SurFFEol

BAYESIAN UPDATING OF PROBABILISTIC TIME-DEPENDENT FATIGUE MODEL: APPLICATION TO JACKET FOUNDATIONS OF WIND TURBINES

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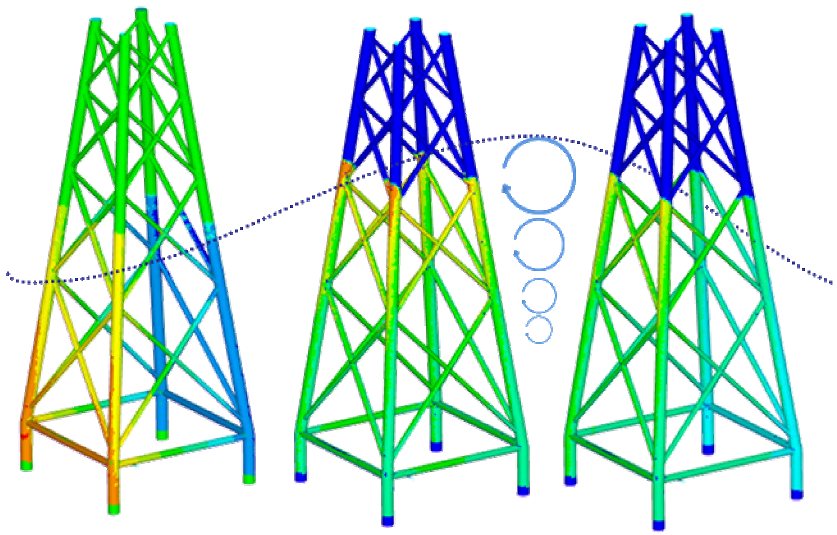
Precend, Nantes, 04/03/2015

(1) STX Europe Offshore Energy Business Unit

Framework :

1. Introduction
2. Monitoring
3. Fatigue
4. Parameters identification
5. Conclusions



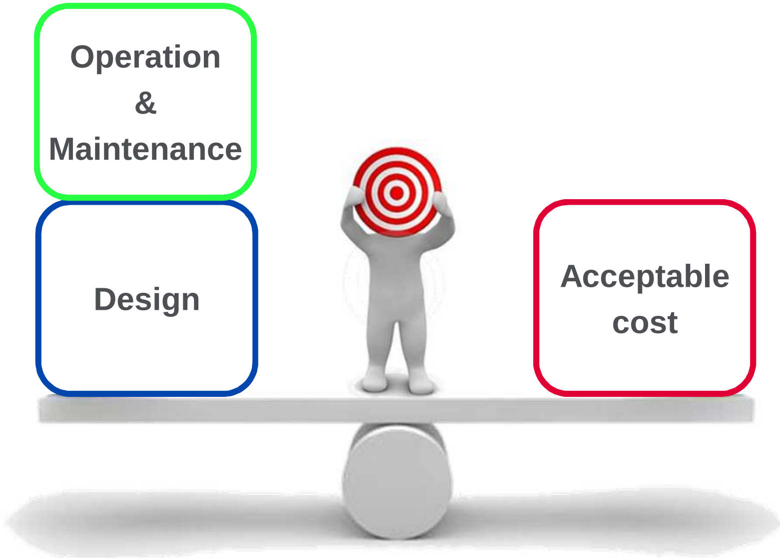
Introduction :

Offshore wind turbine

STX France Solutions strategy :

- Jacket fabrication for OWT
- “The lighter it is, the better is.”

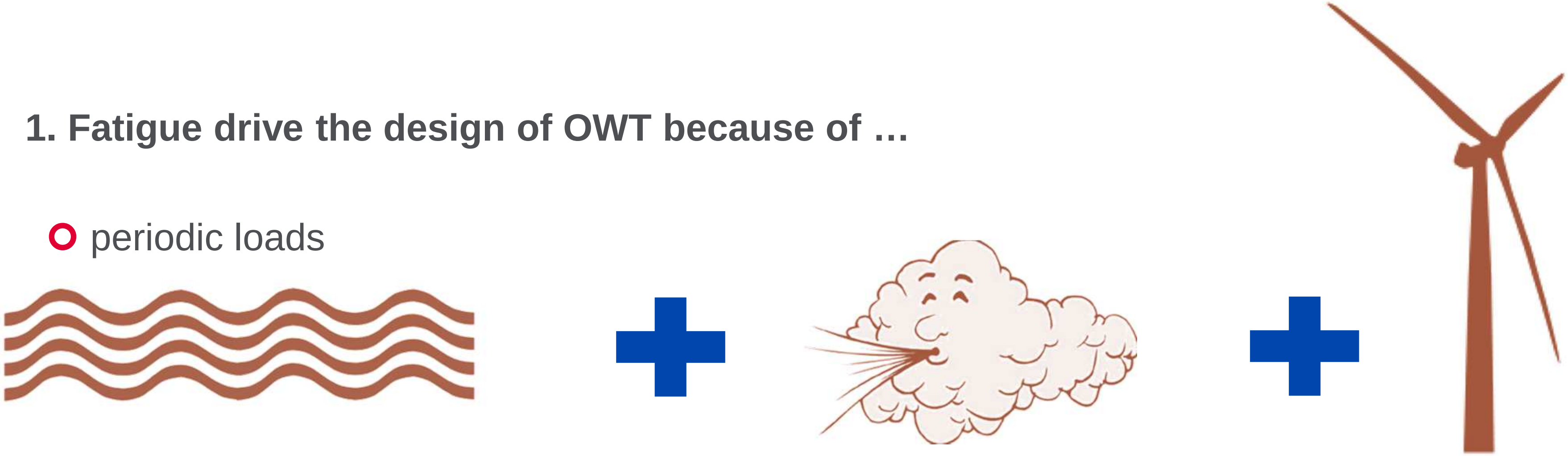
The O&M plan has to be adapted !



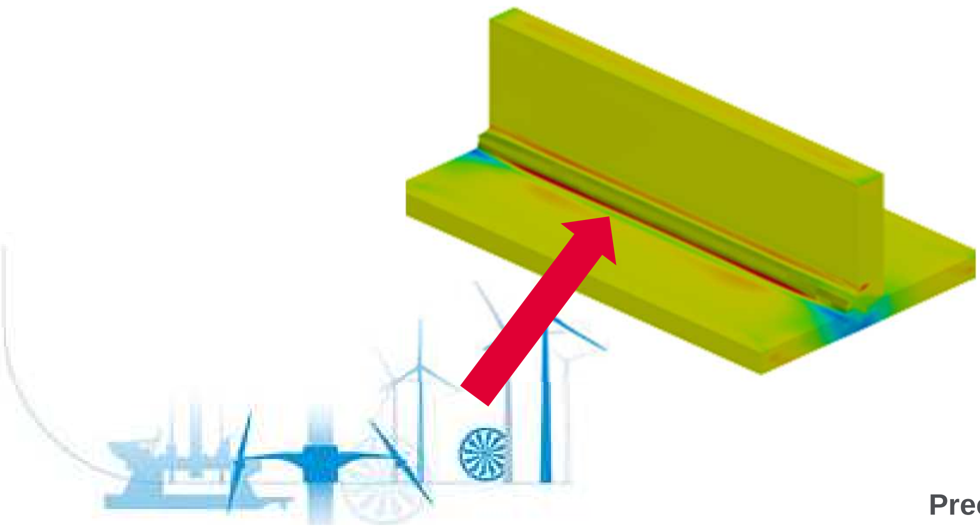
What do we know ?

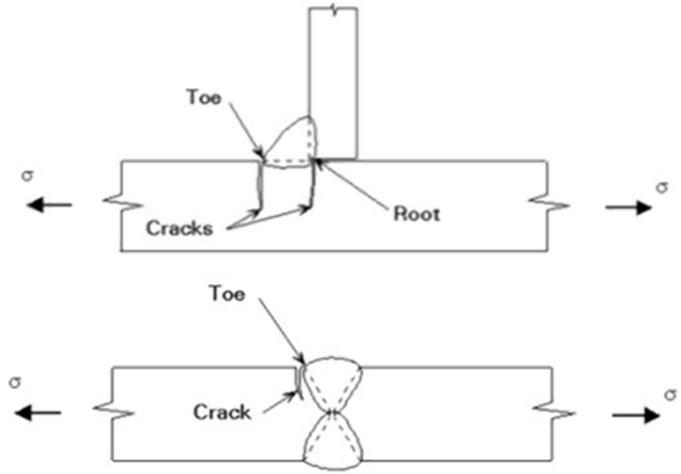
1. Fatigue drive the design of OWT because of …

- periodic loads



- and steel welding create stress concentrations

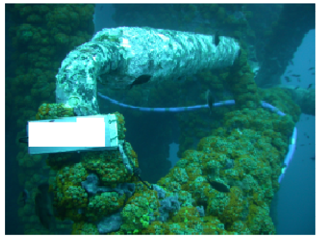




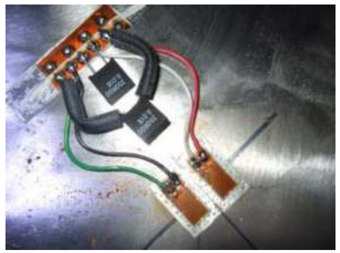
What do we know ?

2. We can use sensors to monitor :

- Environmental parameters
  - Waves height, current and wind speed …



- Structural degradation
  - Marine growth, Corrosion



- Structural monitoring
  - Time series of stress or strain, cracks

State of the art :

- **Guedes Soares C., Garbatov Y.,** « Reliability of maintained ship hulls subjected to corrosion », Journal of Ship Research, Vol. 40, N°3, pp. 235-243 — 1998
- **Moan T., Johannesen J.M., Vårdal O.T.,** « Probabilistic Inspection Planning of Jacket Structures », Offshore Technology Conference, Houston, Texas — 1999
- **Sorensen J.D., Tarp-Johansen N.J.,** « Reliability-based Optimization and Optimal Reliability Level of Offshore Wind Turbines », International Journal of Offshore and Polar Engineering, Vol. 15, N°2, June 2005, pp. 141-146. — 2005
- **Dong W., Moan T., Gao Z.,** « Fatigue reliability analysis of the jacket support structure for offshore wind turbine considering the effect of corrosion and inspection », Reliability Engineering and System Safety 106 11-27 — 2012

State of the art / Differences

Gain :

- 70-80% gain of inspection plan and 3-4x more cracks identified [Moan, 1999]

Why this gain ?

- Redundant structures

Why are we different ?

- Less redundant structures

Scientific objective :

Using a fatigue analysis with a crack initiation approach in a reliability analysis

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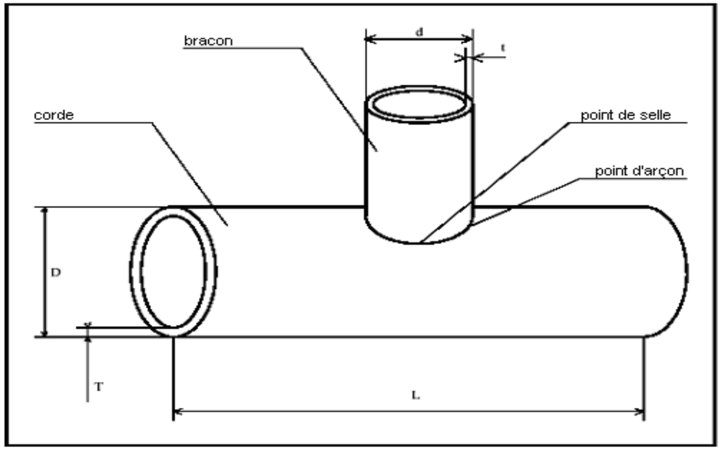
Instrumentation sur BioColmar : cadre SurFFEol

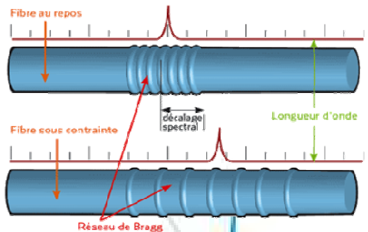
Acteurs : C. Lupi, B. Rocher, Y. Lecieux, D. Leduc, M. Roche, X. Chapeleau (IFSTTAR), S. Chataigner (IFSTTAR), L.M. Cottineau (IFSTTAR) et F. Schoefs

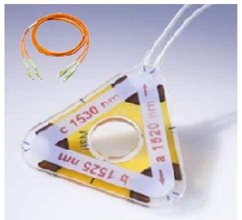


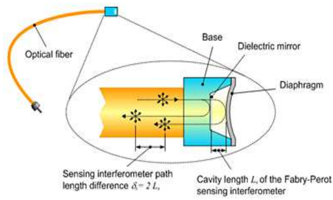
$$\alpha = \frac{2L}{D}$$
$$\beta = \frac{d}{D}$$
$$\gamma = \frac{t}{T}$$
$$\delta = \frac{g}{D}$$

Smart Sensors and integrated SHM system for offshore structures – Duan et al. - 2005

Mesures de déformations par Capteurs à fibres optiques : Bragg et Fabry-pérot







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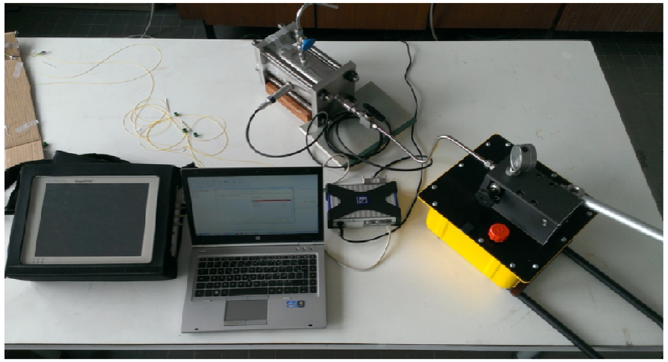
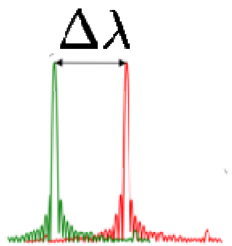
Architecture et étalonnage des capteurs de déformations

Architecture :

3 capteurs en rosettes soudés un par un sur le nœud pour accéder à une information de déformation tensorielle en surface.

1 capteur positionné à l'intérieur du tube libre de contrainte pour compenser les effets de températures et pressions.





$$\lambda = 2n_{\text{eff}}\Lambda$$

Caractérisation des produits du fournisseur en Pression et Température pour correction et protocole de correction établi.

Stratégie d'instrumentation

Caractéristiques des capteurs retenus :

- **Sensibilité 1.2 pm/µepsilon**
- **Gamme mesure ± 2500 µepsilon**
- **Weldable stainless steel package**
- **Dimension 50 (mm)*15 (mm)*0.3(mm)**
- **Poids: 3 g**

Caractéristiques du dispositif de mesure retenu :

- **4 voies de mesures avec 16 capteurs/voies**
- **Répétabilité a) 1 pm pour 1Sampling/s**
  b) 5 pm pour 100 Sampling/s

Acquisition de données :
Station Pégase IFSTTAR

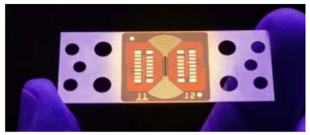
Stratégie d'instrumentation:

Bouclage avec dimensionnement
gamme de déformation subie par nœud

Optimisation Multiplexage en longueur d'onde

Instrumentation nœud T
en fibre optique : pérennité
du capteur dans l'eau sur 20
ans

Confrontation divers capteurs sur essais fatigue :
Jauges résistives et Capteur de Fatigue CrackFist



Instrumentation sur BioColmar : cadre SurFFEol

Biocolonisation

Inspections régulières par plongée ou dispositif optique.

Evaluation de la surépaisseur et de la rugosité

Acteurs : F. Schoefs (GeM), M. O'Byrne (Capacités), A-L. Barillé (Biolittoral), L. Barillé (Biolittoral) et H. Ameryoun (GeM)

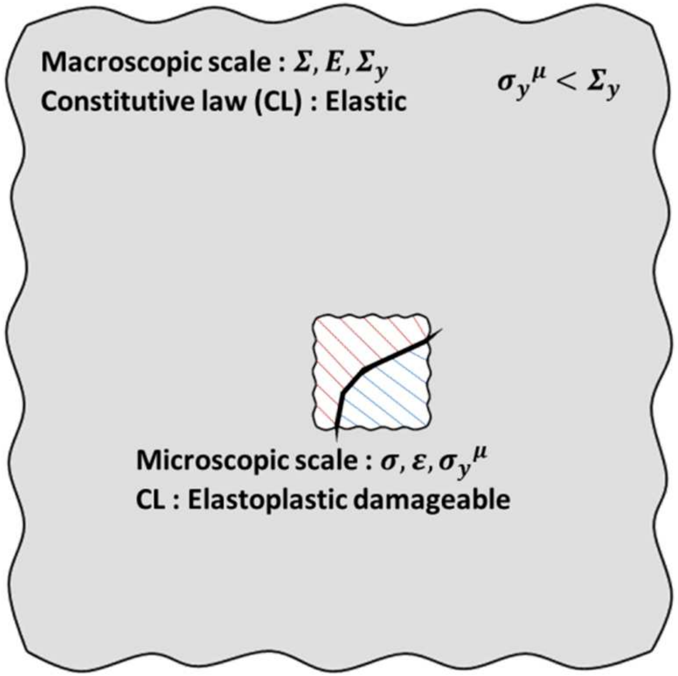
Corrosion

Enregistreur pour la détermination des critères de protection cathodique

Enregistreur de Potentiel de Corrosion 8 voies

Acteurs : L. Gaillet (IFSTTAR) et M. Denecker (IFSTTAR)

Elastoplastic model …



Two scale model [Lemaitre et al., 2004] :

- Fatigue : $\sigma_y{}^{\mu} < \sigma < \Sigma_y$

Localisation :

- Eshelby-Kröner : $\varepsilon = E + b(\varepsilon^p - E^p)$
- Lin-Taylor (1957) : $\varepsilon = E$

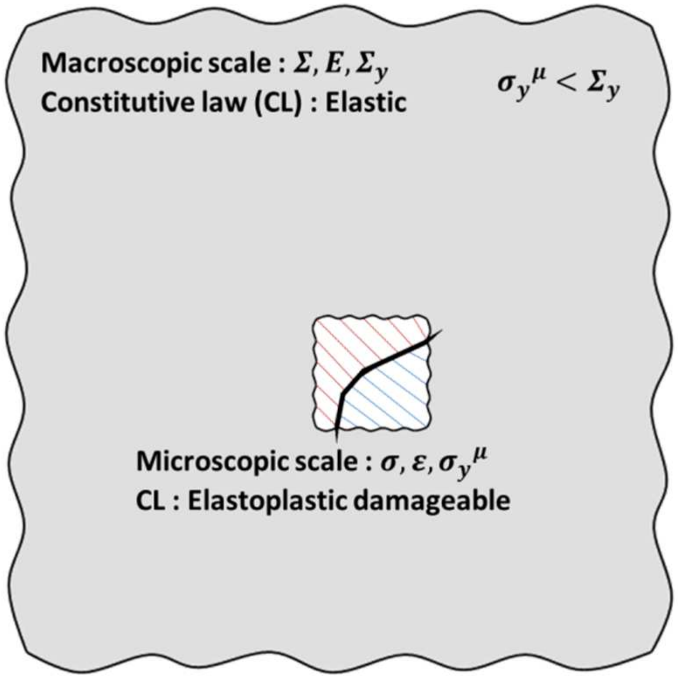
$$b = \frac{2(4-5\nu)}{15(1-\nu)}$$

Hardening :

- Linear kinematic
- Nonlinear kinematic
- Isotropic
- Combination

Snecma

… damageable

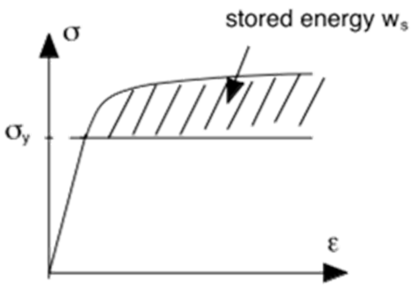


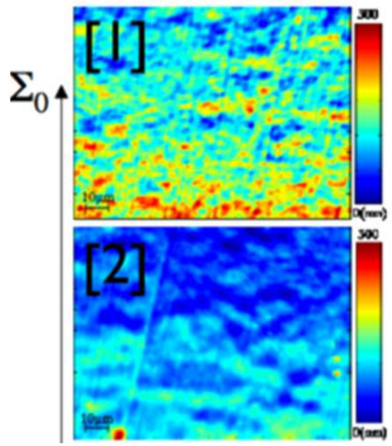
Damage :

- Isotropic ; Orthotropic ; Anisotropic
- Symmetric ; Asymmetric

Damage rate :

- $dD = \left(\frac{Y}{S}\right)^s dp.\mathcal{H}(p - p_d)$
- $dD = \left(\frac{Y}{S}\right)^s dp.\mathcal{H}(w_s - w_d)$





[Poncelet, 2007]

Advantages :

- Mean stress and stress history

$$D = \mathcal{M}_{inc}\left(E(M,t); C, \sigma_y{}^{\mu}, S, s, p_d, D_C\right)$$

Computation process

Beam model

- Wind and wave loads

Step 1

- Loads or displacements

SCF + Stress

- Loads or displacements application

Step 2

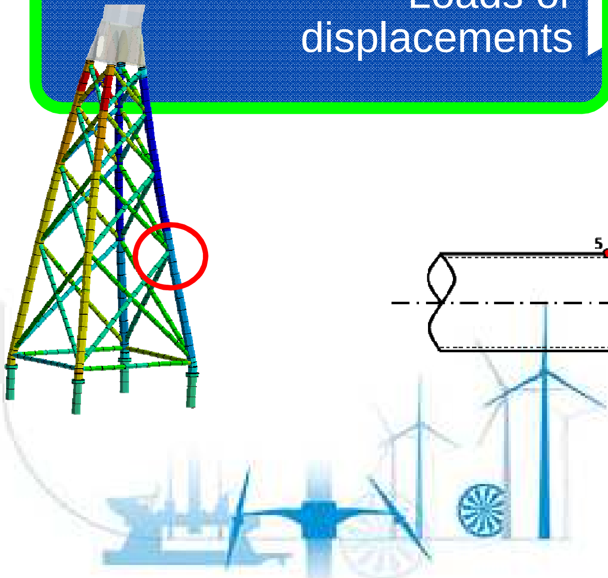
- Combined normal stresses

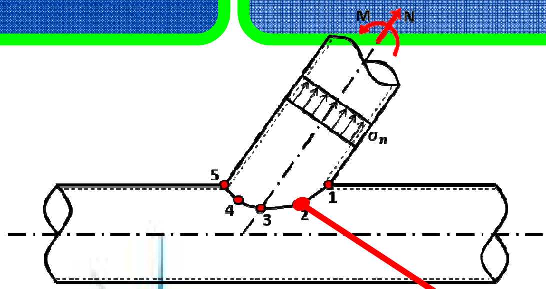
Post-treatment

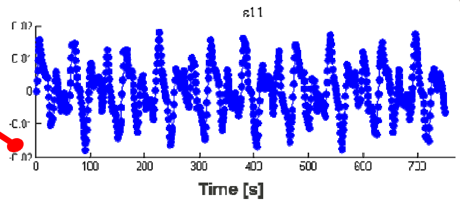
- Solve : Two scales damage model

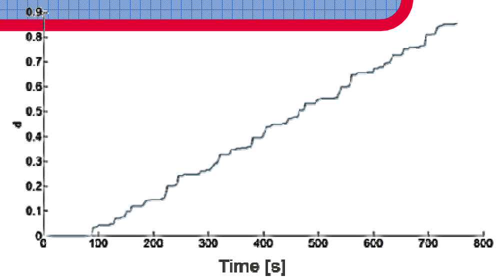
Step 3

Damage



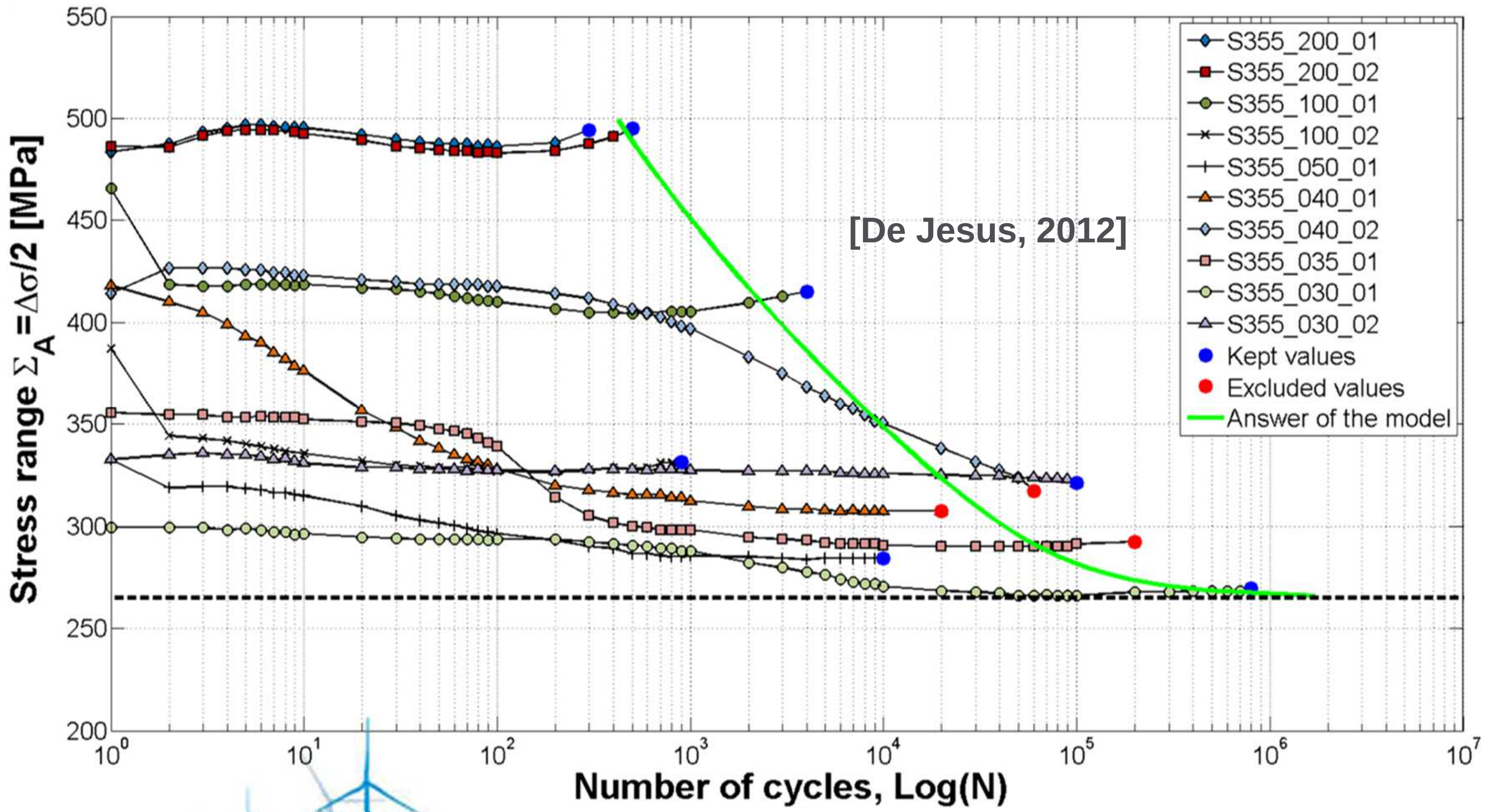




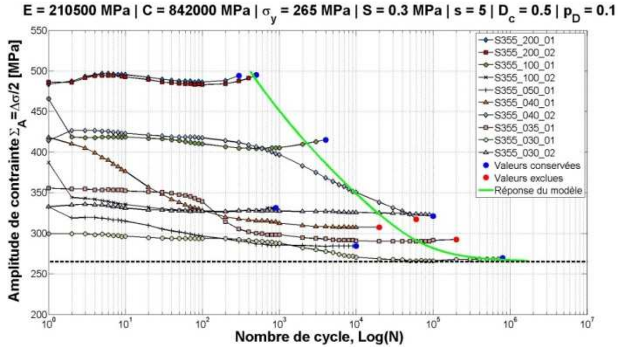


Parameters identification

Analytical expression : $N_R = \mathcal{M}_{an}\left(\varepsilon(M,t); C, \sigma_y{}^{\mu}, S, s, p_d, D_C\right)$



Bayesian updating :



Why ?

- Random observations
- Inverse problem

Principle :

- Enrich the priors of z parameters from observations $y(z_p)$
- Maximizing the likelihood function

$$f_X(x) = \frac{1}{c} p_X(x) L\left(x, \boldsymbol{Y}^{obs}\right)$$

Results :

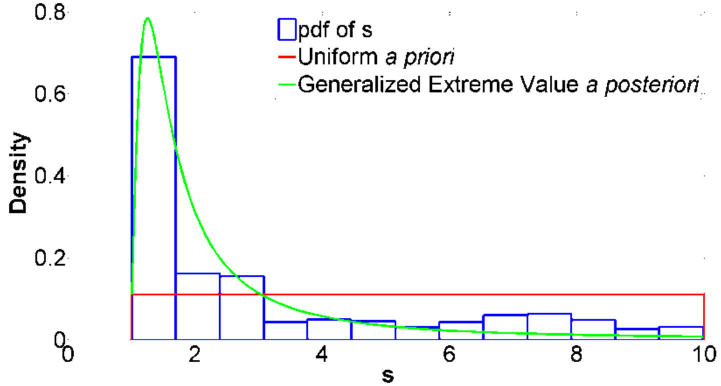
- Posterior distribution of the parameters

$$L\left(z, Y^{obs}\right) = \prod_{p=1}^{P} \varphi\left(\frac{M_{an}(z) - y\left(z_p\right)}{\sigma}\right)$$

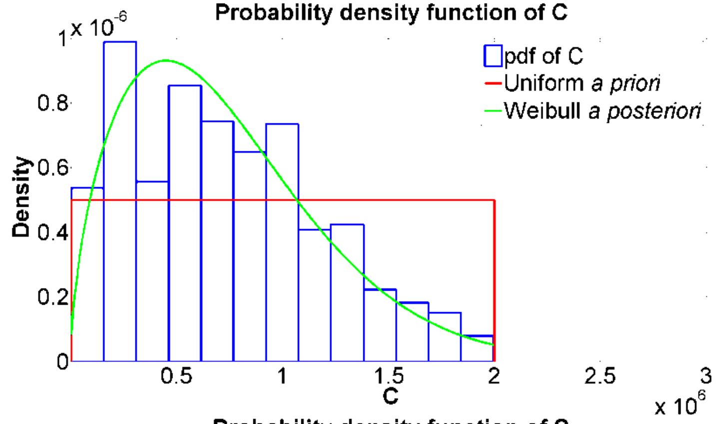
Assumptions over parameters :

- Independent variables
- Uniform distribution a priori

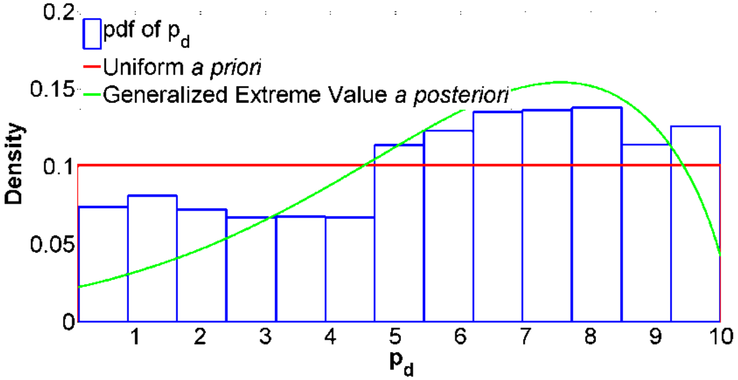
Probability density function of s



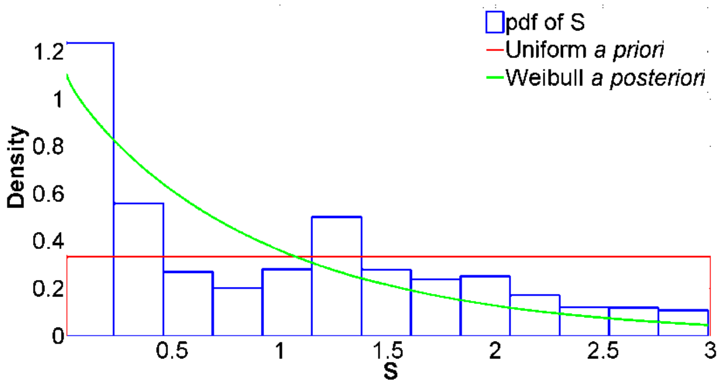
Probability density function of C



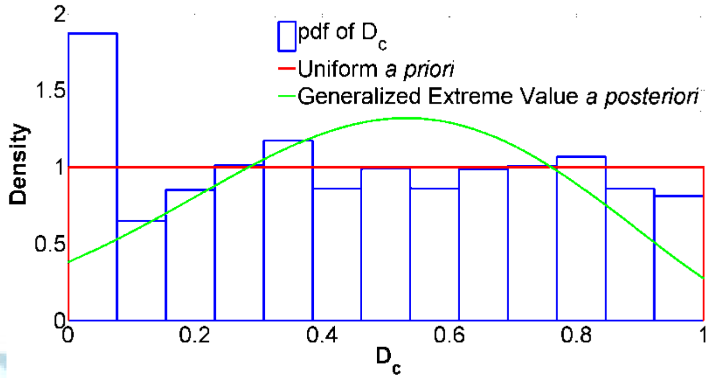
Probability density function of p_d



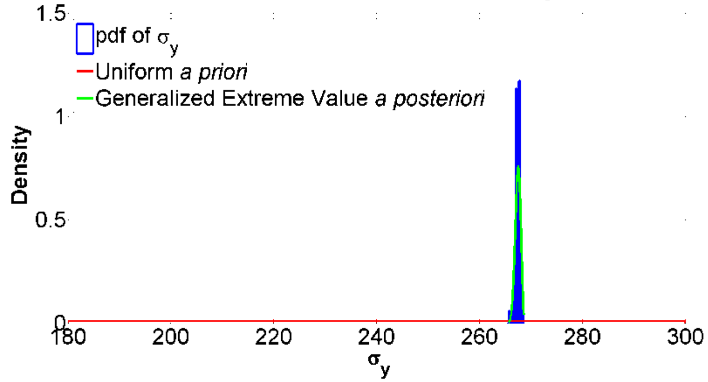
Probability density function of S



Probability density function of D_c



Probability density function of σ_y



Conclusions :

We presented :

- A new method for fatigue analysis which can be updated
- A parameter updating from laboratory tests
- SurFFEol, a project to understand the structural degradations.

The locks :

- Computation process may be time consuming

Outlook :
Updating from SHM

Environmental conditions :

- Wind / wave

Corrosion :

- Thickness
- C_D, C_M

Marine growth :

- Thickness
- C_D, C_M

Structural monitoring :

- Stress / Strains
- Crack

Beam model

Step 1

- Wind and wave loads

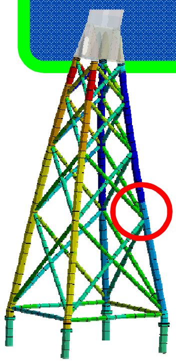
- Loads or displacements

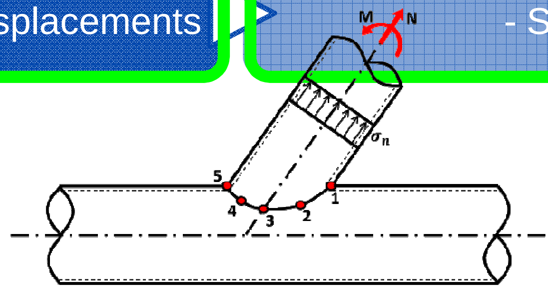
Solid model

Step 2

- Loads or displacements application

- Strains





Post-treatment

Step 3

- Solve : Two scales damage model

Damage

References :

De Jesus A. M. P., « A comparison of the fatigue behavior between S355 and S690 steel grades », *Journal of Construction Steel Research*, 2012

DNV-RP-C203, Fatigue Design of Offshore Steel Structure, 2011

Dong W., Moan T., Gao Z., « Fatigue reliability analysis of the jacket support structure for offshore wind turbine considering the effect of corrosion and inspection », *Reliability Engineering and System Safety*, Elsevier, 2012

Dubourg V., Adaptive surrogate models for reliability analysis and reliability-based design optimization, Thèse de doctorat, Université de Blaise Pascal – Clermont II, 2011.

Lemaitre J., *A Course on Damage Mechanics*, Dunod, 1996.

Lemaitre J., Desmorat R., *Engineering Damage Mechanics*, Springer, 2004.

Magnusson A. K., Variability of sea state measurements and sensor dependence, Brest, 30-01 septembre 2013

Poncelet M., Multiaxialité, hétérogénéité intrinsèques et structurales des essais d'auto-échauffement et de fatigue à grand nombre de cycles, Thèse de doctorat, LMT Cachan, 2007.

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Questions ?

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