Project examples
  - Load sequence effects for fatigue damage calculations: FeLoSeFI Project
  - Monitoring and lifetime prediction: MONITOR Joint Industry Project
  - Corrosion fatigue: Early Research Program

OUTLINE FELOSEFI PROJECT

Estimated reduction of
CAPEX up to 4.5% LCOE
and/or
OPEX up to 0.9% LCOE

- **F**atigu**e** Life **Lo**ad **Se**quence effects
  and **F**ailure-probability driven **I**nspection

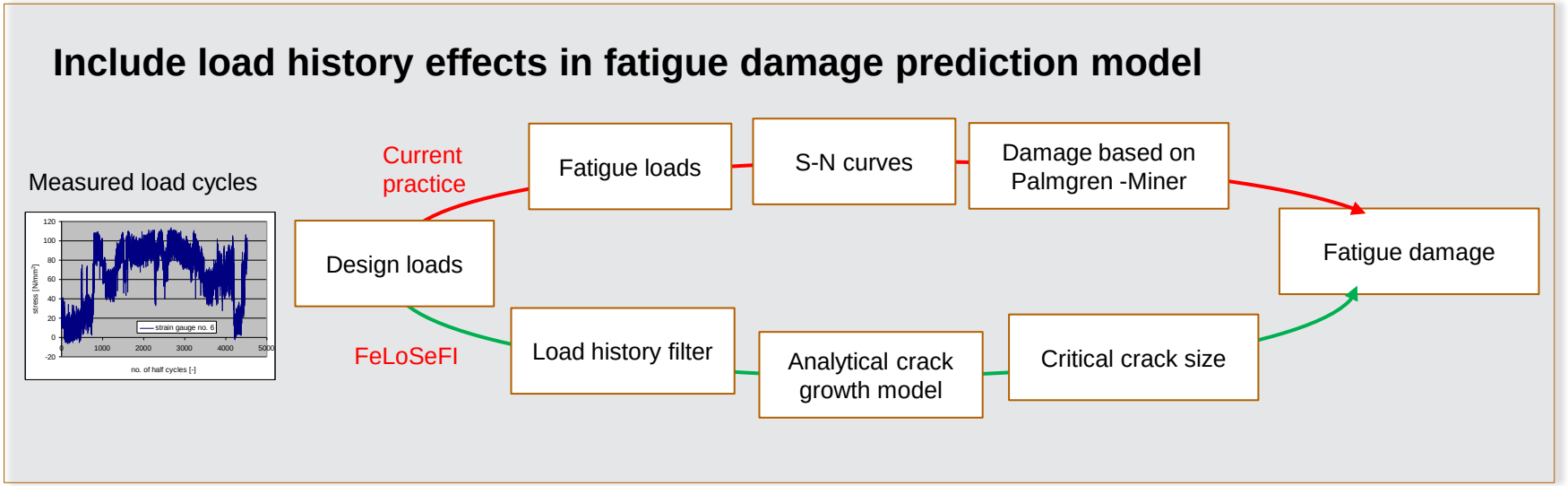
- Focus on fatigue life prediction of welded connections in Offshore Wind structures.
- Improved fatigue model, including load sequence effects
- Improved inspection planning, with potentially extended interval

OUTLINE FELOSEFI PROJECT

- Partners
  - Operator
  - Designer
  - Material supplier
  - Branch organization
  - R&D performers

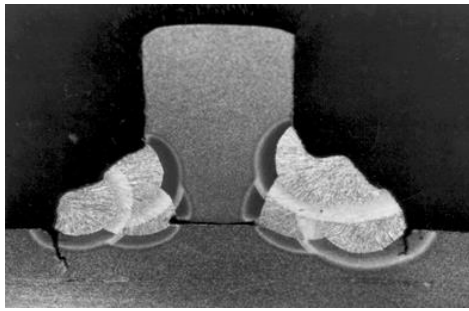
OUTLINE FELOSEFI PROJECT

- Background

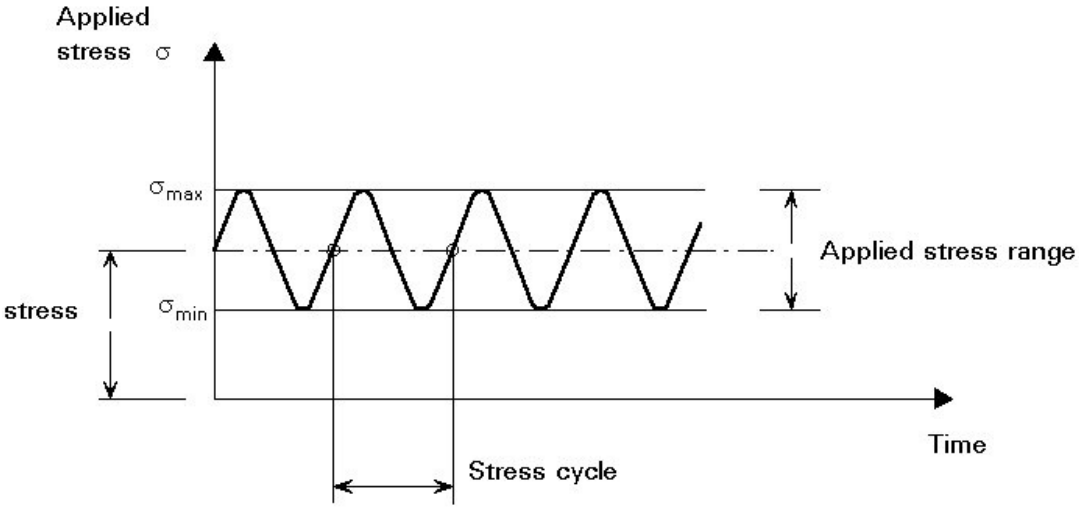


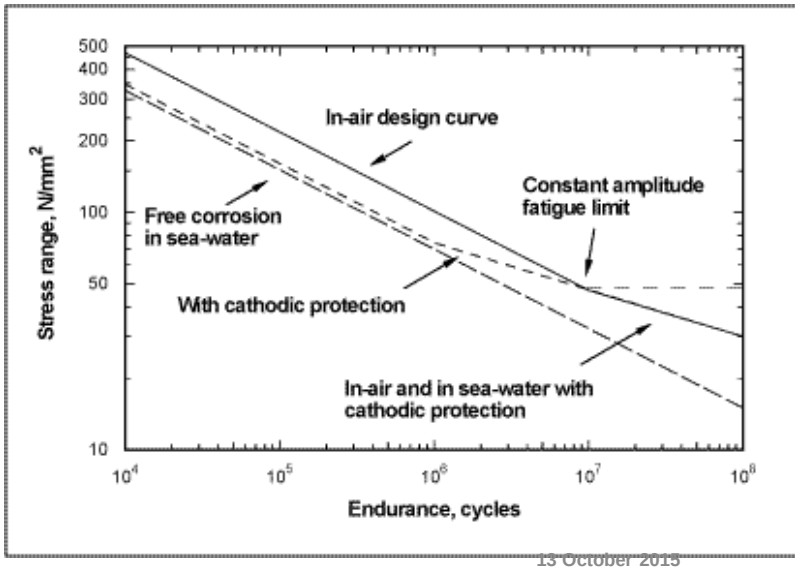
- Expected improved service life (25-50%)

FATIGUE DAMAGE PREDICTION REGULAR APPROACH



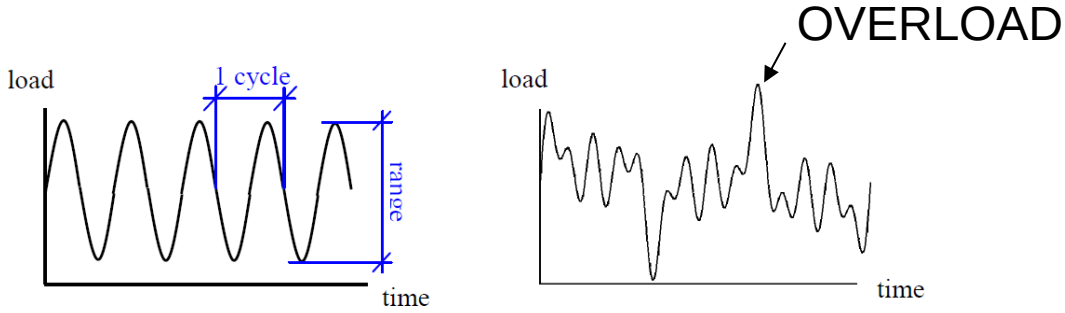
- Conservative material response data “S-N curves”
  - number of constant amplitude stress cycles until failure
  - conservative: large scatter

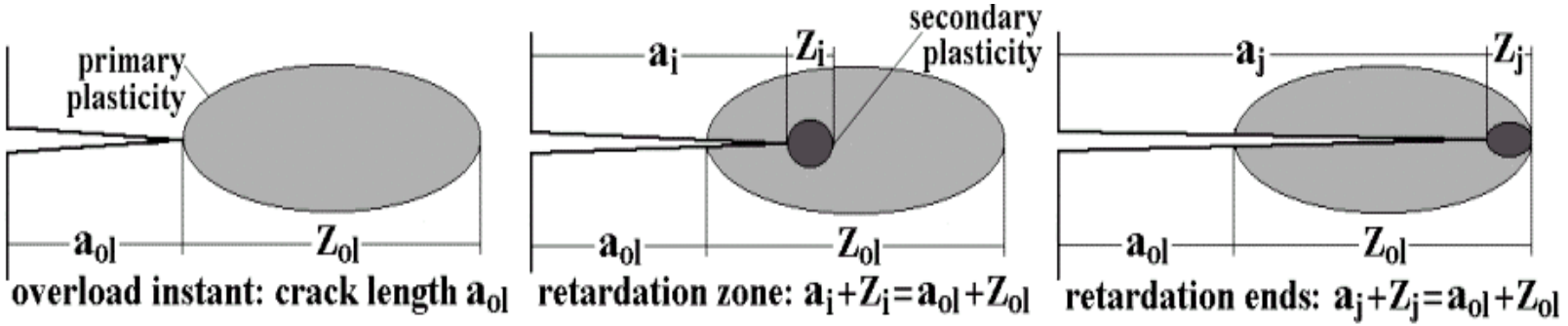




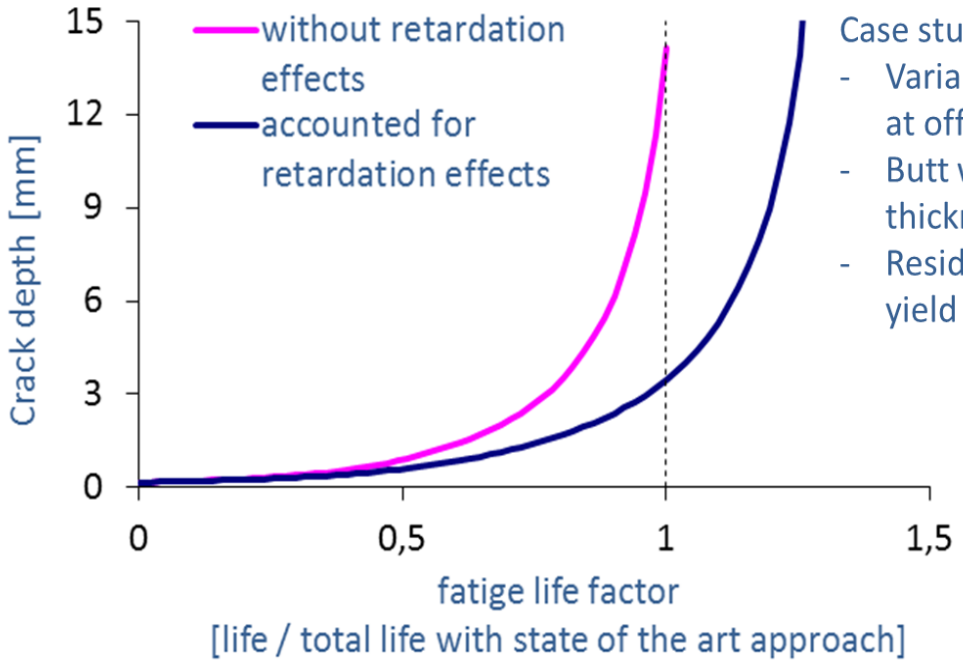
FATIGUE DAMAGE PREDICTION ANALYTICAL CRACK GROWTH MODEL

- Modelling the effect of crack retardation/acceleration
- Yield zone crack growth retardation region – crack closure effect





FATIGUE DAMAGE PREDICTION ANALYTICAL CRACK GROWTH MODEL

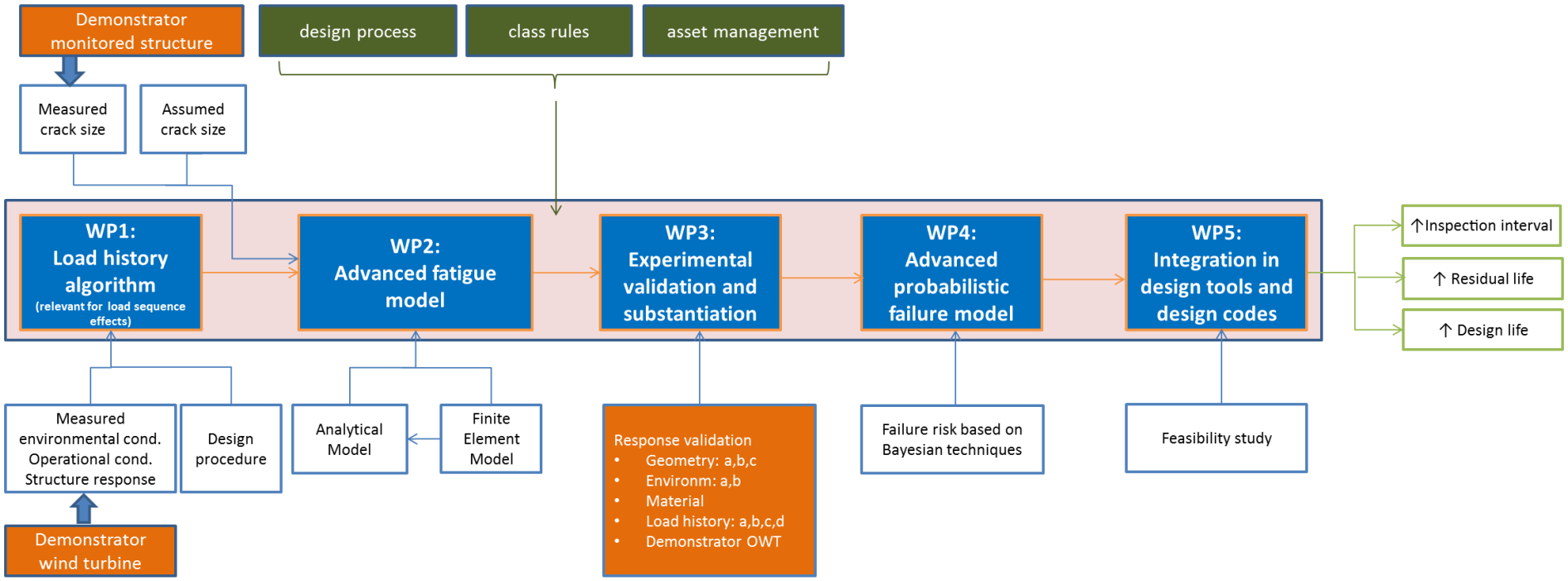


Case study [TNO 2012]

- Variable amplitude load measured at offshore wind structure
- Butt weld between steel pates thickness 70 mm
- Residual stress assumed at 0.5 x yield stress

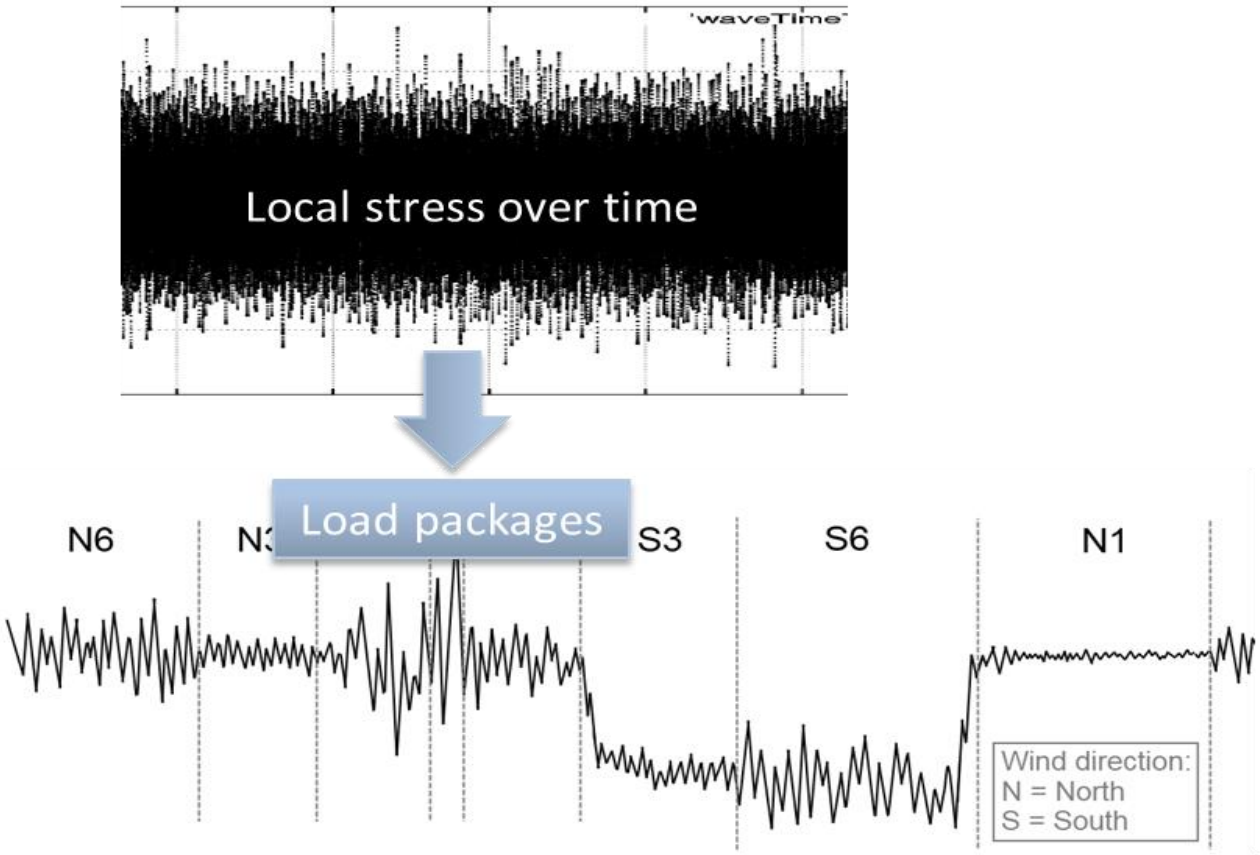
OUTLINE FELOSEFI PROJECT

- Project structure



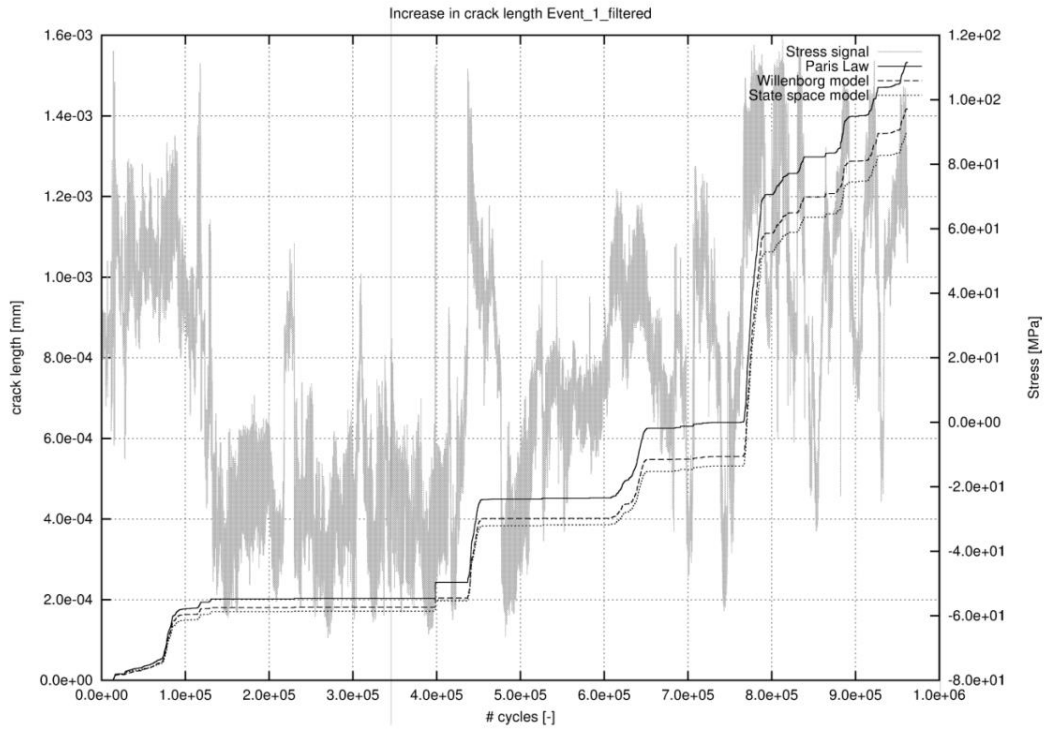
WP1 LOAD HISTORY ALGORITHM

- Identification of load events based on measurement data



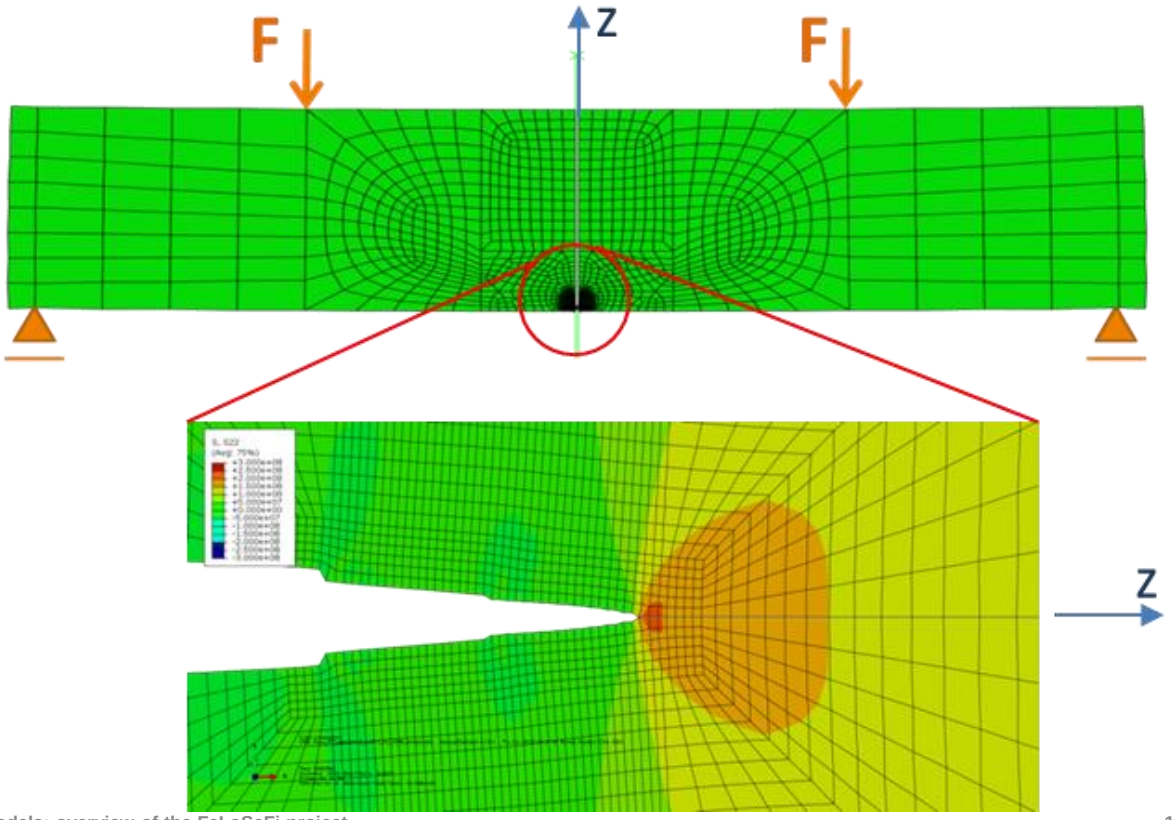
PRELIMINARY RESULTS WP1

- Load history effects: Data reduction algorithm to filter relevant load sequences.
- 10% of all fatigue damage is inflicted by roughly 97% of all cycles counted
- > 90% reduction feasible
- Identification of events



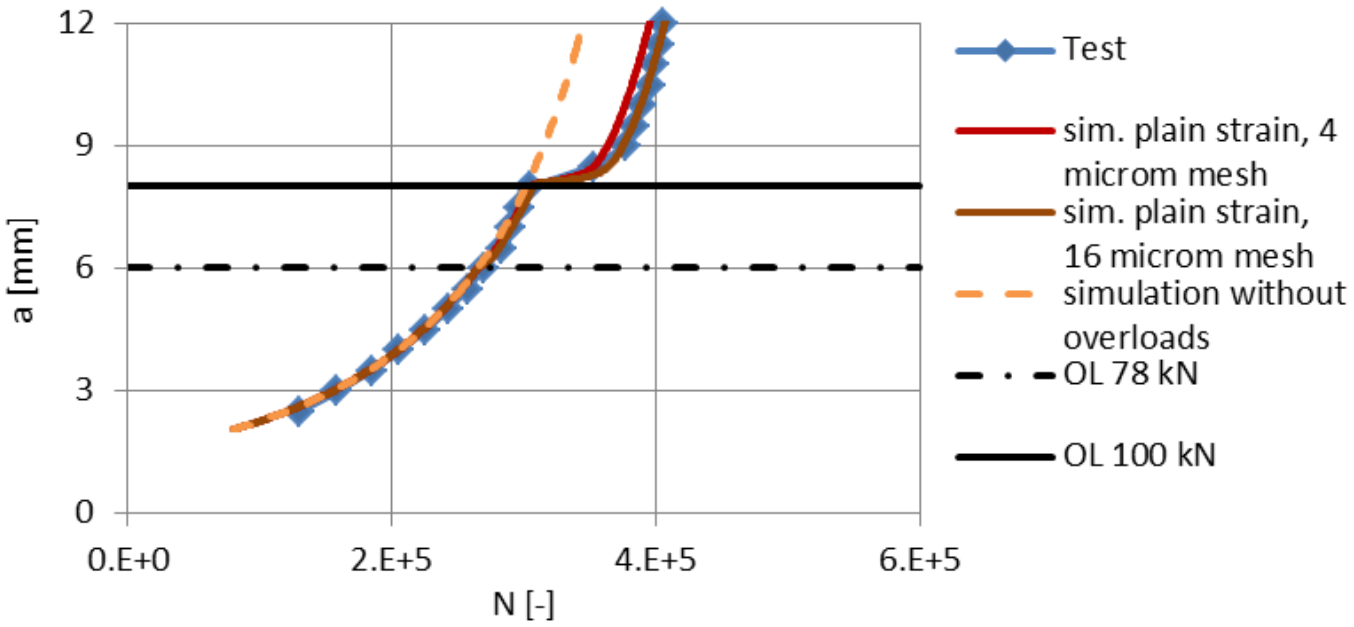
WP2 ADVANCED FATIGUE MODEL

- ‘Fundamental’ understanding fatigue crack growth trough FEM and experiments



PRELIMINARY RESULTS WP2

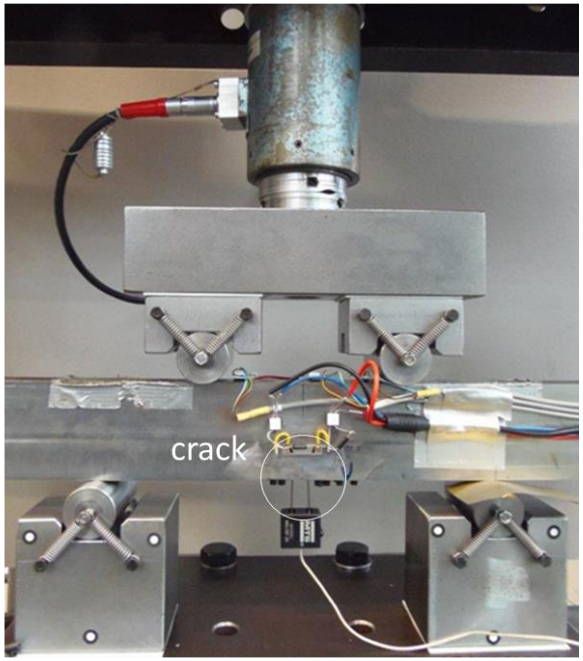
- Results analytical model based on FEM



WP3 EXPERIMENTAL VALIDATION

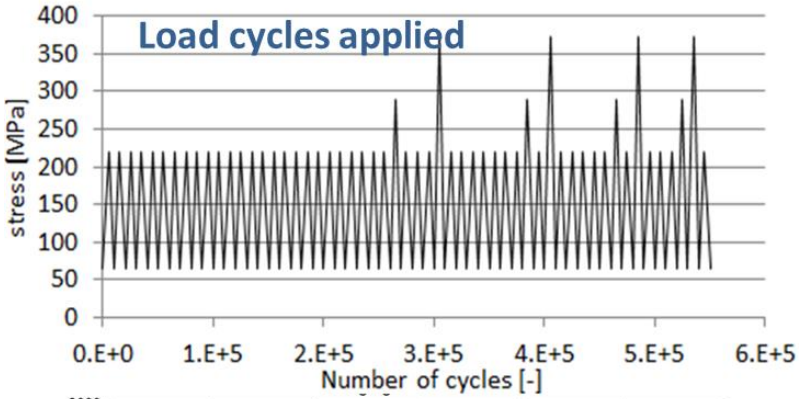
- Four point bending tests and tubular T-joint tests

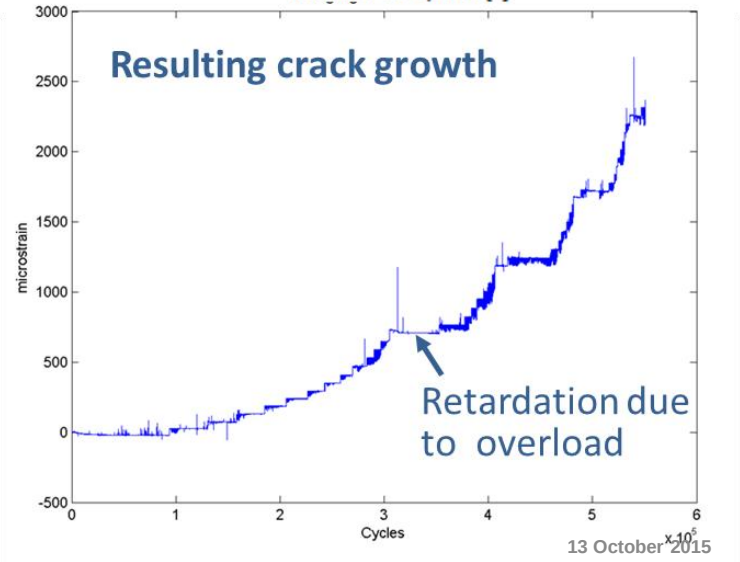
4 p bending fatigue specimen,
heavily instrumented to monitor crack growth in detail



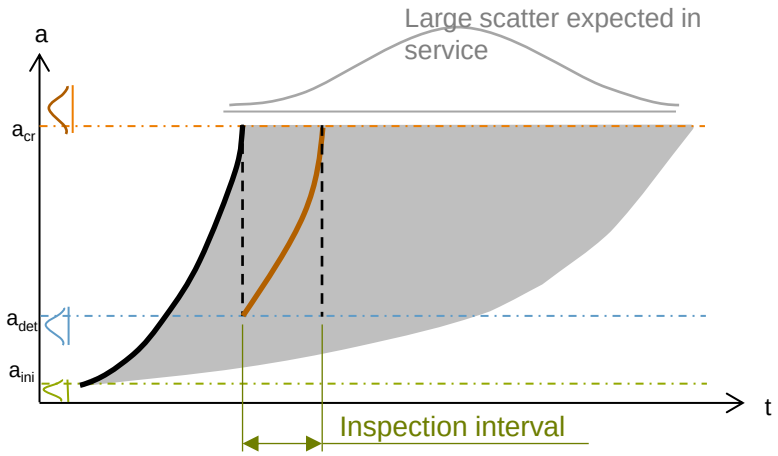
WP3 PRELIMINARY RESULTS

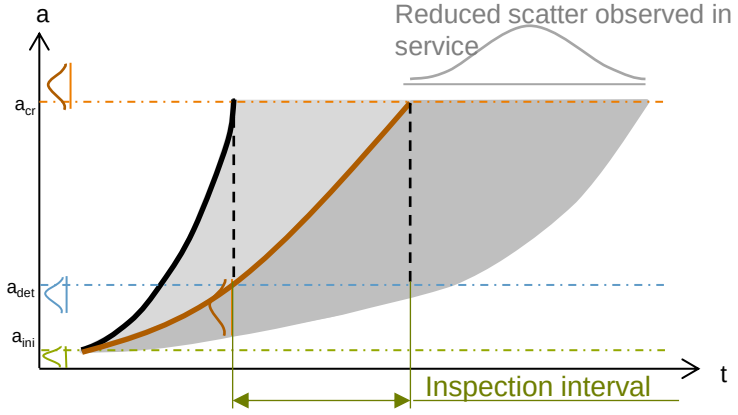
- Incidental overloads clearly show retardation effect





WP4 PROBABILISTIC FAILURE MODEL





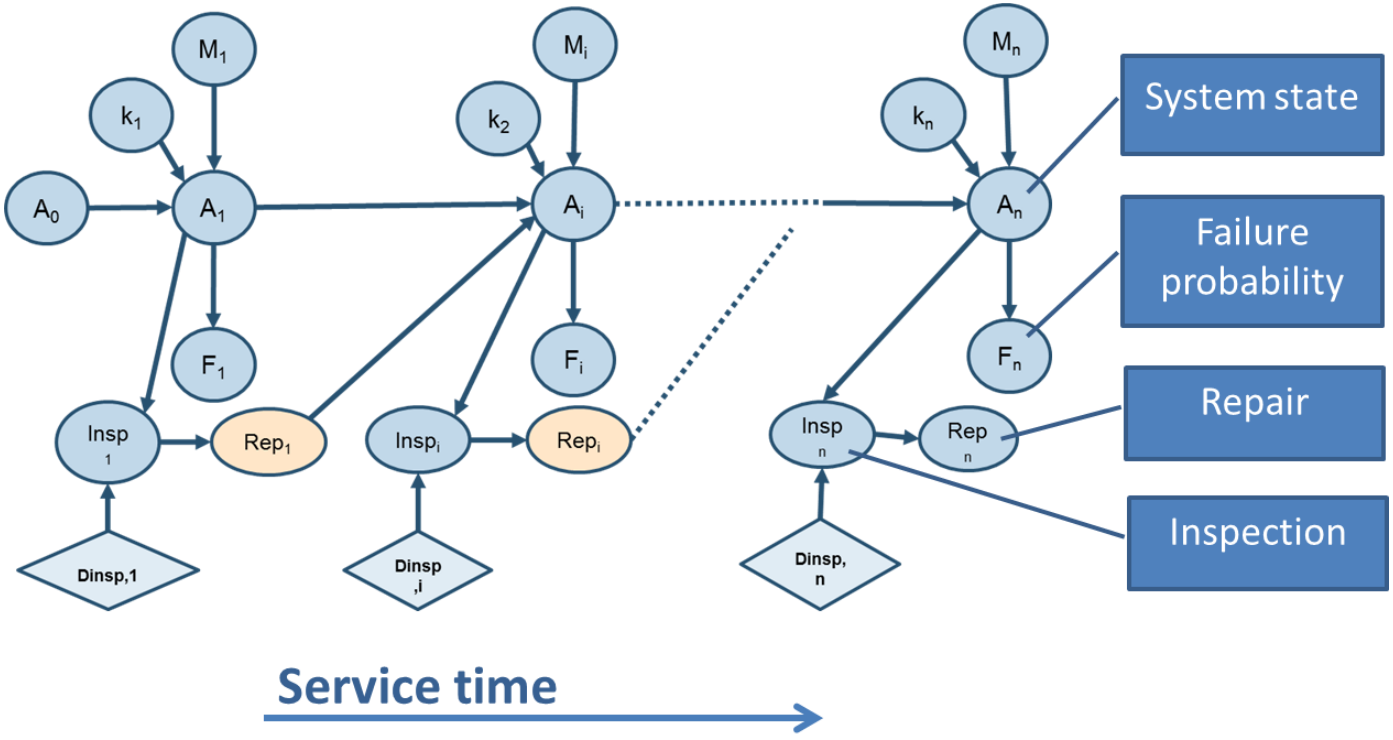
- Design assumptions lead to inspection intervals associated with a certain risk of failure of the structure

Include result of previous inspections via Bayesian network model
Benefits: inspection interval 100% longer and flexibility in inspection

- Observed behaviour of structure allows to adapt inspection interval

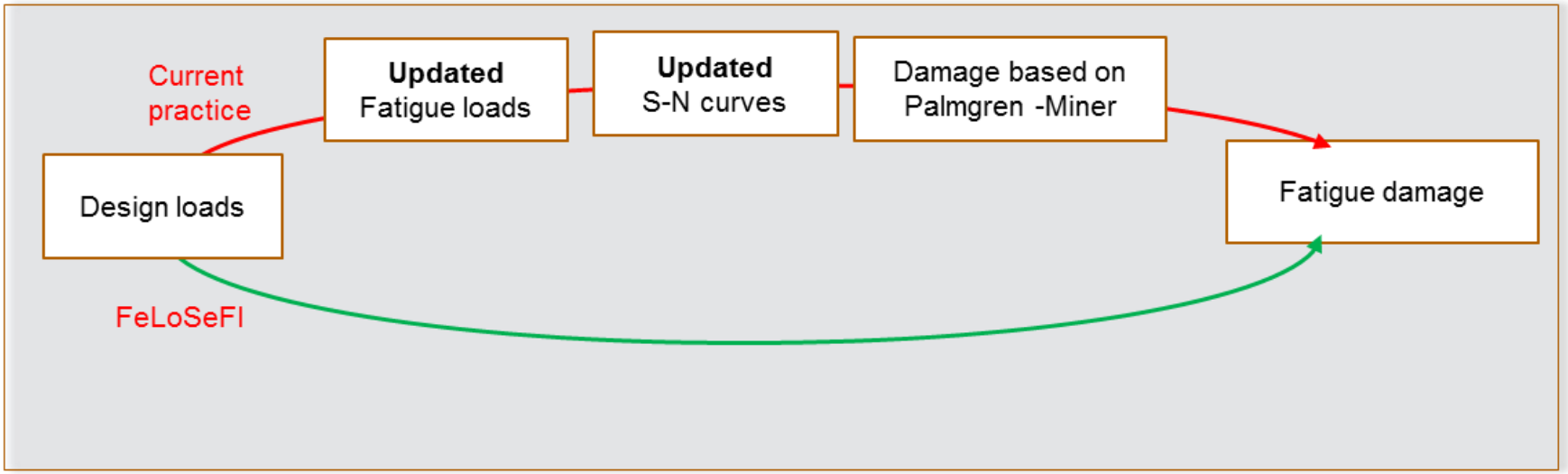
Increased inspection intervals (x2)

WP4 PRELIMINARY RESULTS



WP5 INTEGRATION

- Integration in design tools and design codes.



CONCLUSIONS

Estimated reduction of
CAPEX up to 4.5% LCOE
and/or
OPEX up to 0.9% LCOE

- The project scope and approach result in:
  - A validated fatigue crack growth model that takes load sequence effects into account resulting in a load sequence dependent bonus on the fatigue life. The model will be fed with a load history algorithm for measured and design loads. The model is based on both FEA-models and coupon and realistic size specimens;
  - A probabilistic model to calculate inspection intervals, which includes Bayesian believe techniques that account for results of (previous) inspections.
- Retardation is caused by crack closure effects in the crack tip
- Preliminary results show a typical loading pattern with mean shifts, that are potential source to retardation effect as a result of overloads
- New monitoring data should provide insight in typical loading in jacket structure

THANK YOU FOR YOUR ATTENTION

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PROJECT INITIATIVE CORROSION FATIGUE

- Develop a numerical toolbox aiming at the prediction and quantification of the marine conditions on the corrosion fatigue crack initiation and propagation
- Validate steel structures for wider application with specific corrosive environments
- Focus on corrosion pit development in C-Mn steel (S355) with salt water environment
- Subsea / Splash zone (offshore wind structures)
- Literature study, experimental work and numerical modelling

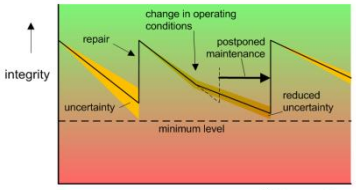
PROJECT INITIATIVE: MONITORING RESIDUAL LIFE

ECN
TNO

Design load
Intended operation
Predicted degradation

Goal:
Wind Farm Optimisation

Residual Lifetime
of the support structure



Load history all turbines
(FleetLeader concept)

Monitoring response & degradation

Monitoring installation loads

Monitoring load on several turbines