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Drawing up an optimized maintenance plan for offshore support structures of wind turbine

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Abstract

With the growth of offshore renewable energy market and especially number of offshore wind farms, maintenance activities are increasing significantly. To limit the cost involved by this phenomenon, it becomes crucial to improve SHM based maintenance of welded joints of steel offshore structures submitted to fatigue process. The work relies both robust numerical computation and probabilistic updating from SHM.

Objectives

A robust method for fatigue analysis of offshore structures :

- Up to now, current fatigue design criteria for offshore structures are based on S-N curves, rainflow cycle counting method and the Miner-Palmgren approach. It is well-known this approach could be over-conservative. In addition, most current fatigue analysis are based on spectral method. This last method does not allow engineers to take into account **time-dependent parameters**.

A probabilistic-based approach for fatigue analysis of offshore structures :

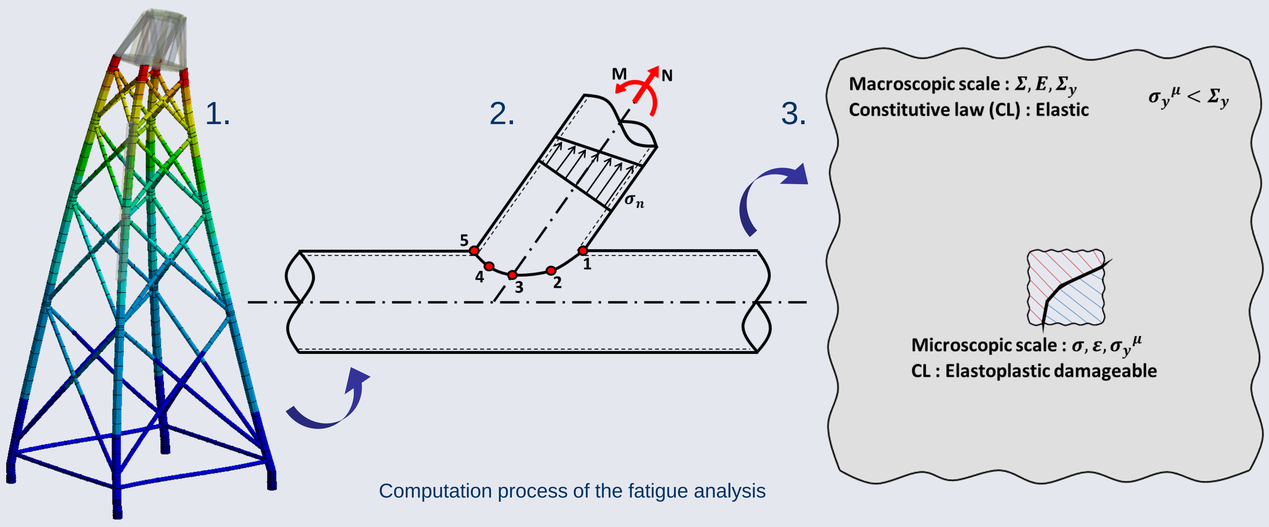
- Because fatigue design parameters have significant uncertainty, a probabilistic approach is also currently under investigation. This method allows us to take into account :
  - Uncertainty of materials parameters included in fatigue analysis.
  - Environmental variability like wave direction, mean wind speed, etc.
  - Uncertainty of measurements issued of structural health monitoring

Fatigue model

A method based on a **two-scale model for high-cycle fatigue life predictions** is currently under development. This method has to take into account the environmental variability like wave direction, mean wind speed, etc. to create a representative time history. This method may be divided in **three steps** :

1. A realistic dynamic coupling method integrating aerodynamic loads, hydrodynamic loads and structural responses of the entire wind turbine is used to compute **time series of loads** applied on the support structure.

2. **Time series of stress** are obtained using a finite element code.

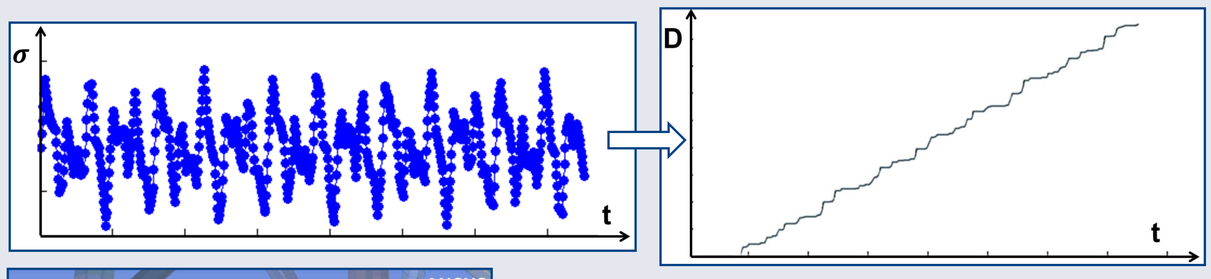


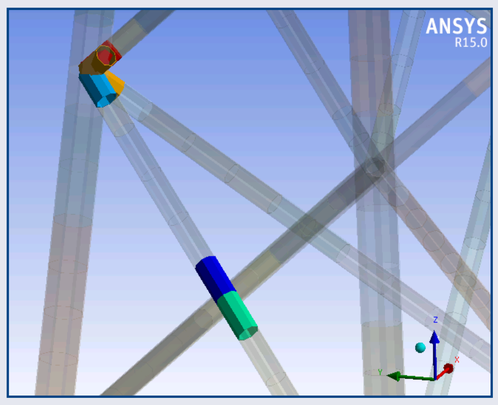
Computation process of the fatigue analysis

3. Sheet metal fabrication and assembly by welding have the disadvantage of being difficult to control. Both processes generate microcracks which are the starting points of macroscopic cracks. Based on this phenomenon, a post-processing of strain results has been performed using the **two scale damage concept** developed by Lemaitre & Desmorat (1).

- Isotropic damage D and effective stress $\tilde{\sigma}$: $$\tilde{\sigma} = \frac{\sigma}{1-D} \quad \text{(I)}$$
- Localisation law of Lin-Taylor : $$\varepsilon = \mathrm{E} \quad \text{(II)}$$
- Damage rate :
  - Cumulative plastic strain threshold $$\dot{D} = \left(\frac{Y}{S}\right)^{s} H(p - p_d)\dot{p} \quad \text{(III)}$$
- Linear kinematic hardening
  - Yield function of plastic criterion : $$f(\tilde{\sigma}, X) = \sqrt{\frac{3}{2}}\|\tilde{\sigma}^{D} - X\| - \sigma_y \quad \text{(IV)}$$

Results for deterministic fatigue analysis

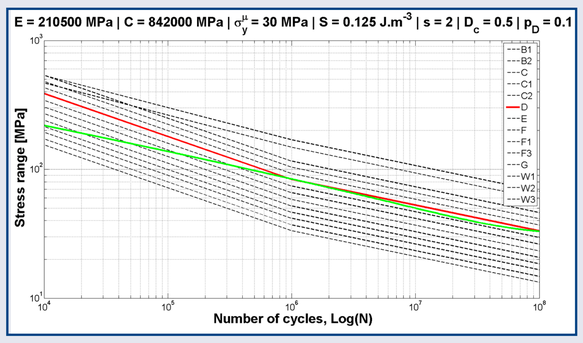




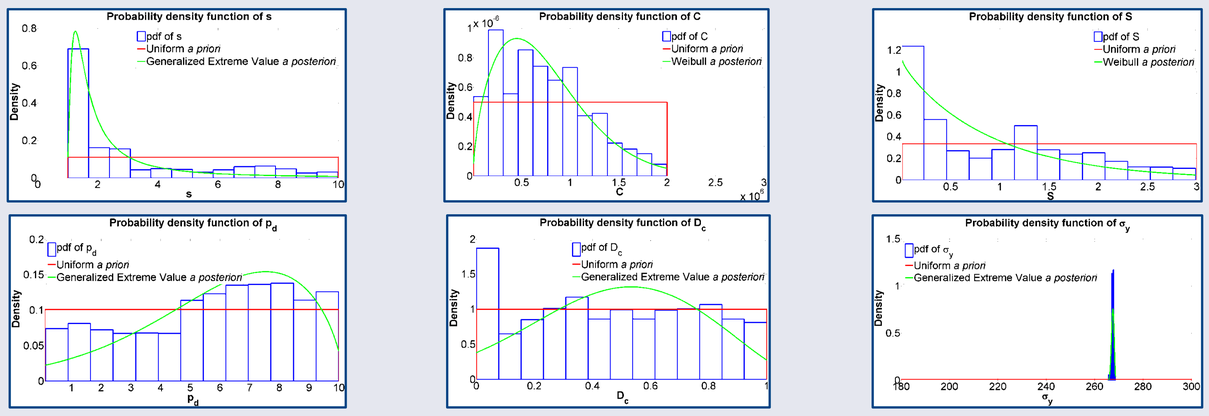
Fatigue analysis is realized for 8 points regularly distributed along the welded tubular joint. For each inspection point, the time-series of stress is an input for the two scale damage model. Damage can be followed all along the study. Reports and damage visualizations are created because the process is integrated in ANSYS Workbench software.

Bayesian updating

Material parameters have to be calibrated over S-N curves defined in classification rules. They can be presented as random variables and their variability can be estimated/updated using Bayesian updating based on Monte Carlo Markov Chains (2).



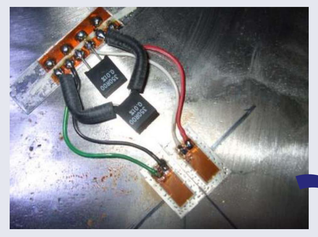
Parameters calibration based on D curve from DNV-RP-C203



Probability density functions of material parameters after Bayesian updating

On going work

Probability of failure can be estimated by using fatigue model and knowledge of variability around parameters (marine growth thickness, corrosion, ...). This is a reliability analysis. This probability can be updated due to SHM or inspections. Following the time evolution of the failure probability, inspection and/or maintenance can be planned. As a perspective, an optimization can be performed in order to reduce operation cost.



Picture from Faulkner (3)

Updated finite elements analysis (Cd, thickness…) and two scales model parameters

Conclusion

Thanks to the structural health monitoring, it allows to have real-time state information to update life expectation of offshore structures and then anticipate their maintenance requirements. With this new fatigue design method of offshore support structures, mixing numerical analysis and structural health monitoring, **reducing future cost of inspection and maintenance** (OPEX) regarding offshore wind farms becomes real. This work is of real interest in an environment where the cost of production of electric power must be reduced.

References

(1) Jean Lemaitre & Rodrigue Desmorat, Engineering Damage Mechanics : Ductile, Creep, Fatigue and Brittle Failures, 2004

(2) B. Rocher, F. Schoefs, M. François, A. Salou., Bayesian Updating of Probabilistic Time-Dependent Fatigue Model: Application to Jacket Foundations of Wind Turbines. *EWSHM – 7th European Workshop on Structural Health Monitoring*, Jul 2014, Nantes, France.

(3) P. Faulkner, P. Cutter and A. Owens, Structural Health Monitoring in Difficult Environments – Offshore Wind Turbines, *EWSHM – 6th European Workshop on Structural Health Monitoring*, Jul 2012, Dresden, Germany