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Reliability approach for fatigue design on mechanical structure in agricultural domain

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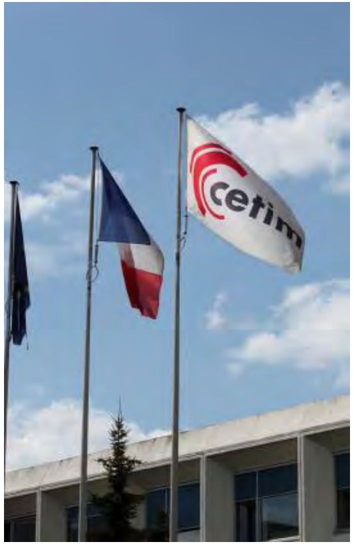
Mechanics,
the source of life and civilisation



629,000 employees, 1st industrial employer in France

121,8 billion Euros of turnover

with more than 40 % concerning export

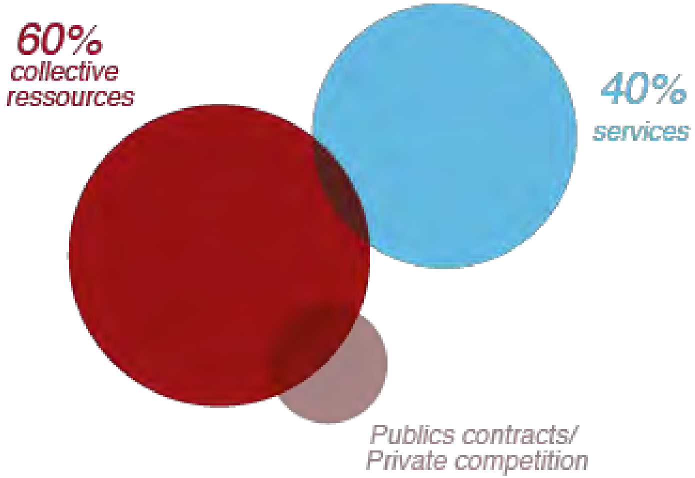
30 200 companies

Any material object is built from mechanical intervention

CETIM, Technological institute of mechanics

Steered by mechanical industrialists under the State's supervision

A **M€ 113** overall business volume



Régi par les articles L521.1 à L521.13 du code de la recherche

6 500 contributing enterprises

- 3 main sites : Senlis, Nantes, Saint-Etienne
- 18 delegations
- 4 associated centres
- Mechatronic centre, NDT centre
- Testing centres

Fondationcetim
sous l'égide de la Fondation de France

Summary

Context…

Fatigue phenomenon involves both safety and economic issues

"...Between 80 - 90% of all structural failures occur through a fatigue mechanism…" "...and could be reduced by 30% by application of current technology…" Battelle Institute.

Hatfield UK, 2000 – rail failure

Hawaii 1988, lap joint failure

Context…

Definition of Fatigue:

Failure under a repeated or otherwise varying load which never reaches a level sufficient to cause failure in a single application.

The initiation and growth of a crack, or growth from a pre-existing defect, until it reaches a critical size.

- Difficult to detect
- sensible of process quality
- Finale breakage in the end.
- Accident cause
- Engaged Manufacturer responsibility

Fatigue behaviour in the design phase of conception

Context…

25.02.2017

Introduce reliability approach in fatigue Design to give a competitive edge in the agricultural industries:

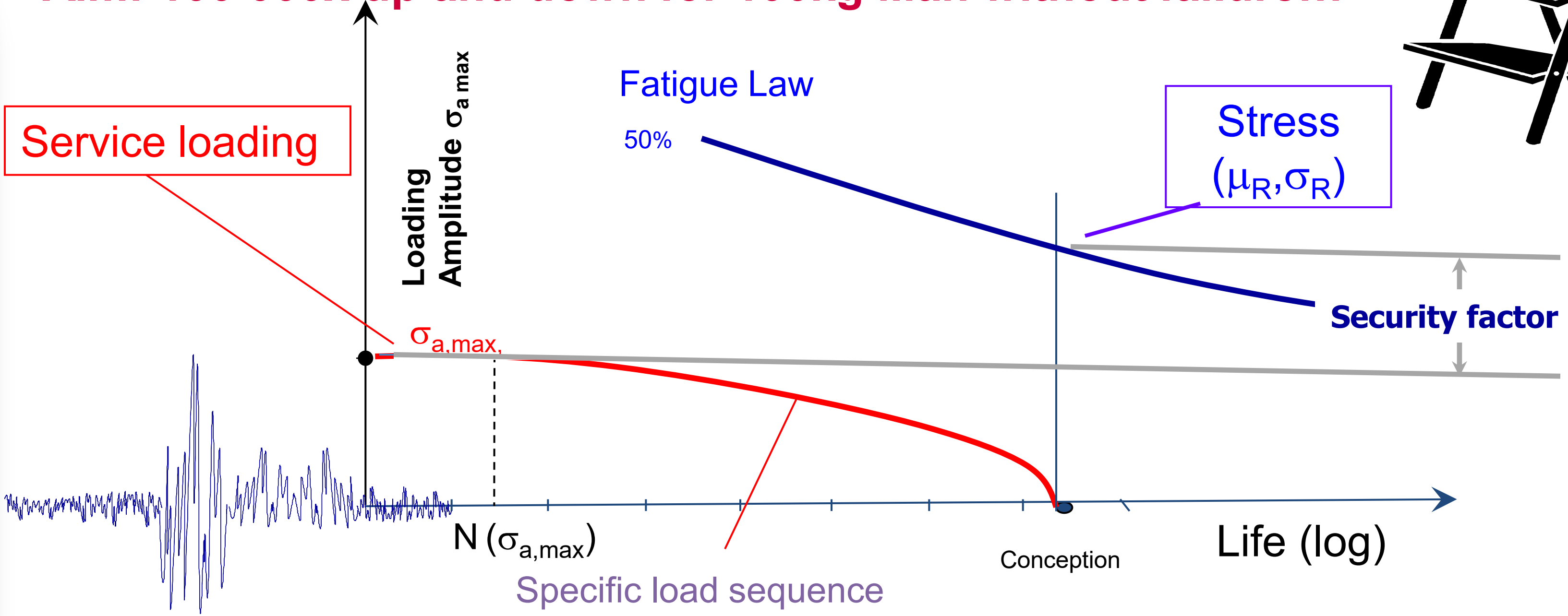
- Failure under a repeated or otherwise varying load which never reaches a level sufficient to cause failure in a single application.
- To develop a general method
- To create tools in a software platform to quantify the risk
- To write Guidance notes and recommendations based on Experienced know how

→ Project management by
the quantification of the risk of failure

Reliability approach 1/5

Stepladder Design – Determinitic approach:

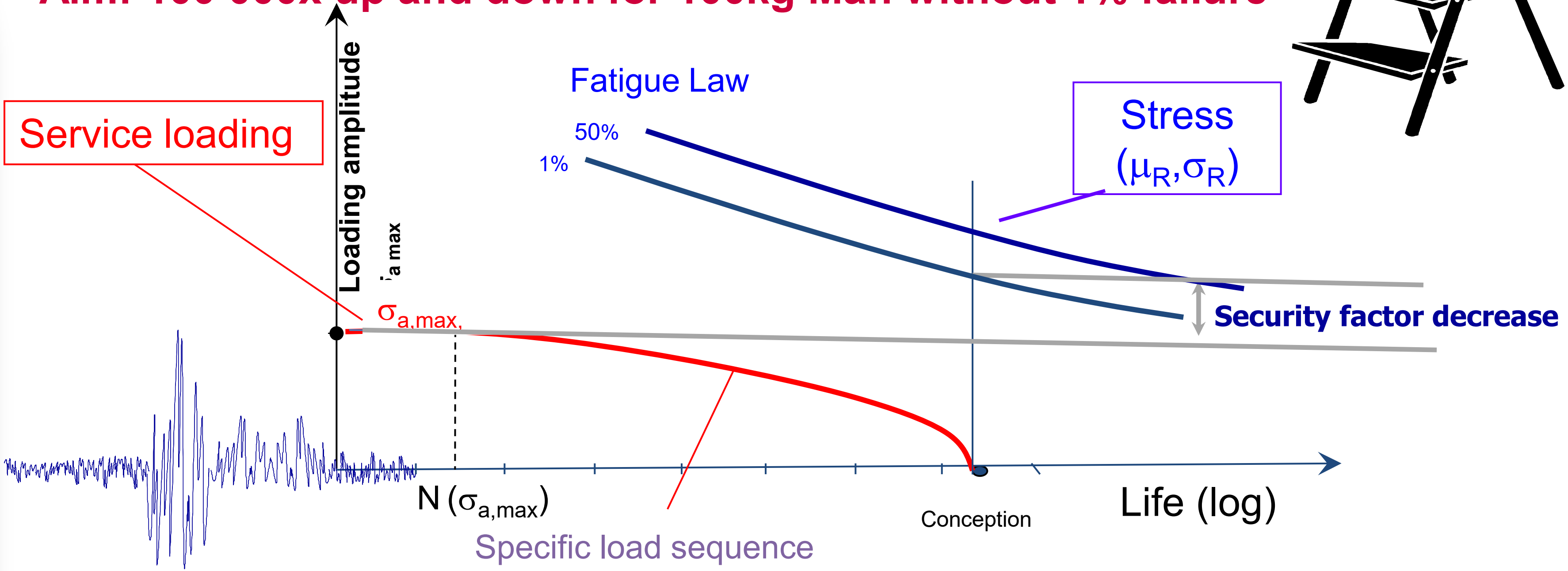
Aim: 100 000x up and down for 100kg Man without failure…



Reliability approach 2/5

Stepladder Design – Determinitic approach:

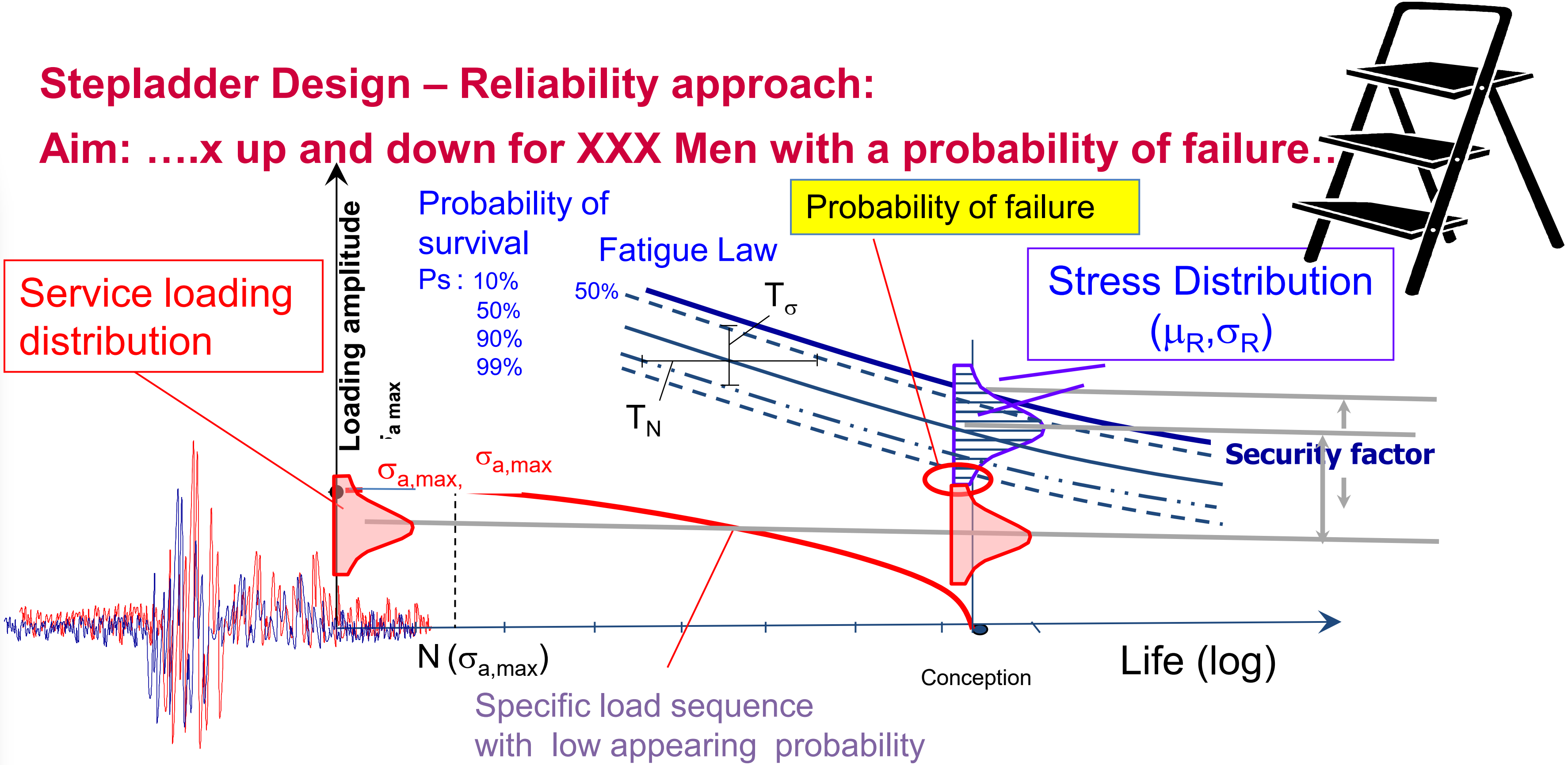
Aim: 100 000x up and down for 100kg Man without 1% failure



Reliability approach 3/5

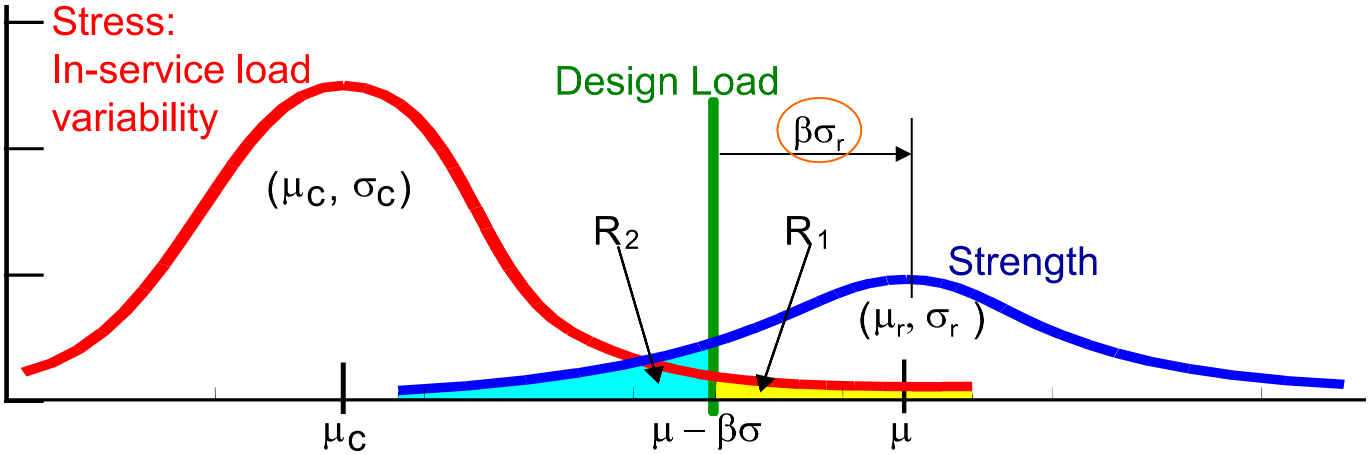
Stepladder Design – Reliability approach:

Aim: ….x up and down for XXX Men with a probability of failure..



Reliability approach 4/5

Principle of the Stress-Strength Interference Method



- To identify the variability of the Loading severity
- To identify the scatter of the Strength, linked to the manufacturing quality, and based on capitalization
- To quantify the risk of fatigue failure

Reliability approach 5/5

How do I need to design a component to satisfy a functionality for an expected time?

INPUT DATA to consider:

- **The service Loading variability or STRESS**
- **The material and manufacturing process Fatigue variability or STRENGTH**
- **The reliability (R=1-Pf) – or Acceptable Probability of Failure Pf**

DIFFICULTIES :

- **Loading definition**
- **Manufacturing quality qualification**
- **Level of target probability definition**

Stress and Mission Profile 1/4

The Stress is the representation of loading variability for different operating conditions (or life) of the structure

The mission profile consists of “elementary situations of life”, depending on work, movement, etc…

Aim of the Agricultural tools mission's analysis:

- Create a strategy to build virtual lives in order to define a statistical distribution of the load severity

Stress and Mission Profile 2/4

3 campaigns of measurement to create the "elementary situations of life" and loading distribution…

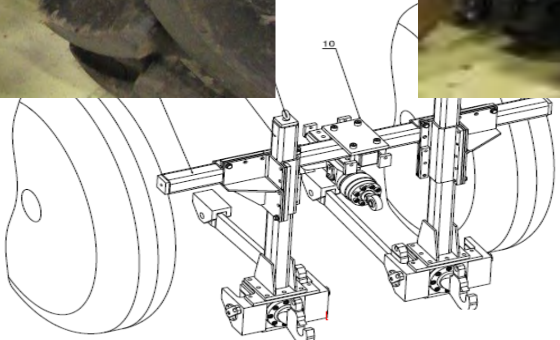
Brush cutter & Tractor

Charger & tractor

Plough & Tractor

Stress and Mission Profile 3/4

Framework design for stress measurements



X sensor direction: +/-200 kN,
Y sensor direction: +/-150 kN,
Z sensor direction: +/-150 kN.

Stress and Mission Profile 4/4

Vidéo

Plough & Tractor case:

Test campaign duration : 1 Wk

- type of actions (travel, ploughing, etc.),
- type of places: road, path, fields, humps
- type of plough body orientation (RH, LH, up),
- types of speed or depth, etc.

Data extraction: 3 wks

- measurement signals : 38
- Elementary life situations : 159
- Nb of equivalent load: 9

Data analysis for reliability approach: 3 wks

Vidéo

Stress and Strength approach on Plough

What are we looking for?

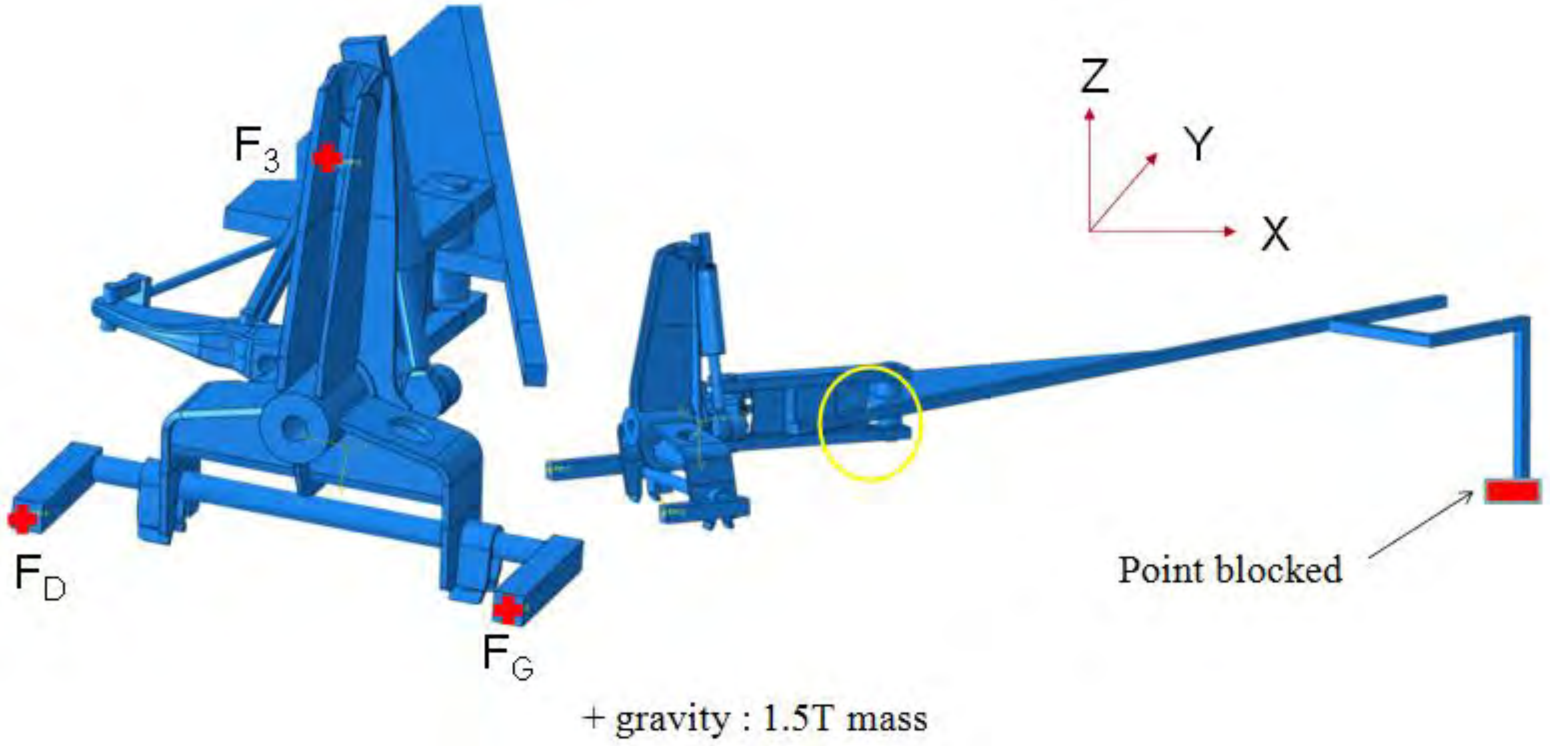
- Design a welded zone of a plough
- Aim : Check the fatigue resistance in service
    - Evalute de probility of failure for a design and a loading
    - ***necessary to compare similar values***,

Input data requirement:

- CAD of the part: plough,
- Boundary conditions (B.C.),
- Distribution of the loadings in-service in Loads,
- Characteristic of the welded assembly in fatigue.

Plough case

Welded part and Limit conditions



Plough case

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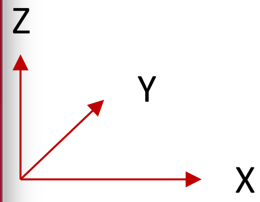
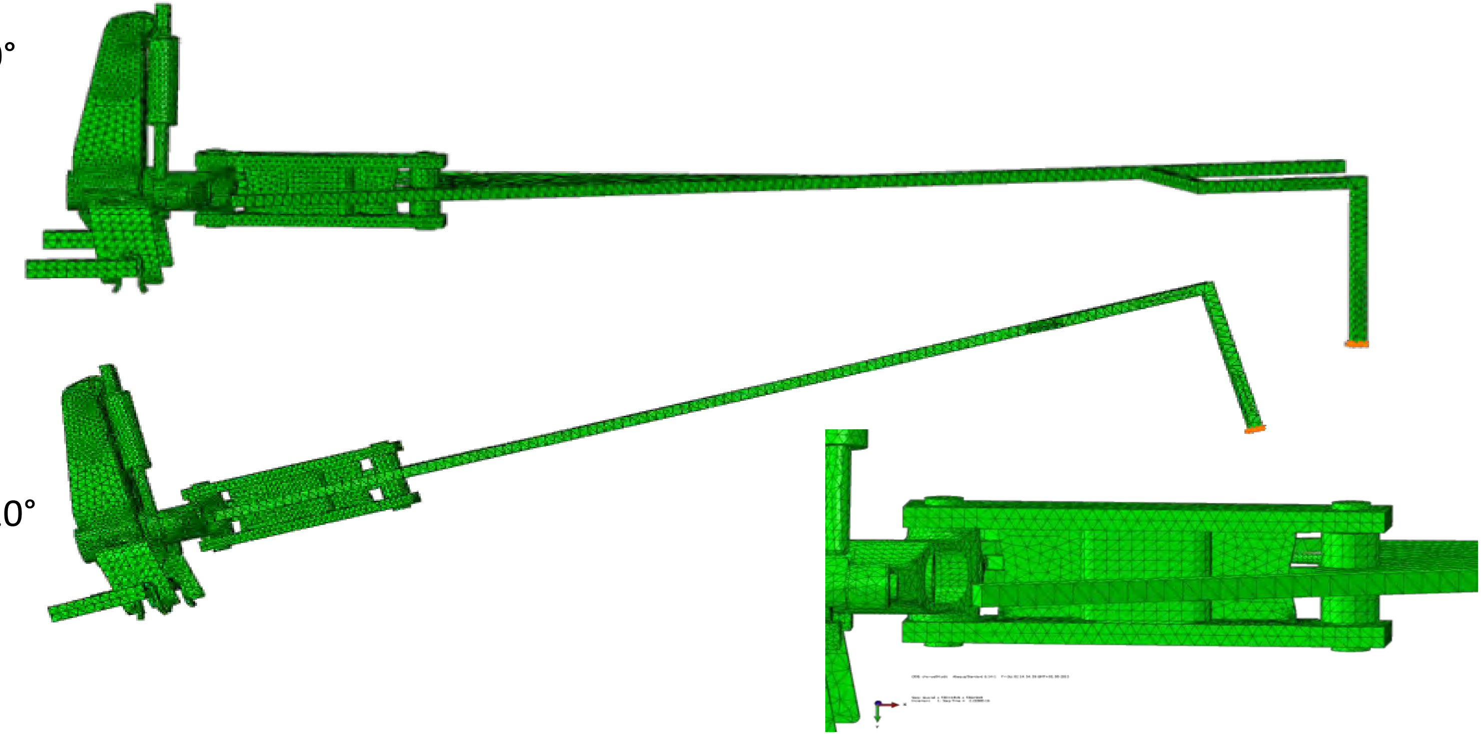
Two positions of work and FE model

Position 0°





Position 20°

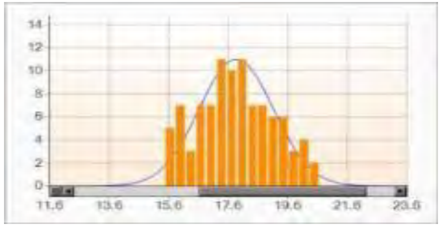
Plough case

Load distribution from measurements

distribution of equivalent loading amplitudes at N = 10^6 cycles for a welded part (Basquin slope b = 3)

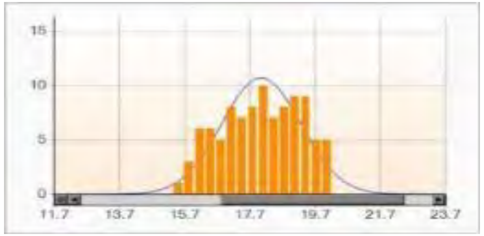
1^{er} case : plough at 0°(working position)

- $F_{XG} = F_{XD}$ = + 17 kN et F_{X3} = 0 kN
- F_{ZD} = 18 kN, $F_{ZG} = F_{ZD}$ / 2 = 9 kN et F_{Z3} = 0 kN



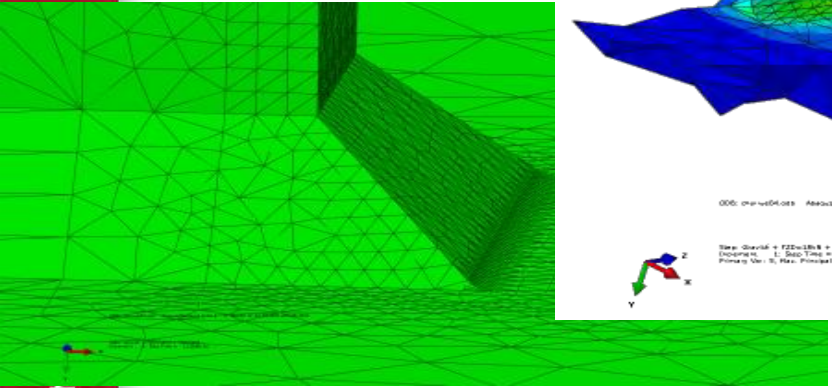
2^{nd} case : plough at 20°(transport position)

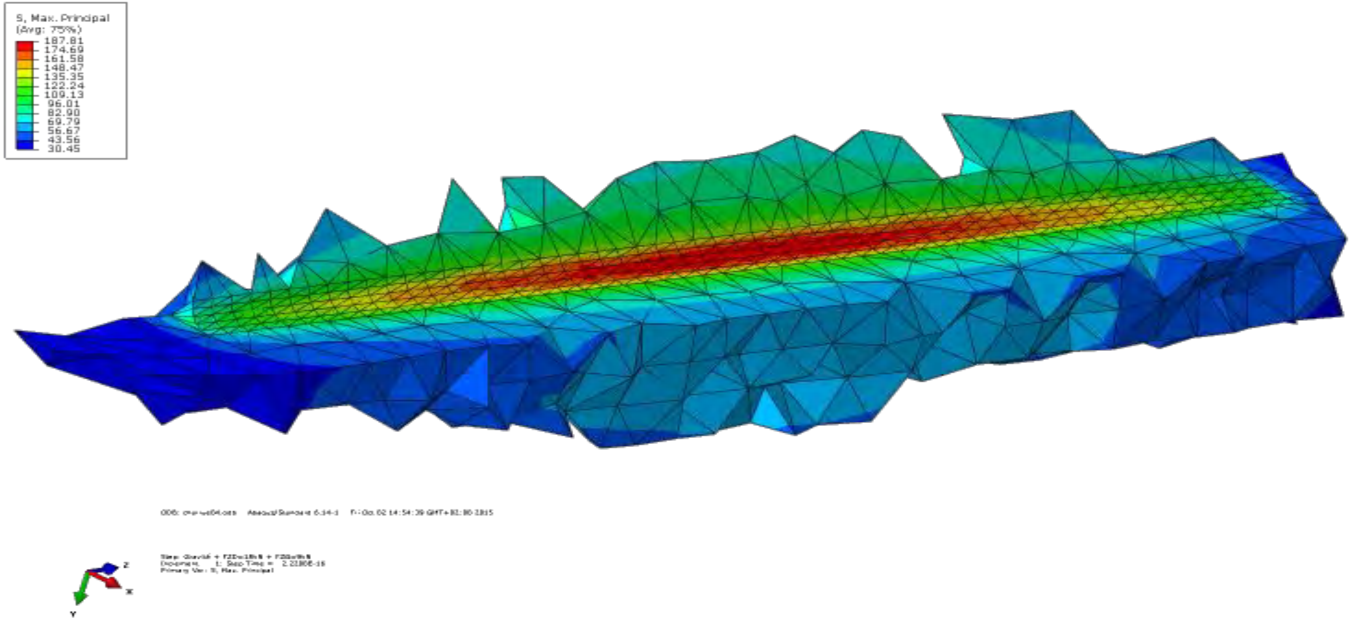
- $F_{XG} = F_{ZD}$ = -17 kN et F_{X3} = 21 kN
- F_{ZG} = -14 kN, F_{ZD} = -18 kN et F_{Z3} = + 17 kN



Plough case

Stress results





Plough case

Stress results

1st case : at 0°(Work position)

- $F_{XG} = F_{XD}$ = + 17 kN et F_{X3} = 0 kN — σ_a = -70 MPa
- F_{ZD} = +18 kN, $F_{ZG} = F_{ZD}$ / 2 = +9 kN et F_{Z3} = 0 kN — σ_a = +190 MPa

2nd case : at 20°(Transport position)

- $F_{XG} = F_{XD}$ = -17 kN et F_{X3} = +21 kN — σ_a = +110 MPa
- F_{ZD} = -18 kN, F_{ZG} = -14 kN et F_{Z3} = +17 kN — σ_a = -240 MPa

Variability

- CV = 0,07 sur F_{XG}, F_{XD} et F_{ZD}
- CV = 0,04 sur F_{ZG} et F_{X3}, F_Z

Nota : fake values for the demonstration

Plough case

Stress combination

Load combinaison : FX & FZ in-phase

1st case : at 0°…

- for N = 10^6 cycles, σ_a = +190 -70 = +120 MPa

  d'où $\Delta\sigma_C$ = 240 MPa

Variability:

- CV = 0,07

Plough case

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Strength

"notch stress" method (radius 1 mm in weld toe) from IIW → FAT 225

for N = 10^6 cycles,

$\Delta\sigma_R$ = 283 MPa at 95% of probability of survival with a confidence interval of 75%

Dispersion

CV = 0,1 (usual quality level)

Strength distribution

- Mean value: $\Delta\sigma_{R,m}$ = 353 MPa

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Plough case

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Deterministic Approach (at N= 10^6 cycles)

- **Equivalent stress in service**

  $\Delta\sigma_C$ = 240 MPa

- **Strength**

  $\Delta\sigma_R$ = 283 MPa at 95% of probability of survival and 75% of confidence interval

- **Design criteria**

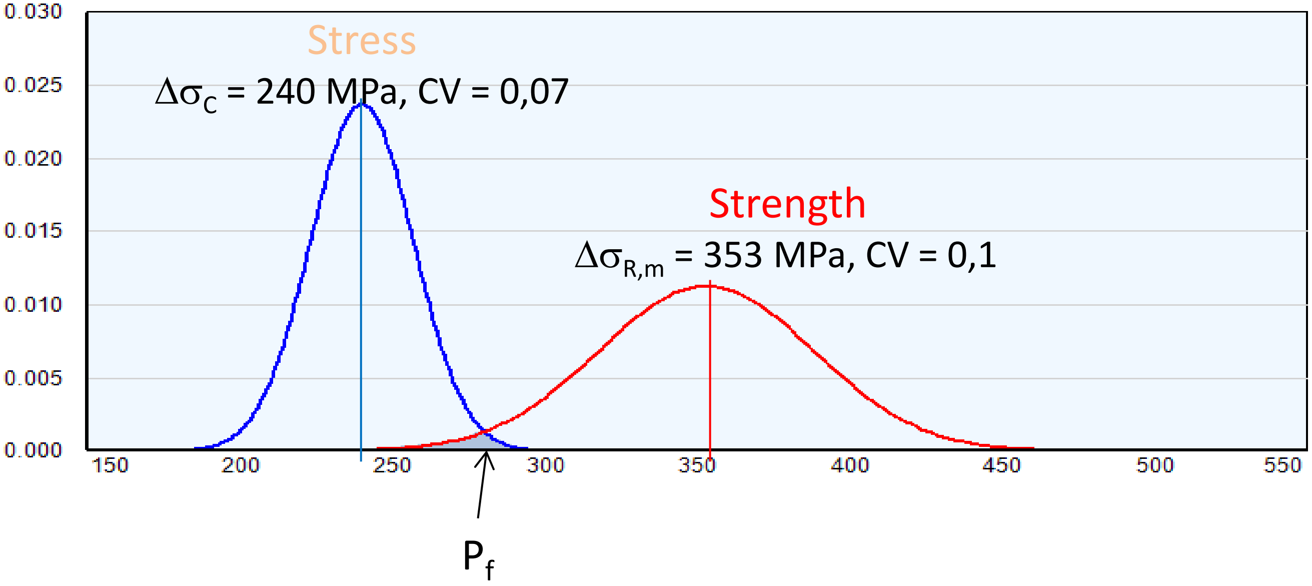
  $\Delta\sigma_C < \Delta\sigma_R \Rightarrow \Delta\sigma_C = 240 \text{ MPa} < \Delta\sigma_R = 283 \text{ MPa}$

- **Security factor**

  $\gamma = \Delta\sigma_R / \Delta\sigma_C = 1{,}18$

Plough case

Reability Approach

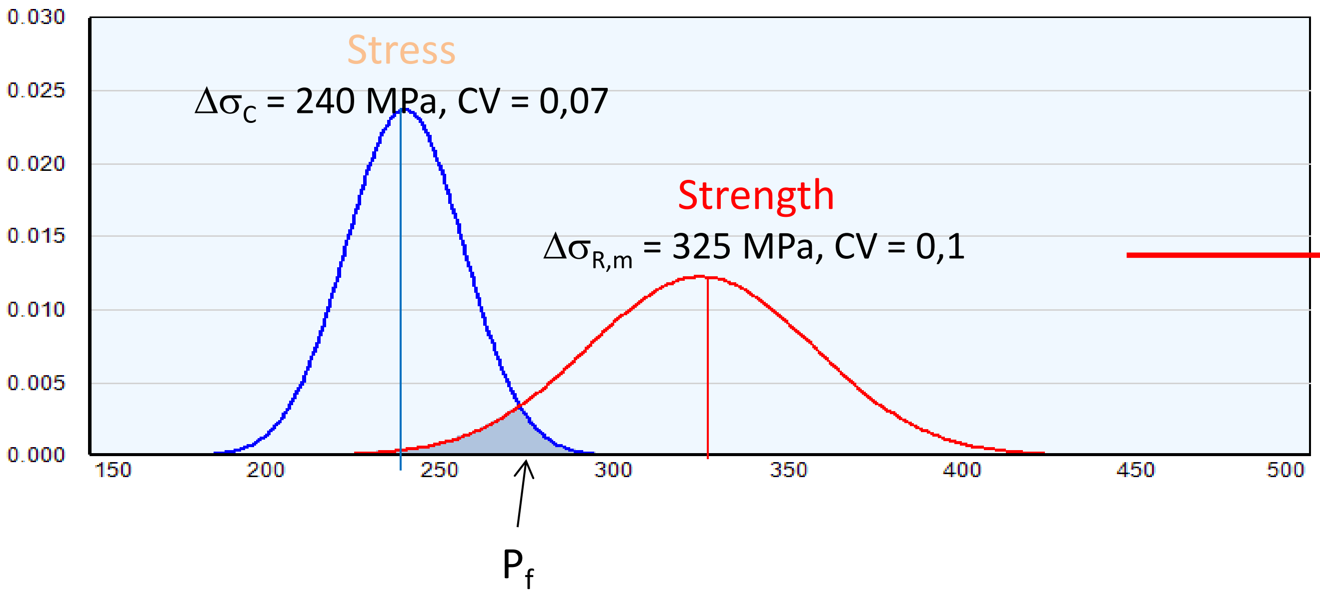


Probability of failure : $P_f = 1{,}923.10^{-3}$ with a confidence level of 75%

Plough case

Reability Approach

We fix a probability of failure of : $P_f = 10^{-2}$ with a confidence level of 75%



Weld may be unclassed…

Plough case

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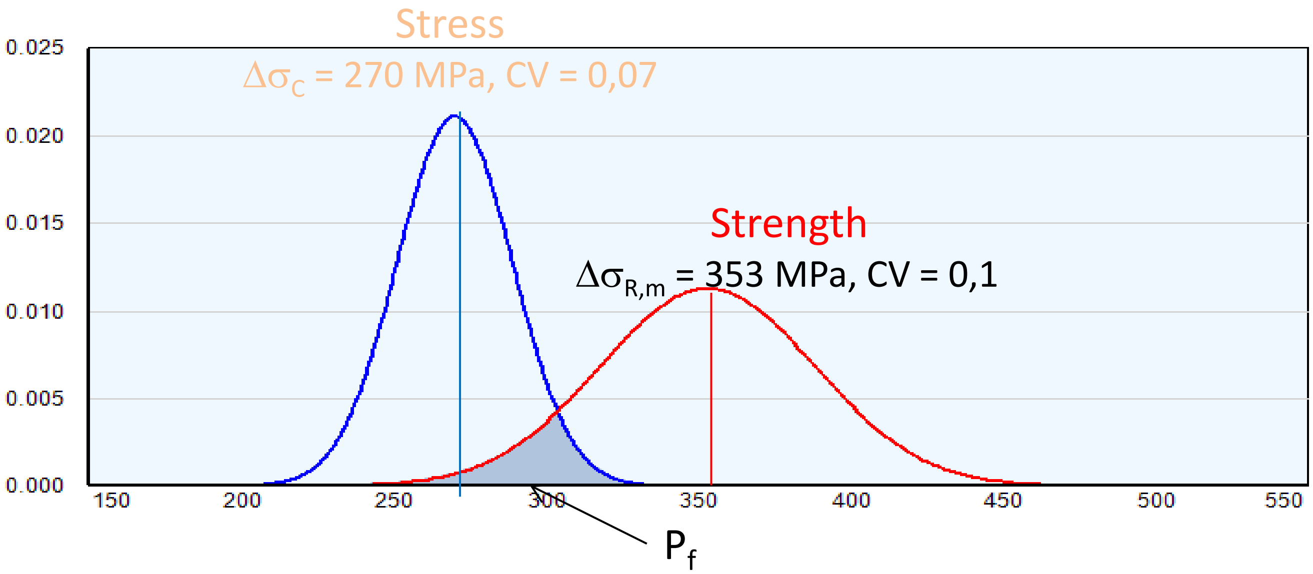
Reability Approach

We assume a severe loading : from 240MPa to 270MPa



Probability of failure : $P_f = 1{,}909.10^{-2}$ with a confidence level of 75%

Conclusions

Long and expensive campaigns of measurement on 3 tools with tractor

Complete Stress/Strength methodology on a plough

Predictive reliability at the design stage

- Good knowledge of the loading mission profile
- Acceptance criteria consistency

Reliability at the manufacturing stage

- Quantification and manufacturing quality control

Reliability in service

- Rapid assessment of the evolution of the risk associated with a change in component mission cetim 5.0

To the future

fatigue design2017

29 & 30 November 2017 - Senlis, France

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To the future