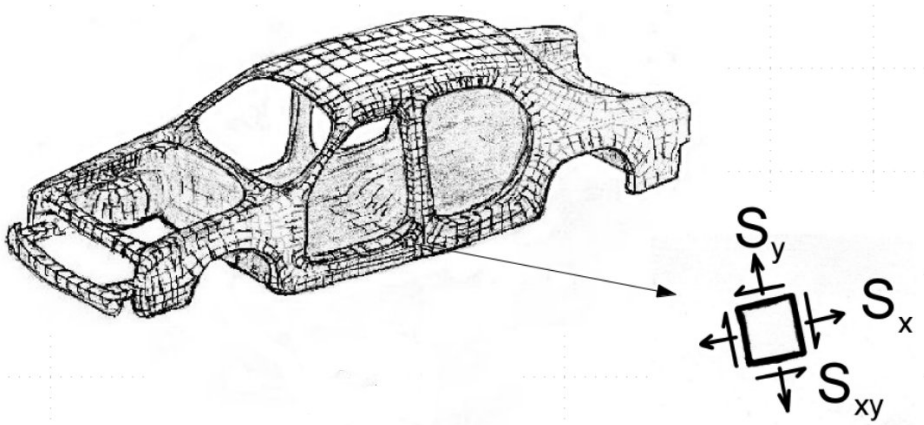
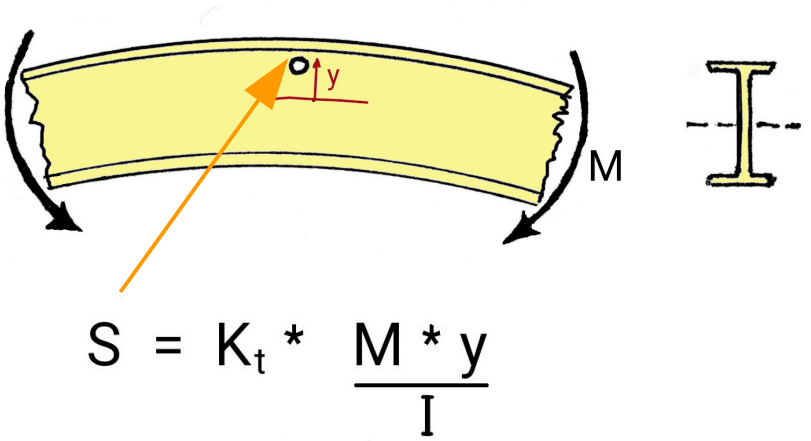
# Using Calculated Elastic Stress as Input for Crack Initiation Life Prediction




Elastic
Finite Element
Analysis




Simple
Elastic Analysis

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Elastic finite element analysis (FEA) is now commonly used to determine the stress in components and structures. For fatigue purposes the loads on the structure are transformed computationally into stresses of individual elements using the principles of component equilibrium and compatibility of elements.

A large FEA model can consist of several million elements; whereby in large structures the elements are initially coarse, and upon solution are sub-divided into smaller elements for improved hot spot stress delineation. Many structures also exhibit complex loading systems which often require special treatment e.g.: http://fde.uwaterloo.ca/Fde/Notches.new/feaFatigueCase2.html

The end result is a stress history of elements at stress-raisers and fatigue hot spots. From that point onwards the fatigue simulation is carried out in the same manner as a simple elastic computation of stresses at a hole in a beam for example.

These elastic stress estimates can easily exceed the yield point, which, as explained in Chapter 7, will require some sort of plasticity correction such as the Neuber method.

In our example here we will be using an end loaded cantelever beam made of ASTM A36 steel. The beam, constructed by the Fatigue Design & Evaluation committee of SAE, is welded at the fixed end with an expected Stress Concentration Factor at the weld toe of about Kt = 2.0 in test series 1 and machined (no weld) in test series 2.
In the test program it was difficult to measure crack length during the short period of time after crack initiation. We will be using a crack initiation approach in our simulations in this chapter sub-section. Overviews of test series 1 and 2 are located near the bottom of the web page: http://fde.uwaterloo.ca/Fde/CaseStudies/casestudies.html under the heading "Total Life Project".

In order to carry out a fatigue analysis an engineer usually requires descriptions of three items:

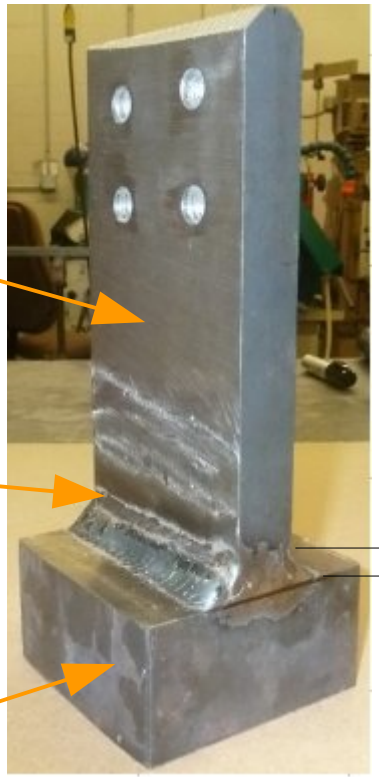
1. Loads 2. Material 3. Geometry

"Loads" implies any measured set of deflections, load, or variables that translate through the component or structure into fatigue hot-spot stresses and strains.

"Material" denotes a fatigue stress-strain-life curve for the given component's material. This needs to include the effects of processing, such as heat treatments etc, and environment such as corrosion.

"Geometry" effects require the translation of "Loads" into the hot-spot stresses and strains; the results of a finite element analysis for example, or a Kt calculation.

## Geometry:




Assume: Kt = 2.0 for welded
Kt = 1.784 for machined

# Loads

R = Pmin / Pmax

## Part 1. Welded "T" beam, Constant amplitude tests

| | | mpa | |
|---|---|---|---|
| Pmax(kN) | R | Smax | Smin |
| 24 | 0.1 | 488 | 48.8 |
| 24 | 0.3 | 488 | 146.4 |
| 24 | 0.5 | 488 | 244. |
| 17 | 0.5 | 345 | 172.5 |
| 14 | 0.1 | 248 | 24.8 |
| 14 | 0.3 | 248 | 74.4 |

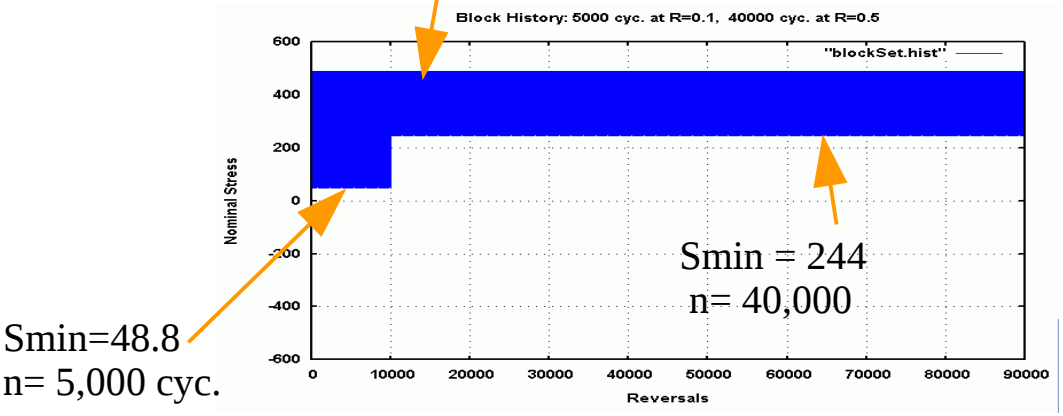
## Part 2. Machined "T" beam, Constant amplitude tests

| Pmax(kN) | R | Smax | Smin |
|---|---|---|---|
| 24 | 0.1 | 488 | 48.8 |
| 24 | 0.3 | 488 | 146.4 |
| 18 | 0.1 | 366 | 36.6 |
| 10.8 | -1.0 | 219.6 | -219.6 |

## Block Loading:

| Pmax(kN) | R | Smax | Smin |
|---|---|---|---|
| 24 | 0.1/0.5 | 488 | 48.8/244 |

Smax = 488 mpa



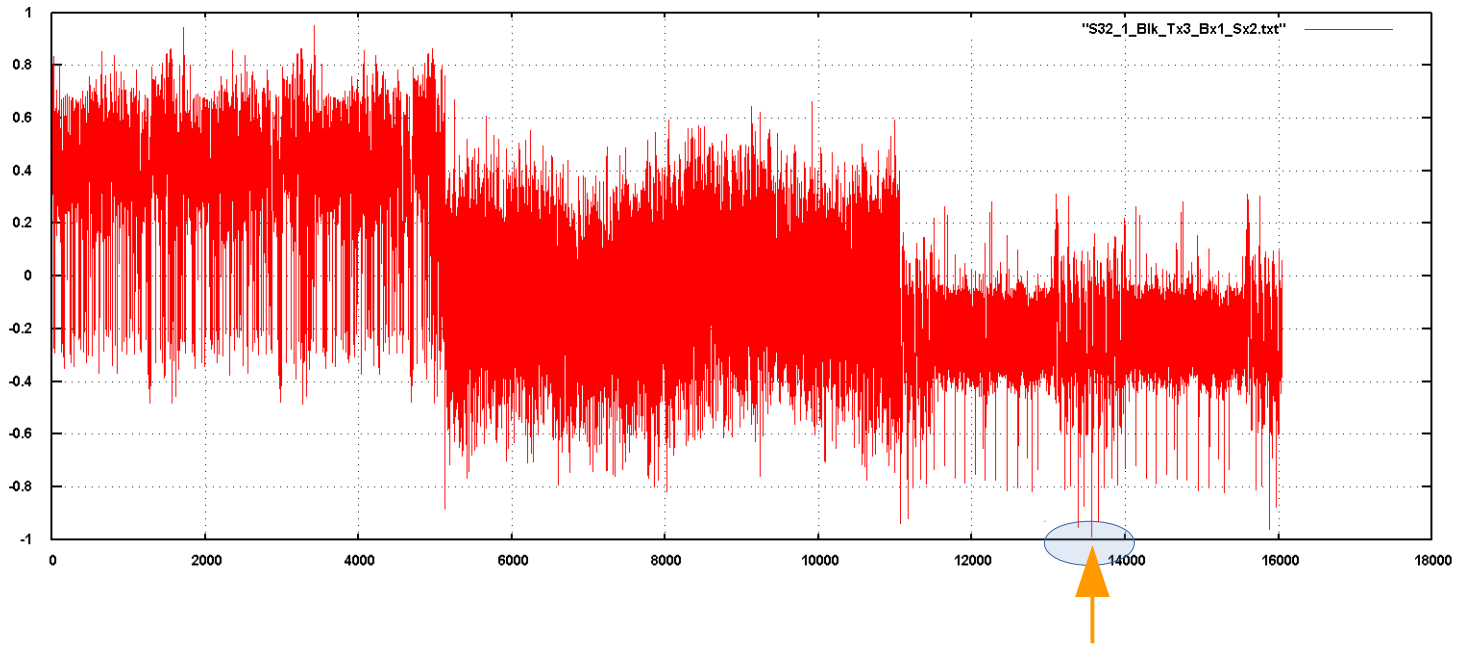

Smin=48.8
n= 5,000 cyc.

# Loads, continued

Variable amplitude test

Plot : http://fde.uwaterloo.ca/Fde/Loads/TotalLife/S32_1_Blk_Tx3_Bx1_Sx2.png

Pmin =24 kN




Smin = 488 mpa (plus Kt= 1.784 )

Segments of the history are from the F.D.&E Comm. Keyhole test series. It is a concatenation of: 3 Transmission + 1 Bracket + 2 Suspension histories.

The history is provided as a reversal by reversal text file

http://fde.uwaterloo.ca/Fde/Loads/TotalLife/S32_1_Blk_Tx3_Bx1_Sx2.txt

Download it for cycle counting and fatigue damage analysis.

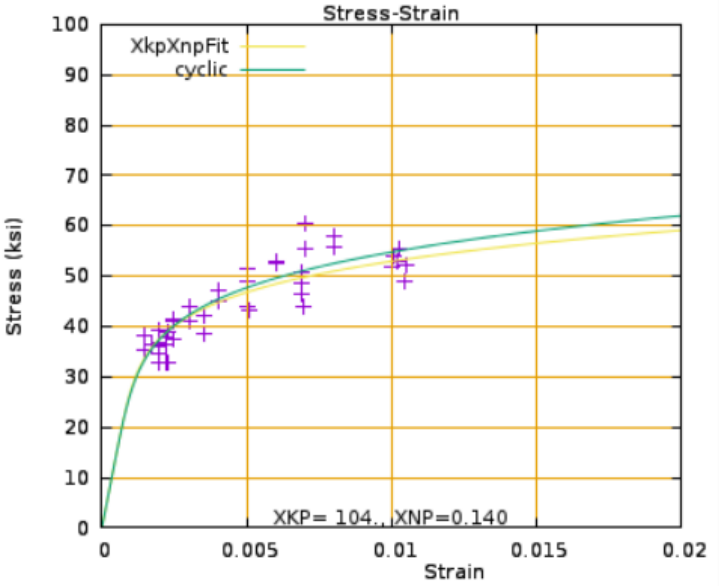
Raw crack initiation data A36 steel:

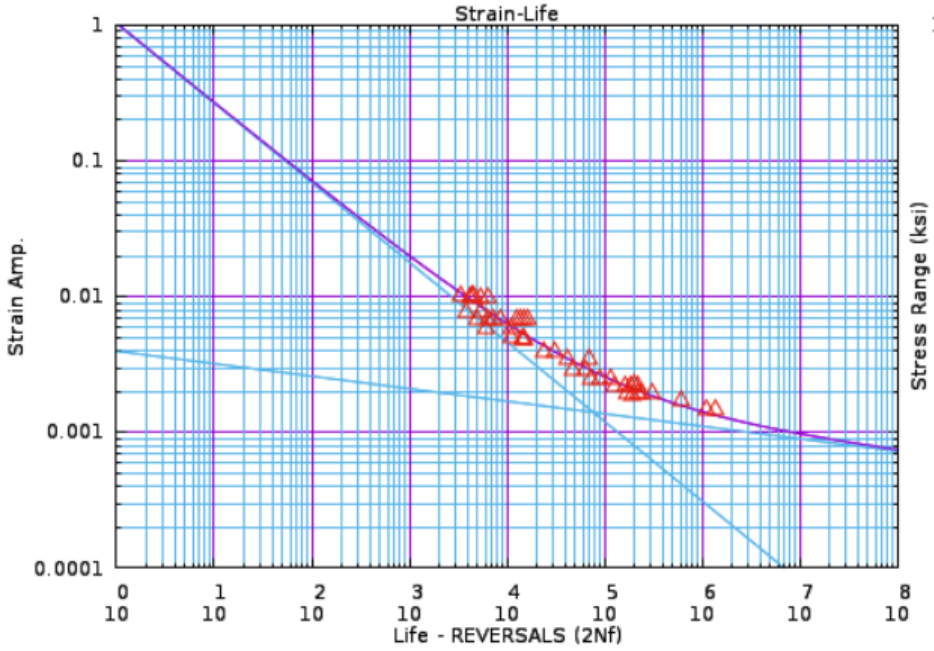
http://fde.uwaterloo.ca/Fde/Materials/Steel/Lowcarbon/A36/mergedA36_3.html

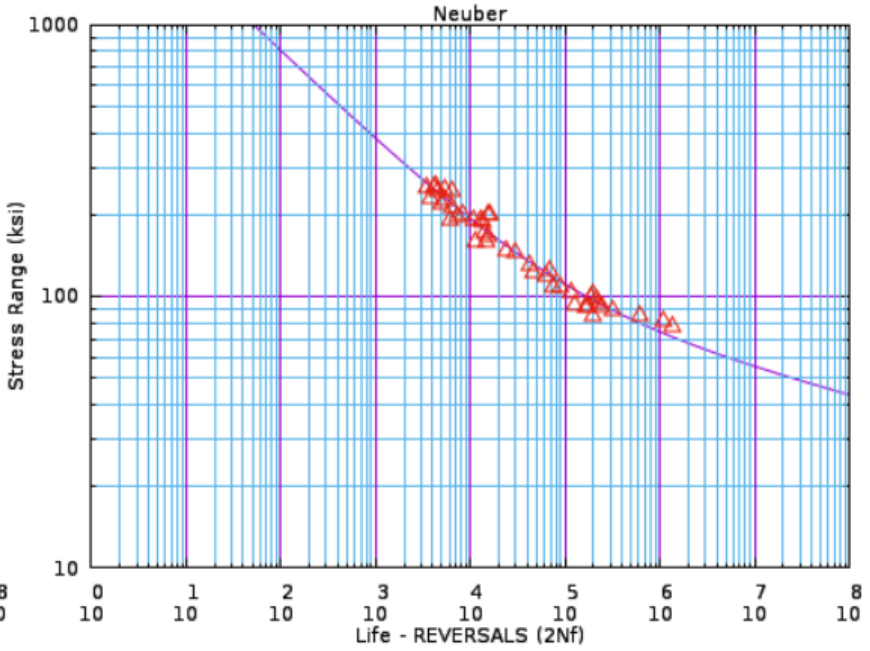
ASTM-A36 Structural BHN= 138

# A36 Steel Merged Data Sets
# Ref.1: P.Dindinger report to Fat.Des.+Eval. Comm. Apr.2012
# Ref.2: G.A.Miller and H.S.Reemsnyder, 'Strain-Cycle Fatigue of Sheet and
# Plate Steels I: Test Method Development and Data Presentation,'
# SAE Paper 830175, Detroit MI, Feb28-Mar.4, 1983
# Ref.3: P.Dindinger report to Fat.Des.+Eval. Comm. 2013 4x4bar.

| Monotonic Props. | | Cyclic Props. | |
|---|---|---|---|
| ELAS. MOD.= | 29528. KSI, 204. GPA | K' = | 116.8 KSI, 805.MPA |
| YIELD,0.2%= | 38. KSI, 265. MPA | N' = | 0.1572 |
| ULT. STRG.= | 69. KSI, 476. MPA | F. STRG COEF= | 117.3 KSI, 809.MPA |
| K = | 0.0 KSI, 0. MPA | F.STRG EXP, b= | -0.0922 |
| N = | 0.0000 | FAT DUCT COEF= | 1.0285 |
| RED. IN AREA = | 0.0 | F.DUCT EXP, c= | -0.5862 |
| T. FRAC. STG.= | 0.0 KSI, 0. MPA | Exp Cyc Yld = | 44. Ksi, 303.MPA |
| T. FRAC. STR.= | 0.000 | Fit Cyc Yld = | 43. Ksi, 300.MPA |
| No. data points= | 44 | | |



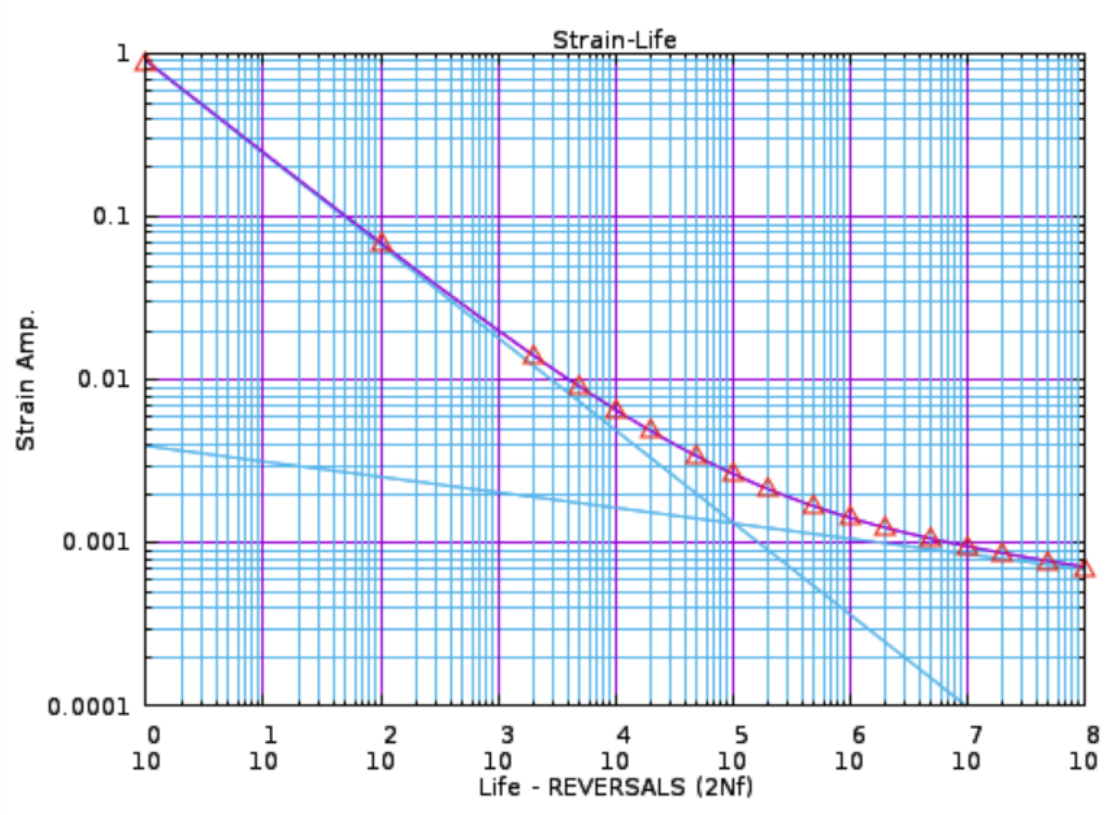



In the previous page one notes that there is a lack of data in the long life region.
We will need to extrapolate along the traditional fit line for computations.
A fitted file for fatigue damage analysis is available at:

http://fde.uwaterloo.ca/Fde/Materials/Steel/Lowcarbon/mergedA36_fitted.html

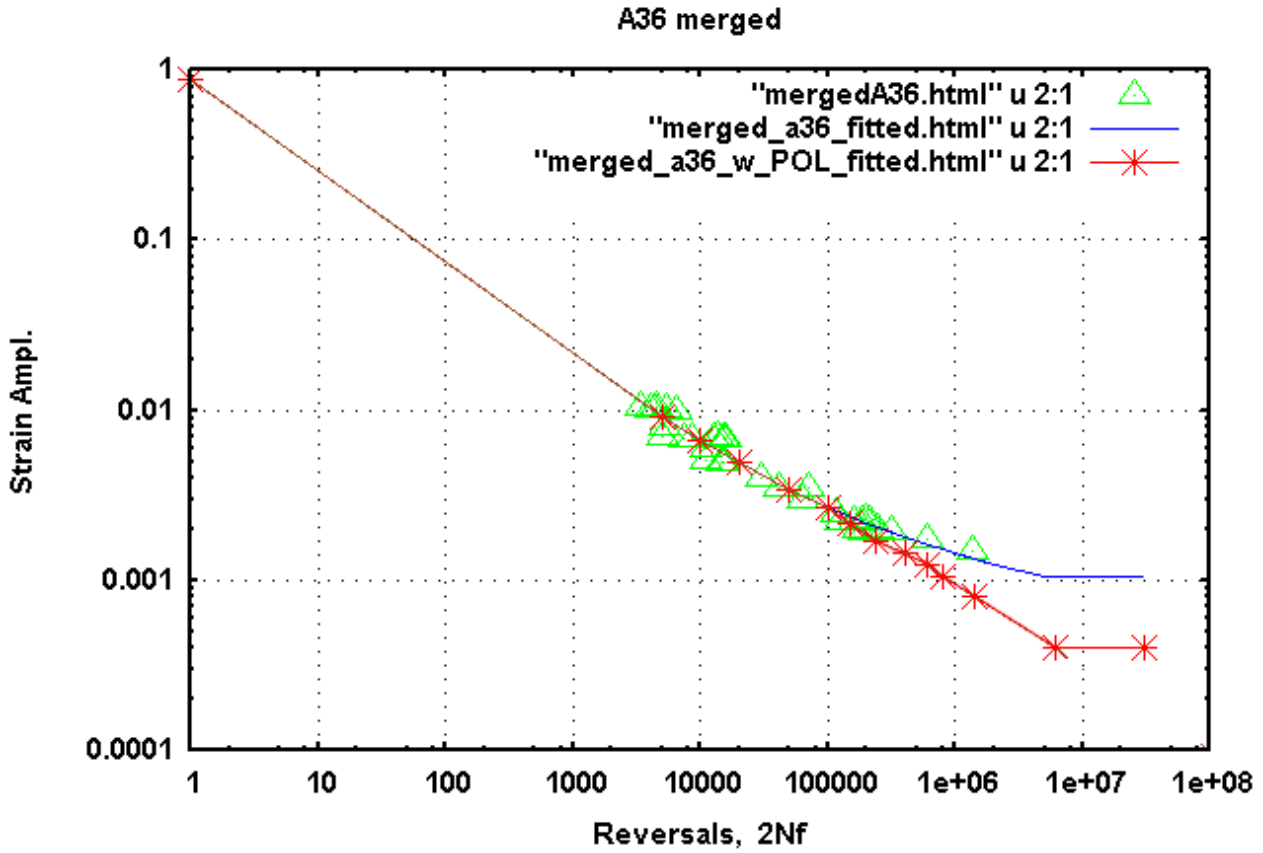
You will need to open it in your web browser → View Source → Save to local



For the variable amplitude history predictions we will need a Periodic Overload fitted file. Test data does not exist for such a "POL" fitted file. One can, however, estimate a fit line from other POL material tests. A file has been created from estimates :

http://fde.uwaterloo.ca/FatigueClass/Notes/merged_a36_w_POL_fitted.html

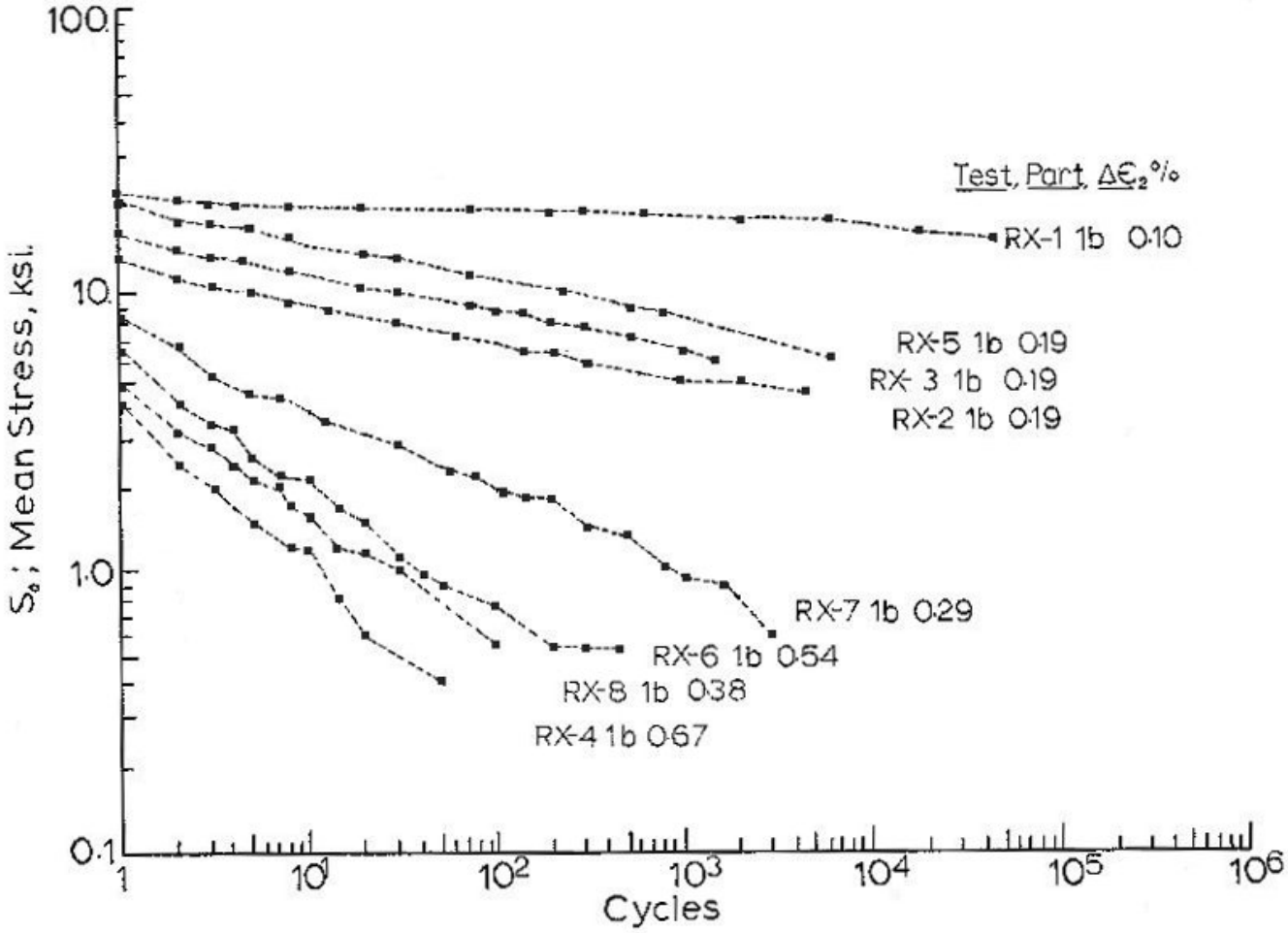
Please download this file for our analysis.



For determination of cyclic mean stress relaxation tendency we can use the data for SAE1015. Both ASTM A36 steel and this SAE1015 have similar carbon content and hardness.

Given a hysteresis loop strain range we can use the relaxation data in this graph → to determine how quickly a mean stress will relax.

We will assume that this relaxation also applies to residual stresses caused by welding.




Mean Stress vs. Cycles at Secondary Strain Range $\Delta\epsilon_2$ for Part 1b of all Tests. (First application of Cycles at $\Delta\epsilon_2$)

# Software Preparations

1. Collect the information regarding Geometry, Loads, and Material, as described in the previous pages and place files in a working folder.

2. If the load history is complex use Rainflow counting to define the individual sets of cycles. A rainflow cycle count program can be downloaded here:

   https://github.com/pdprop/pdprop/blob/Master/CleanPdprop/pdrain.f

   Click on the "Raw" button on that page.
   When the file appears as text in your web browser click on File → Save Page and place it in your folder. The compile statement is near the top of the file when viewed with an editor such as vi.

   If the history is simple, such as constant amplitude(CA), or a few sets of different CA, you can define the cycle sets manually. Each set should consist of

   Srange Smean No._of_cycles Smax Smin

   These are the data lines in a rainflow cycle count file as described in the Chapter 9 on Cycle Counting.

3. Download the calculation program saefcalc2.f from:

   https://github.com/pdprop/pdprop/blob/Master/CleanPdprop/saefcalc2.f

   Click on the "Raw" button on that page. As above, save it and compile it.

4. Similarly download and compile the utility programs:

   https://github.com/pdprop/pdprop/blob/Master/CleanPdprop/hilo2.f
   https://github.com/pdprop/pdprop/blob/Master/CleanPdprop/delete1arg.f

5. Download a script to run all this and generate a report from:

   https://github.com/pdprop/pdprop/blob/Master/CleanPdprop/makeRepSaefcalc2

   Same save process as above. No need to compile but you need to make it executable:

   chmod 755 makeRepSaefcalc2

# Calculations

1. Determine the max and min values of S32_1_Blk_Tx3_Bx1_Sx2.txt

   ```
   hilo2  <  S32_1_Blk_Tx3_Bx1_Sx2.txt
   ```

2. Scale the history to the desired **nominal** stress near the weld toe.
   In our case the largest absolute rev. is = -0.9956, and we want it to be 488 mpa :

   ```
   awk  '{print $1*488/0.9956 }'  <  S32_1_Blk_Tx3_Bx1_Sx2.txt   > t3b1s2.hist
   ```

3. Get rainflow cycle counts: The peak and valley file t3b1s2.hist
   contains only one column of data thus:

   ```
   ./pdrain  1  < t3b1s2.hist    > t3b1s2.rain
   ```

4. Run the life calculation program

   ```
   ./saefcalc2  merged_a36_w_POL_fitted.html  2.0  <  t3b1s2.rain  > t3b1s2_Kt=2.out
   ```

   fitted file

   Kt

5. Fatigue life predictions can be displayed with command:

   ```
   grep  \#xcalc3  < t3b1s2_Kt=2.out
   ```

6. If your system has linux software htmldoc and gnuplot you can create a full report on the simulation with command:

   ```
   ./makeRepSaefcalc2  t3b1s2_Kt=2.out
   ```

7. The resulting report should look like this: http://fde.uwaterloo.ca/FatigueClass/Notes/t3b1s2_Kt=2.out.pdf