Written examination in *Fatigue Design*

for the Master's Programmes Solid and Fluid Mechanics (MPAME),
Advanced Engineering Materials (MPAEM) and Naval Architecture (MPNAV)

- Date: Monday 2010-08-28
- Time: 0845 - 1245
- Location: M– Building
- Teacher: Lennart Josefson, phone 7721507
- Solutions will be available 2010-08-30 at the Department of Applied Mechanics
- Corrected examinations will be available 2010-09-17 at the Department of Applied Mechanics

The written examination consists of two parts: one theoretical part of 14 points in total, and one problem solving part consisting of three problems each with a value of 12 points. A fully correct solution of the complete exam gives a maximum of 50 points.

Theoretical part:
This part must be solved first. No aids are allowed, ie this part is to be solved without textbooks, hand calculator etc. The solution of this part shall be handed in separately, before you continue with the problem part.

Problem part:
This part may be solved using text books and text material distributed during the course, see below. These aids may be collected when the solutions to the theoretical part have been handed in. Short notes in the course material are allowed. Note, however, that solved problems to exercises from the course are NOT allowed as aids. A hand calculator may be used. When in doubt about the hand calculator being a full computer, the teacher should be consulted to permit the hand calculator.
NOTE: To obtain maximum points for each problem, the solution must be clearly motivated and all the equations used from the literature should have a clear reference.

Allowed literature during the problem part:

- Dowling, N.E. (2006) *Mechanical Behavior of Materials*, Third Edition, Prentice-Hall, Upper Saddle River, NJ, USA, 912 pp.
- Fatigue Design (MMA115) Course Material on Multiaxial Fatigue
- Extract from SSAB Sheet Steel Handbook
- Mathematical Tables and Handbooks in Engineering like KTH:s *Formelsamling i hållfasthetslära*, or Roark R.J. and Young, W.C., *Formulas for Stress and Strain*.

The marks are given as (the sum of points from the theoretical and problem parts):

- Not passed 0 – 19 points
- 3 = passed 20 – 29 points
- 4 = very good 30 – 39 points
- 5 = excellent 40 - 50 points

THEORETICAL PART (14 p)

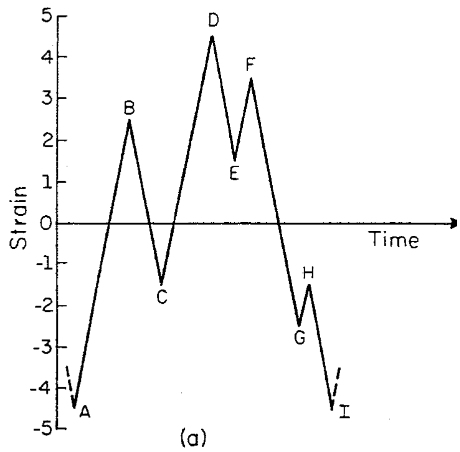
Question 1 (4p)

a) Describe, in principle, the Juvinall procedure to construct a *S-N* diagram.

b) Why does surface roughness decrease the fatigue limit? Does it have an influence on the fatigue life is the total life is in the order of 10 000 cycles? Motivate! [Note that a yes/no answer does not give any credit points without a plausible explanation]

Question 2 (3p)

A strain sequence measured in a material point is shown below. This strain sequence is then repeated. Evaluate strain cycles with amplitudes and mid strains for the load sequence using rainflow count.



Question 3 (4p)

a) Explain the general concept of shakedown and in particular the concepts of elastic shakedown and plastic shakedown!
b) If you have a material with linear isotropic hardening and a homogenous state of stress, which material response of elastic shakedown, plastic shakedown or ratchetting will you obtain?
c) Describe the Palmgren-Miner damage summation rule. In particular state whether this rule can account for history effects (e g from overloads), and if so how.

THEORETICAL PART (14 p), cont'd

Question 4 (3p)

A thin plane sheet is loaded by a bi-axial stress system in two different configurations. Which configuration can sustain the highest σ_a-magnitude? Motivate, for example by using the Dang Van method.

Configuration a) $\sigma_x = \sigma_a \sin(\omega t)$, $\sigma_y = 2\,\sigma_a \sin(\omega t)$

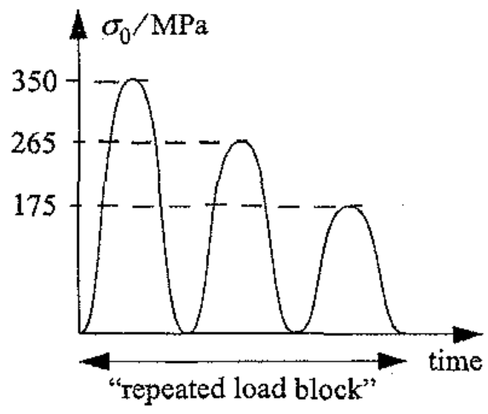
Configuration b) $\sigma_x = \sigma_a \sin(\omega t + \pi)$, $\sigma_y = 2\,\sigma_a \sin(\omega t)$

PROBLEM PART (36 p)

NOTE: To obtain maximum points for each problem, the solution must be clearly motivated and all the equations used from the literature should have a clear reference (author, page and equation number)

Question 5 (12p)

A large structural component loaded in tension contains an embedded penny shaped (circular) crack. The crack is subjected to mode I loading by a uniform nominal stress σ_0. The stress varies in time as shown in the Figure below. The initial radius of the crack is a_o = 1 mm. Calculate the number of load blocks that is needed to grow a crack to failure of the component by fracture.
Data:
Plate thickness t = 5 cm, yield stress = 1200 MPa, K_{Ic} = 100 MPa m$^{1/2}$, parameters in the Paris crack growth law $C = 6.25\cdot10^{-12}$ and m = 4.0 ([a] = m and [σ] = MPa).



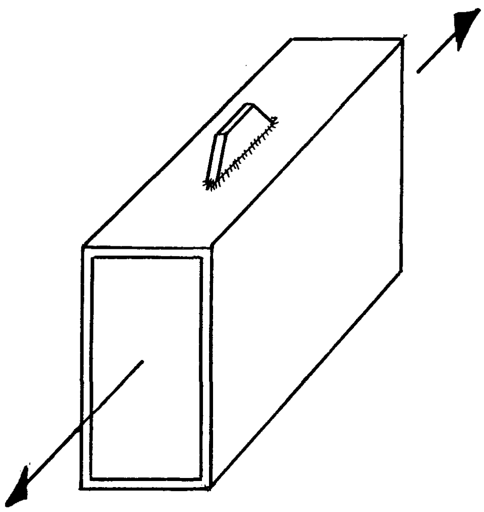
PROBLEM PART (36 p), cont'd

Question 6 (12p)

An attachment is fillet welded to a load-carrying box beam in a truck. The beam is subject to a membrane stress as shown in the Figure. The risk of failure is $Q_B = 0.1$. Both the attachment and the beam has the plate thickness $t = 8$ mm. You may put $\gamma_f = 1$.

a) The fillet weld has the weld quality level *WC*, and shall have a fatigue life of $n_t = 1*10^7$ cycles if it is subject to a variable amplitude load with the collective parameter $\kappa = 1/3$. Determine the dimensioning stress range σ_{rd}.

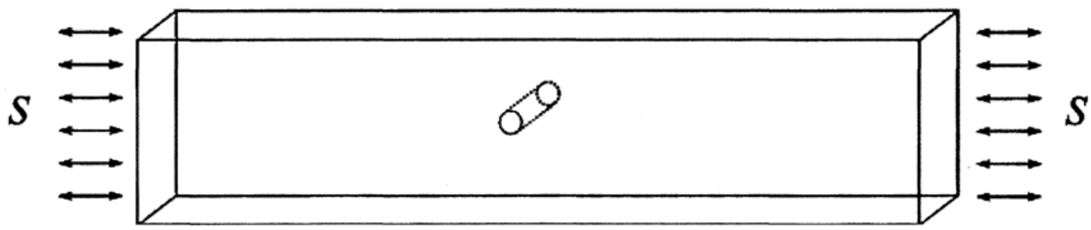
b) For the same load spectrum with the particular dimensioning stress range σ_{rd} determined in (a), one would like to increase the fatigue life to $n_t = 1*10^8$ cycles. Can this be achieved by grinding the weld toe so that the weld quality level becomes *WB*?



PROBLEM PART (36 p), cont'd

Question 7 (12p)

A flat bar of an elastic, linearly deformation hardening plastic material has a rectangular cross section. A small through-the-thickness circular hole has been drilled in the bar at its centre axis. The hole can be considered as small compared to the component geometry.



The bar is subjected to an alternating stress $S = \pm\ 200$ MPa.
Estimate the number of cycles to fatigue failure by use of Neuber's method. Note that the material is assumed to be elastic, linearly deformation hardening (also at *cyclic* loading) see the figure below.

Use Young's modulus of elasticity $E = 200$ GPa, tangent modulus $E/10$, and the yield strength $\sigma_0 = 400$ MPa. Further, $\sigma_f' = 1200$ MPa, $\varepsilon_f' = 1.0$, $b = -0.1$, and $c = -0.62$.

a) Evaluate the fatigue life presuming the mid stress is zero!
b) Make a *rough estimate* of the fatigue life in the case of an added static residual stress of $S = 100$ MPa. Hence the total stress $S = 100 \pm 200$ MPa.