Planning of operation and maintenance using risk and reliability based methods

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Introduction - O&M in offshore wind farms

Corrective maintenance
Run-to-failure

Preventive maintenance
• Time/condition based
• Risk-based inspections

Risk-based techniques can be used for optimal planning of
• future inspections / monitoring (time / type)
• decisions on maintenance/repair on basis of (unknown) observations from future inspections / monitoring
taking into account uncertainty and costs
Successful application in offshore oil & gas
Particular applicability to wind farms – low safety restraints
Theoretical basis – Bayesian preposterior decision theory

- Decision rule \( d(s) \)
- Reliability modeling
Theoretical basis – Reliability modeling

Analysis of failure probabilities based on different types of information:

- Observed failure rates – Classical reliability theory
- Probabilistic models for failure probabilities – Structural Reliability Theory:
  Limit state modeling & FORM / SORM / simulation
Theoretical basis – Damage modeling

Deterioration – damage accumulation:

- Deterioration processes are connected with significant uncertainty
- Observations of the actual deterioration / condition by monitoring or inspections can be introduced in the models and significantly improve the precision of forecasts

- Corrosion
- Erosion
- Fatigue
- Wear
- Etc.
Life cycle model

Simplified life cycle model – wind turbine is represented by a single component blade/welded detail

**Modules**

- **Environment**
  - wind/wave time series
- **Component health**
  - damage and reliability models for blade/welded details
- **Maintenance strategy**
  - inspection scheduling
  - decision criteria for repair
- **Access to wind turbine**
  - weather limitations for vessels
Example applications

Inspection planning for wind turbine blades
• Condition based
• Risk based
• Minimise life cycle cost
• What is the impact on overall cost?

Design of welded steel details
• Reducing safety factors – reduced material consumption
• Regular inspections – maintain reliability levels
• What is the impact on overall cost?
Failure modes

- Shells
  - erosion
  - delamination
  - cracking
- Cracking on main spar
- Debonding of glue joints
- Random (lightning) or unknown
Inspection planning for wind turbine blades

Initial cracking  ➔  Development  ➔  Failure

Deformed panel

Undeformed panel

Bladena, 2014
Inspection planning for wind turbine blades

- cracks generated at random locations on trailing edge blondline
- size of cracks generated using lognormal distribution
Inspection planning for wind turbine blades

Fracture mechanics approach

\[ \frac{da}{dt} = \frac{A(\Delta K)^m}{(1-R)^m(1-\lambda_W)} \]

- simulations on NREL 5MW turbine
- determine stress distribution for operational wind speeds

Aero-elastic simulations (FAST/TURBSIM)
Inspection planning for wind turbine blades

- failure limit modeled as stochastic variable
- failure limit and material parameters calibrated to fit observed failure frequencies
Optimisation study

Fixed inspection interval 2 years
Decision criteria - damage threshold
  - failure probability

Lower overall cost from risk optimisation
Example 2 - welded detail

Design of welded steel details accounting for inspections
- Reducing safety factors – reduced material consumption
- Regular inspections – maintain reliability levels
- What is the impact on overall cost?

Damage model
- 1 dimensional fracture mechanics model based on *
- Material parameters calibrated to fit * reliability estimates

*Sørensen JD. Reliability-Based Calibration of Fatigue Safety Factors for Offshore Wind Turbines

DeepWind February 2015 Trondheim
Safety factor reduction

Required inspection plan determined in [Sørensen JD, 2012]

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<th>$\gamma_m [-]$</th>
<th>Inspection interval [years]</th>
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Life cycle model used to estimate overall cost for “repair on detect policy”

$$C(\gamma_m) = C_c \cdot \gamma_m + n_i \cdot C_i + E[n_r] \cdot C_r$$

Inspection cost is expressed as [%] of capital cost
Cost of repair is fixed at 4 times cost of inspection
Safety factor reduction

Overall cost

Fig. 6. (a) Total lifetime cost - surface (b) Total lifetime cost - sections
Conclusions

- Potential for lowered lifetime O&M cost through risk-based inspection planning
- Potential for lowered safety factors through risk-based inspection planning
- Two applications presented by illustrative examples

Future work

- More examples to be developed
- System aspects
- Applications of Bayesian networks tools are being investigated
- Applications using NORCOWE reference wind farm
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Thank you for your attention!