ASME Cyclic Creep Evaluation of Critical Piping Component using CREEP Subroutine and ORNL Test Data

SCIENCE IN THE AGE OF EXPERIENCE - 2016

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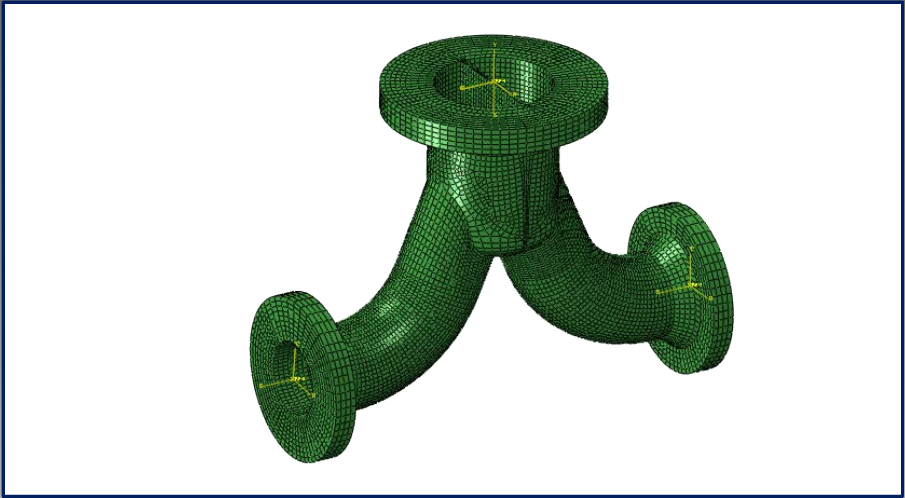
Problem Description

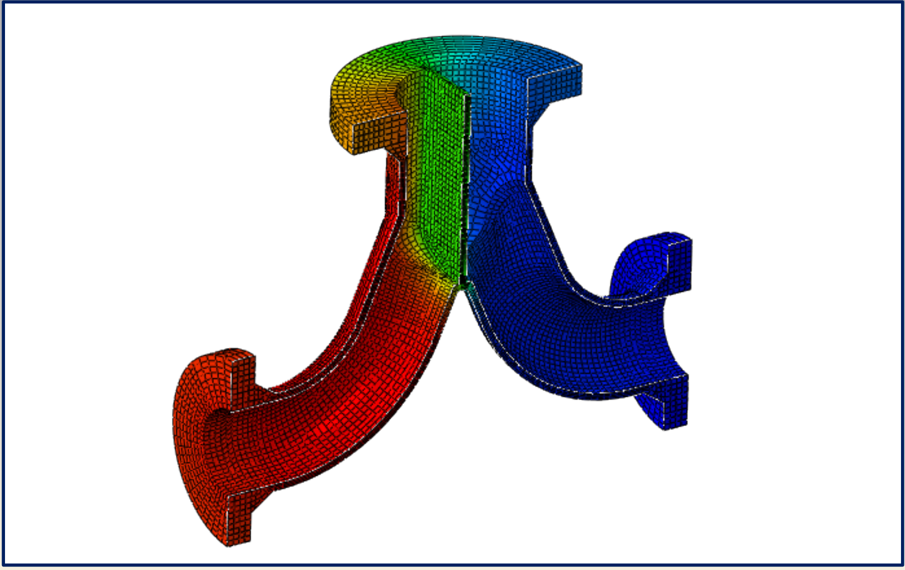
- Cyclic Creep Service – 800-H Material
- ASME Section III-NH (Nuclear Code) Required for Evaluation of Cyclic Creep Conditions
- Primary and Secondary Creep Modeling Necessary – Short Duration Creep Events
- Creep Relaxation Affects Progression of Plasticity
- Use of Abaqus/Standard - Inelastic Analysis

FEA Model Description

- Pipe Wye Component
- Inner Chamber Divider
- Fixed by CaesarII Input
- Displacement Controlled
- Orphan Mesh – Mirrored
- Internal Pressure
- Multi-Stage Cycles



- Flow Alternates
- External Skin Coefficients
- Internal Skin Coefficients
- Ambient Set to 70°F
- Steady Operating Case
- To Flow Case #1
- To Steady Operating Case
- To Flow Case #2



Analysis Procedure

- Run Cycle-By-Cycle Analysis Considering Elastic-Plastic and Creep Effects
- Use CREEP Subroutine to Model Primary and Secondary Stages for 800-H
- Separate Steps for Developing Plasticity and Creep
- Evaluate Cycle-By-Cycle Analysis using ASME Section III-NH (Nuclear) Code

CREEP Subroutine Data

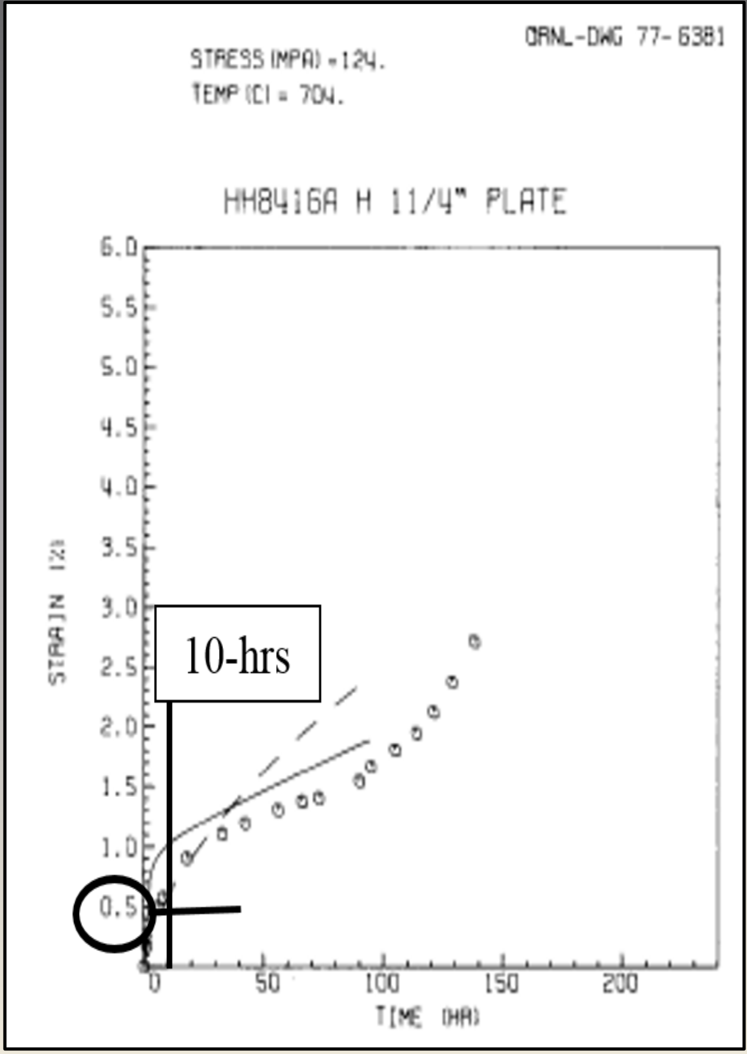
$$\log(\dot{e}_2) = 24.31 - \frac{40270}{T} + \frac{7040}{T} \cdot \log(\sigma)$$

- Total Creep Strain Rate f(T, σ) from ORNL
- $\dot{e}_2$ = strain rate (primary and secondary)
- T = temperature (°C)
- σ = stress (MPa)

Survey of Available Creep and Tensile Data for Alloy 800H by M.K. Booker, V.B Baylor, and B.L.P. Booker, a production of Oak Ridge National Laboratory (ORNL), 1978

Over 100+ raw data plots of strain versus time, at defined temperatures and stresses, using various plate thicknesses.

Creep initiation considered instantaneous



CREEP Subroutine - 1

800H_creep_english.for

(Global Scope)

```
      SUBROUTINE CREEP(DECRA,DESWA,STATEV,SERD,EC,ESW,P,QTILD,
     1 TEMP,DTEMP,PREDEF,DPRED,TIME,DTIME,CMNAME,LEXIMP,LEND,
     2 COORDS,NSTATV,NOEL,NPT,LAYER,KSPT,KSTEP,KINC)
C
      INCLUDE 'ABA_PARAM.INC'
C
      CHARACTER*80 CMNAME
C
      DIMENSION DECRA(5),DESWA(5),STATEV(*),PREDEF(*),DPRED(*),
     1 TIME(3),COORDS(*),EC(2),ESW(2)
C
C DEFINE CONSTANTS
C UNITS ARE ENGLISH -- PSI, Farenhite, Hours
C
      A=24.31D0
      B=40240.0D0
      C=7040.0D0
      TEMP_CUTOFF=1000.0D0
      T=TEMP
```

$$\log(\dot{e}_2) = 24.31 - \frac{40270}{T} + \frac{7040}{T} \cdot \log(\sigma)$$

A = 24.31

B = 40.270

C = 7040

ORNL Equation NOT Valid Below 1000°F

CREEP Subroutine - 2

```
C      FACTOR1 AND FACTOR2 NEED TO BE COMPUTED FOR MODIFYING
C      QTILD AND T
       FACTOR1=6.8947D-3
C      T CHANGED FROM FARENHITE TO CELSIUS
       T1=(T-32.0)*5.0D0/9.0D0
```

FACTOR1 – Conversion from MPa to psi

T1 – Conversion from °C to °F

QTILD – Equivalent Deviatoric Mises Stress, σ

```
C TO ADDRESS MINIMAL CREEP OCCURRING BETWEEN TEMP 900-1100
      DECRA(1) = 1.D-10
      DECRA(5) = 1.D-30
C      WRITE(6,*) 'DECRA(5), T', DECRA(5), T
```

DECRA(1) – Equivalent (Uniaxial) Deviatoric Creep Strain Increment = EXP(F)*DTIME

DECRA(5) – Partial Derivative of Strain Rate with Respect to QTILD

DTIME – Time Increment (hrs)

CREEP Subroutine - 3

```
      IF(T.GE.TEMP_CUTOFF) THEN
C      QTILD, NEEDS TO BE MODIFIED AS SHOWN BELOW
       IF(QTILD.LE.0.0D0) QTILD=1.D-2
       QTILD1 = QTILD*FACTOR1
C      WRITE(6,*) 'QTILD', QTILD1, QTILD
       F=A-B/T1+(C/T1)*LOG(QTILD1)
C      WRITE(6,*) 'VALUE', F
C       STOP
C      PRINT*, F
       DECRA(1) = EXP(F)*DTIME
```

QTILD can not be 0 or negative

Virtually no creep in compression

F = Log ($\dot{e}_2$) – Taken straight from ORNL Eqn

DECRA(1) – Equivalent (Uniaxial) Deviatoric Creep Strain Increment = EXP(F)*DTIME

DECRA(1) – Strain over a differential length of time

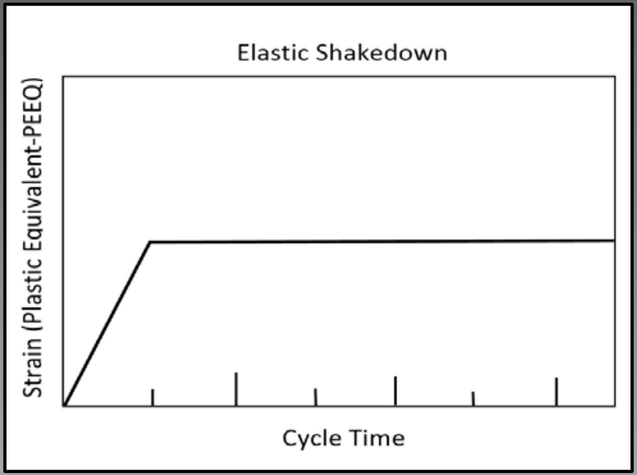
CREEP Subroutine - 4

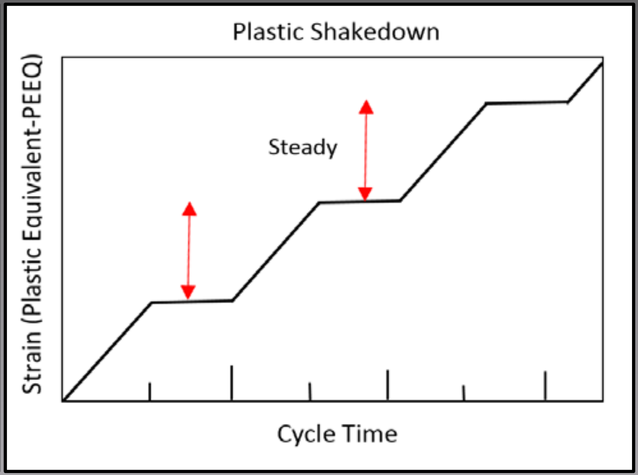
```
      IF(LEXIMP.EQ.1) THEN
C       DECRA(5) = 1.D-10
C       IF(QTILD1.GE.1.0D-5) THEN
        DECRA(5) = (DTIME*EXP(F)*C/(T1*QTILD1))*FACTOR1
C       WRITE(6,*) 'DECRA(5) & 1', DECRA(5), DECRA(1), QTILD1
C       END IF
      END IF
     END IF
C
     RETURN
     END
```

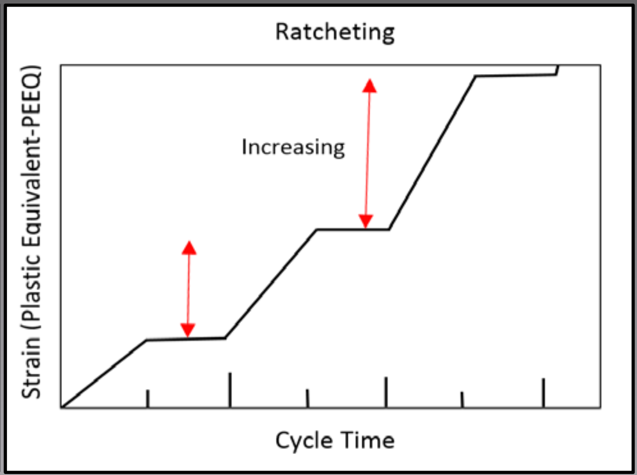
Implicit Condition Statement

DECRA(5) – Partial Derivative of Strain Rate with Respect to QTILD

Shakedown and Ratcheting







Elastic Shakedown

- One Time Plastic Event
- Twice Yield Limit

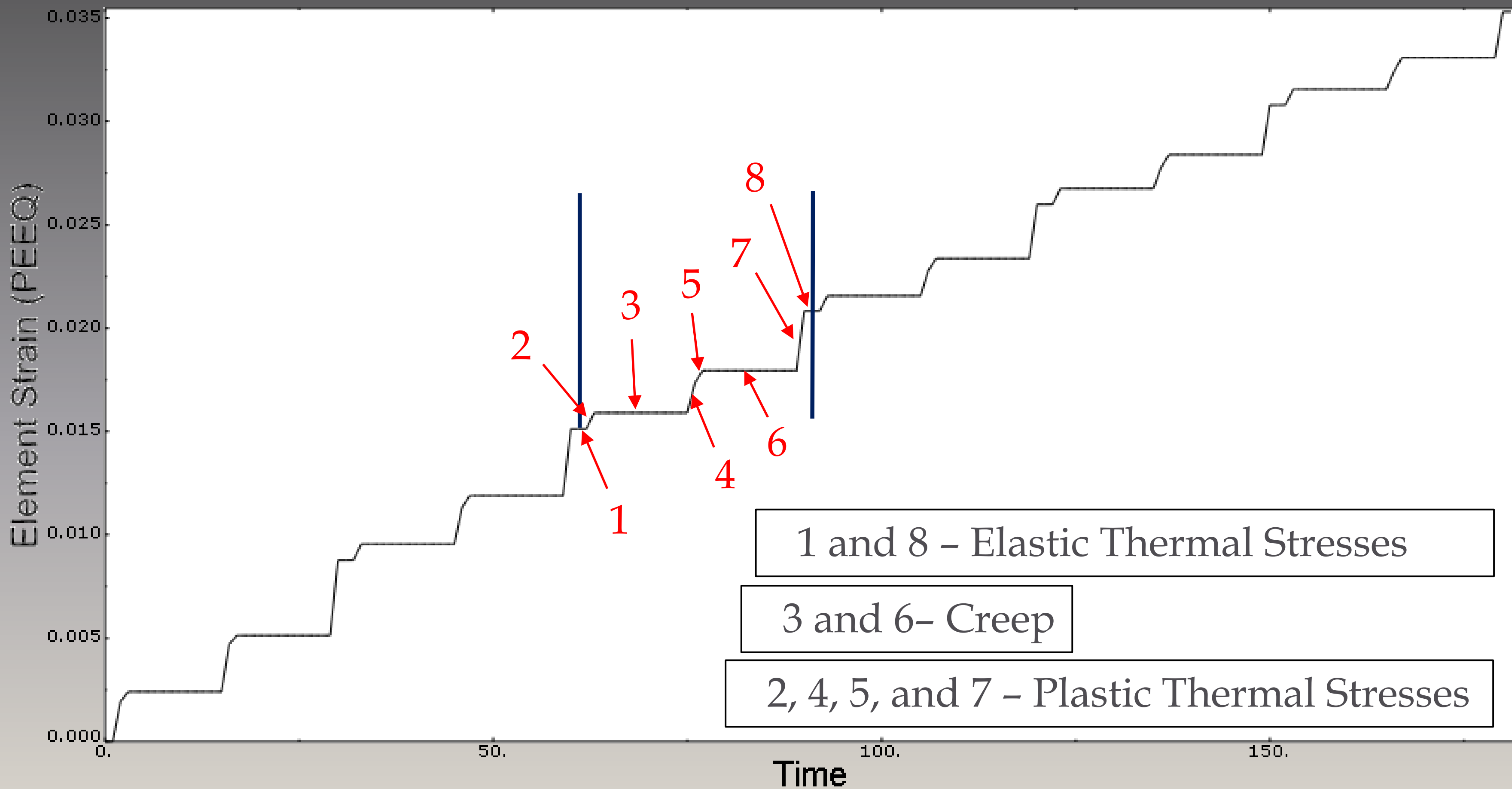
Plastic Shakedown

- Reoccurring constant strain amplitude
- Displacement Controlled Loading

Ratcheting

- Increasing Strain Per Cycle
- Load-Controlled (Requires Pressure)

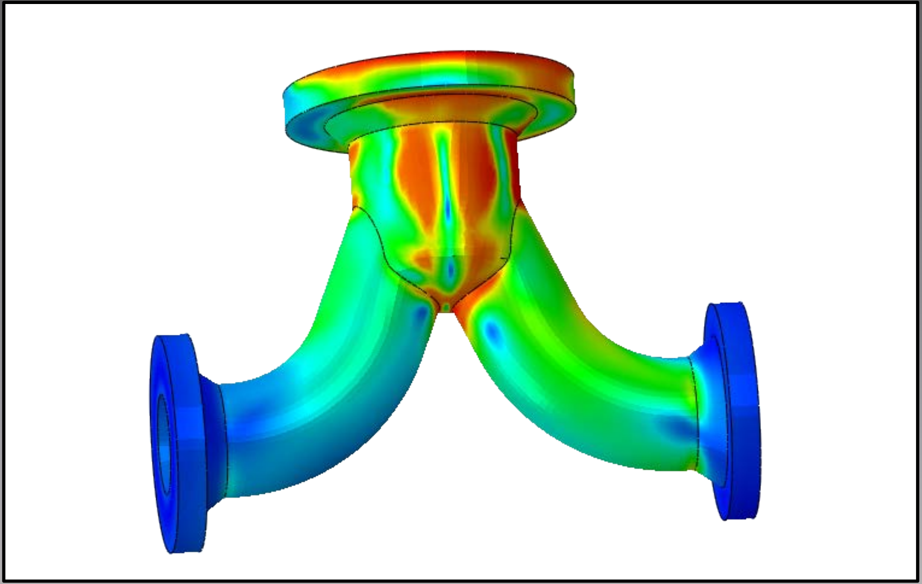
Results – Plastic Accumulation



1) Ambient-Operating (No Strain after 1st), **2)** Operating-Leg1HighTemp (Strain Slight Ramp-Up), 3) Creep-Leg1 (No Strain) **4)** Leg1HighTemp-Operating (Strain Ramp), 5) Operating-Leg2HighTemp (Strain Slight Ramp-Up), 6) Creep-Leg2 (No Strain), 7) Leg2HighTemp-Operating (Strain Ramp), ReturntoAmbient (NoStrain)

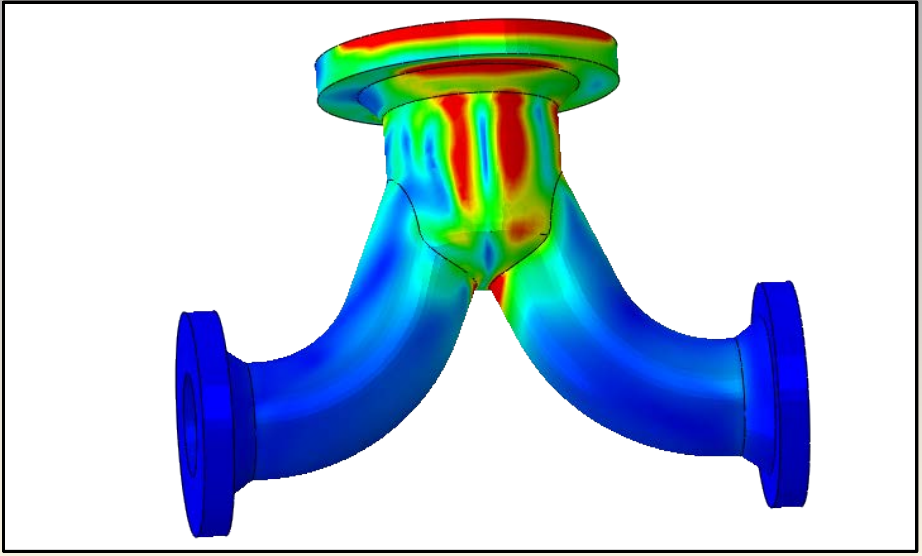
Creep Relaxation

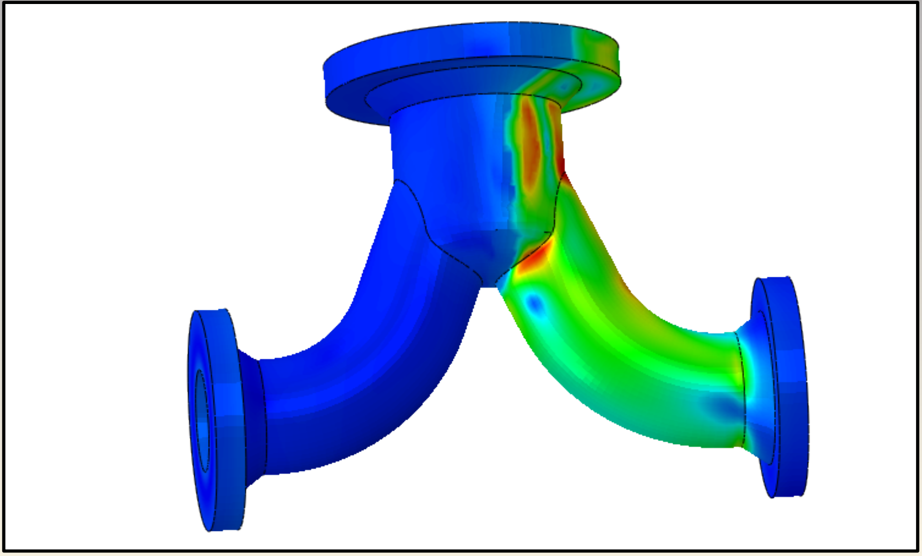
One leg subjected to high temperature and resultant creep relaxation. Then repeats for opposite leg



Some creep relaxation of opposite leg, but maximum stress on that leg remains.

Back to operating causes additional strain accumulation.





Equivalent Strain Range
ASME III-NH-T-1413

$$\Delta\epsilon_{equiv,i} = \frac{\sqrt{2}}{2(1+\vartheta^*)}\left[\left(\Delta\epsilon_{xi}-\Delta\epsilon_{yi}\right)^2+\left(\Delta\epsilon_{yi}-\Delta\epsilon_{zi}\right)^2+\left(\Delta\epsilon_{zi}-\Delta\epsilon_{xi}\right)^2+\frac{3}{2}\left(\Delta\gamma_{xyi}^2+\Delta\gamma_{yzi}^2+\Delta\gamma_{zxi}^2\right)\right]^{\frac{1}{2}}$$

1. Determine, at nodes of interest, all six strain components ($\epsilon_{x,y,z}$ and $\gamma_{xy,yz,zx}$).

2. Determine extreme (maximum or minimum); designate as "o".

3. Calculate each change in strain at each node at each internal cycle inflection.

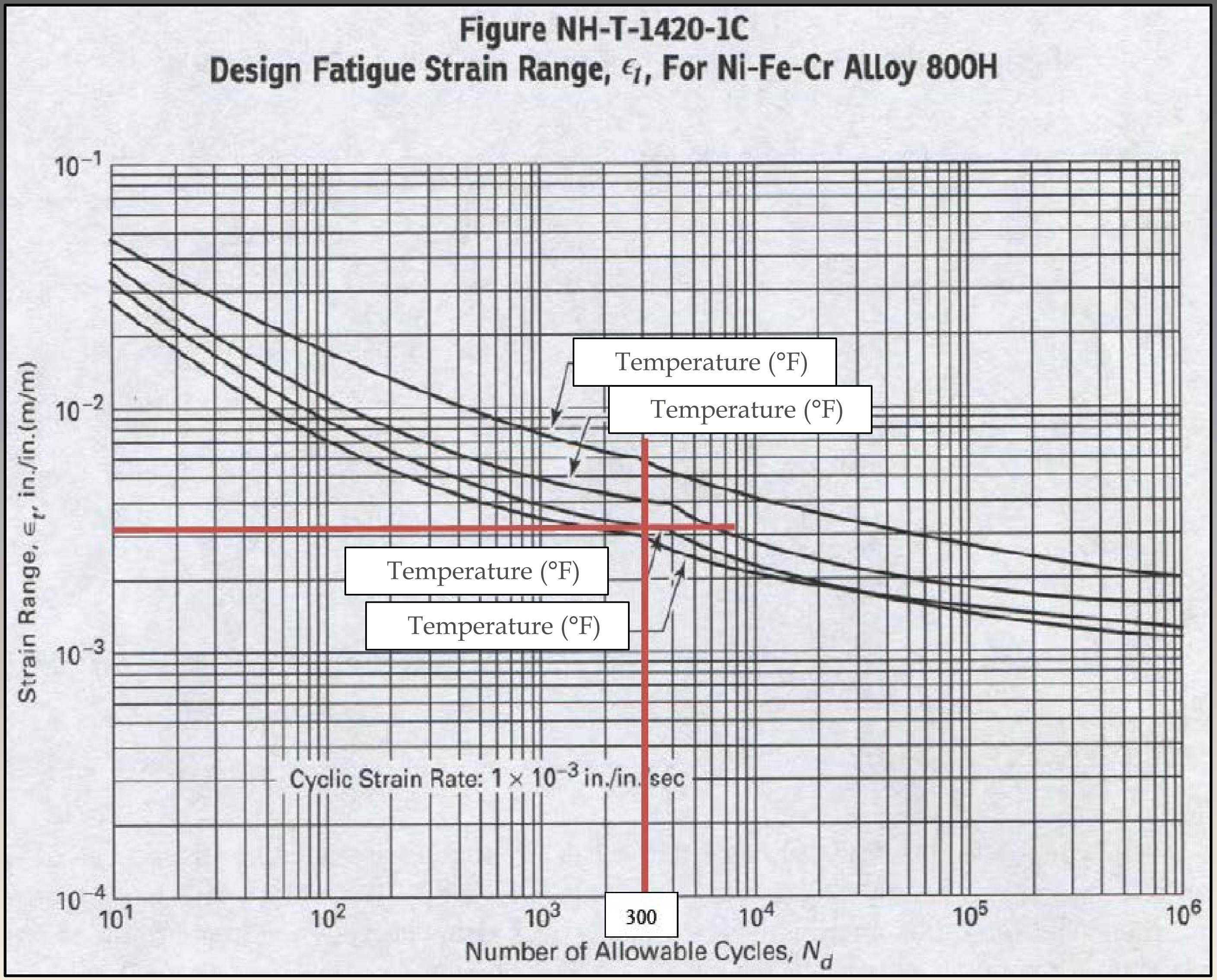
$$\Delta\epsilon_{xi} = \epsilon_{xi} - \epsilon_{xo}$$

$$\Delta\gamma_{xyi} = \gamma_{xyi} - \gamma_{xyo}$$

4. Calculate the equivalent strain range for each internal cycle point (Top Eqn).

5. Define $\Delta\epsilon_{max}$ as the maximum value from Step 4.

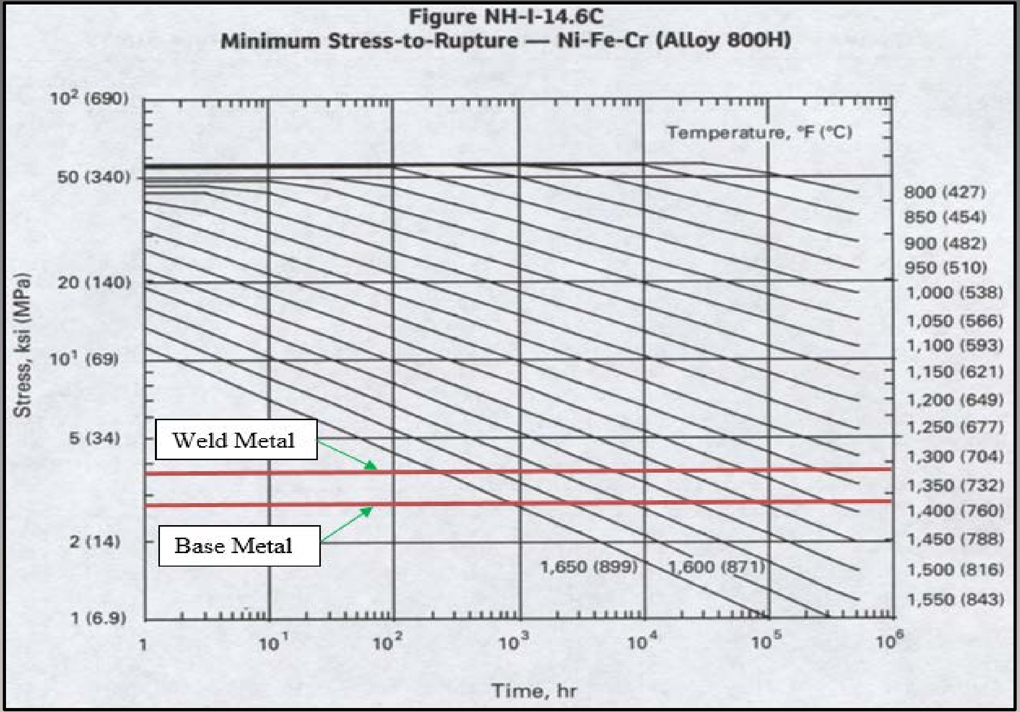
ASME III-NH Evaluation Curve



Minimum Stress-to-Rupture ASME III-NH Figure NH-I-14.6C

Weld metal (Inco-82, SFA-5.14 ERNiCr-3) stress rupture factor is a divisor of 0.8 per Table NH-I-14.10C-2.

Creep is insignificant based on calculated stress values.



Averaged maximum principal stress over the last cycle used to calculated von Mises Stress Intensity, divided by K' (0.67 for Alloy 800-H per Table NH-T-1411-1). For inelastic analysis with Alloy 800-H, multiplier factor to SI is 1.0.

This stress equivalent/K' value is used in Figure NH-I-14.6C to determine allowable time duration (Td).

Creep-Fatigue Analysis ASME III-NH-T-1411

$$\sum_{j=1}^{p}\left(\frac{n}{N_d}\right)_j + \sum_{k=1}^{q}\left(\frac{\Delta t}{T_d}\right)_k \leq D$$

Per NH-T-1715 (Creep-Fatigue Reduction Factors), the Nd value in vicinity of a weld shall be one-half the value permitted for the parent material.

Creep term is 0.

Solve for n.

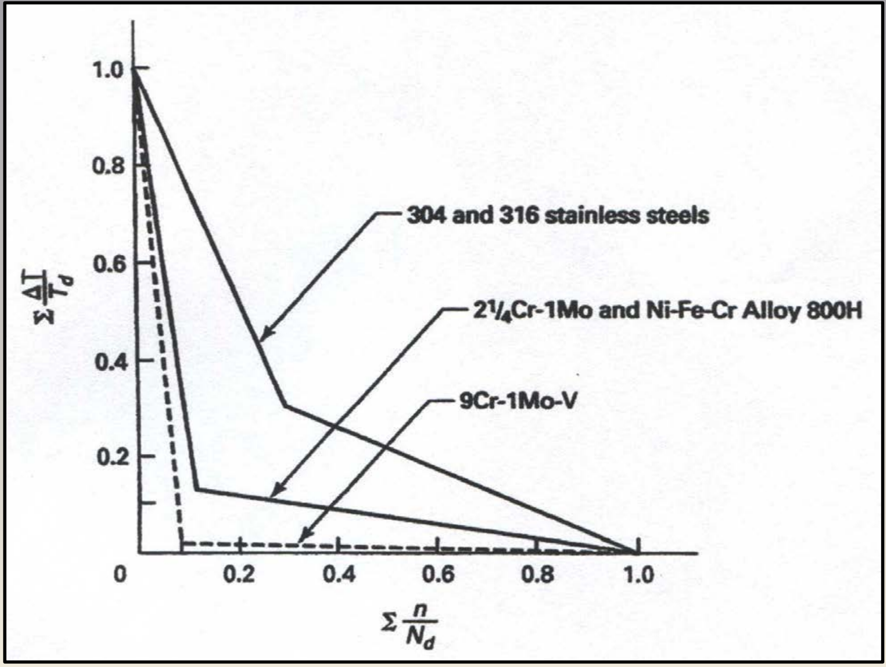
n = number of applied cycles

N_d = number of design allowable cycles (Slide 14)

Δt = duration of time at creep

Td = allowable duration at creep temperature

D = total creep-fatigue damage, inside the boundaries of Figure NH-T-1420-2 (to right)



Conclusions

- CREEP Subroutine necessary to properly capture short term primary creep effects

- With creep relaxation, creep stress was low enough to make creep damage insignificant

- Creep and creep relaxation, however, did affect the plastic strain range

- ASME III-NH (High Temperature Nuclear Code) is used to evaluate an allowable number of operating cycles

Acknowledgements

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Thank You

Questions or Comments?