Fatigue testing

Lecture at SP Technical Research Institute of Sweden
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Static testing of a bridge in 1890

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‘Traditional’ fatigue design

- **Need for *material data***
  - (Distribution of) Fatigue Limit
  - Wöhler curve (for different probability levels)
  - da/dN, crack propagation rates

- **Take various factors into account by using *empirical formulas***
  - Volume dependence
  - Influence from mean level of applied load
  - Influence from surface roughness
  - Influence from notches
  - Influence from type of loading (i.e. variable amplitude)
  - …..

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Different types of fatigue tests

- **Material testing**
  - Must be done for every material
  - Test specimens used
  - A lots of tests are run to take statistical variations into account

- **Component testing**
  - Only a part of the construction is tested, for example testing of welds and other types of joints
  - Often done as uniaxial random loading
  - Less expensive than construction testing

- **Construction testing**
  - Used to verify calculations, i e calibrate calculation models
  - Should be done for new types of constructions, but not needed if similar constructions have been tested
  - Usually multiaxes testing with random loading, i e very expensive

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What you need for fatigue testing

- **Transducers for measuring**
  - Strain at the test object
  - Displacement
  - Load applied to the test object
- **Actuator for applying prescribed loads**

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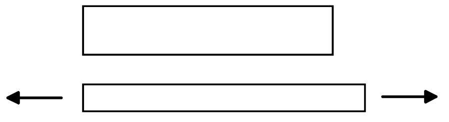
Strain gage



$$R = \rho \frac{L}{A}$$

L+ΔL, A-ΔA, ρ+Δρ

The resistance increase:

- **Increased length**
- **Reduced cross sectional area**
- **Increased resistivity (piezoresistiv effect)**

Gage factor: $$K = \frac{\Delta R / R}{\Delta L / L} = 1 + 2\nu + \frac{\Delta \rho / \rho}{\Delta L / L}$$

Increased length

Reduced cross sectional area

Increased resistivity

K≈2 (metals) K~100 (semi conductor)

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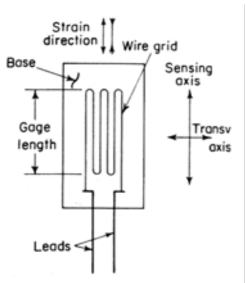
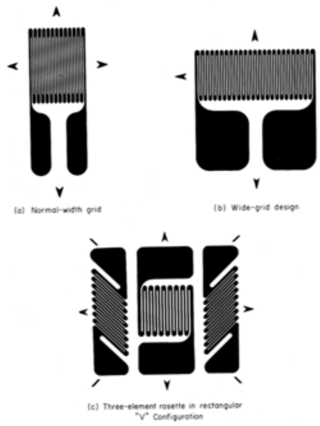
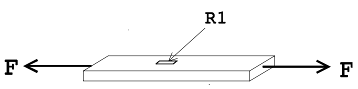
Practical layout of strain gauges

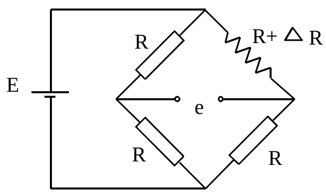




Converting strain to an electrical voltage

Wheatstone bridge





$$e = \frac{K \cdot E}{4} \varepsilon$$

- **We have converted a mechanical quantity (strain) to a proportional electrical voltage**
- **Electrical voltages can easily be measured / conditioned by electrical instruments and / or sampled to a computer**

Strain gauge (Rosette)

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Several strain gauges

By using several strain gauges stress gradients can be measured

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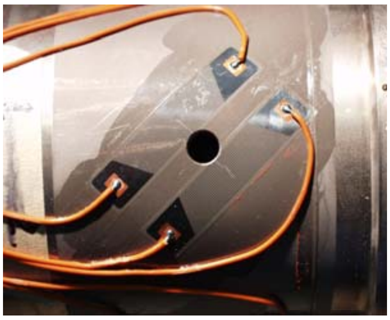
Crack propagation gauge



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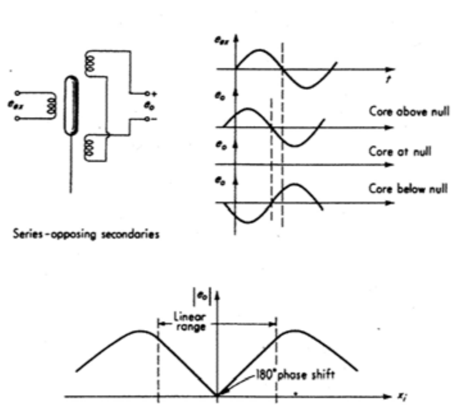
Differentialtransformator (LVDT)



Relative transducer ⇒ a fix reference point is required

A carrier frequency is used ⇒ Signal conditioning with a phase sensitive rectifire

Non linear at large displacements

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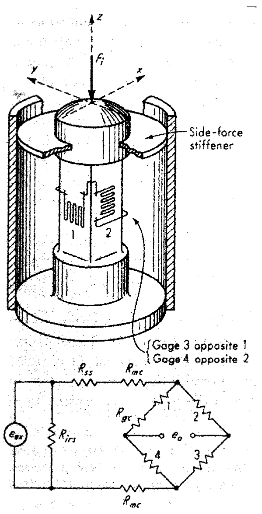
Measuring load



Resistive load cell:

The load will deform a column in the load cell

The deformation will change the resistance of the strain gauges

The resistance change is converted to an electrical voltage by the Wheatstone bridge

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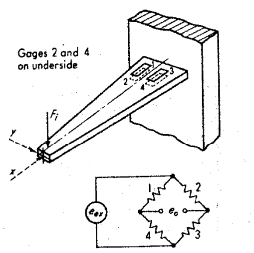
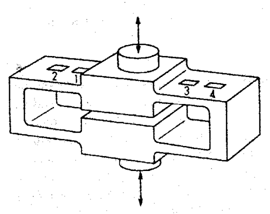
Different types of load cells



Console beam:

To increase the sensitivity (higher strain) the strain is obtained from bending



Beam transducer:

At large loads the upper and lower blocks hit each other (over load protection)

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Fatigue testing by rotating bend

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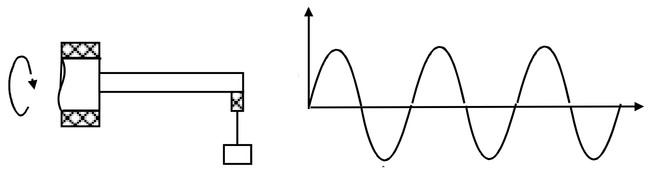

- Oldest test facility
- A lot of material data are obtained by this type of machine
- Only sinusoidal (constant amplitude) loading
- High testing frequencies (hundreds of Hz)

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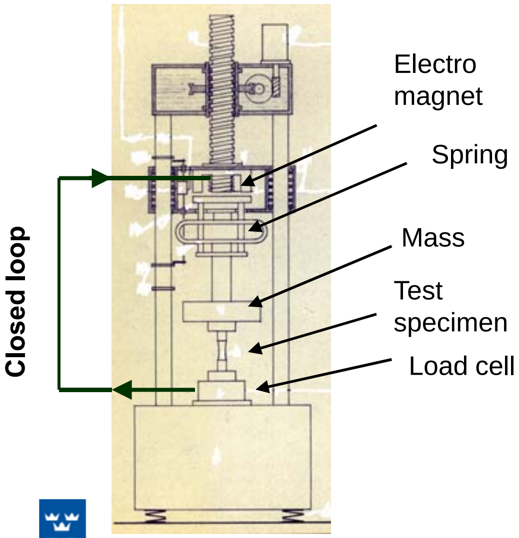
Fatigue testing in a resonance machine



The oscillator (spring – mass system needs small I/P effect (current to the electro magnet) to maintain a sinusoidal motion at its resonance frequency

By a closed loop the current is adjusted to obtained the prescribed load amplitude

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Resonance machine (cont..)

- Axial loading of a test specimen
- Only sinusoidal (constant amplitude) loading
- High testing frequencies (Hundreds of Hz)
- Suitable for determining the fatigue limit

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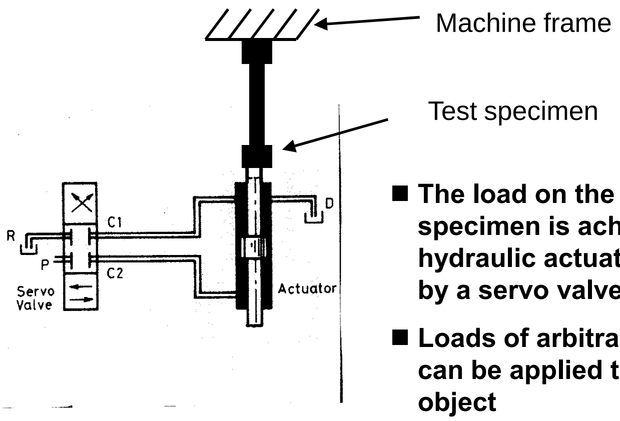
Servohydraulic testing machine



- **The load on the test specimen is achieved by a hydraulic actuator controlled by a servo valve**
- **Loads of arbitrary shapes can be applied to the test object**
- **Rather low test frequencies <50 Hz**

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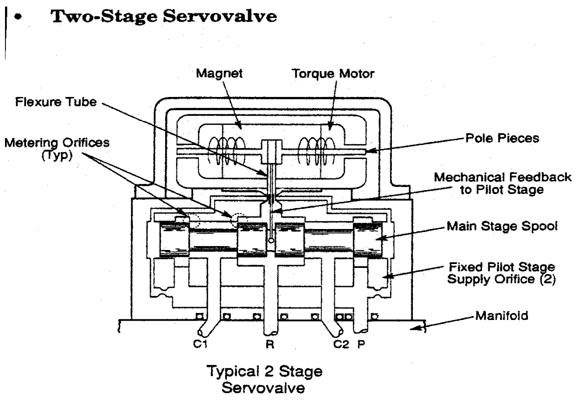
Servohydraulic testing machine (cont …)



Typical 2 Stage Servovalve

By a servovalve an electrical current is converted to an oil flow

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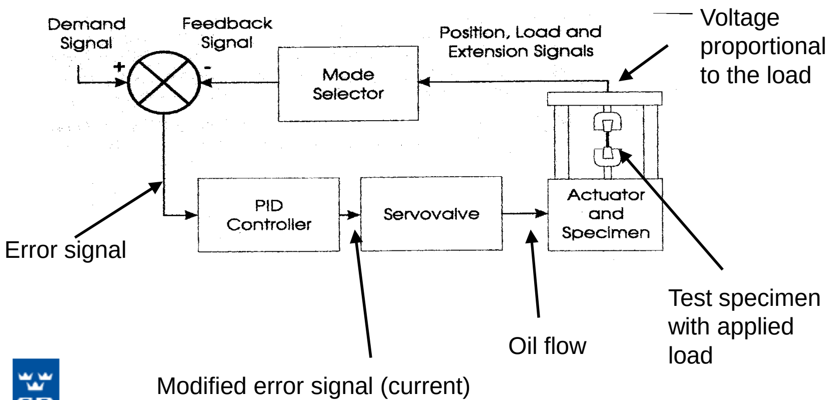
Servohydraulic testing machine (cont …)

A servohydraulic testing machine controlled by a closed loop system

The servo valve is controlled by the error signal (Demand – Feedback)



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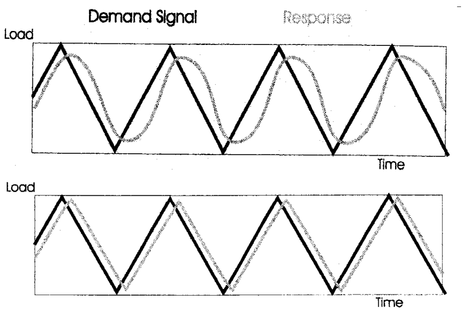
Servohydraulic testing machine (cont …)

Good response only if the PID regulator is tuned

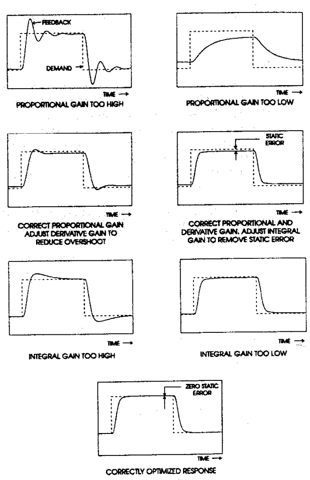
No general tuning due to different stiffness of different specimens



Badly tuned loop, the prescribed load level is not obtained

Correctly tuned loop, Note the phase delay, this is due to the time it takes for pistons to move and oli to flow

Tuning a PID regulator



P-term (proportional gain)

- Fast response

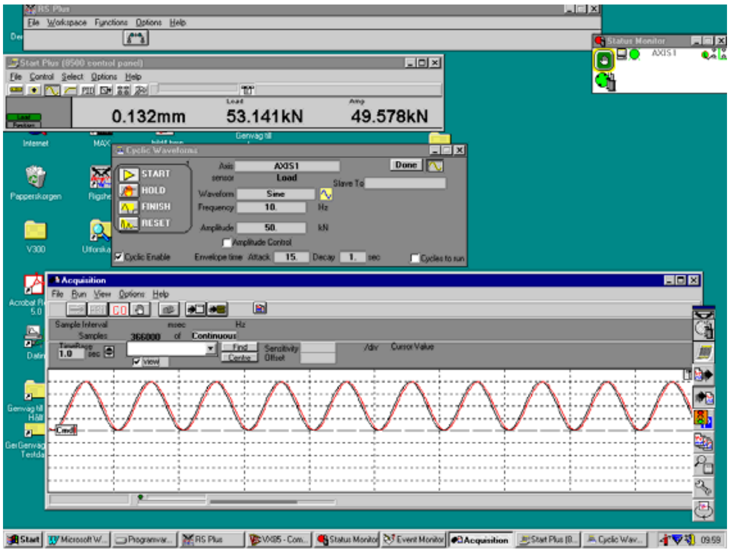
D-term (derivative gain)

- Damping (reduce over shots due to high P-gain)

I-term (integral gain)

- Reduce static errors (badly balanced valves, oil leakage, ….)

10 Hz test frequency; good response, but slow!



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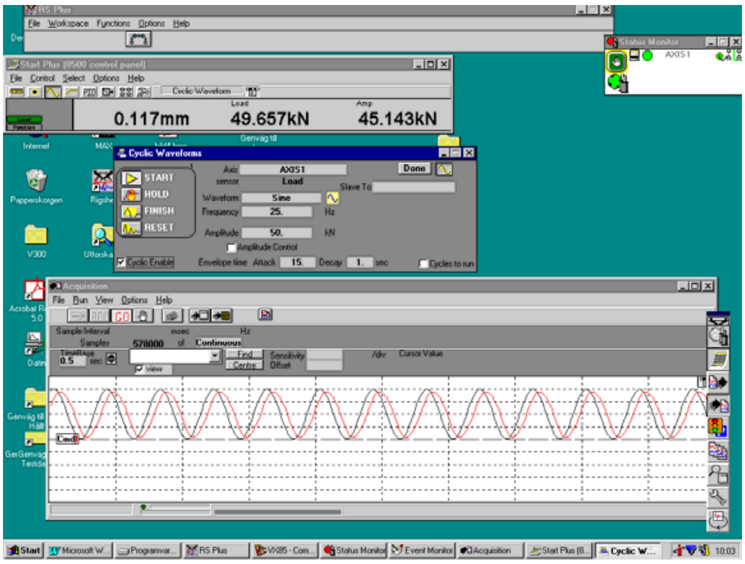
25Hz test frequency; lost 10% in amplitude!



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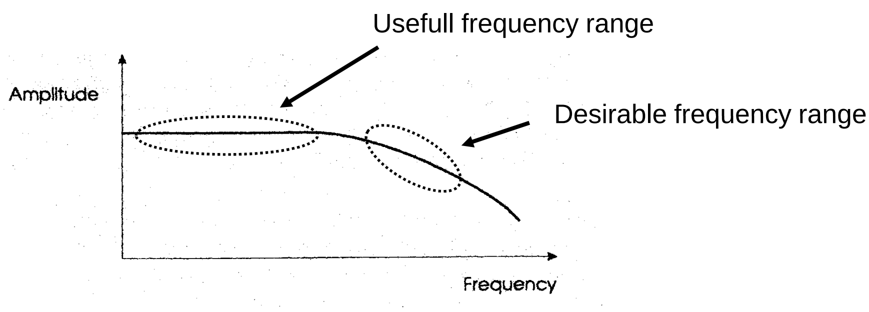
Amplitude response of a S/H testing machine



The drop in amplitude response can be compensated by 'over driving', i e use a higher level of the drive signal than the wanted load-level. This can be done automatically, AMPLITUDE CONTROL

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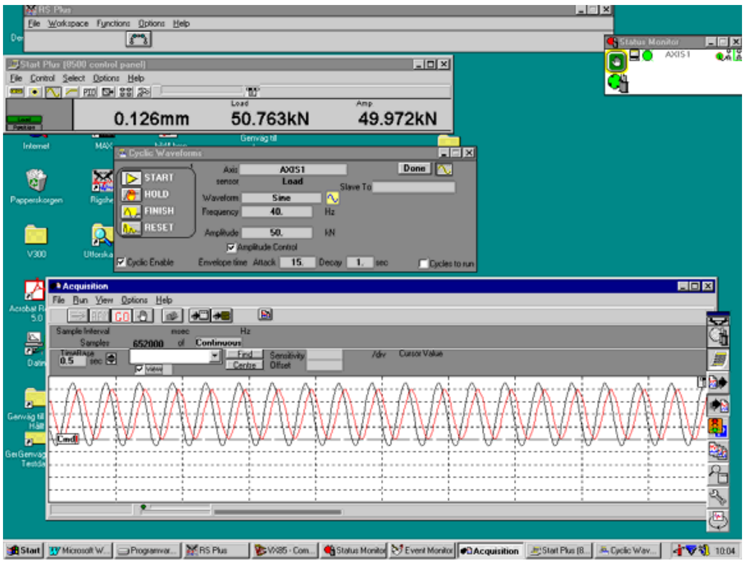
Test frequency 40Hz + amplitude control; Good response



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Variable amplitude testing

- It is a risk that the high load levels are not reached, the results from the fatigue test are then not correct
- Only using the PID regulator will give a rather low test frequency as all load peaks in the time-history must be achieved
- AMPLITUDE CONTROL can not be used as the amount of 'over driving' is different for high and low load levels

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Variable amplitude testing (cont …)

- Measure the transfer function of the testing machine (quotients between the response and drive signals at different frequencies)
- Transform the load signal to the frequency domain and multiply it with the inverse transfer function.
- Transfer back to the time domain and use this corrected signal as drive signal at the test
- NB the method will only work if the transfer function is linear and does not change during the test. However, it is wellknown that propagating cracks will change the transfer function and the response is nonlinear

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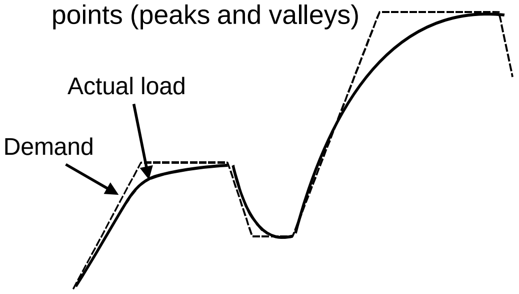
Variable amplitude testing (cont …)

The demand load signal is given as a sequence of turning points (peaks and valleys)



- Let the machine put a ramp to the next turning point
- Then a hold time until the actual load has reached this level
- A new ramp to the next turning point

This technique will work even if the test specimen softens (or hardens) during the test

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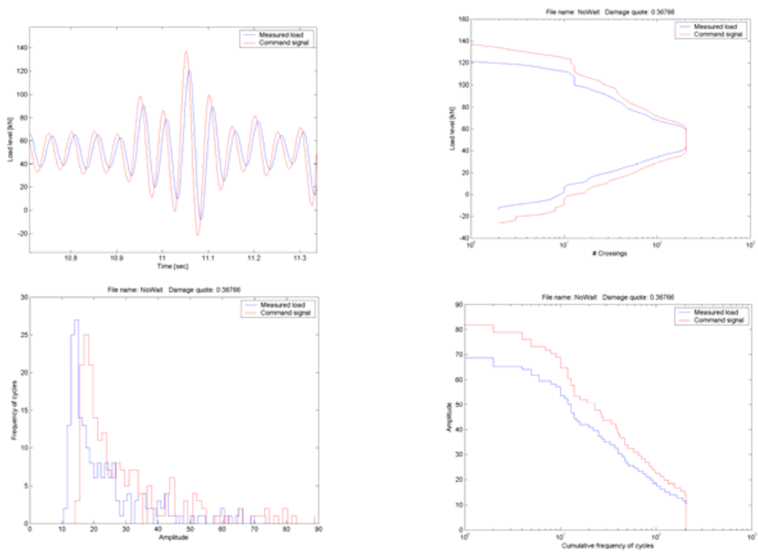
No correction



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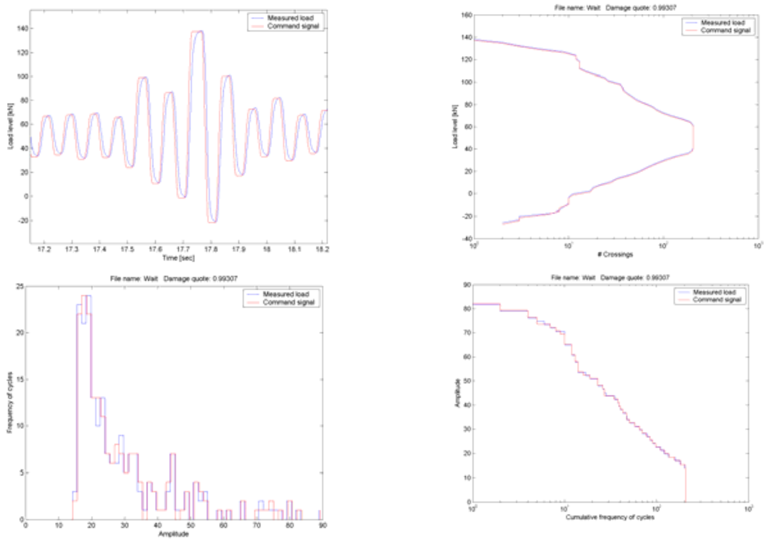
Correction



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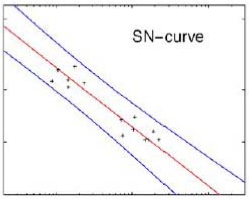
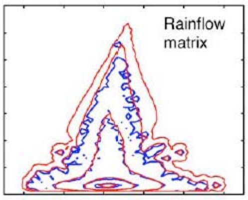
The component testing approach

1 Field measurement

4 Dimensioning





2 Load analysis

3 Laboratory component testing

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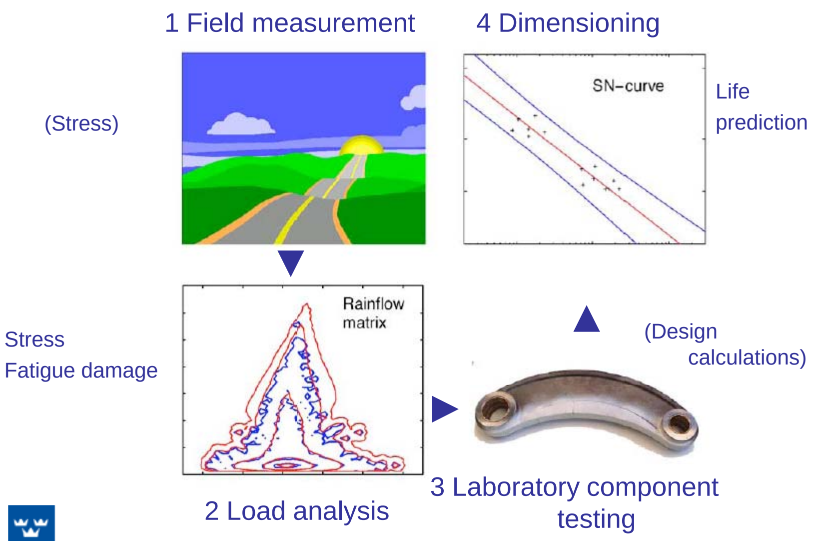
Calculations in component testing approach



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The component testing approach

- + Comparatively accurate prediction
- - Fatigue life time restricted to component.

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Alternative: The calculation approach

- Alternative:
- Computer model
- Calculate stresses and fatigue life time.

- Which information is then needed?
- 1. Load data (from field measurement and load analysis)
- 2. Material data (from material testing instead of component testing)
- 3. Geometric design (CAD)

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The calculation approach requires more theory

- The calculation approach requires much more modelling of the ”physics” of the load, material and geometry which is automatically included in the component approach.

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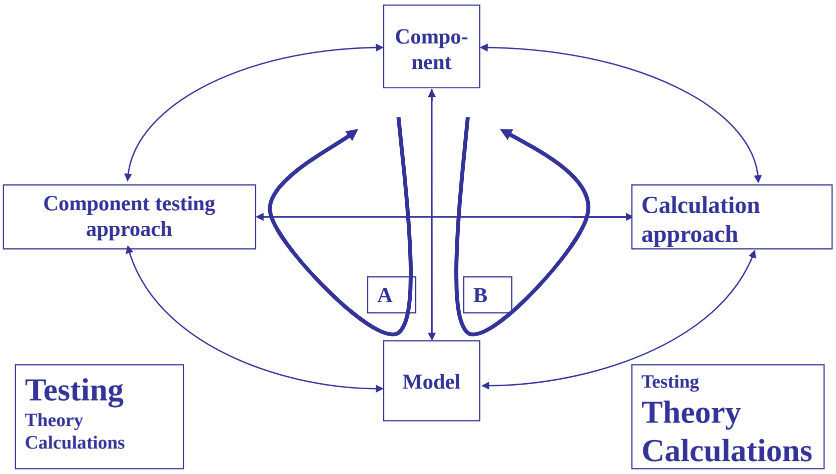
Two alternative ways to model reality



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UTMIS – The Swedish Fatigue Network

- As a testing and research institute SP is a link between the academic institutions and companies
- UTMIS = The Swedish fatigue network – www.utmis.org
- The purpose of UTMIS is within the area of fatigue to
- Spread information and knowledge to the industry
- Increased cooperation between academia and industry
- Increase competence in Swedish industry
- Initiate projects that develop the field

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