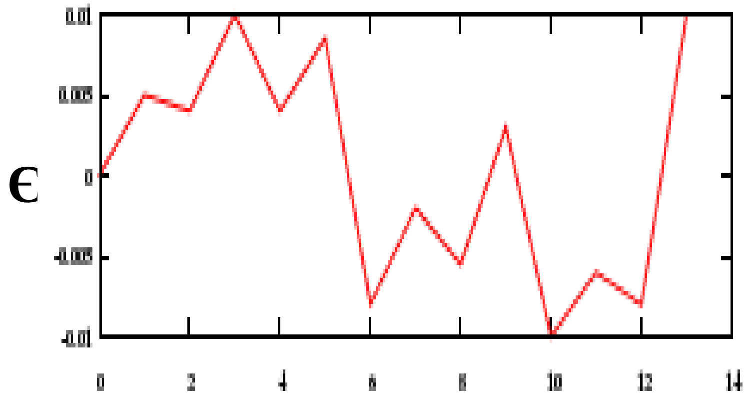
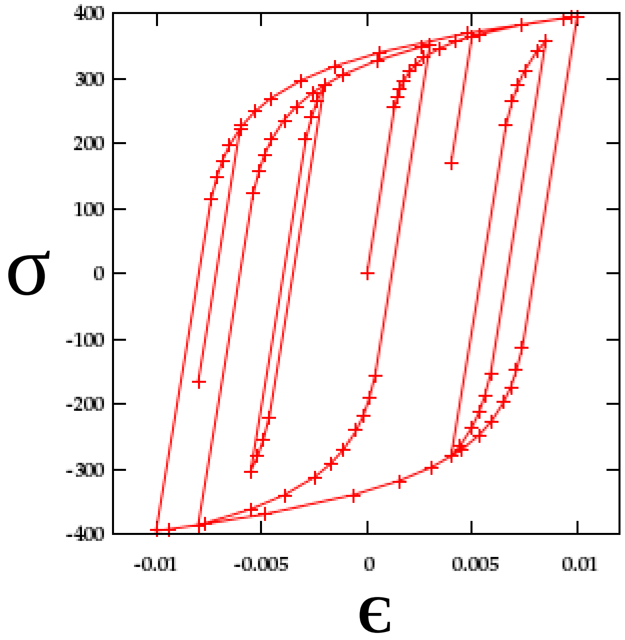
Using a Material Memory Model to Simulate Stress Response and Fatigue Life given a Strain History





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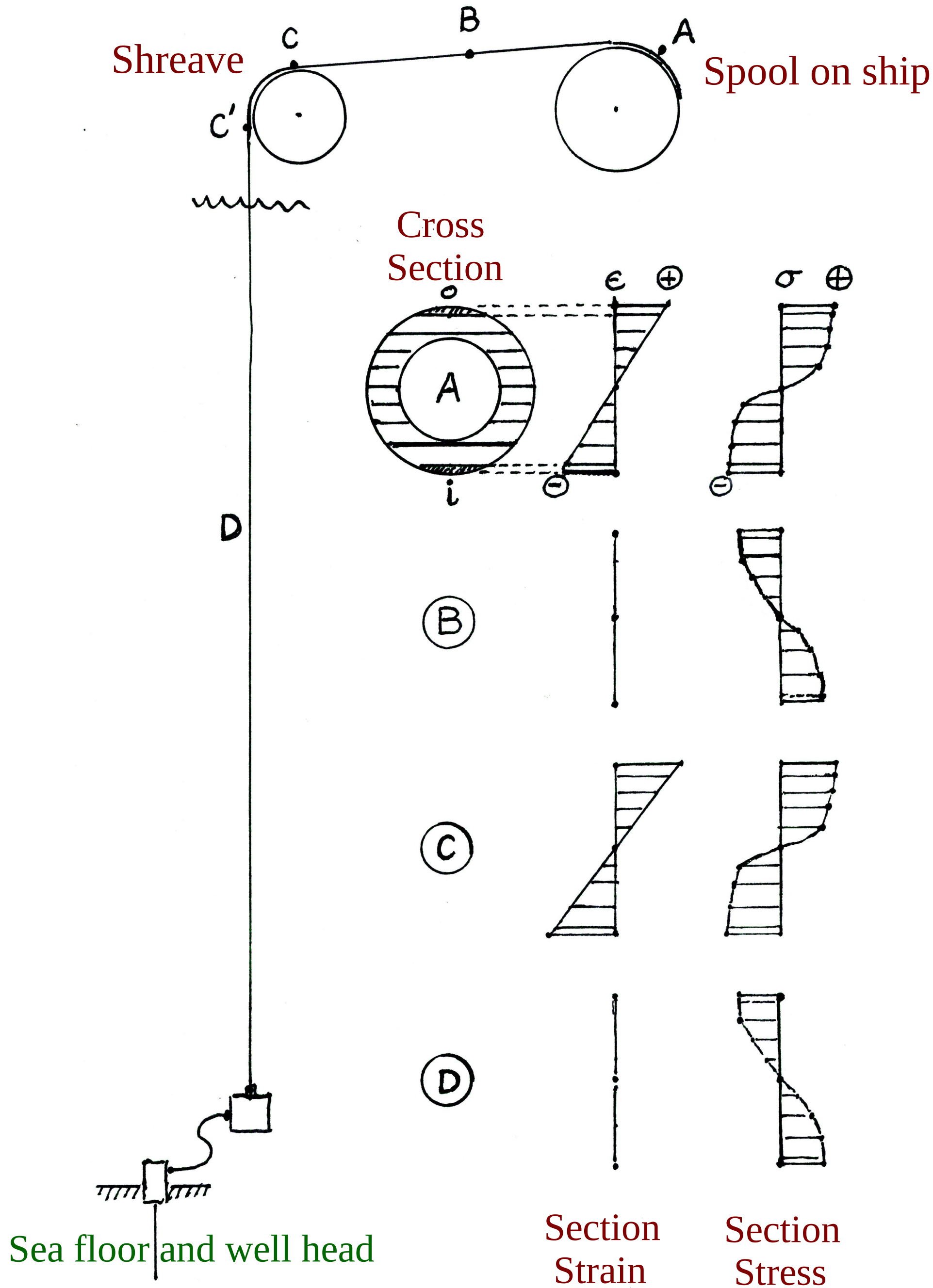


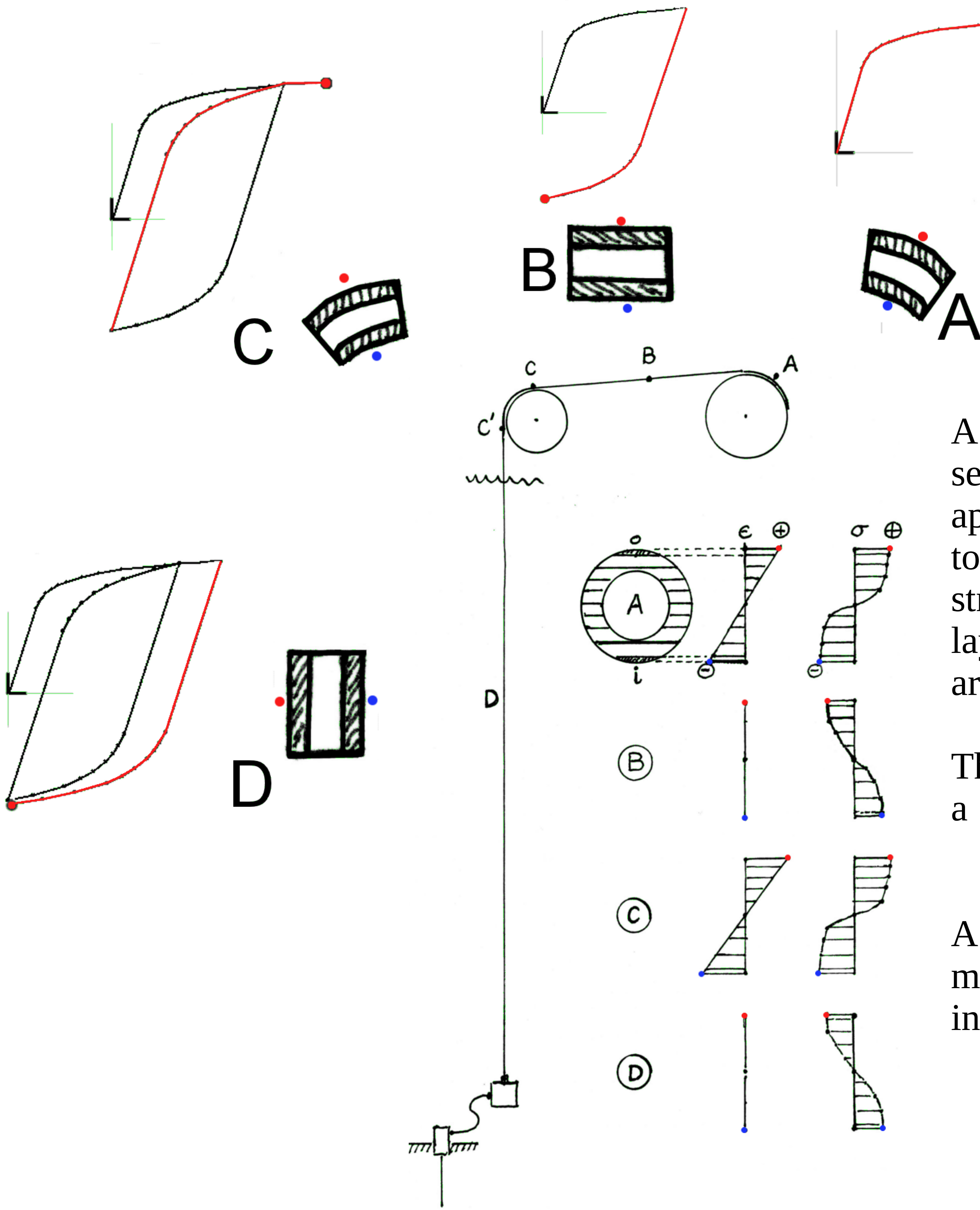
Coiled steel tubing is often used in the oil industry to service wells. In this off-shore example a large spool of coiled tubing is located on a ship and then un-rolled and lowered into the water down to the well head, where a connection is made and fluids are pumped in or withdrawn from the well.

The process requires that the steel tube is plastically deformed,

1. when it is originally spooled (A)
2. when unspooled and straightened (B)
3. when bent again over the shreave (C)
4. as it is lowered and pressurized (C', D)
5. Due to ship motions points at A to D are subjected to additional cyclic strains.

The above events are reversed during retraction and re-spooling.

These tubes have a finite life due to the large plastic strains encountered; typically 200 well service jobs.



A simplified analysis divides a section of tube into layers and applies a material memory model to each layer. In this figure the strains experienced by the outer layer, due to the geometry changes, are shown.

This case would be an example of a process that is primarily

strain controlled fatigue.

A solution requires a material memory model that uses strain inputs.

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

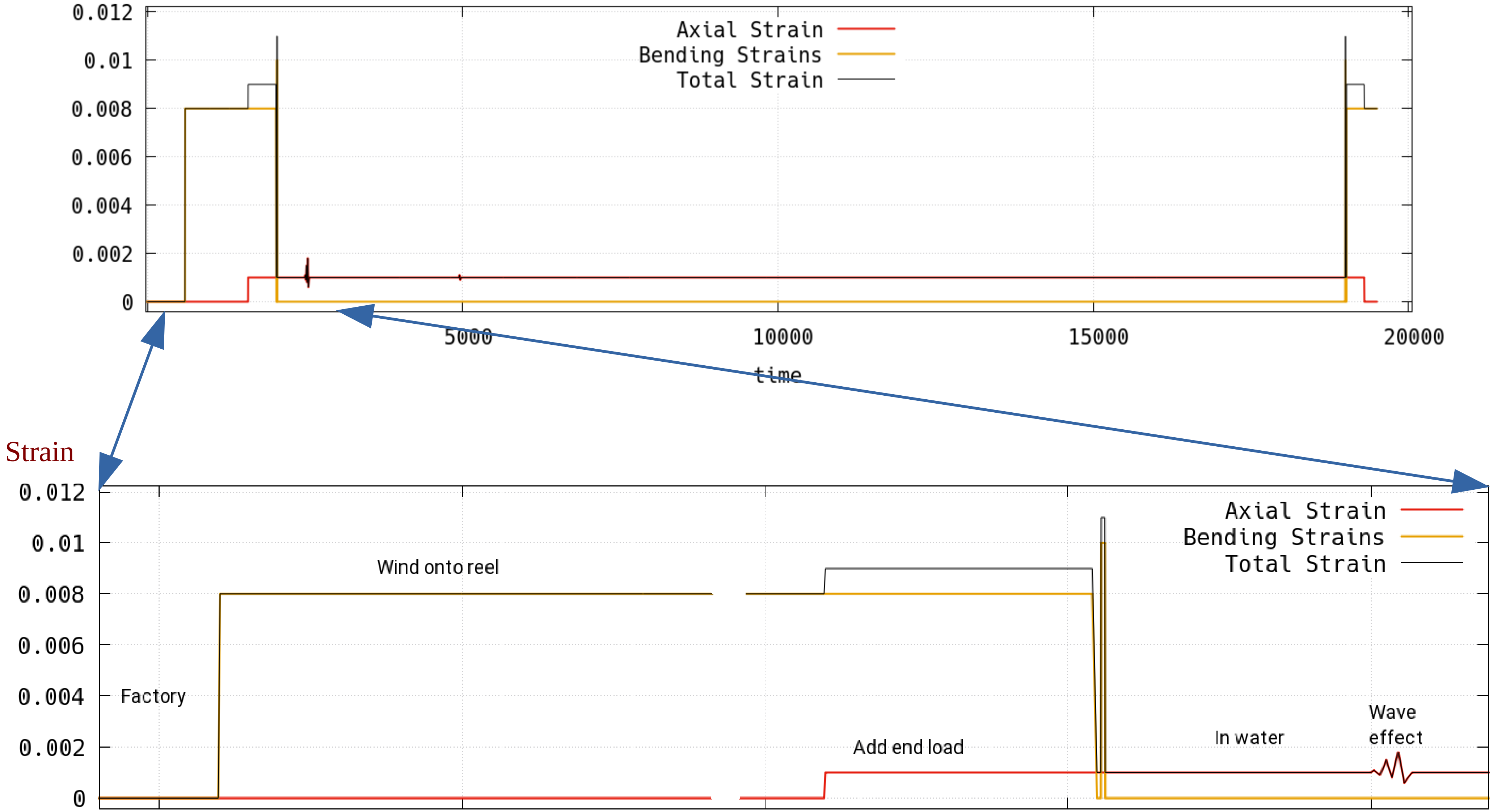
1. Loads 2. Material 3. Geometry

"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.

In the coiled tubing case the loads would be the strains caused by the spooling/re-spooling process, pressure loads due to pumping, end weight and self-weight effects as the tube hangs in the water, and ship and water movement loads. Each loading type could be measured or computed as a channel. Spooling strain vs. extension from the spool could be channel 1, self weight effects vs. extension channel 2; pressurization vs. time channel 3, etc. In this example case we will only consider the strain on a surface element during extension and retraction of the tube. A more realistic case would have to consider all the load channels and superimpose them for each section of the tube.



Exercise:

1.Download a program to filter out small cycles and non-reversal points:

http://fde.uwaterloo.ca/FatigueClass/Notes/smallCycleFilter.f.txt

then rename using:

```
mv smallCycleFilter.f.txt  smallCycleFilter.f
```

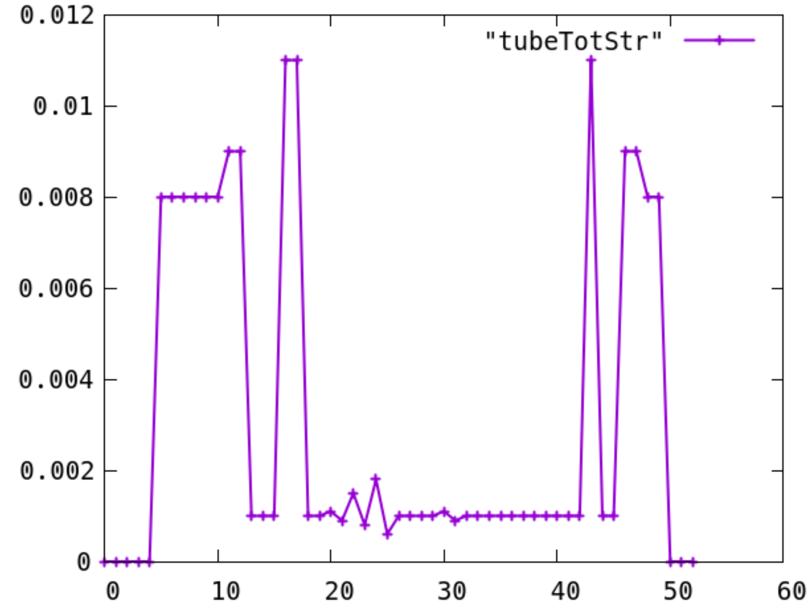
then compile it with the line in the head of the file.

2. Download the coiled tubing data file:

http://fde.uwaterloo.ca/FatigueClass/Notes/strains1b.txt

This file contains the "membrane" or axial strain in column 2 and the bending strain in column 3. We need the total strain. Thus do:

```
grep  -v   \^\#    strains1b.txt  |  awk '{print ($2+$3)}'   > tubeTotStr
```



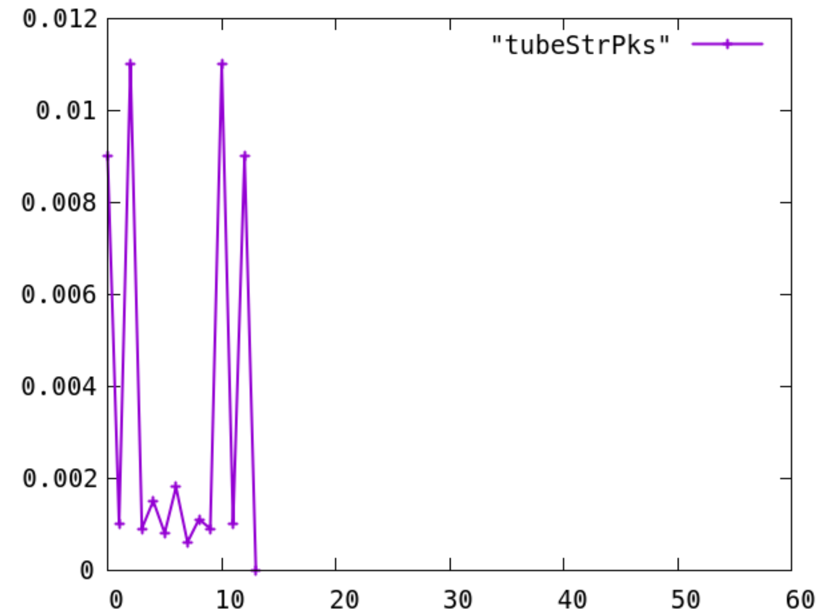
3. Use gnuplot to create the upper figure.

4. Use the smallCycleFilter.f program to create the peaks only file

```
smallCycleFilter 1.0 0.0001 < tubeTotStr > tubeStrPks
```

0.00900
0.00100
0.01100
0.00090
0.00150
0.00080
0.00180
0.00060
0.00110
0.00090
0.01100
0.00100
0.00900
0.00000

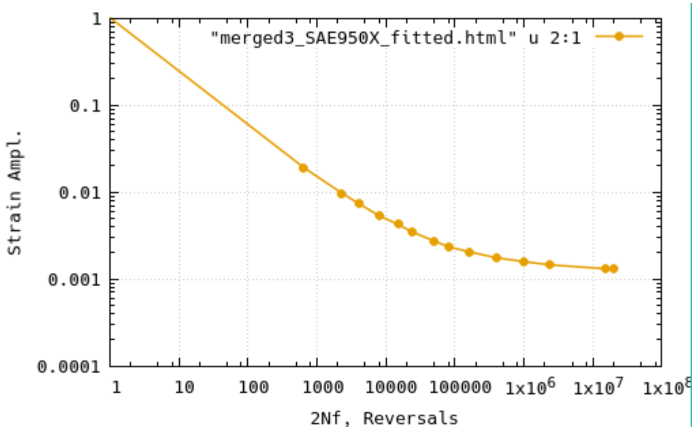
5. Plot the peaks file.

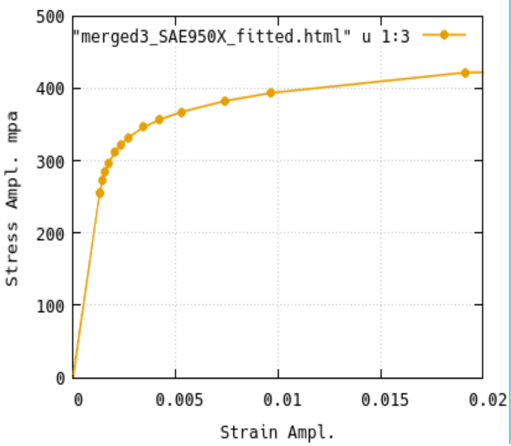


We need this type of file to simplify life for the memory simulation model.

For many coiled tubing applications the **Material** is probably a variant of HSLA-350; a High Strength, Low Alloy 350mpa yield steel that does not significantly cyclically harden or soften. Such a neutral stress response to cyclic straining is important for maintaining the geometry of the tube and the loads on the equipment involved in the spooling process. A fitted file for HSLA-350 (old designation SAE950X) can be viewed or downloaded here:

http://fde.uwaterloo.ca/Fde/Materials/Steel/Hsla/Merged950X/merged3_SAE950X_fitted.html





The tube **Geometry** description for this particular example is fairly simple. The surface strain of the outer layer of the tubing is defined by the radius of the spool and shreave, and the strains caused by the self weight and end of tubing loads.

The strains can be assumed to be linearly distributed across the inner layers according to the "plane sections will remain plane" rule for bending. Additional effects due to pressurization are not considered in the present description.

A more detailed example description can be found here:

http://fde.uwaterloo.ca/Fde/CTube/pdStressStrain.html

Using **pdStressStrain2.f**

When a set of strains or stresses is repeated (each is termed a "block") the first application is different from the rest due to the presence of the first loading stress-strain curve.

A repetition of a history would be expected from measurements of a proving ground vehicle, where a specific number of circuits without fracture would be required for a "pass" for customer sales.

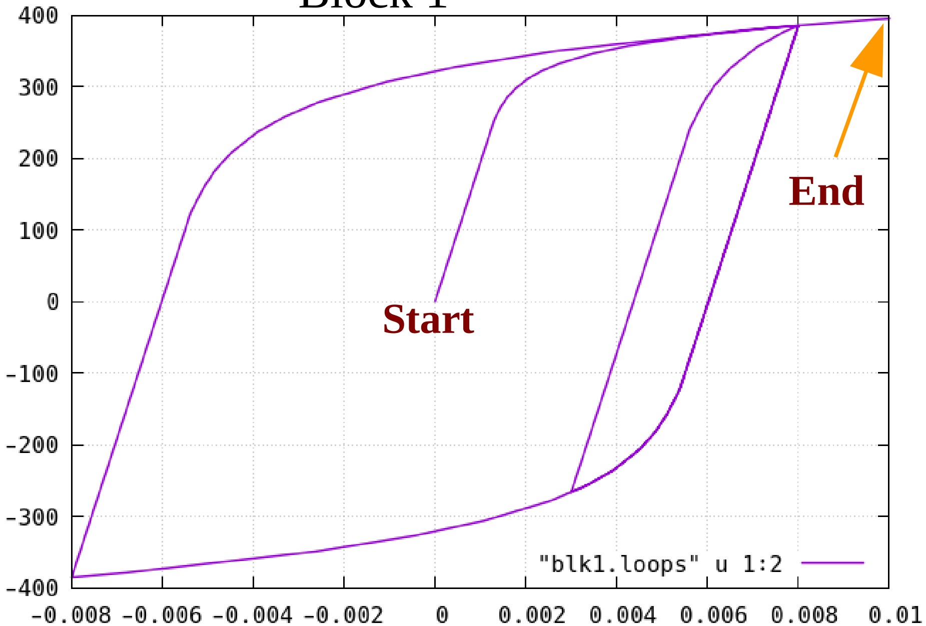
```
#Strain hist-1
0
0.008
-0.008
0.008
0.003
0.010
```

Some histories are not repetitive however. The coiled tubing case described previously is different for various applications of depth, pressure, etc.

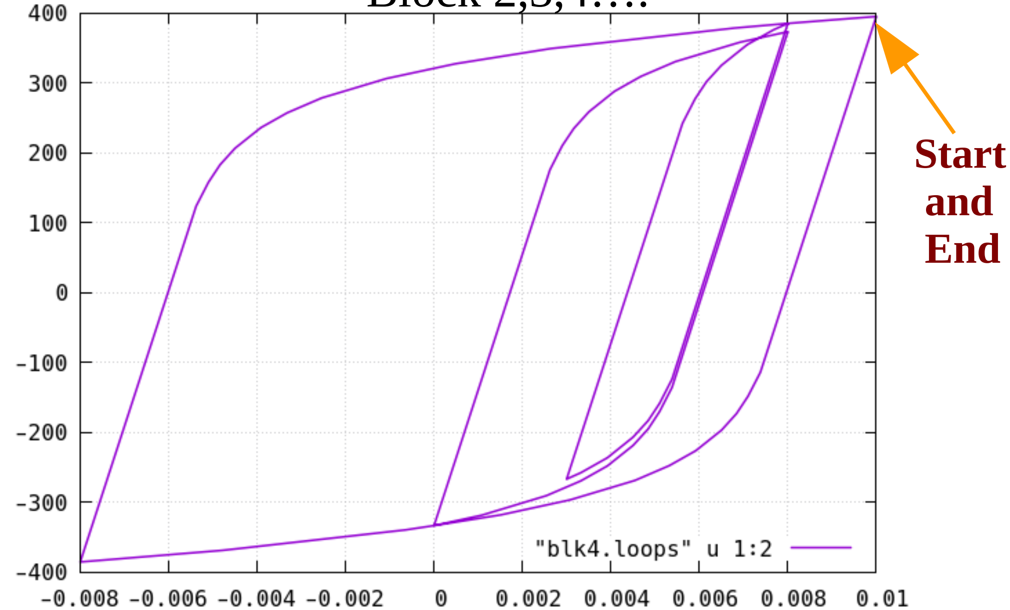
It is up to you as the engineer to decide if your history is repetitive or not.

In a repeated sequence the first block may cause a different amount of fatigue damage than the subsequent blocks.

Block 1



Block 2,3,4….



Exercise with **pdStressStrain2.f**

1. Download and compile pdStressStrain2.f
   (a) Download: http://fde.uwaterloo.ca/FatigueClass/Notes/pdStressStrain2.f.txt
   (b) Rename: mv pdStressStrain2.f.txt pdStressStrain2.f
   (c) Compile: See compile statement in head of file

2. Create a strain history file (or copy the file from previous page)
   in the same folder: http://fde.uwaterloo.ca/FatigueClass/Notes/histStr-1.txt

3. Place a fitted curve material file into the same folder. merged3_SAE950X_fitted.html

4. Run the simulation. e.g.:
   ```
   ./pdStressStrain2  merged3_SAE950X_fitted.html  1.0    1  <histStr-1.txt  >histStr-1.out
   ```
   As the program runs you will see lines such as:

   ```
   # History Reps. completed: nblk=        2
    #TOTDAM90=  0.1576673E-02 Total Block Reps. to failure=     1268.5   Tot. Revs. thus far=        11
    #HistRepeat nblk=        2  TotalDamage=  0.1576673E-02,  Block    2  damage =  0.9414061E-03
   ```

   but most of the output will be streamed into file histStr-1.out (in this case).
   Use vi to view some of this file. In vi use $G to get to the last line in file.

5. Create files for plotting of hysteresis loops. In the output file loops are defined by lines
   such as #plotloops 0.00562 242.0 4 6
   (a) extract all the loop info:
   ```
   grep \#plotloops  histStr-1.out   | delete1arg  >  histStr-1.loops
   ```

5. (continued)

The resulting loop file will contain lines such as :

```
0.00000    0.0     1         1
0.00000000      0.00000000             1          2
0.00131  254.6     1          2
0.00131  254.6     1          2
0.00145  271.9     1          2
0.00158  284.3     1          2
….  etc
```

The 1st column is strain. The 2nd stress, 3rd is block no., and 4th is reversal in that block

One could at this point plot all the loops from this file.

```
gnuplot>  plot   "histStr-1.loops" u 1:2  w   l
```

If only a specific block is needed a command such as:

```
awk    '{if( $3 == 4 ) {print $1" "$2" "$3" "$4}}'   < histStr-1.loops    > blk4.loops
```

will extract only the loops for block 4 for example.

If there is only one block and only a few reversals are needed one can further reduce the data with a command such as:

```
awk   '{if( $4 > 2 && $4 < 5 ) {print $1" "$2" "$3" "$4}}'  < blk4.loops   > blk4R3-4.loops
```

and then use gnuplot.