



9th International Fatigue Congress

May 14-19 2006 • Atlanta, Georgia, USA

Fatigue on drill string conical threaded connections, test results and simulations

L. Bertini,
M. Beghini,
C. Santus

University of Pisa,
mechanical dept.
Italy



A. Baryshnikov

ENI S.p.A.
Milano.
Italy



Contents

Short introduction to drilling technology

- drill string and drill pipes, fatigue failures on drill pipes
- steel heavy construction vs. aluminum light construction

Full scale fatigue tests

- description of test rigs
- test results

Finite Element simulations

- FE model dedicated to threaded connection

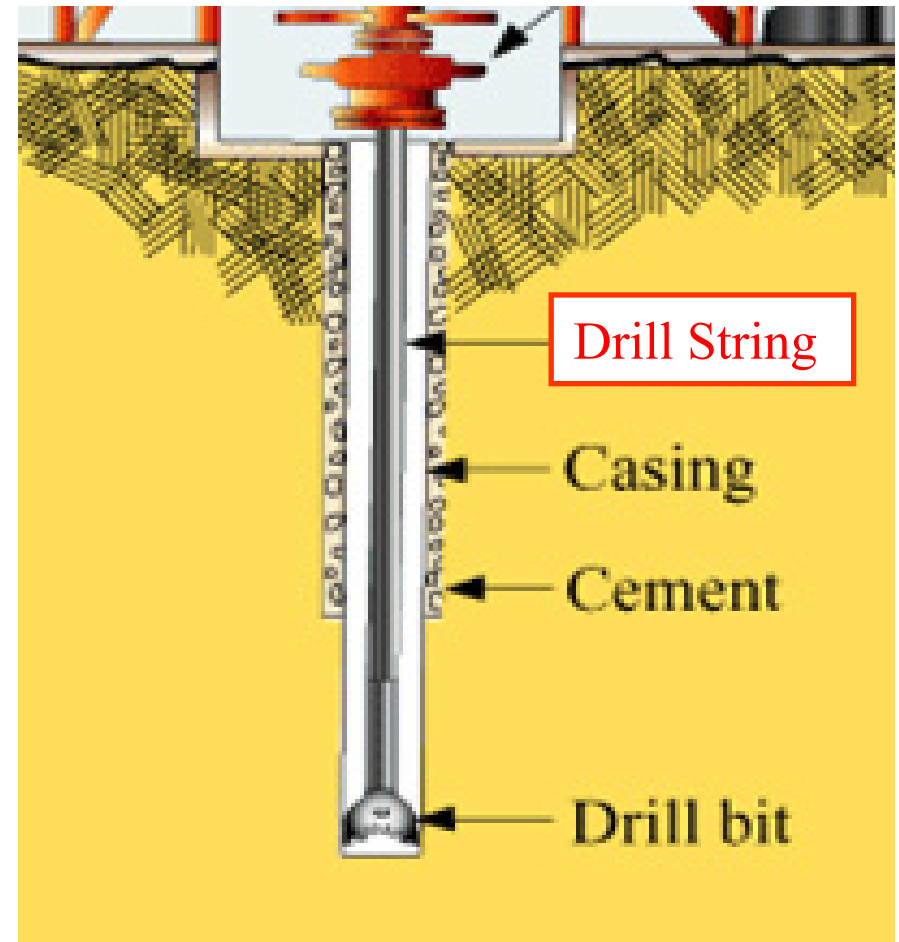
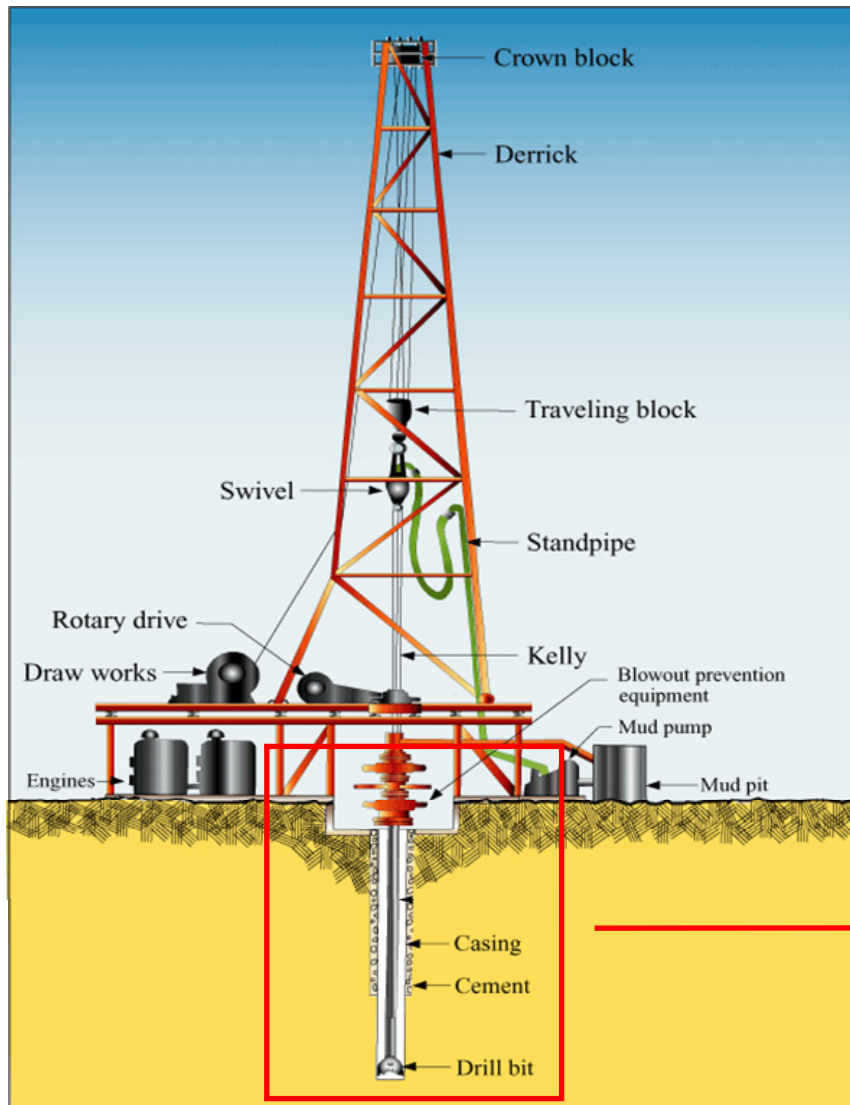
Fatigue models

- classic approach (Gerber, k_f , surface effect)
- test results correlation

Conclusions

Short introduction to drilling technology

drill string and drill pipes, fatigue failures on drill pipes



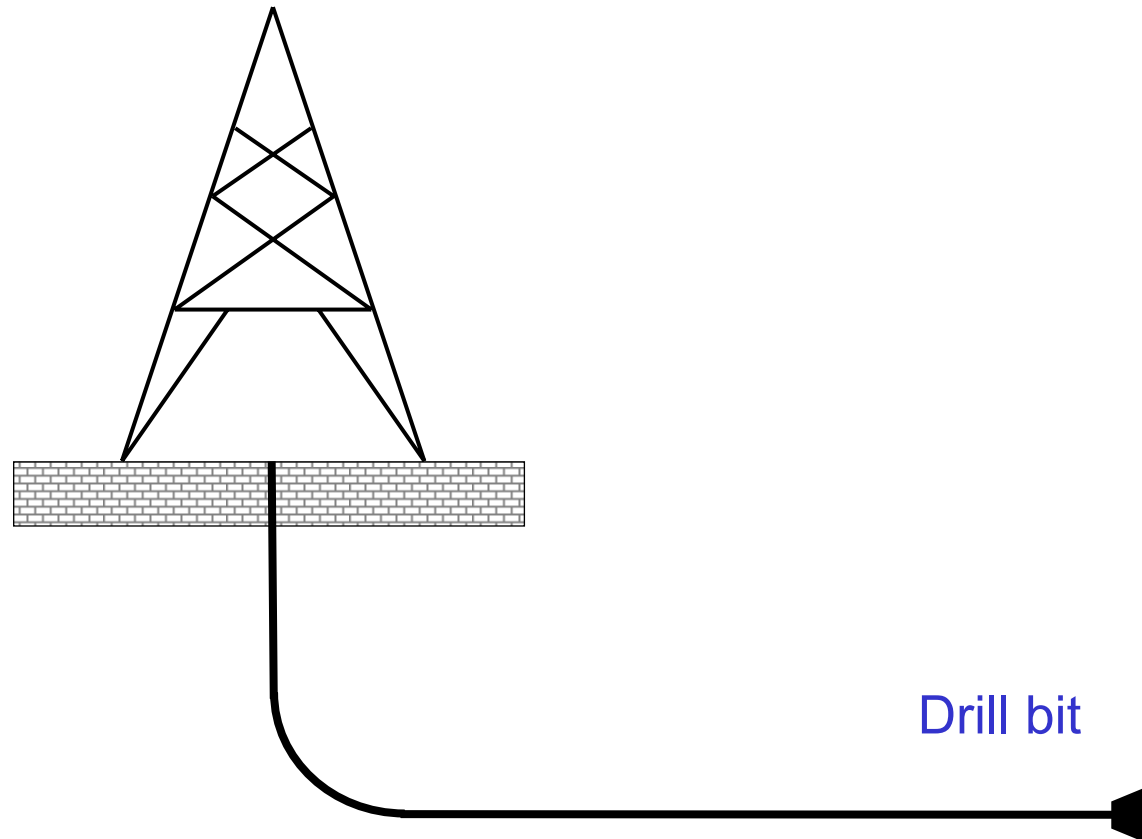
Short introduction to drilling technology

drill string and drill pipes, fatigue failures on drill pipes

Basic nomenclature

Drill string:
hundreds of **drill pipes**
connected through threaded
connections

Drill pipe length ~ 10m
Drill string max. length ~ 5km

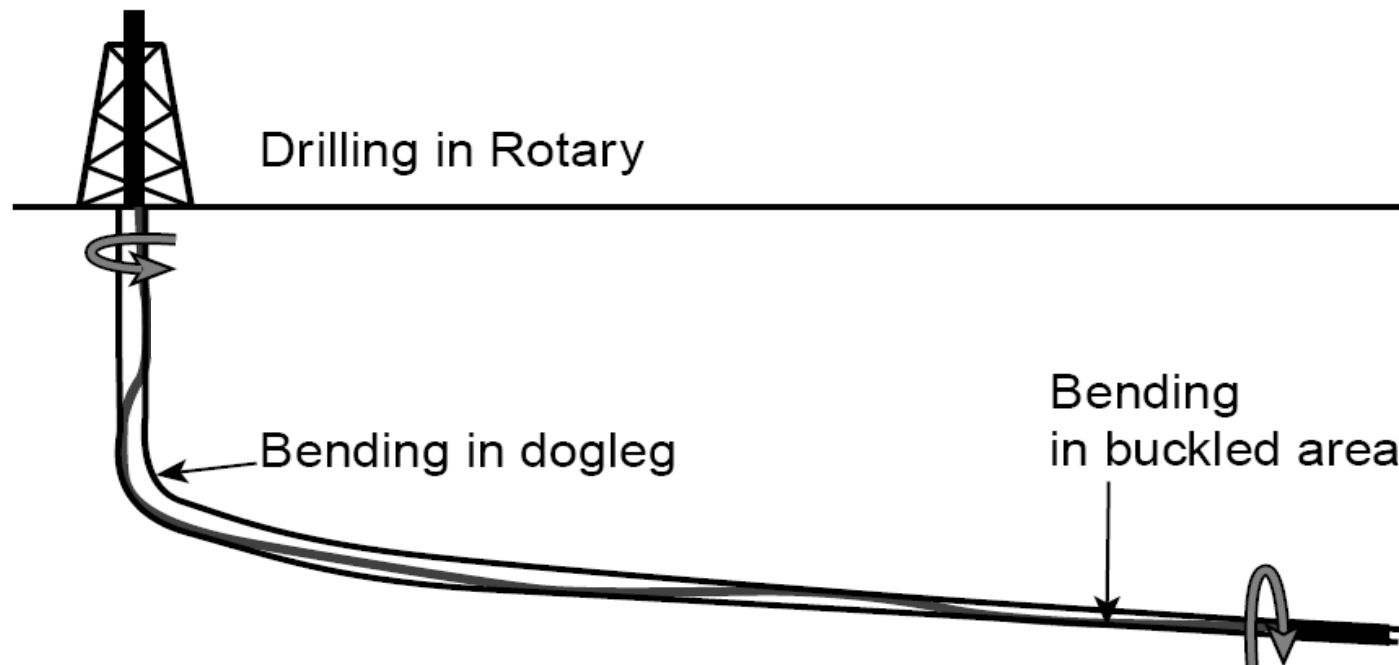


Dog leg segment, for
deviated drilling

Short introduction to drilling technology

drill string and drill pipes, fatigue failures on drill pipes

Fatigue locations along drill string



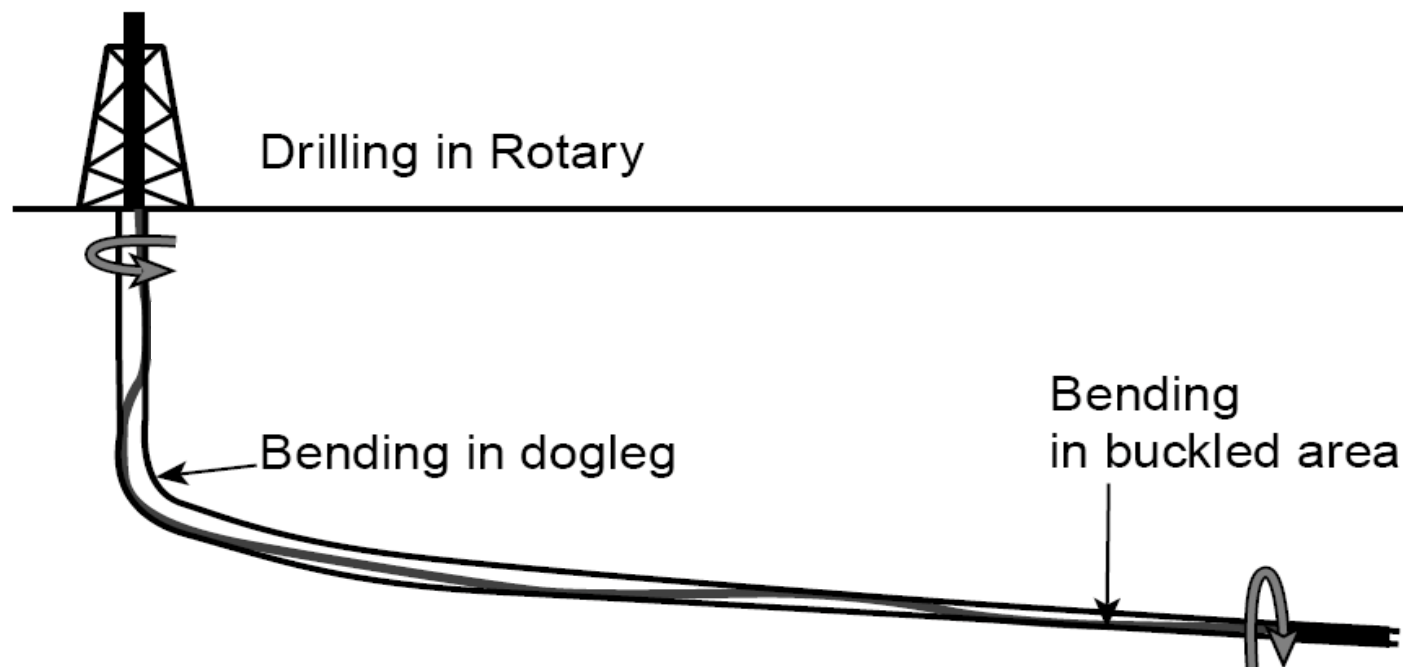
Rotating **bending fatigue**,
due to dogleg on the upper
part of the string

Lateral **bending fatigue**, due
to buckling on the lower part
of the string

Short introduction to drilling technology

drill string and drill pipes, fatigue failures on drill pipes

Fatigue locations along drill string

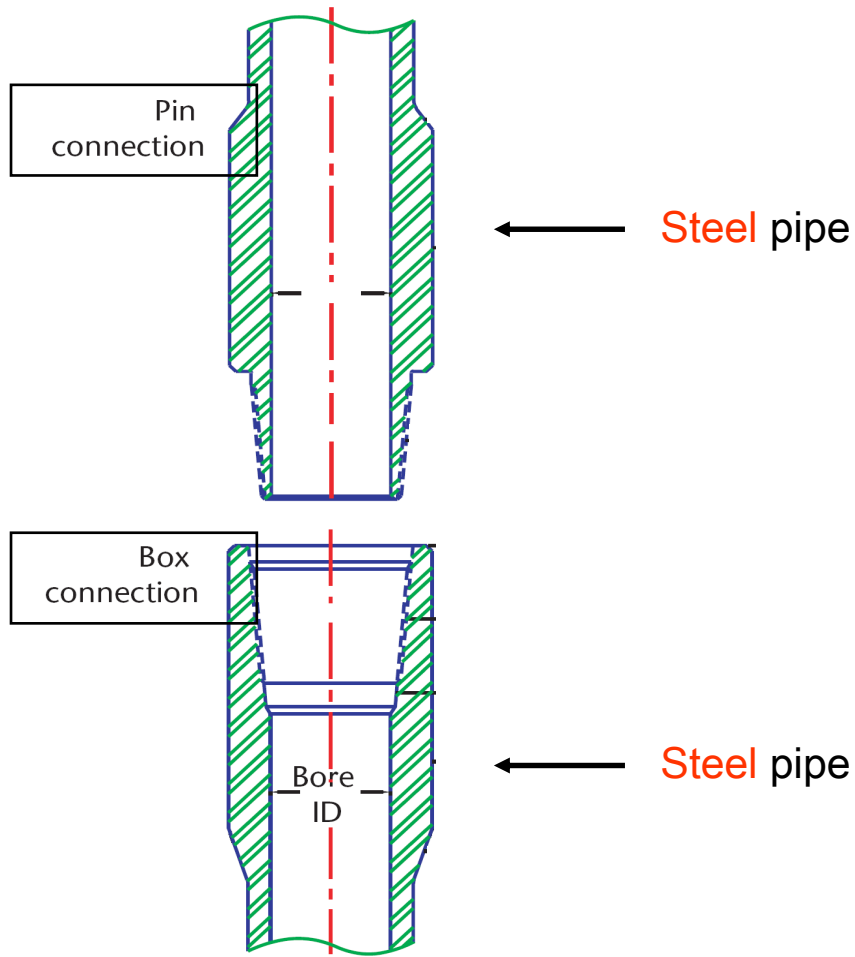


Fatigue accounts for 70 % of failures

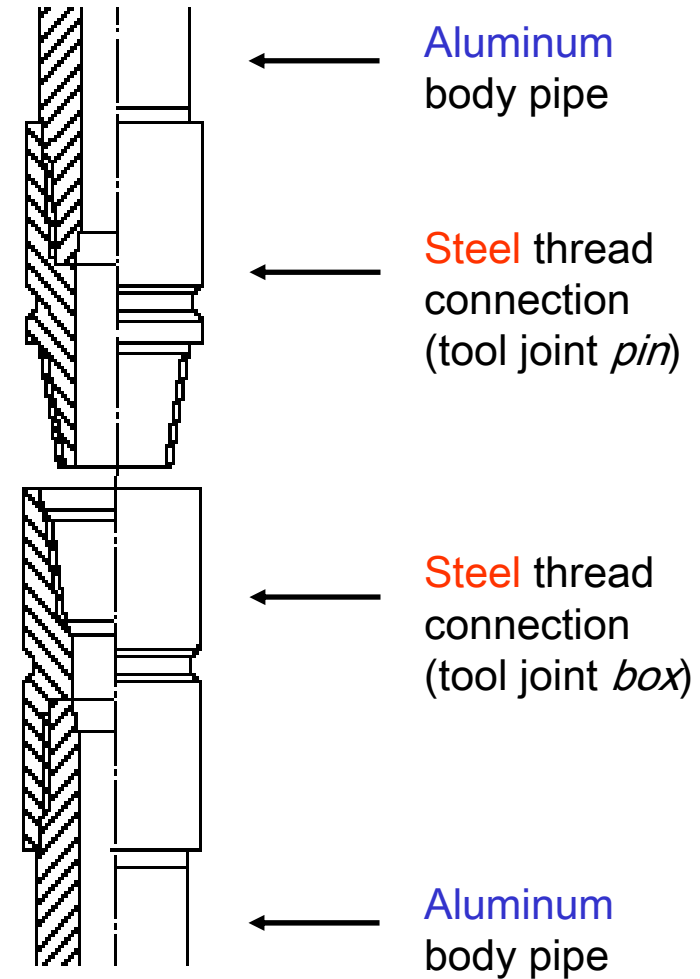
Corrosion, **Stress-Corrosion**, **Wear**, **Static stresses** are further detrimental effects in **combination** with fatigue

Short introduction to drilling technology

drill string and drill pipes, fatigue failures on drill pipes



Steel construction

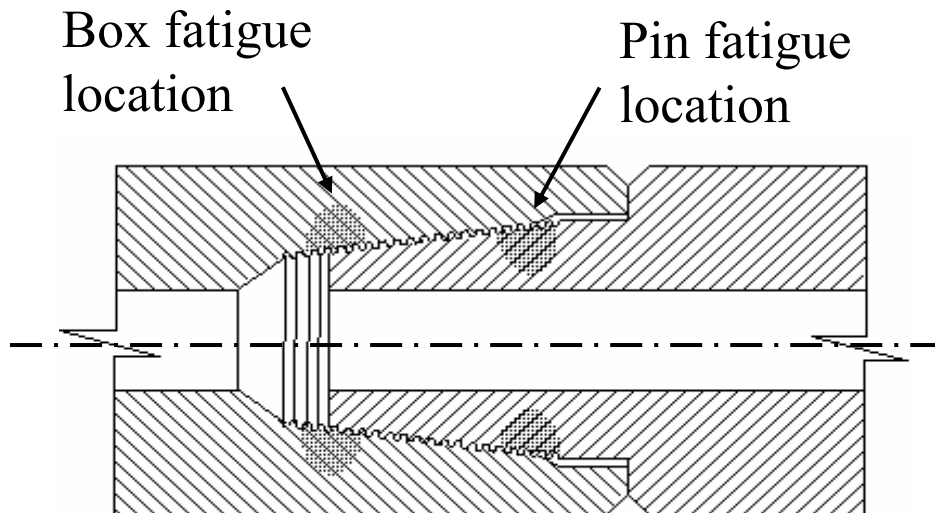


Aluminum construction

Short introduction to drilling technology

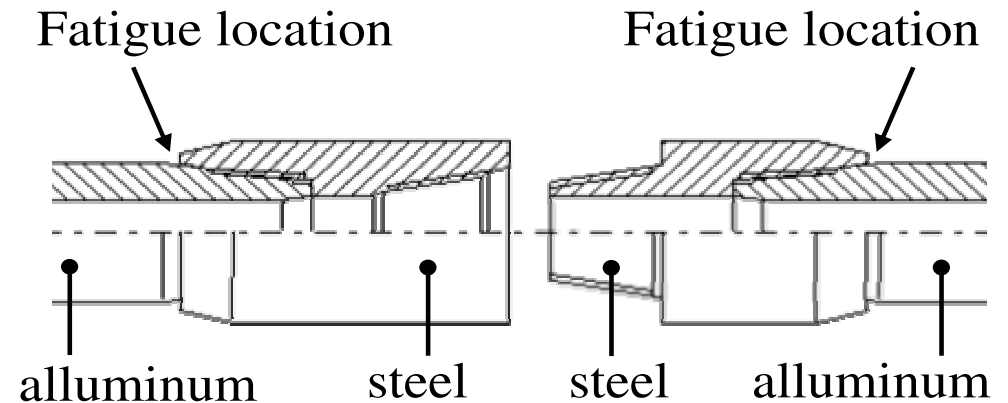
steel heavy construction vs. aluminum light construction

Steel construction
fatigue locations



Last Engaged Thread
- **Notch** effect
- **Mean stress** effect
(particularly for pin side)

Aluminum construction
fatigue locations



Box side

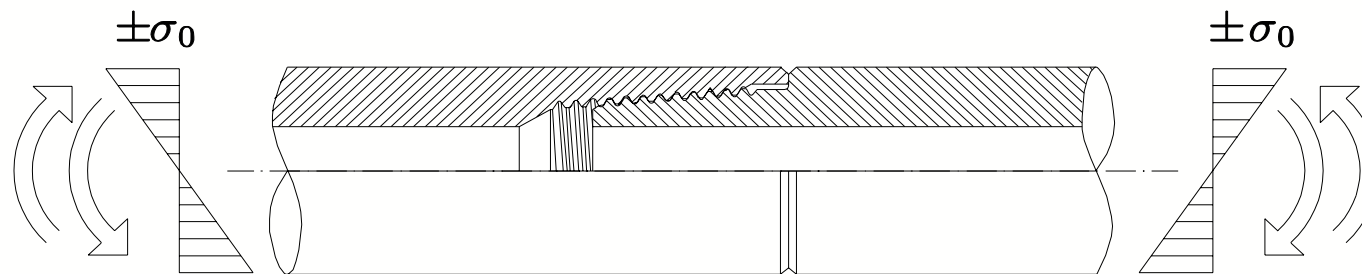
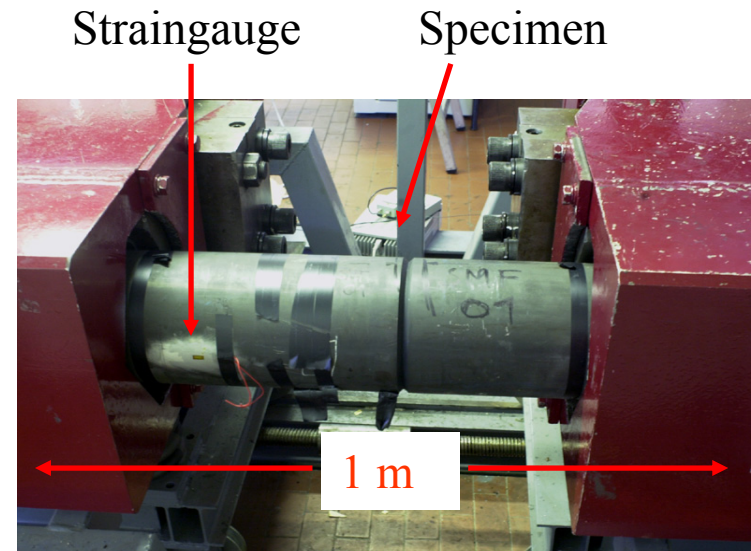
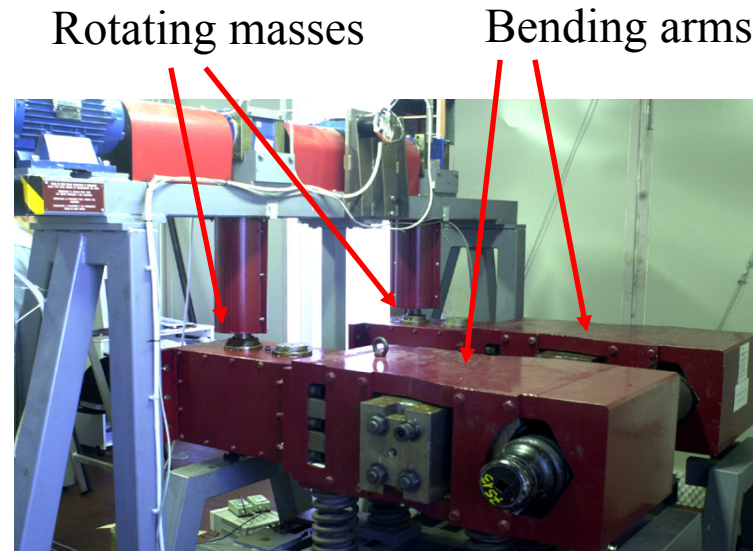
Pin side

Conical shoulder
Aluminum-Steel interface:
- **Fretting** nucleation
(different material stiffness)

Full scale fatigue tests

description of test rigs

Test rig for **steel** construction

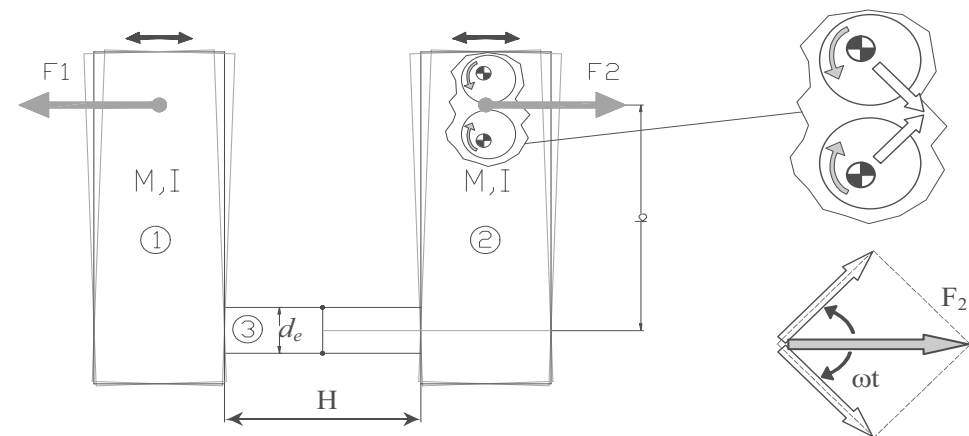
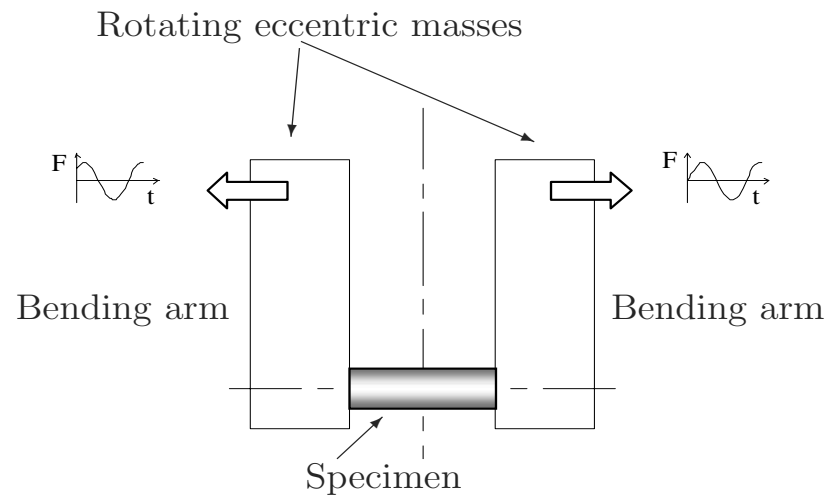


Alternating Bending

Full scale fatigue tests

description of test rigs

Test rig for **steel** construction

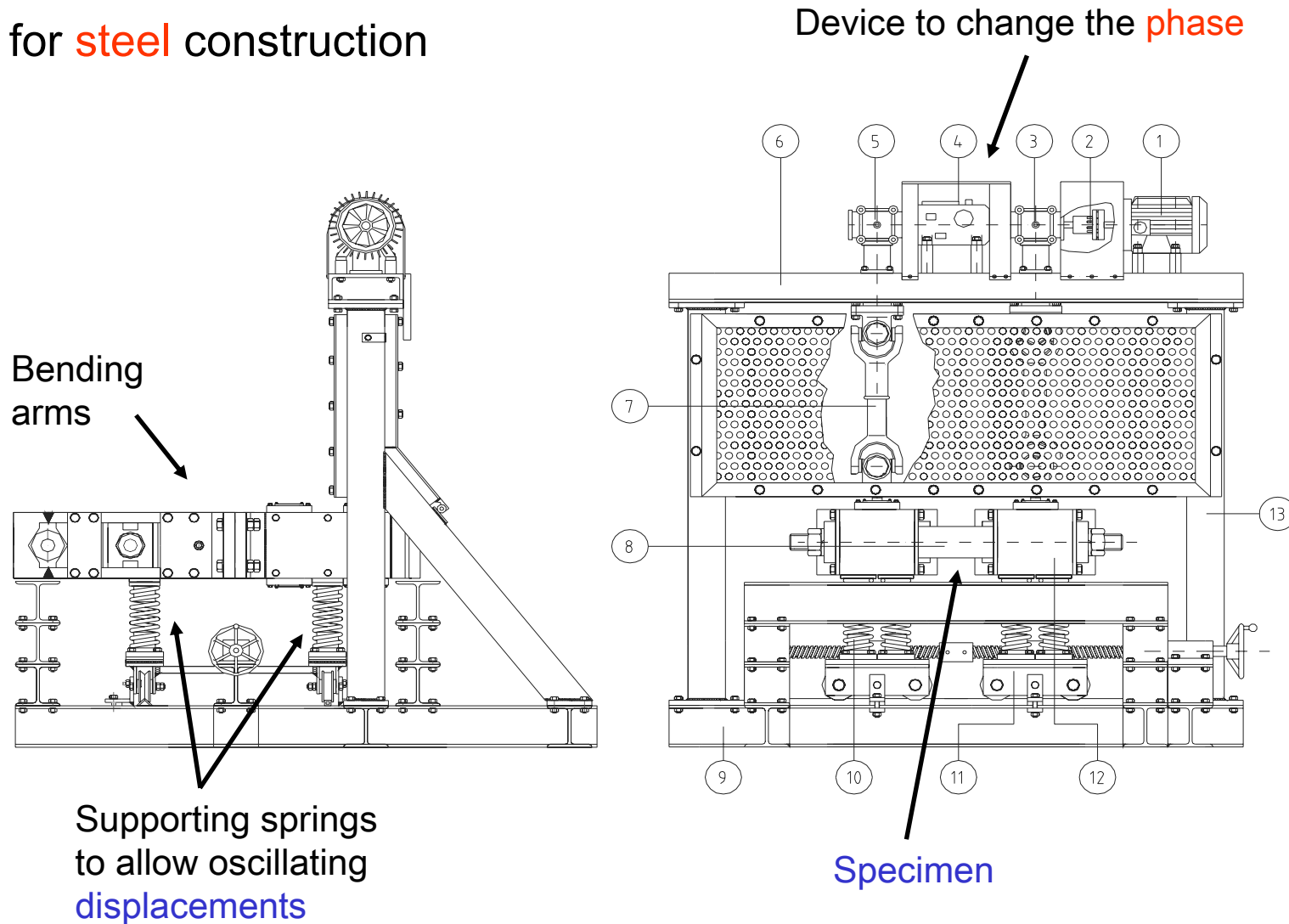


The **phase** between the two couple of eccentric masses control the stress amplitude

Full scale fatigue tests

description of test rigs

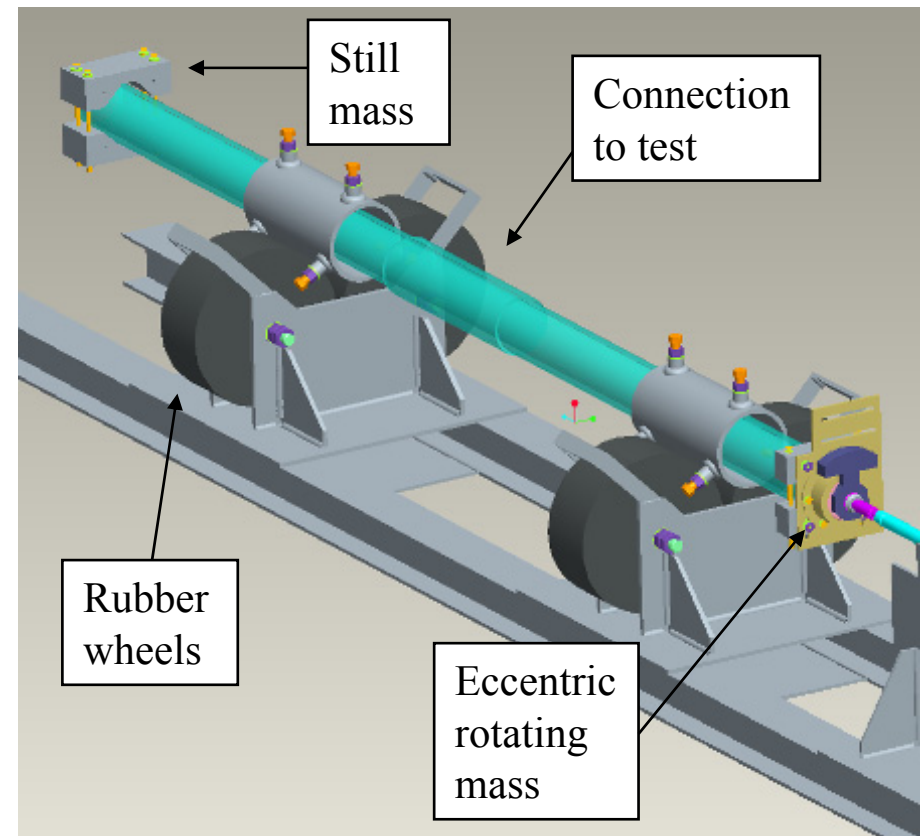
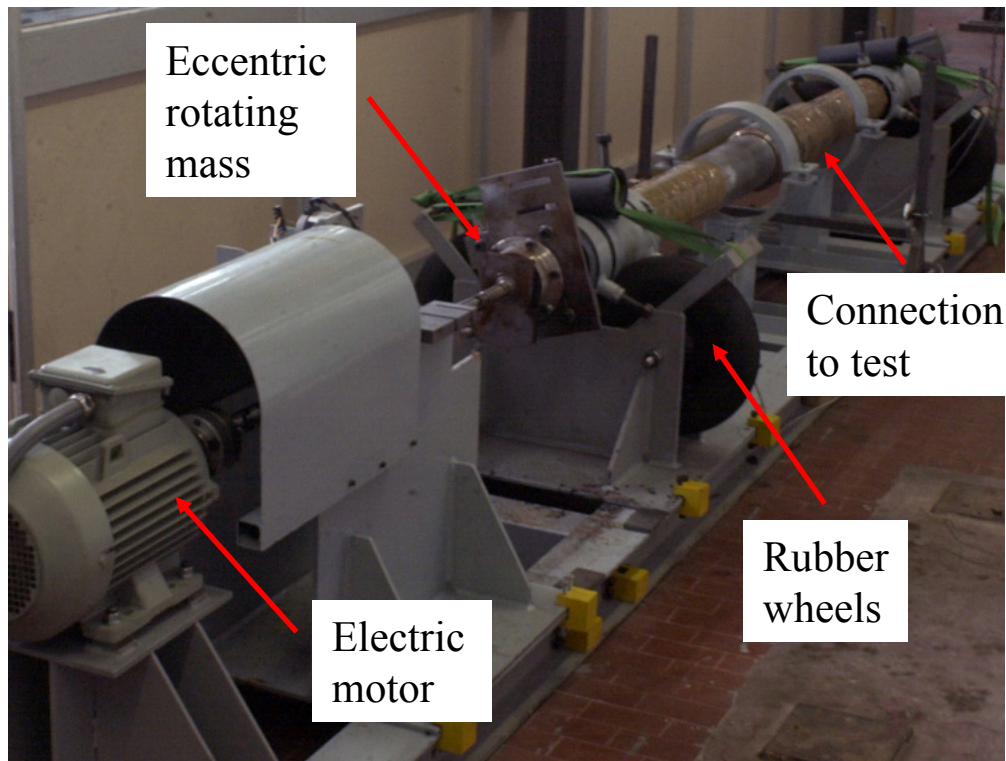
Test rig for **steel** construction



Full scale fatigue tests

description of test rigs

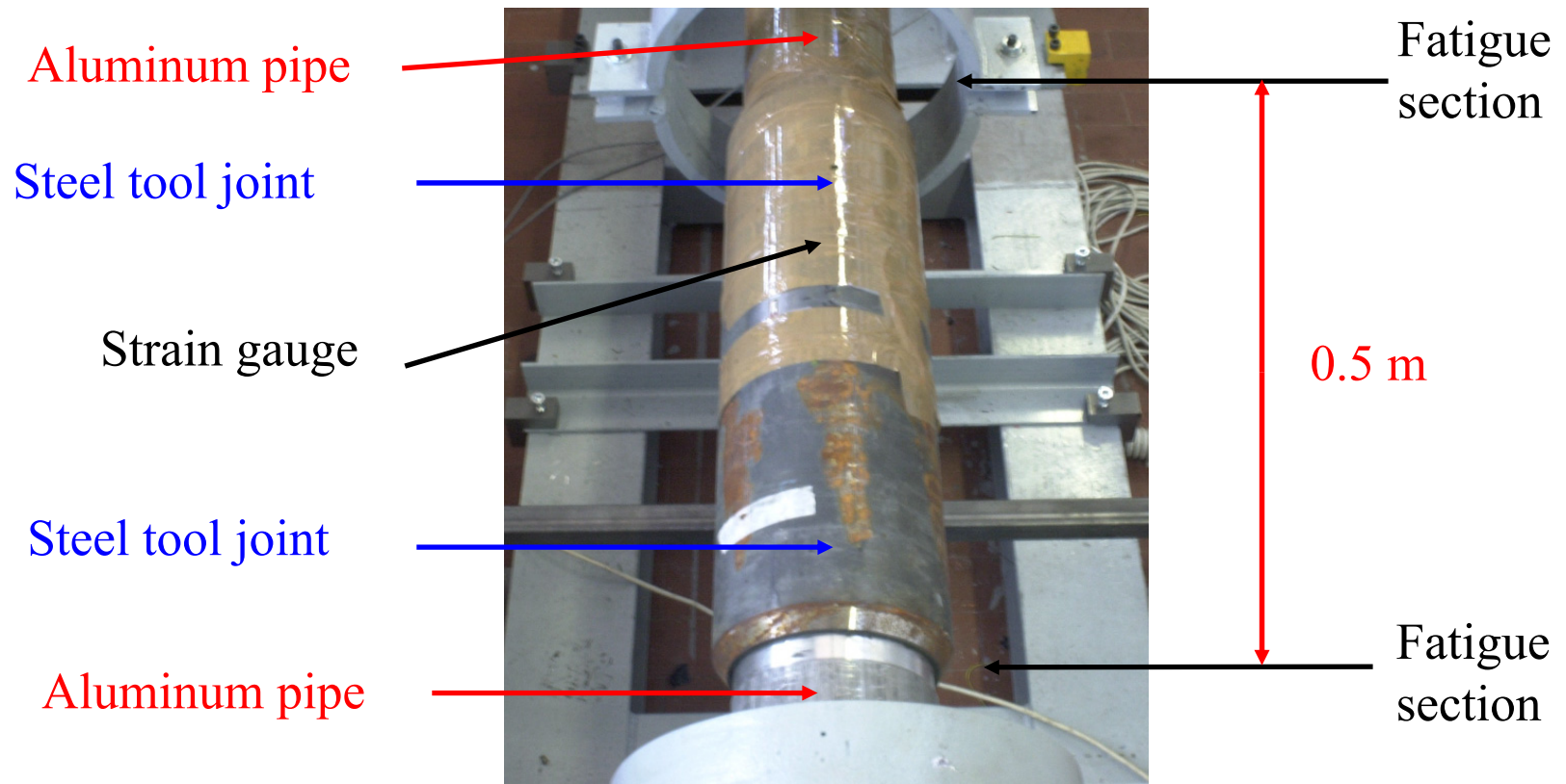
Test rig for **aluminum** construction



Full scale fatigue tests

description of test rigs

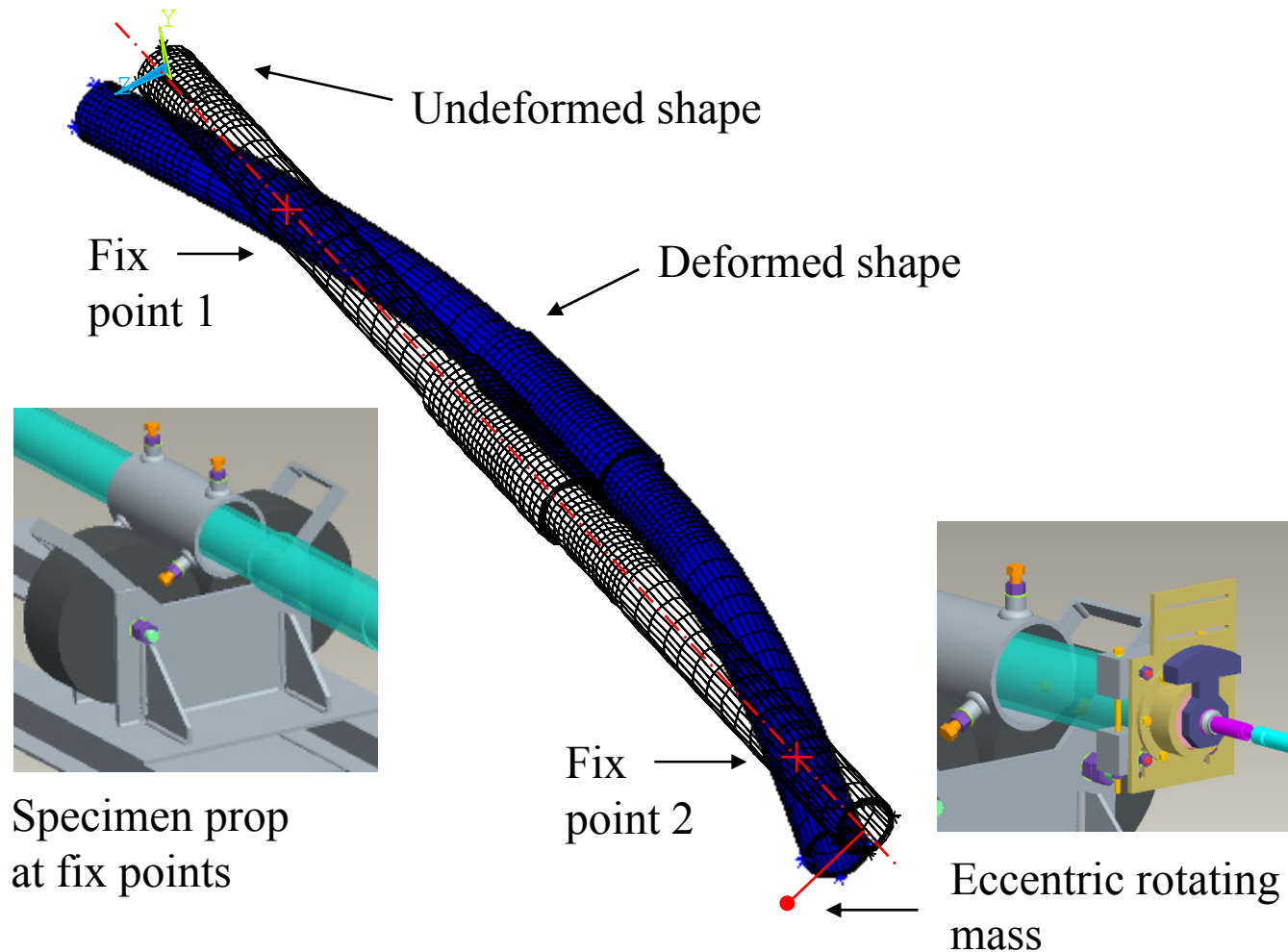
Test rig for **aluminum** construction



Full scale fatigue tests

description of test rigs

Test rig for **aluminum** construction



Full scale fatigue tests

description of test rigs

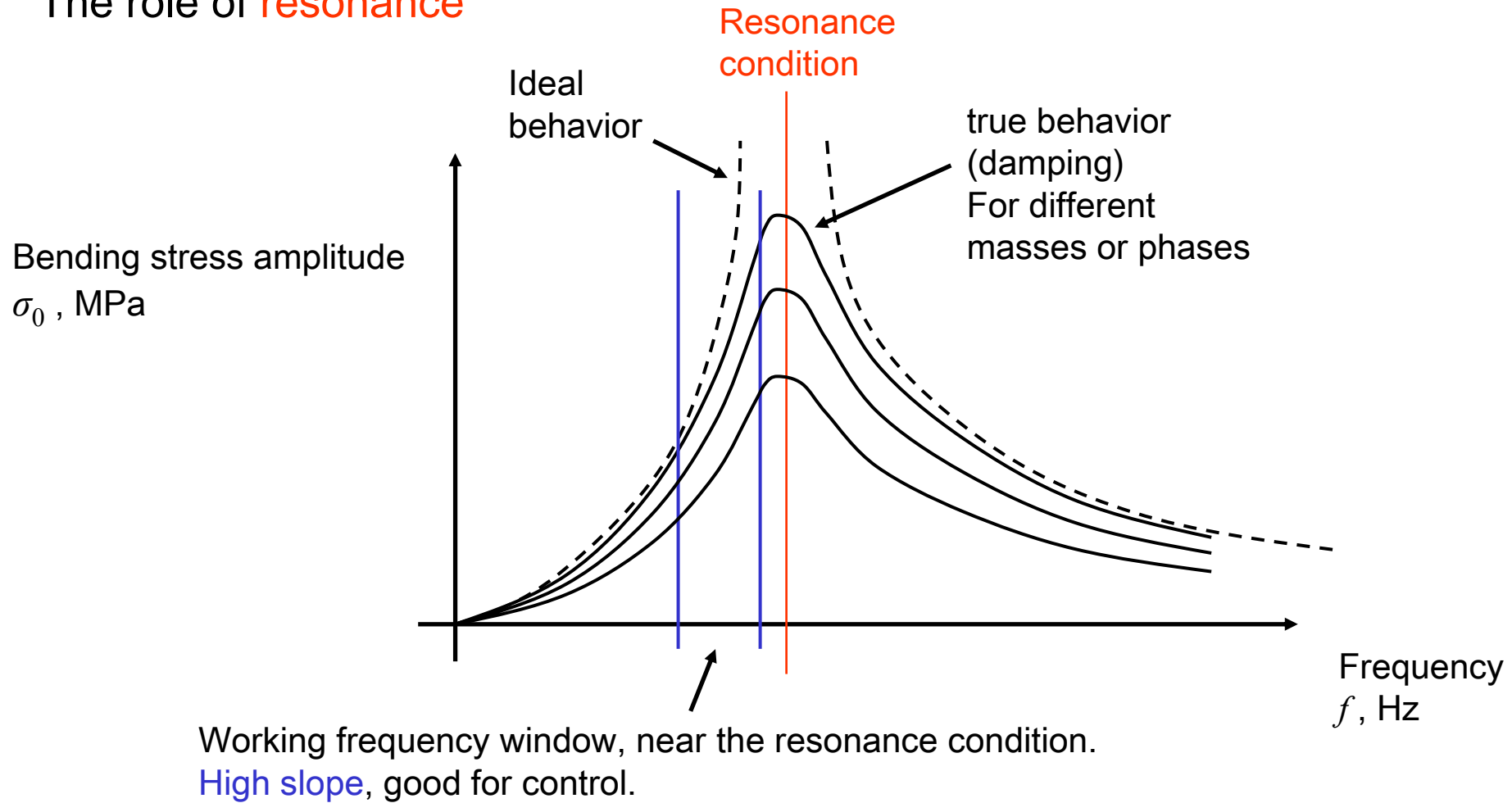


ResonantTestRig.avi

Full scale fatigue tests

description of test rigs

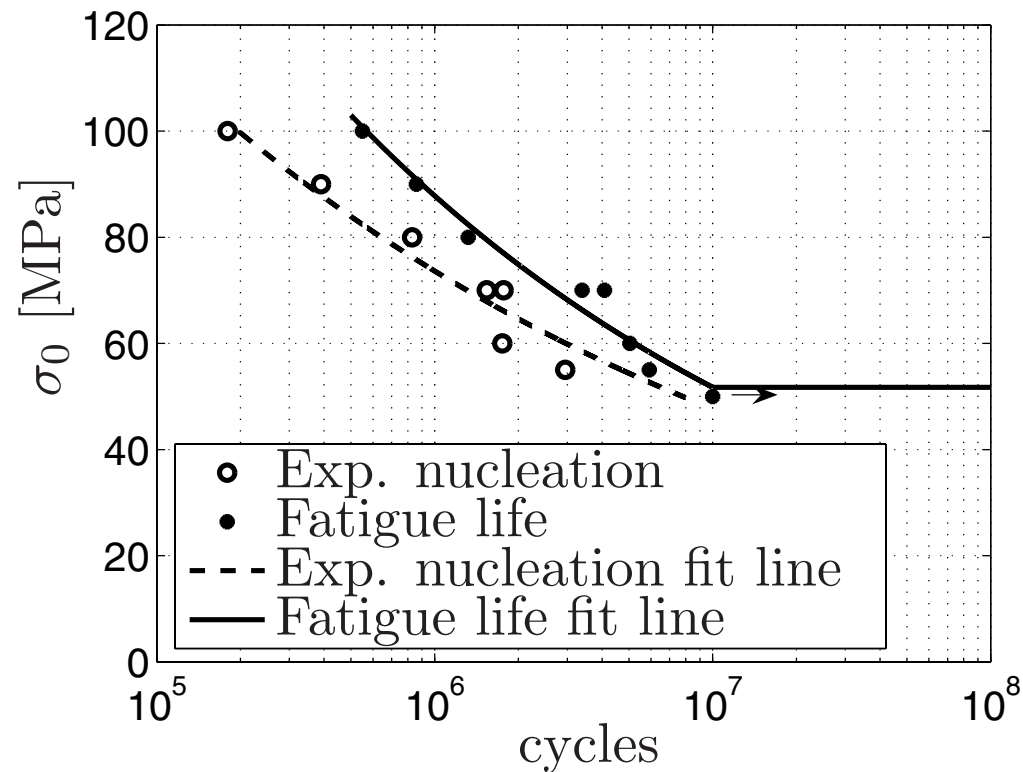
The role of **resonance**



Full scale fatigue tests

test results

Steel construction test results



Experimental nucleation is fatigue life when the smaller crack can be detected through dynamic behavior control.

The Exp. Nucleation life includes a **large portion of propagation** fatigue life.

In other words nucleation/propagation can be resolved only when a **large** fatigue crack appears in the structure.

Only pin side failure have obtained in this fatigue test set

Full scale fatigue tests

test results

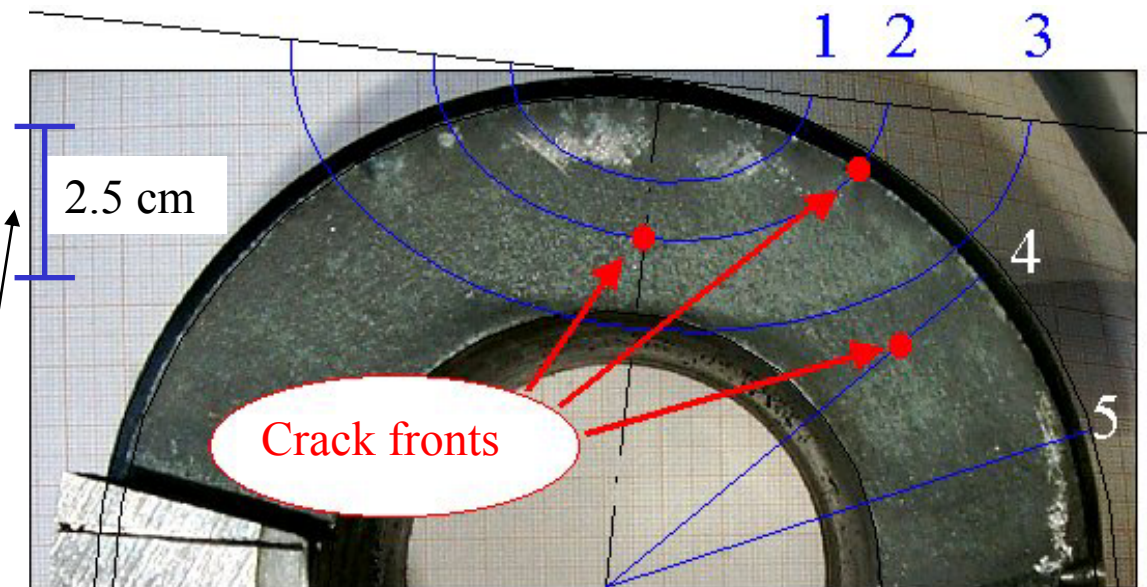
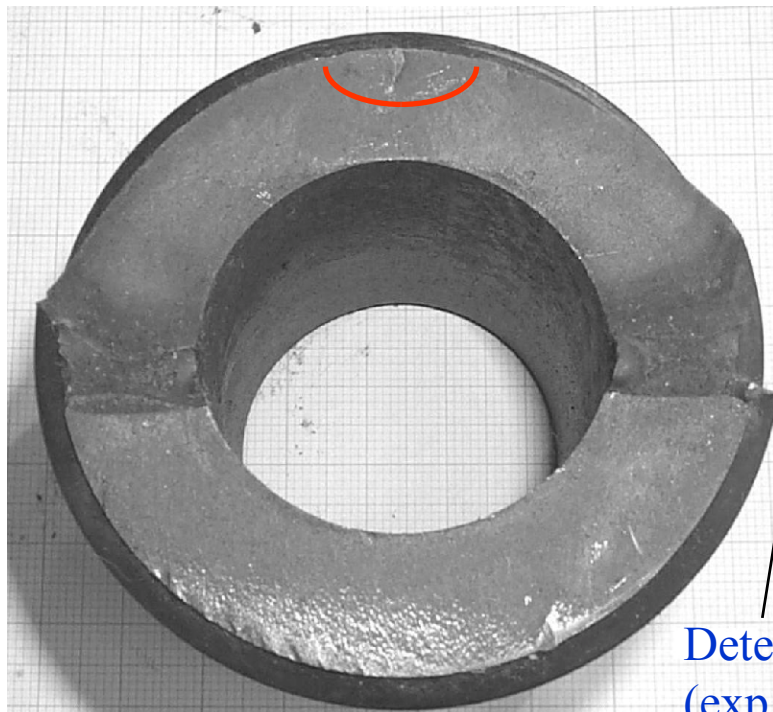
Steel construction test results

Fatigue fracture section (pin)

fatigue crack starting from last engaged **thread root**

High toughness leads to a large wall-through crack, before brittle fracture

(material: **AISI 4145H**)

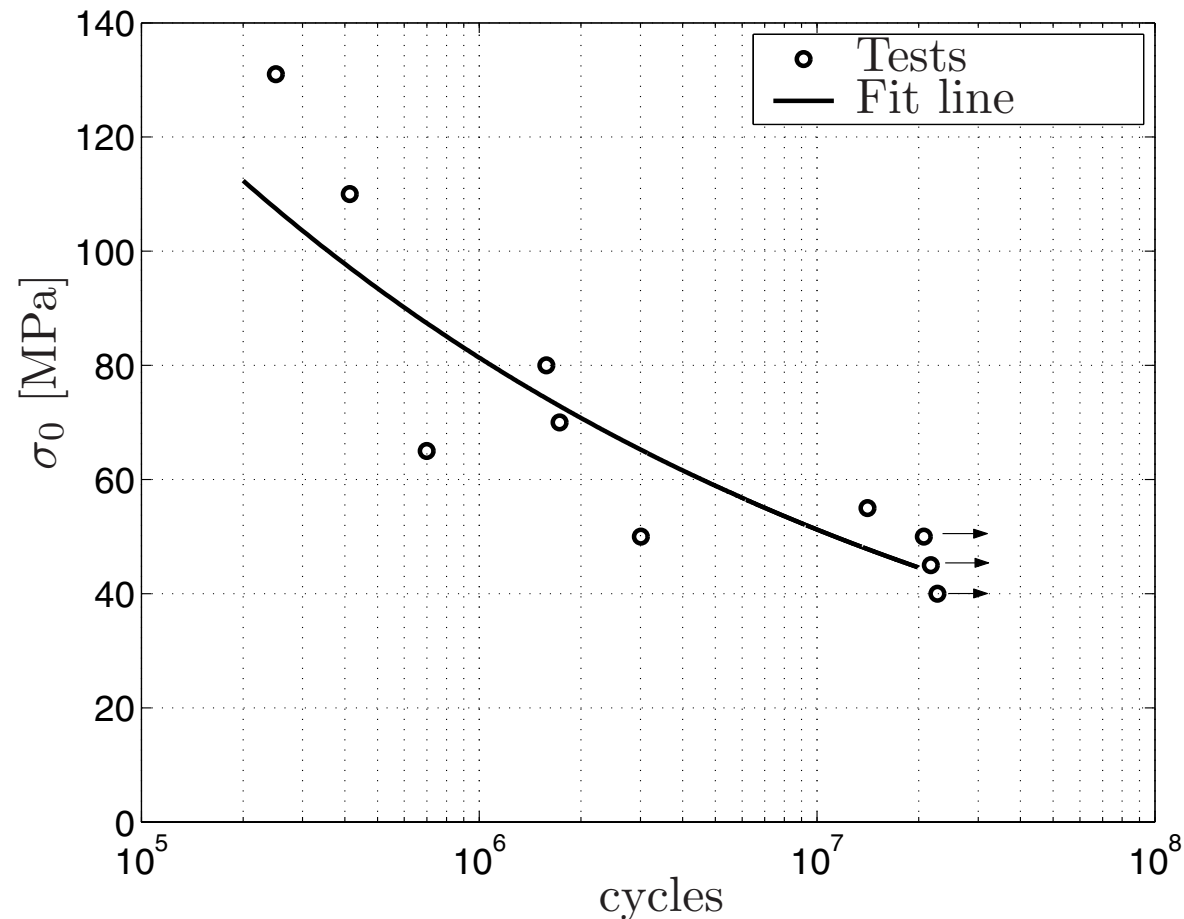


Detectable size
(exp. nucleation)

Full scale fatigue tests

test results

Aluminum construction test results



The aluminum alloy here used shows **brittle** behavior.

Then propagation phase can not be distinguished from dynamic behavior.

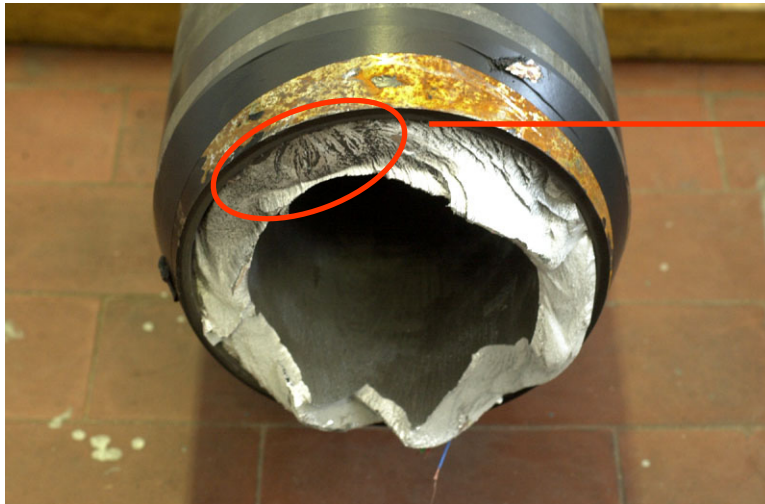
Full scale fatigue tests

test results

Aluminum construction test results

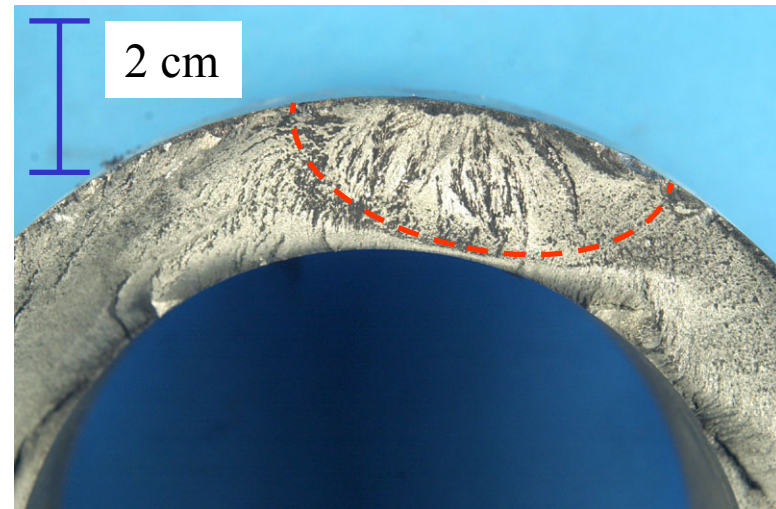
Crack surface, showing:

- **initiation** point
- **brittle** behavior



Fracture toughness is not enough to allow **wall-through** crack.

(material AA 7014-T6)



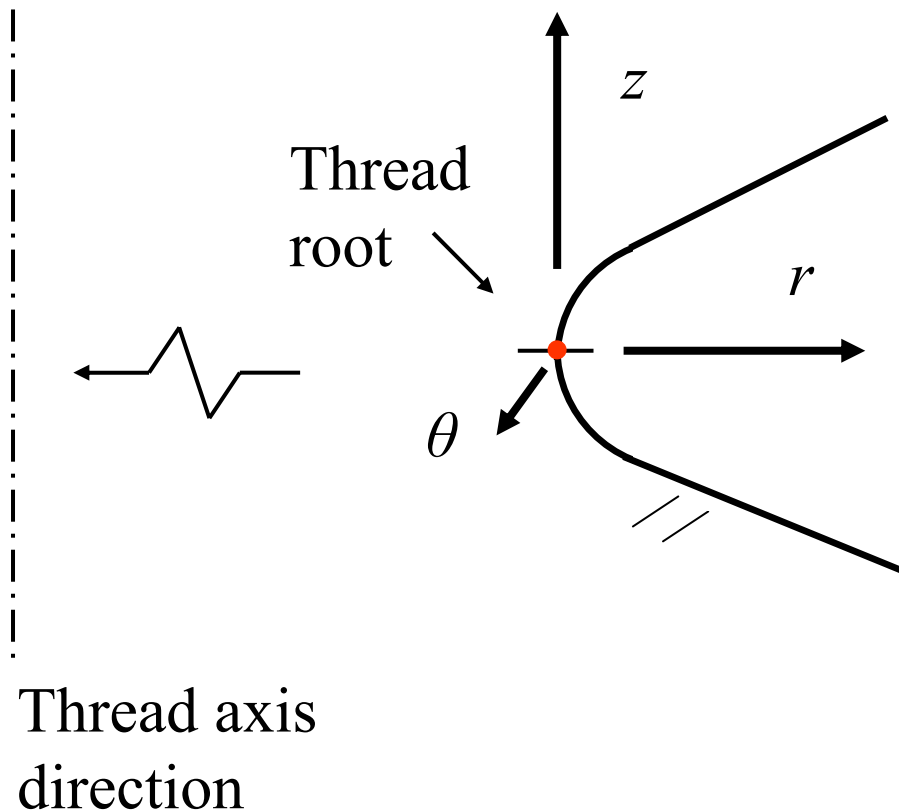
After reaching this front, **brittle fracture** happens.

Until this condition, dynamic behavior control is almost steady.

Finite Element simulations

FE model dedicated to threaded connection

Steel construction FE model



Under bending load the stress state is **biaxial** at the thread root surface:

$$\sigma_r = 0$$
$$\sigma_z > \sigma_\theta > 0$$

$$\tau_{r\theta} = \tau_{rz} = \tau_{\theta z} = 0$$

$$\varepsilon_\theta \sim 0$$

Stress state is similar to **plain strain** condition.

The **make up** produces a strong presetting, and then a plastic zone around the thread root can be found.

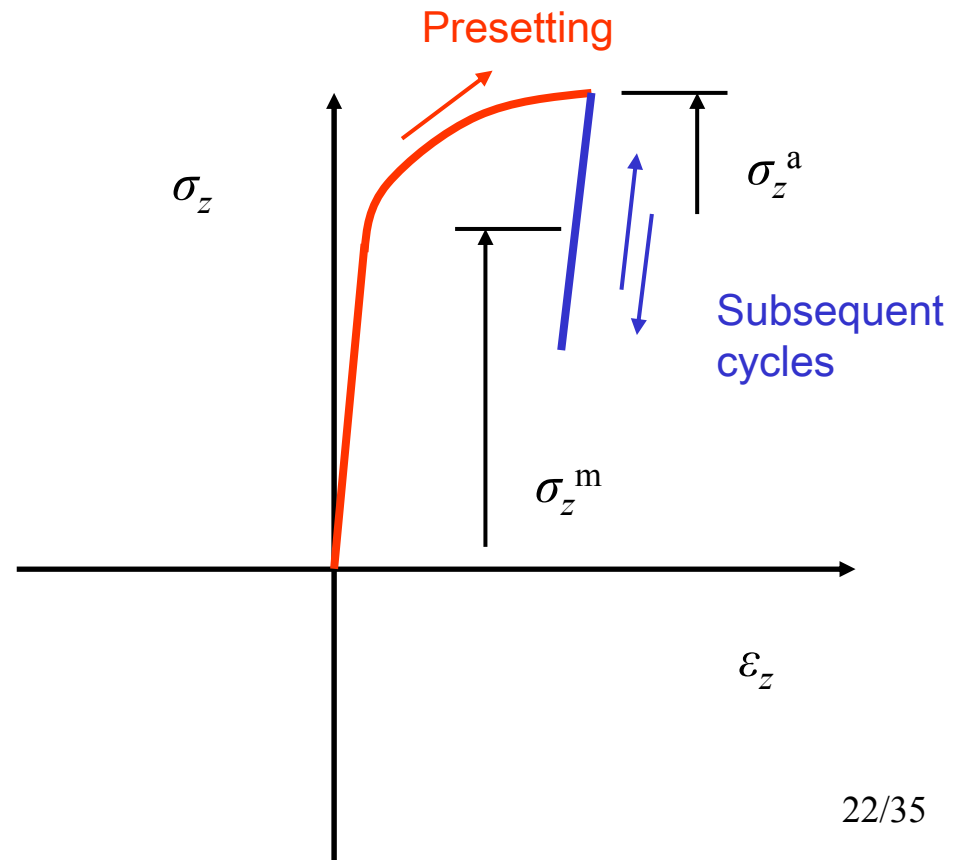
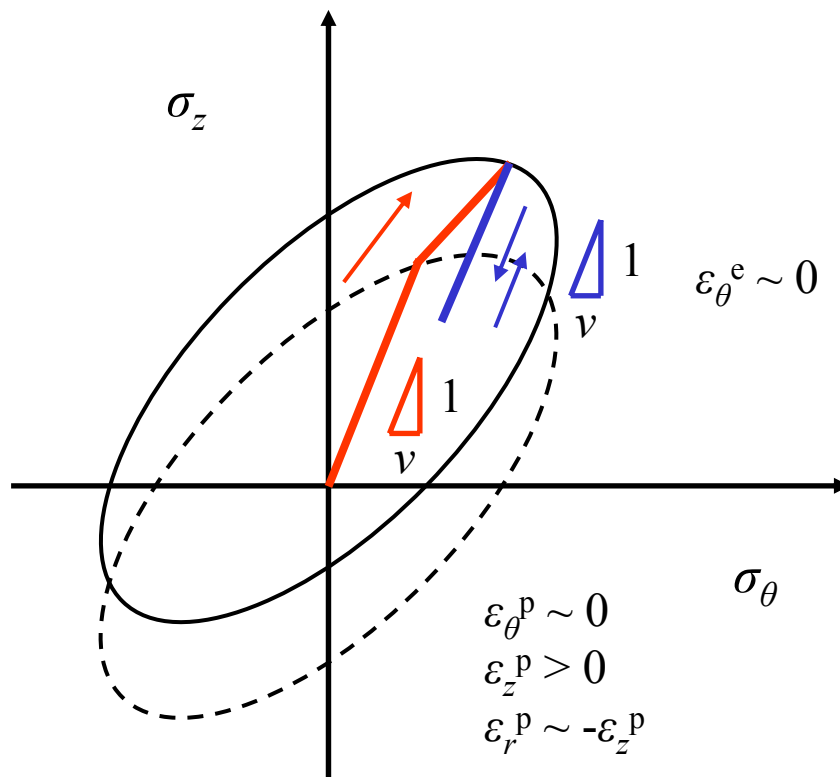
Finite Element simulations

FE model dedicated to threaded connection

Steel construction FE model

Elastic shakedown at the last engaged thread root after presetting:

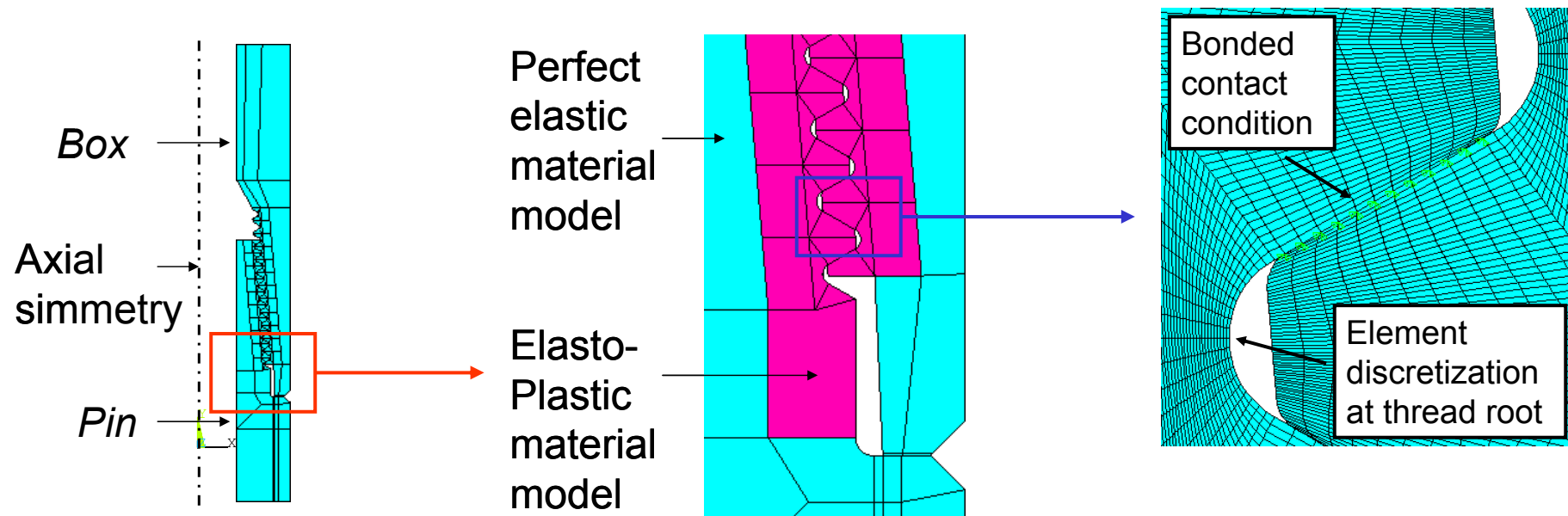
- *linear kinematic hardening* can be assumed
- *limited* subsequent stress amplitude



Finite Element simulations

FE model dedicated to threaded connection

Steel construction FE model



2D axial symmetry, to avoid cumbersome 3D analysis

Elasto-plastic material model, with linear kinematic hardening behavior

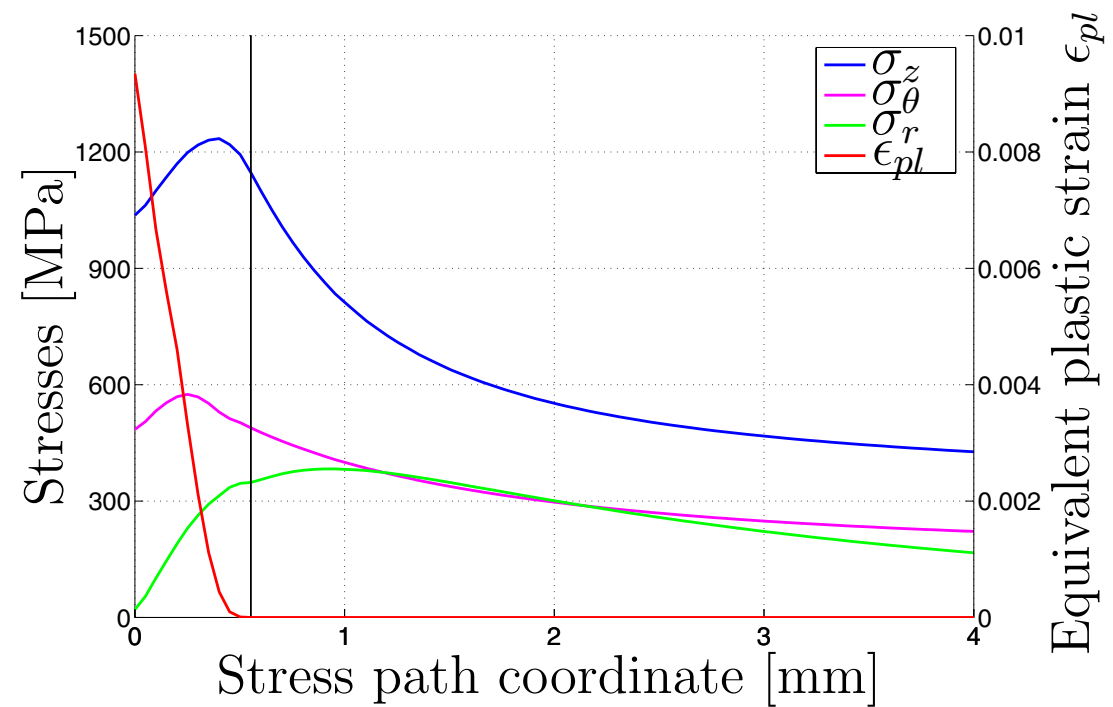
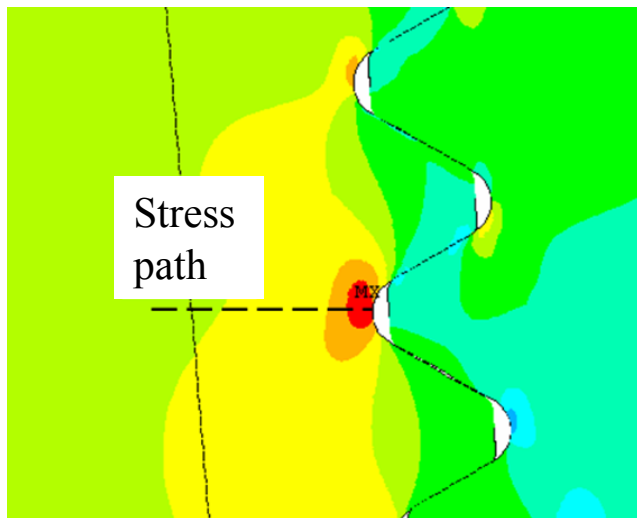
Contact is modeled as closed gap since no contact loss is assumed.

Finite Element simulations

FE model dedicated to threaded connection

Steel construction FE model

Stress path along thread root bisector, after **presetting**

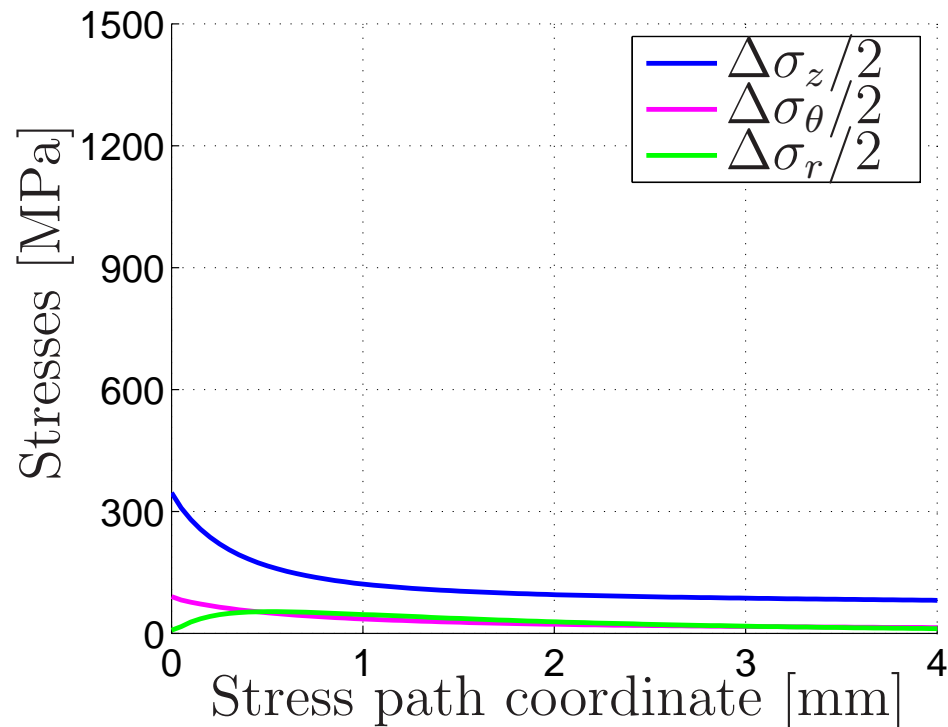
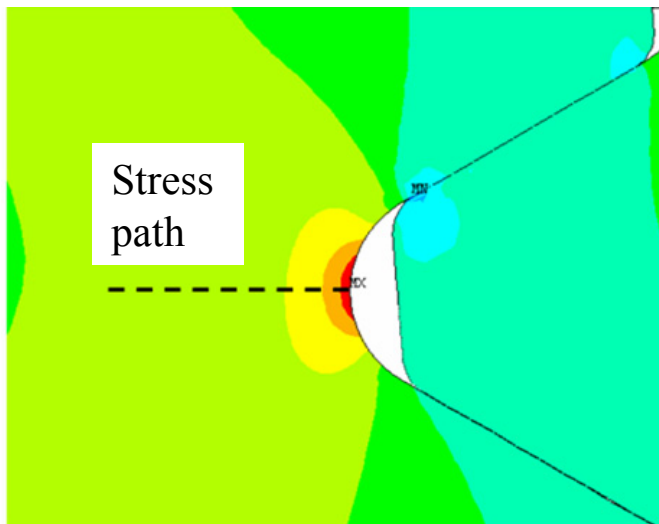


Finite Element simulations

FE model dedicated to threaded connection

Steel construction FE model

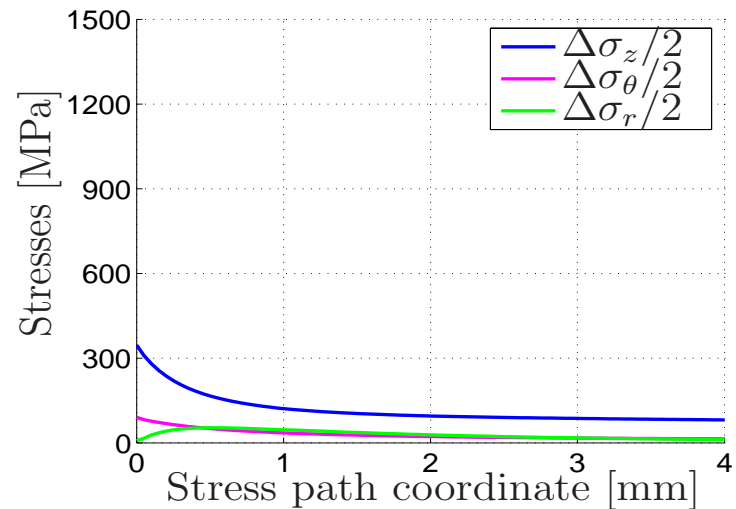
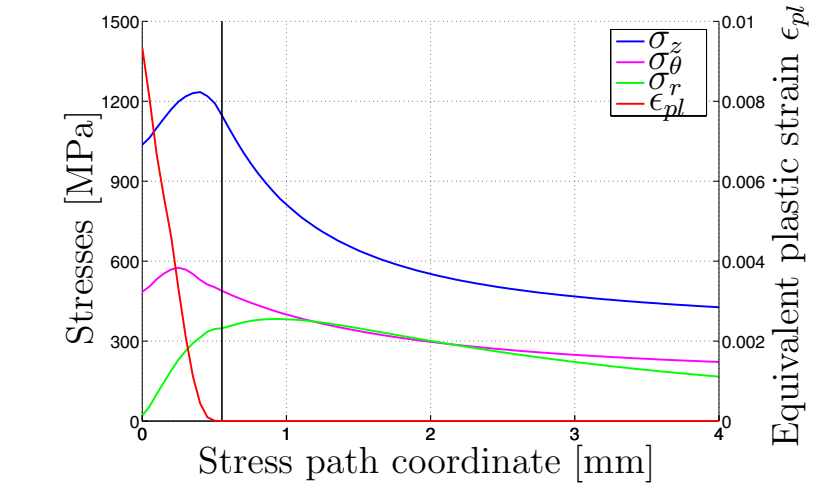
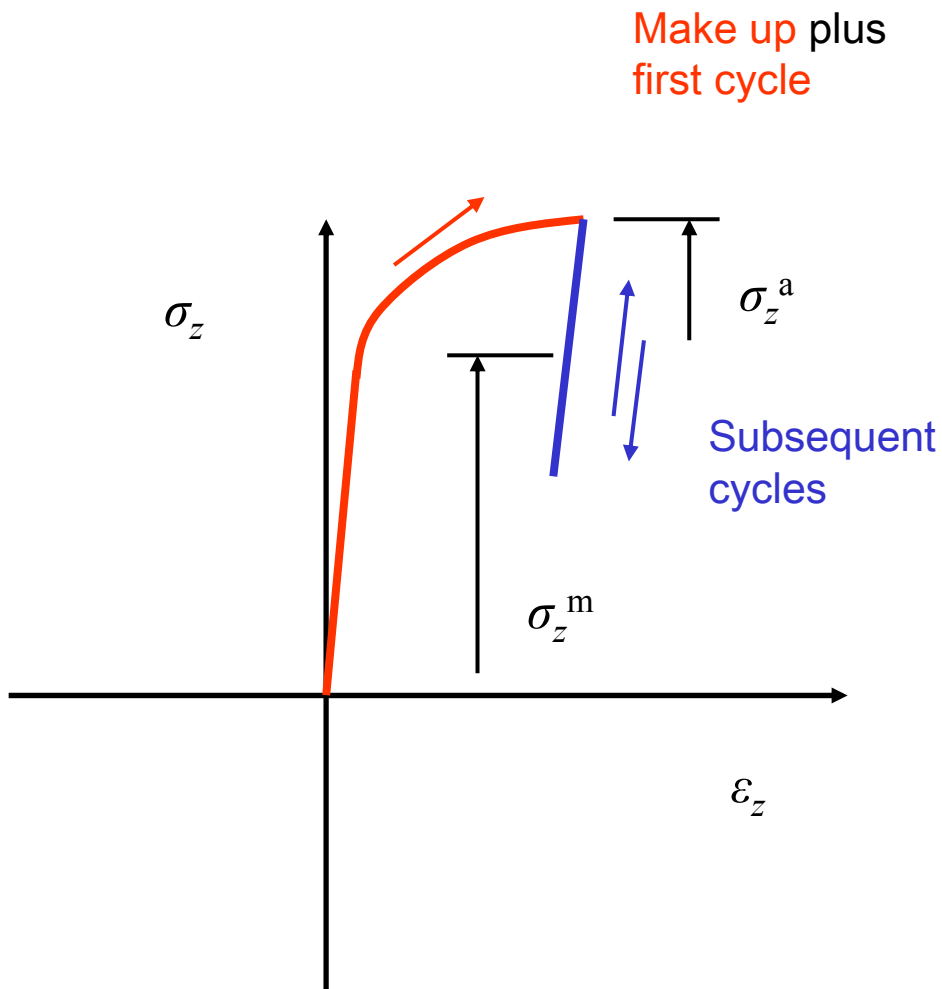
Stress path along thread root bisector, after elastic analysis.



Finite Element simulations

FE model dedicated to threaded connection

Steel construction FE model



Fatigue models

classic approach (Gerber, k_f , surface effect)

Steel construction fatigue life prediction model

To propose a valid fatigue model the following issues need to be considered:

- reference **S-N** curve, with plain specimens, to relate load to fatigue finite life

- **mean stress** effect

(the strong presetting of the connection induce high tensile stresses)

- **notch** effect

(high gradient at the thread root)

- **surface state** effect

(the machining to generate thread geometry can play a role in terms of fatigue nucleation)

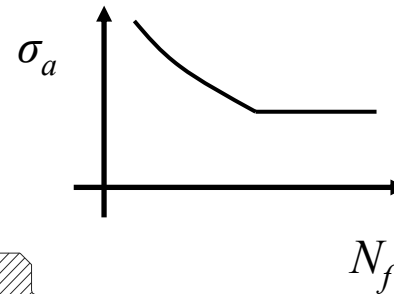
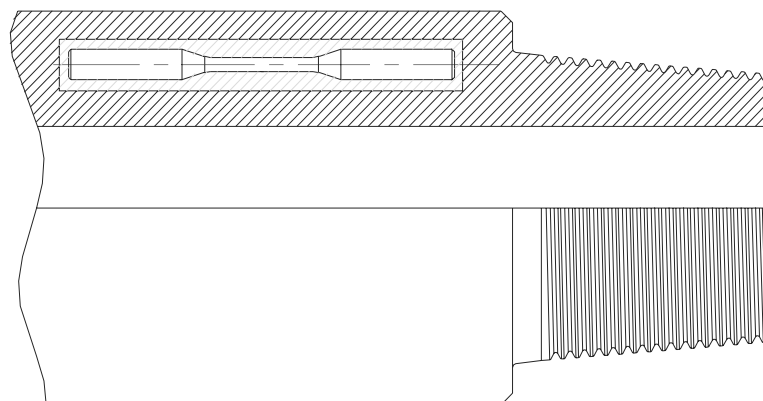
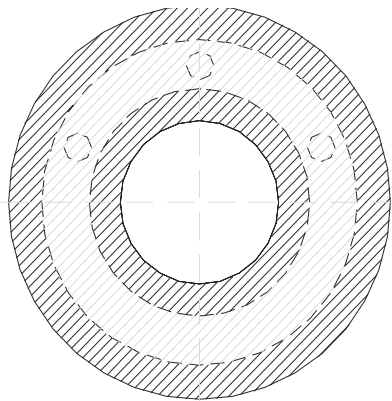
Fatigue models

classic approach (Gerber, k_f , surface effect)

reference **S-N** curve

Several plain specimen were **extracted from real component** to test as close as possible in terms of:

- heat treatment,
- grain orientation.



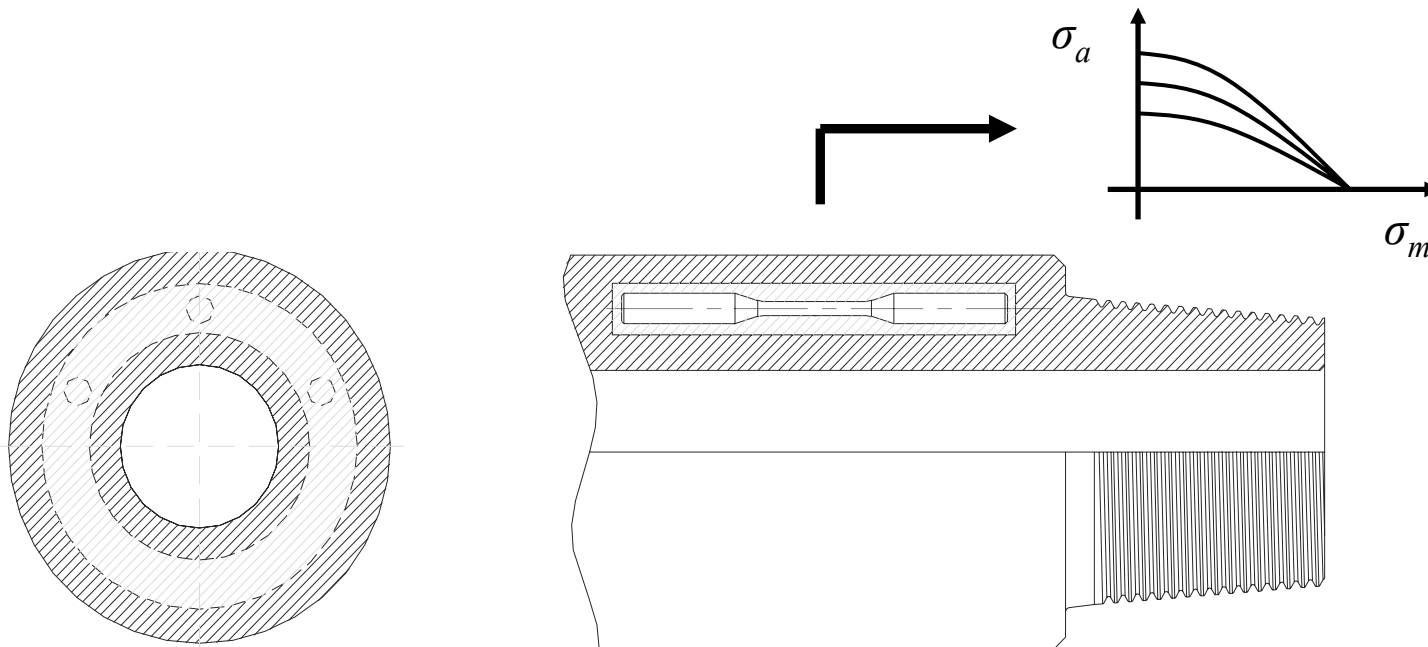
Fatigue models

classic approach (Gerber, k_f , surface effect)

mean stress effect

To take into account mean stress, the Gerber (parabola) model is considered.

Gerber parabola shows better fit with plain specimen extracted from real component tested at positive mean stress ratios.



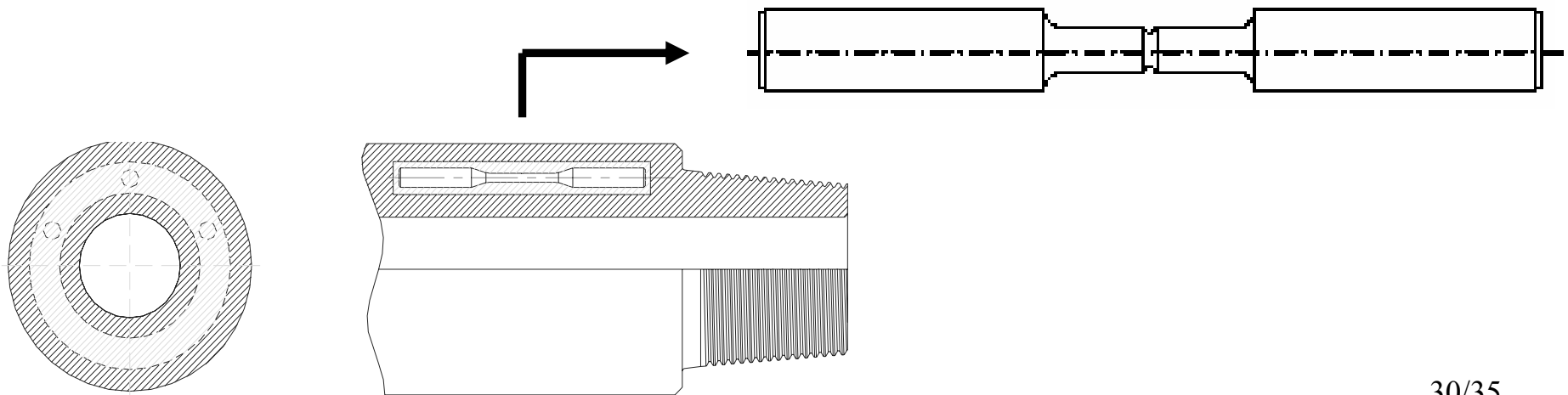
Fatigue models

classic approach (Gerber, k_f , surface effect)

notch effect

To take into account notch effect the following steps were considered:

- Same notch radius to determine the fatigue notch factor k_f
- Also notched specimen are extracted from real component, and the notch bisector has same orientation as thread root bisector



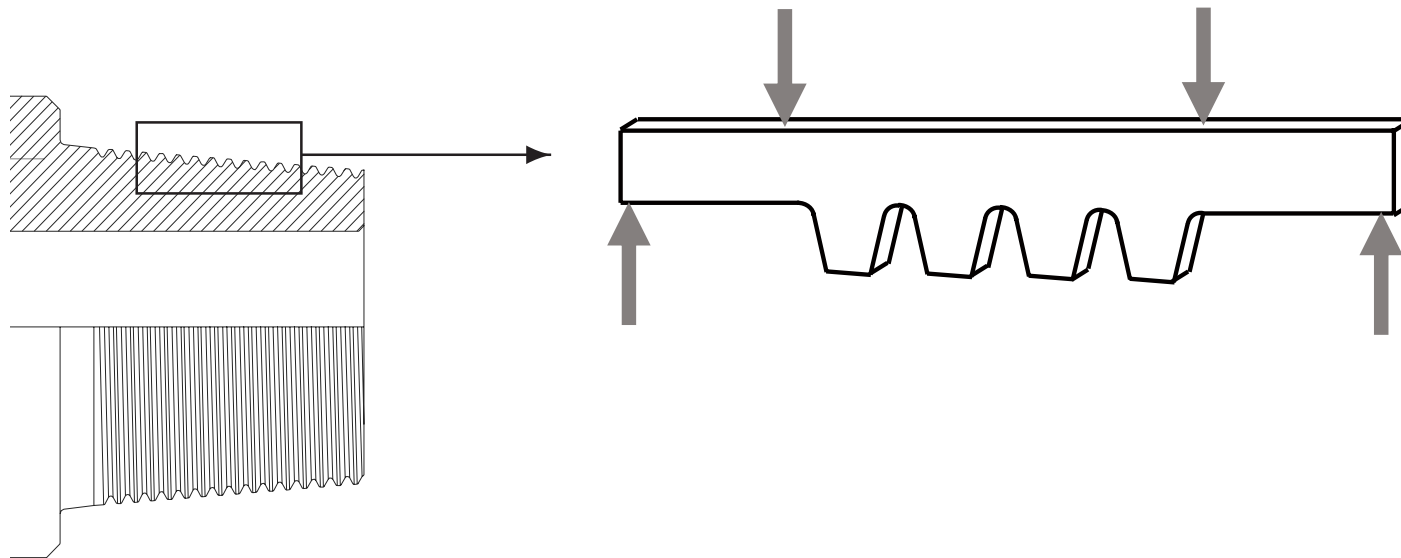
Fatigue models

classic approach (Gerber, k_f , surface effect)

surface effect

Finally particular care is dedicated to the surface effect:

- Small scale specimen **extracted from thread geometry** were tested to reproduce as close as possible surface conditions

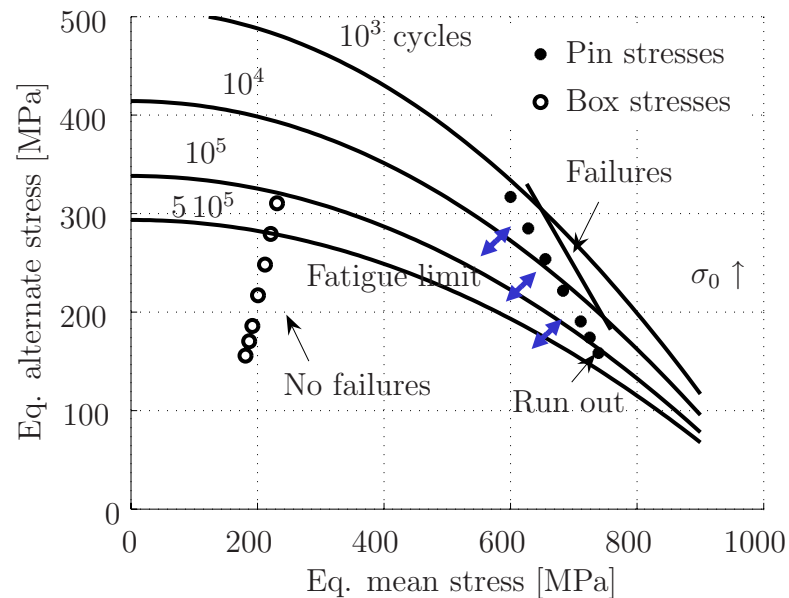


Fatigue models

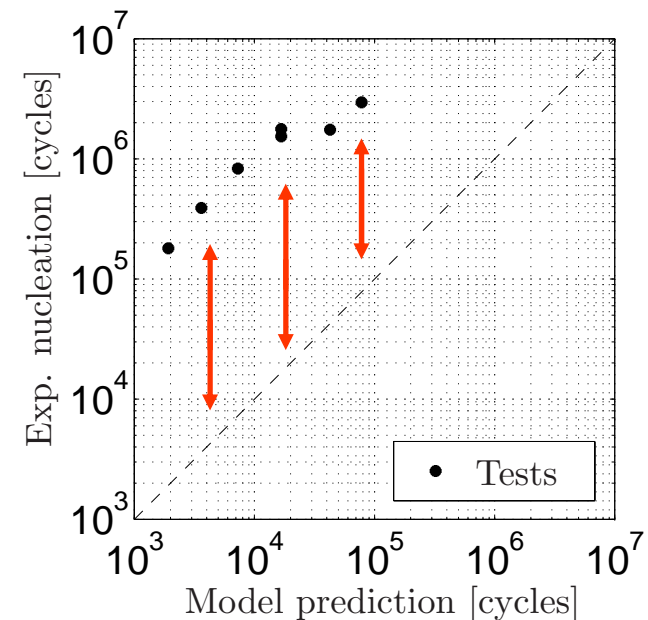
test results correlation

The correlation is here presented as:

- Equivalent stresses against material limit at different cycles (left)
- $\log N_{\text{predicted}} - \log N_{\text{Exp.Nucl.}}$ diagram (right)



Not so bad in terms of stresses.



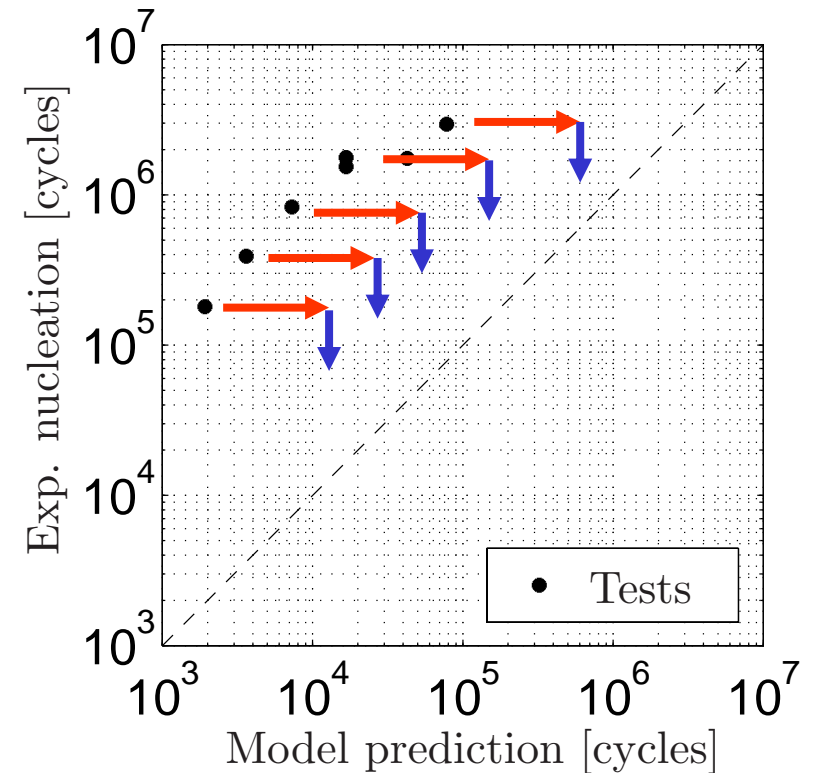
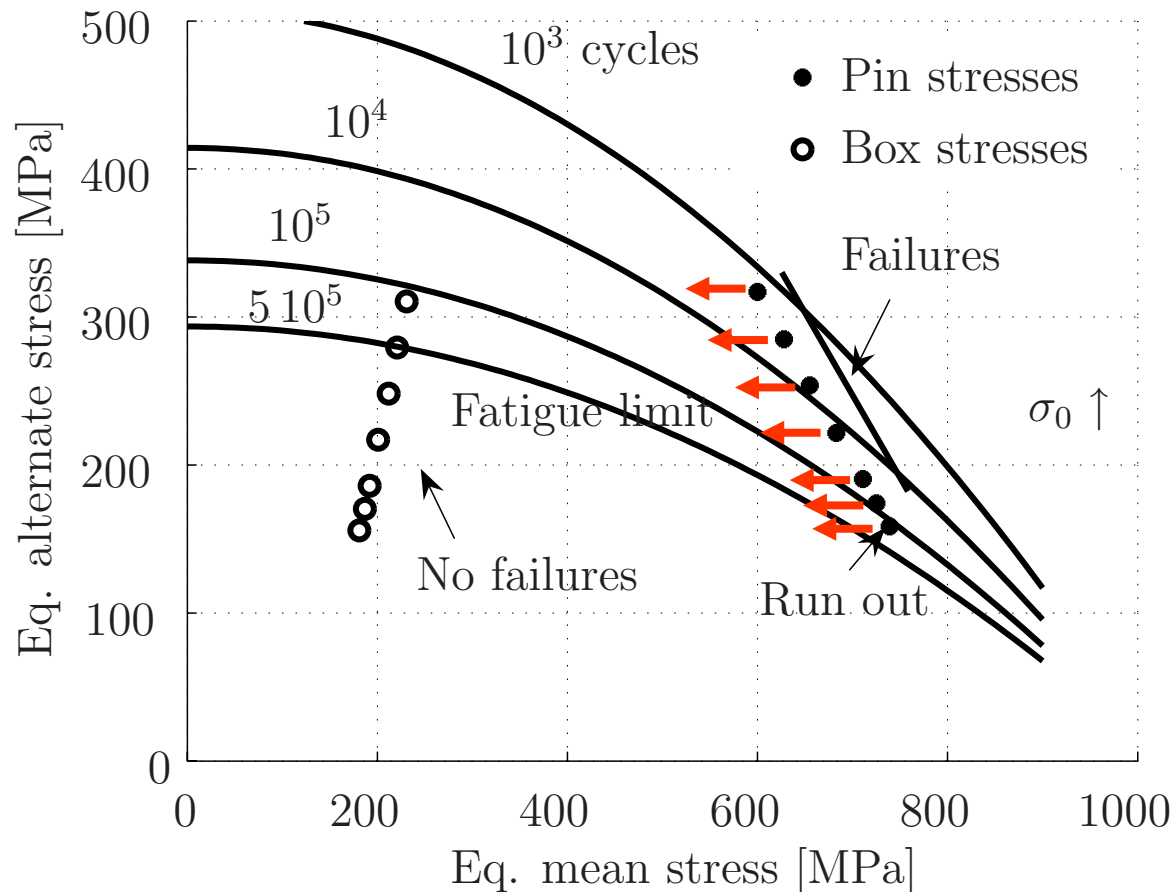
Wide discrepancy in terms of cycles.

Fatigue models

test results correlation

Possible sources of mismatch:

- **bad assessment of mean stress** (uncertainty of make up presetting, possible material cyclic relaxation since it cycles at high mean stress)
- **big portion of propagation**



Conclusions

- Demanding **full scale fatigue tests** were proposed along with the description of resonance **test rigs**.
- Finite element dedicated to thread geometry was presented
 - **elastic-plastic** analysis was needed for the high presetting,
 - kinematic hardening was able to model **elastic shakedown**
- Fatigue model proposed deals with **simple tools** for fatigue evaluation (Gerber, k_f , surface effect) and calibration of the model is based on **small scale specimen as close as possible to real component conditions**.
- To improve the correlation **fatigue crack propagation** should be included, but:
how much is the nucleation/propagation crack length??

Conclusions

*Were **expensive** full scale fatigue tests necessary ??*

YES, because:

- Some fatigue issues are hard to be **thought** *a-priori*.
- From **small** to **full** scale, propagation can play an important role. Though prediction is **conservative**, large mismatch can be found.

*If we have to **avoid** full scale testing:*

Specimens, as close as possible to **real component conditions**, are needed, to calibrate fatigue models.