BAM
Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

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Reliability assessment of monitored jacket support structures of offshore wind turbines

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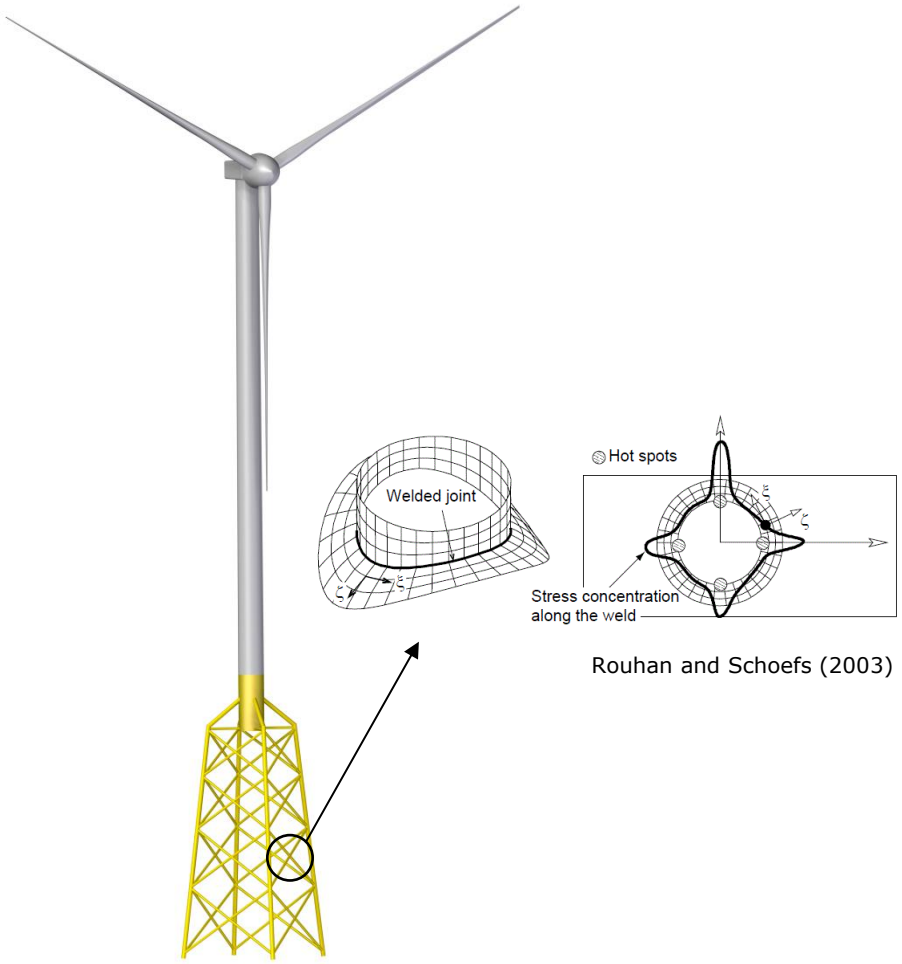
Fatigue of jacket structures

Linked picture: http://www.windkraft-journal.de/wp-content/uploads/2013/11/alpha-ventus.jpg

Reliability of jacket structures subjected to fatigue

Deterioration model

- Fatigue deterioration is modeled at hotspot level using fracture mechanics
- A welded connection fails as soon as a fatigue crack grows beyond a critical size
- A structural element fails as soon as a welded connection fails

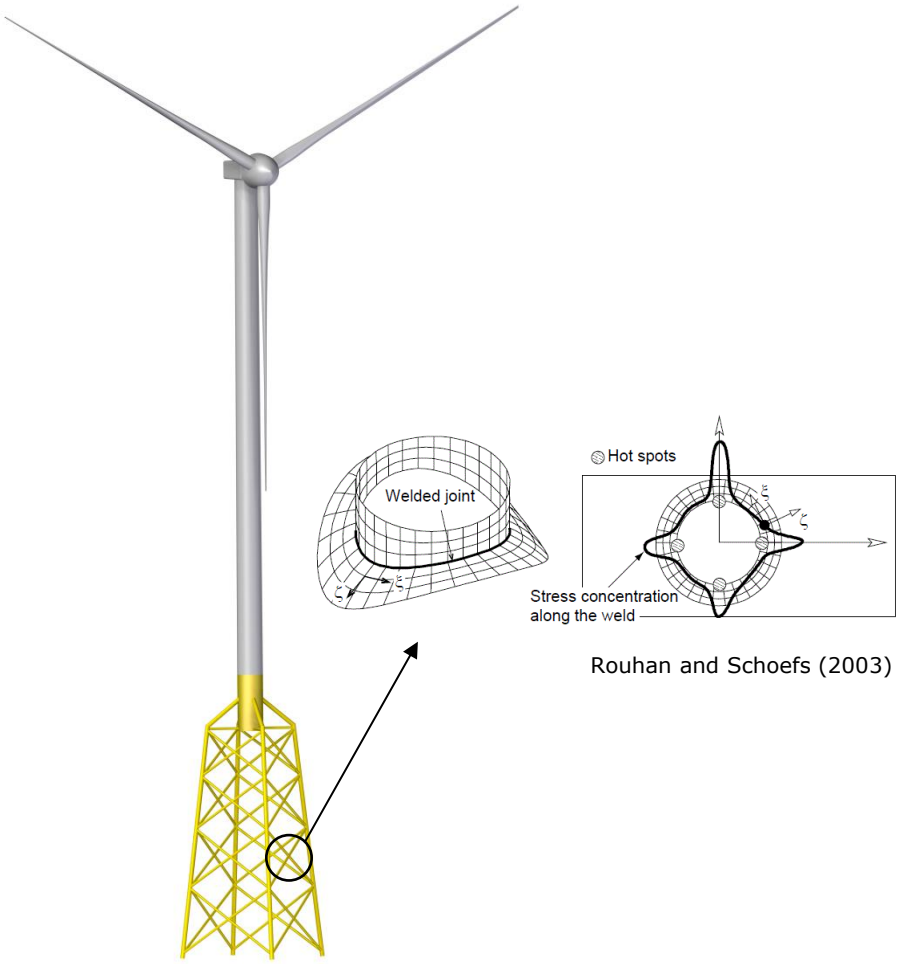


Rouhan and Schoefs (2003)

Deterioration model

Fatigue model parameters $\mathbf{X}$ are uncertain

- Random fatigue loading
- Material parameters
- Initial conditions
- Model uncertainties

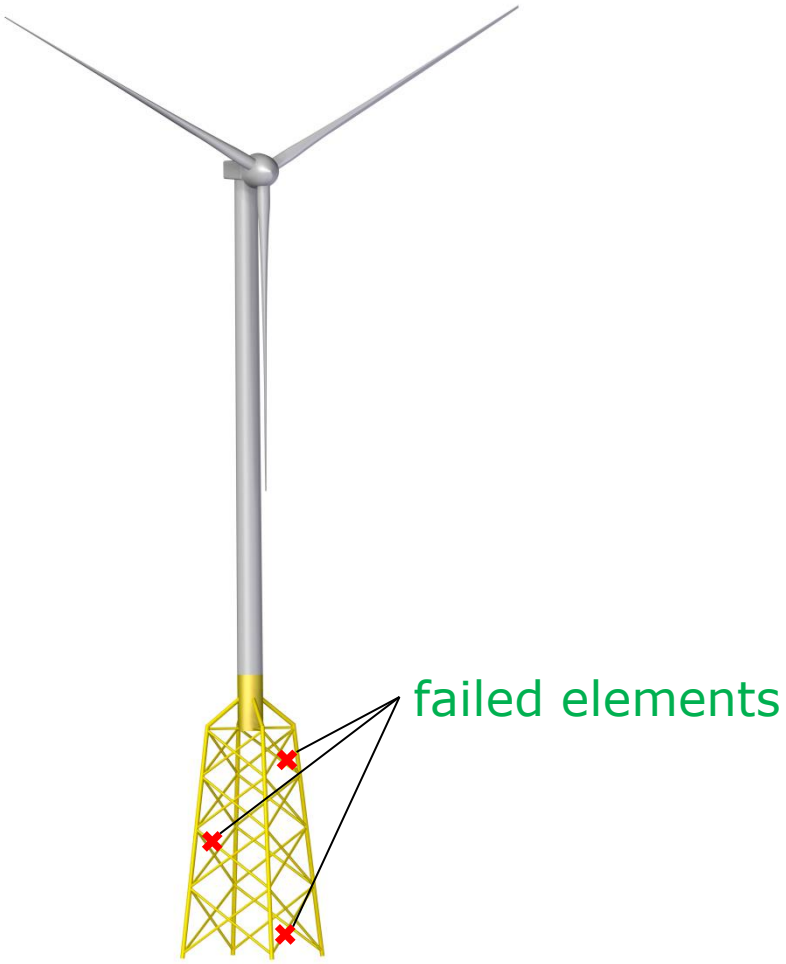


Rouhan and Schoefs (2003)

Deterioration model

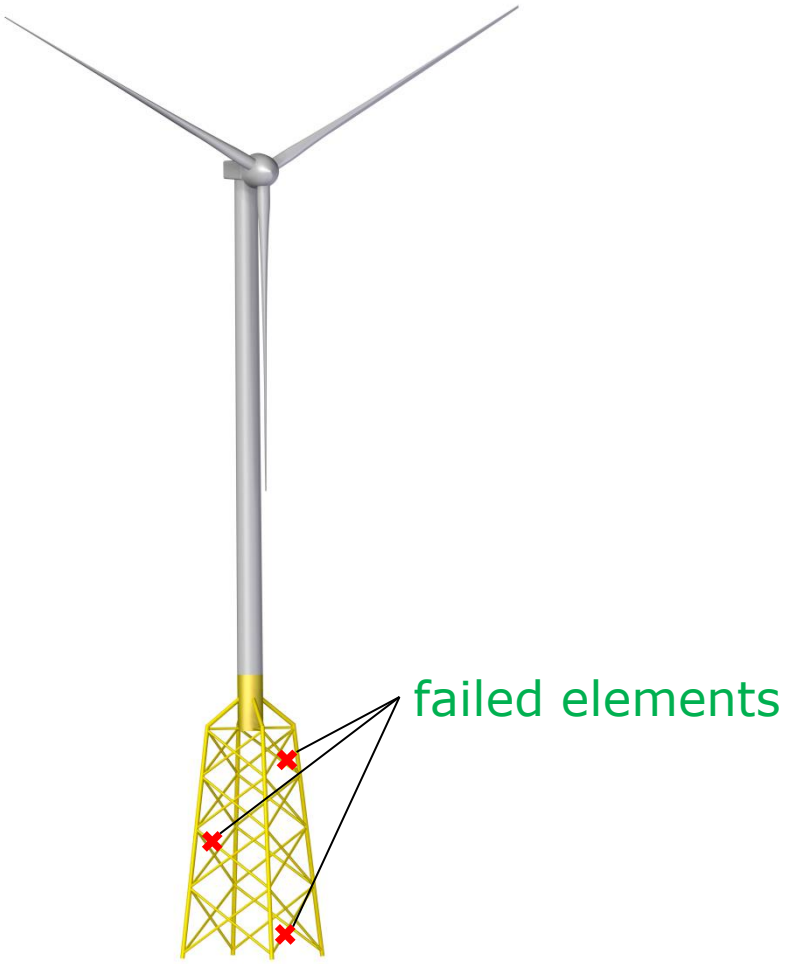
- System deterioration state $\mathbf{D}_t$ in terms of failed elements
- $\mathbf{D}_t$ is a function of uncertain fatigue model parameters $\mathbf{X}$

$$\mathbf{D}_t = h(\mathbf{X}, t)$$



Structural model

- Failure probability of weakened system
- Remove failed elements from structural model according to $\mathbf{d}_t$
- Compute conditional system failure probability $\Pr(F_t|\mathbf{D}_t = \mathbf{d}_t)$

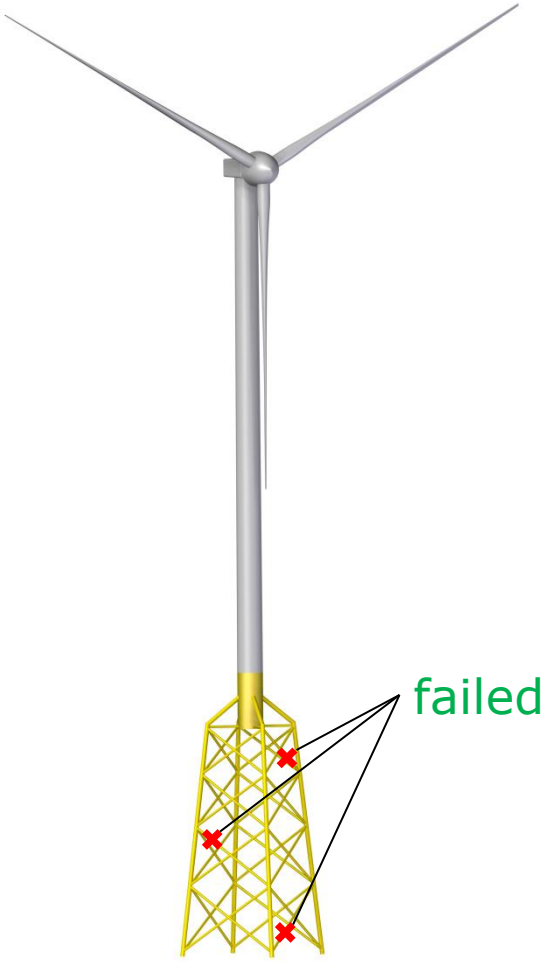


Coupling of deterioration and structural model

System failure probability

$$\Pr(F_t) = \int_{\mathbf{x}} \Pr(F_t|\mathbf{D}_t = h(\mathbf{x}, t))\, f_{\mathbf{X}}(\mathbf{x})\, d\mathbf{x}$$

$$= \int_{\mathbf{x}} \Pr(F_t|\mathbf{X} = \mathbf{x})\, f_{\mathbf{X}}(\mathbf{x})\, d\mathbf{x}$$

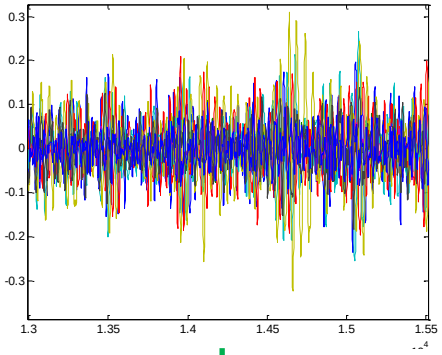


Reliability updating with damage detection information

Subspace-based damage detection

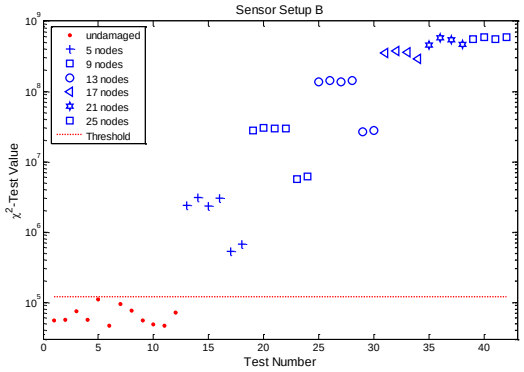
- Suitable for detecting fatigue damage in jacket structures
- Utilizes dynamic structural response without extracting modal parameters
- Dynamic response signals are processed by subspace-based damage detection algorithm
- Compares reference state with current state

Acceleration signals

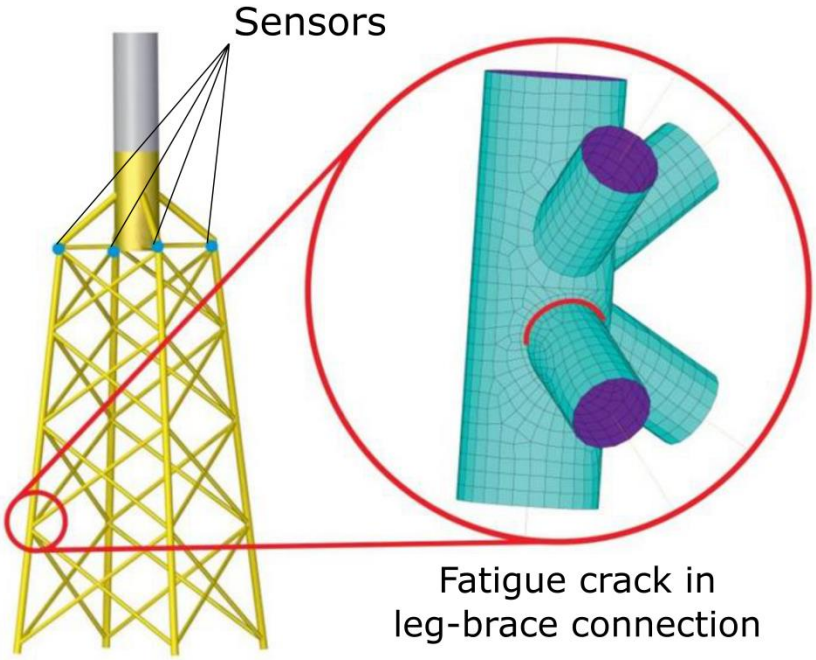


Subspace-based damage detection algorithm

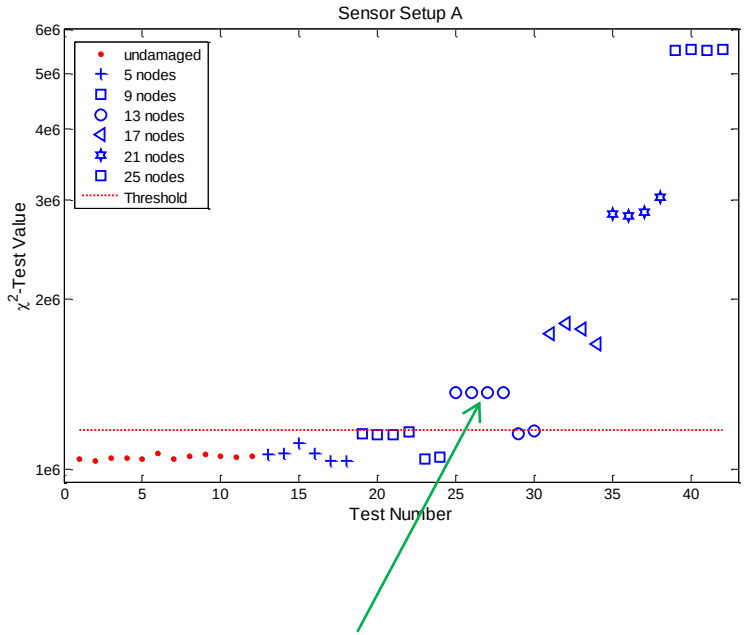
Damage indicator (detection/no detection)



Possible system configuration



Results from simulation



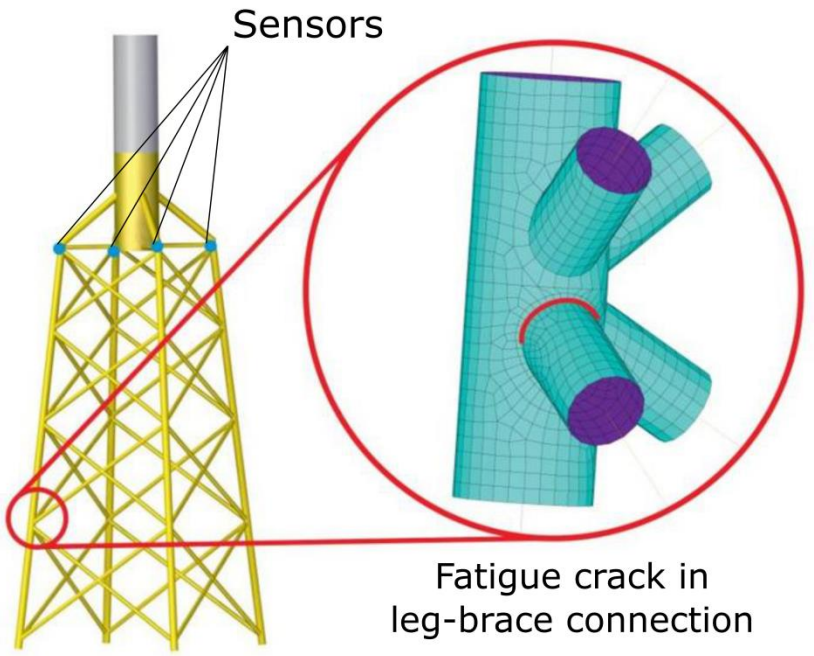
Detectable damage:
22% reduction in
bending stiffness

Probability of detection

Probability of detection $\Pr(Z|\mathbf{D}_t = \mathbf{d}_t)$ describes quality of detection system

Detection system is not perfect due to many uncertain factors:

- Environmental conditions
- Measurement uncertainties of sensor and amplifier system
- Uncertainties in damage detection algorithm



Likelihood function

Link between monitoring outcome and model parameters

$$\Pr(Z|\mathbf{D}_t = \mathbf{d}_t) \longrightarrow \Pr(Z|\mathbf{D}_t = h(\mathbf{x}, t)) \longrightarrow \Pr(Z|\mathbf{X} = \mathbf{x})$$

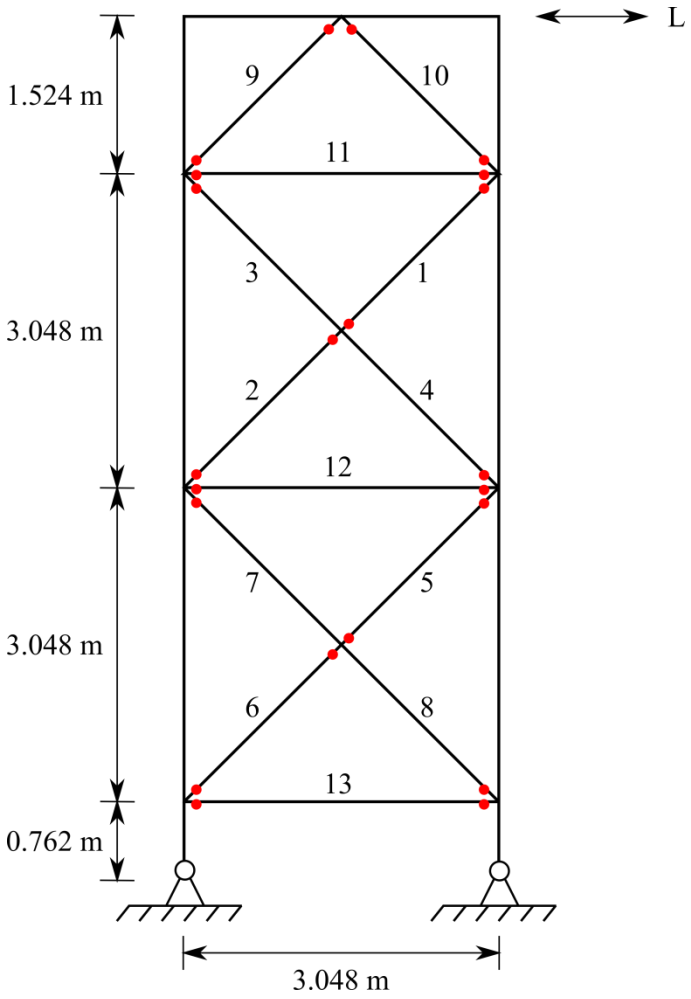
Bayes theorem

Updated system failure probability

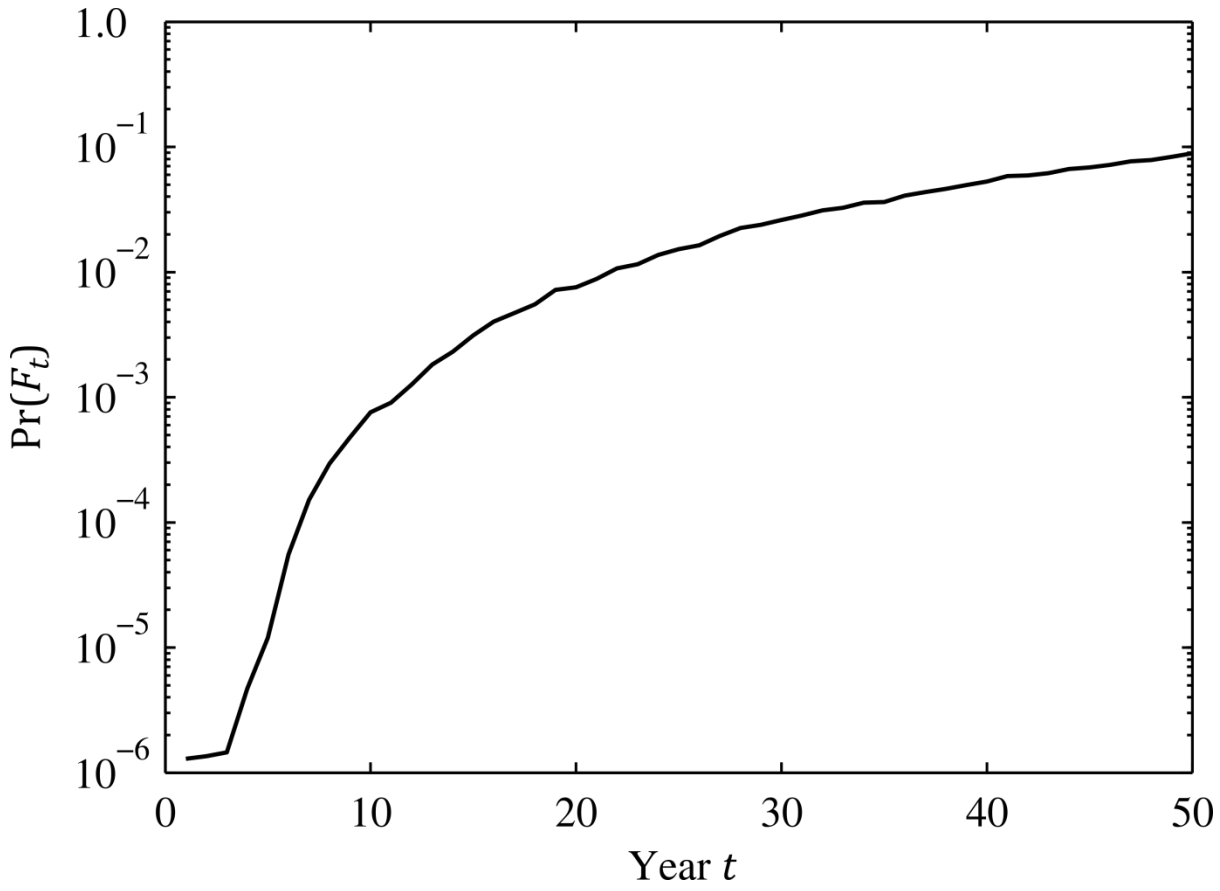
$$\Pr(F_t|Z) = \frac{\Pr(F_t \cap Z)}{\Pr(Z)} = \frac{\int_{\mathbf{x}} \Pr(F_t|\mathbf{X}=\mathbf{x}) \Pr(Z|\mathbf{X}=\mathbf{x}) f_{\mathbf{X}}(\mathbf{x})\, d\mathbf{x}}{\int_{\mathbf{x}} \Pr(Z|\mathbf{X}=\mathbf{x}) f_{\mathbf{X}}(\mathbf{x})\, d\mathbf{x}}$$

Numerical example

2D jacket-type structure

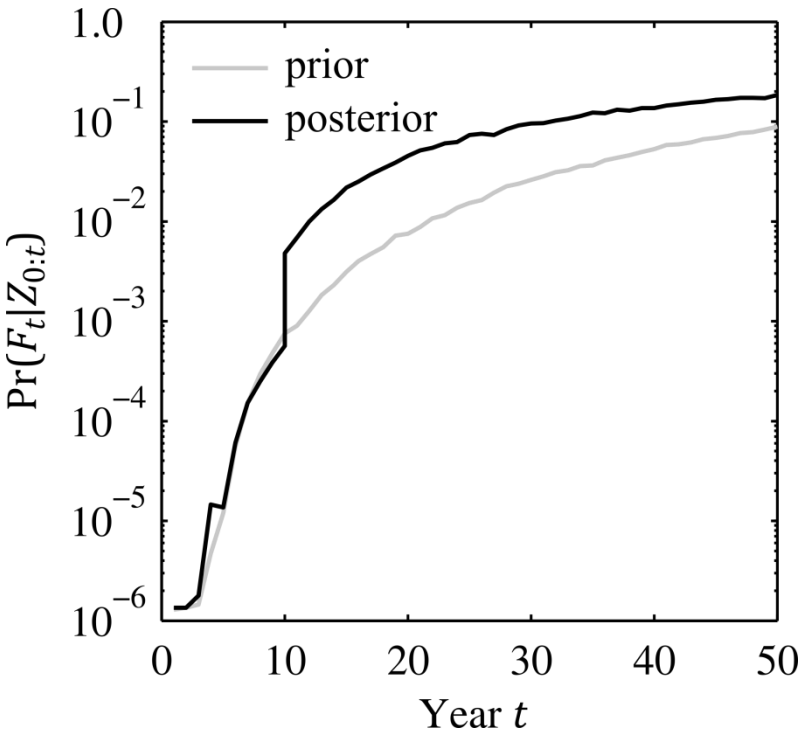


Prior system failure probability

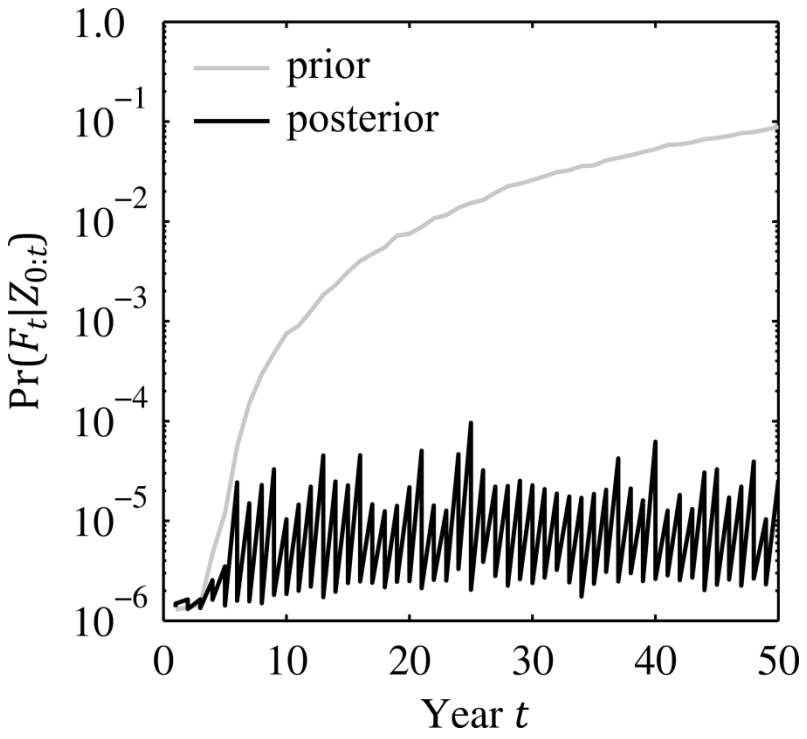


Posterior system failure probability

Monitoring in year 10
Damage detection



Monitoring once a year
No damage detection



Conclusions

Conclusions

- Reliability assessment of monitored jacket structures
- Damage detection system
- Probability of detection (active field of research!)
- Approach forms the basis for decisions on maintenance actions and future inspection efforts

References

- Hille F., Petryna Y., Rücker W. (2014): Subspace-based detection of fatigue damage on jacket support structures of offshore wind turbines, 7th European Workshop on Structural Health Monitoring, Nates France

- Schneider R., Thöns S. and Straub D. (submitted to *Structural Safety*, July 2015): Reliability analysis and updating of deteriorating structural systems with subset simulation.