Appendix C

Material Calculations

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APPENDIX C - Bruce A Boiler Divider Plate Material Properties

C.1 Temperature

$°F \equiv 1K$

$T_{D20\_inlet} := 579 \cdot °F$ (see Design Manual SCI-33110 page 10-3)

$T_{D20\_outlet} := 509 \cdot °F$

The divider plate average metal temperature is $T_{ave} := \frac{1}{2} \cdot \left(T_{D20\_inlet} + T_{D20\_outlet}\right)$

In the followings, material properties will be calculated at $T_{ave} = 544 \cdot \text{temperature}$

Material properties were taken from ASME code, Section II, 1995 edition.

C.2 Density of Carbon steel

$\rho := 0.279 \cdot \frac{lb}{in^3}$ (ASME code Section II, part D, page 620) $slug \equiv 386.4 \cdot lb$

$\rho = 0.000722 \cdot \frac{slug}{in^3}$

C.3 Material SA515 Gr. 70 (divider plate panels and filler plate)

This material is a C-Si steel with maximum carbon content of 0.33 % (ASME code Section II part A, page 794).
From ASME code, Section II, part D, Table TM-1 :

$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot °F \qquad E := \begin{pmatrix} 27.1 \cdot 10^6 \\ 26.5 \cdot 10^6 \end{pmatrix} \cdot psi$

$E_a := \text{linterp}(T, E, 544 \cdot °F)$

The interpolated value of E @ 544 ° F $E_a = 2.6836 \cdot 10^7 \cdot psi$

From ASME code Table Y-1 (page 460) :

$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot °F \qquad Sy := \begin{pmatrix} 30.7 \cdot 10^3 \\ 28.1 \cdot 10^3 \end{pmatrix} \cdot psi$

$Sy_a := \text{linterp}(T, Sy, 544 \cdot °F)$

The interpolated value of Sy @ 544 ° F $Sy_a = 29556 \cdot psi$

The yield strain $\varepsilon_y := \frac{Sy_a}{E_a}$ $\varepsilon_y = 0.0011$

From ASME code Table U (page 424) : $Su := 70000 \cdot psi$

Form ASME code Section II part A page 794 : $\varepsilon_u := 17 \cdot \%$

Let $\sigma_{eng} := Su$ $\quad\varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$$\sigma_{true} := \sigma_{eng} \cdot \left(1 + \varepsilon_{eng}\right) \qquad \sigma_{true} = 81900 \cdot psi$$

$$\varepsilon_{true} := \ln\left(1 + \varepsilon_{eng}\right) \qquad \varepsilon_{true} = 0.157$$

The ultimate true plastic strain is

$$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.154$$

C.4 Material A108-1018 (lap plates and clamps)

This material is a plain carbon steel with carbon content of approximately 0.18 % (AISI specification 1018, 1 means carbon steel, 0 means no alloy, 18 means 0.18 % carbon). The Young's moduli according to ASME code Table TM-1 are :

$$T := \begin{bmatrix} 70 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot °F \qquad E := \begin{bmatrix} 29.5 \cdot 10^6 \\ 28.8 \cdot 10^6 \\ 28.3 \cdot 10^6 \\ 27.7 \cdot 10^6 \\ 27.3 \cdot 10^6 \\ 26.7 \cdot 10^6 \end{bmatrix} \cdot psi \qquad C \le 0.3\%$$

$E_a := \text{linterp}(T, E, 544 \cdot °F)$

The interpolated value of E @ 544 ° F $\quad E_a = 2.7036 \cdot 10^7 \cdot psi$

For this material, Sy's are available for up to 400°F in ASME Code Case N71-16. Since these Sy's are identical to those of SA-516 Gr. 60, yield stresses of SA-516 Gr. 60 for temperatures above 400°F was used for this material.

$$T := \begin{bmatrix} 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot °F \qquad Sy := \begin{bmatrix} 32.0 \cdot 10^3 \\ 29.2 \cdot 10^3 \\ 28.3 \cdot 10^3 \\ 27.4 \cdot 10^3 \\ 25.9 \cdot 10^3 \\ 23.6 \cdot 10^3 \end{bmatrix} \cdot psi$$

Ref: ASME Code Case N71-16, page 225

$Sy_a := \mathrm{linterp}(T, Sy, 544 \cdot °F)$

The interpolated value of Sy @ 544 ° F $\quad Sy_a = 24888 \cdot psi$

The yield strain $\quad \varepsilon_y := \dfrac{Sy_a}{E_a} \qquad \varepsilon_y = 0.00092$

From ASME code Case N71-16, page 230 : $\quad Su := 50000 \cdot psi$

From ASME code Section II part A page 799 (for SA-516 Gr. 60) : $\varepsilon_u := 21 \cdot \%$

Let $\quad \sigma_{eng} := Su \qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$$\sigma_{true} := \sigma_{eng} \cdot \left(1 + \varepsilon_{eng}\right) \qquad \sigma_{true} = 60500 \cdot psi$$

$$\varepsilon_{true} := \ln\left(1 + \varepsilon_{eng}\right) \qquad \varepsilon_{true} = 0.1906$$

The ultimate true plastic strain is

$$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.1884$$

C.5 Material SA-105 Gr.II (tubesheet)

This material is a C-Si steel with maximum carbon content of 0.35 % (ASME code Section II part A, page 152).
From ASME code, Section II, part D, Table TM-1 :

$$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot °F \qquad E := \begin{pmatrix} 27.1 \cdot 10^6 \\ 26.5 \cdot 10^6 \end{pmatrix} \cdot psi$$

$E_a := \mathrm{linterp}(T, E, 544 \cdot °F)$

The interpolated value of E @ 544 ° F $\quad E_a = 2.6836 \cdot 10^7 \cdot psi$

From ASME code Table Y-1 (page 460):

$$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot °F \qquad Sy := \begin{pmatrix} 29.1 \cdot 10^3 \\ 26.6 \cdot 10^3 \end{pmatrix} \cdot psi$$

$Sy_a := \mathrm{linterp}(T, Sy, 544 \cdot °F)$

The interpolated value of Sy @ 544 ° F $\quad Sy_a = 28000 \cdot psi$

The yield strain $\quad \varepsilon_y := \dfrac{Sy_a}{E_a} \qquad \varepsilon_y = 0.00104$

From ASME code Table U (page 424) : $Su := 70000 \cdot psi$

Form ASME code Section II part A page 153 : $\varepsilon_u := 22 \cdot \%$

Let $\sigma_{eng} := Su$ $\varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$$\sigma_{true} := \sigma_{eng} \cdot (1 + \varepsilon_{eng}) \qquad \sigma_{true} = 85400 \cdot psi$$

$$\varepsilon_{true} := \ln(1 + \varepsilon_{eng}) \qquad \varepsilon_{true} = 0.1989$$

The ultimate true plastic strain is

$$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.1957$$

C.6 Material SB-304 Typ. ER-Ni-Cr3 (tubesheet cladding, TS seatbar weld)

This material is a bare welding nickel alloy (ASME code Section II, part C, SFA-5.14). The major elements are (SFA 5.14, page 294) : 3% Mn, 3% Fe, 20% Cr, the remainder is Ni. The density of the elements according to Marks' handbook 7th edition (page 6-67) is :

$$\rho_{Fe} := 0.284 \cdot \frac{lb}{in^3} \qquad \rho_{Mn} := 0.268 \cdot \frac{lb}{in^3} \qquad \rho_{Cr} := 0.260 \cdot \frac{lb}{in^3} \qquad \rho_{Ni} := 0.322 \cdot \frac{lb}{in^3}$$

$$\rho := 0.03 \cdot \rho_{Mn} + 0.03 \cdot \rho_{Fe} + 0.20 \cdot \rho_{Cr} + 0.74 \cdot \rho_{Ni}$$

$$\rho = 0.000794 \cdot \frac{slug}{in^3}$$

Young's modulus for this material, which UNS number is N06082, is not listed on ASME Table TM-4. The values for SB-168 N06600, which has very similar chemical composition (72Ni-15Cr-8Fe) to this material, was used :

$$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot {}^\circ F \qquad E := \begin{pmatrix} 29.0 \cdot 10^6 \\ 28.7 \cdot 10^6 \end{pmatrix} \cdot psi$$

$$E_a := \mathrm{linterp}(T, E, 544 \cdot {}^\circ F)$$

The interpolated value of E @ 544 ° F $E_a = 2.8868 \cdot 10^7 \cdot psi$

Yield stress for this material, which UNS number is N06082, is not listed on ASME Table Y-1. The values for SB-168 (Table Y-1, page 572) was used :

$$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot {}^\circ F \qquad Sy := \begin{pmatrix} 28.8 \cdot 10^3 \\ 27.9 \cdot 10^3 \end{pmatrix} \cdot psi$$

$Sy_a := \text{linterp}(T, Sy, 544 \cdot °F)$

The interpolated value of Sy @ 544 ° F $\quad Sy_a = 28404 \cdot psi$

The yield strain $\quad \varepsilon_y := \frac{Sy_a}{E_a} \qquad \varepsilon_y = 0.00098$

From ASME code Table U (for SB-168 N06600, page 420) : $\quad Su := 80000 \cdot psi$

Form ASME code Section II part B page 186 (for SB-168) : $\quad \varepsilon_u := 30 \cdot \%$

Let $\quad \sigma_{eng} := Su \qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$\sigma_{true} := \sigma_{eng} \cdot (1 + \varepsilon_{eng}) \qquad \sigma_{true} = 104000 \cdot psi$

$\varepsilon_{true} := \ln(1 + \varepsilon_{eng}) \qquad \varepsilon_{true} = 0.2624$

The ultimate true plastic strain is

$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.2588$

C.7 Material SB-166 (tubesheet seatbar)

This material is a Ni alloy (72Ni-15Cr-8Fe N06600). From ASME code Table TM-4 :

$$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot °F \qquad E := \begin{pmatrix} 29.0 \cdot 10^6 \\ 28.7 \cdot 10^6 \end{pmatrix} \cdot psi$$

$E_a := \text{linterp}(T, E, 544 \cdot °F)$

The interpolated value of E @ 544 ° F $\quad E_a = 2.8868 \cdot 10^7 \cdot psi$

From ASME code Table Y-1 (page 572) :

$$T := \begin{bmatrix} 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot °F \qquad Sy := \begin{bmatrix} 35.0 \cdot 10^3 \\ 32.7 \cdot 10^3 \\ 31.0 \cdot 10^3 \\ 29.8 \cdot 10^3 \\ 28.8 \cdot 10^3 \\ 27.9 \cdot 10^3 \end{bmatrix} \cdot psi$$

$Sy_a := \text{linterp}(T, Sy, 544\cdot°F)$

The interpolated value of Sy @ 544 ° F $\quad Sy_a = 28404\cdot psi$

The yield strain $\quad \varepsilon_y := \dfrac{Sy_a}{E_a} \qquad \varepsilon_y = 0.00098$

From ASME code Table U (page 420) : $\quad Su := 80000\cdot psi$

Form ASME code Section II part B page 169 (cold worked Su=80ksi) : $\quad \varepsilon_u := 30\cdot\%$

Let $\quad \sigma_{eng} := Su \qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$$\sigma_{true} := \sigma_{eng}\cdot\left(1 + \varepsilon_{eng}\right) \qquad \sigma_{true} = 104000\cdot psi$$

$$\varepsilon_{true} := \ln\left(1 + \varepsilon_{eng}\right) \qquad \varepsilon_{true} = 0.2624$$

The ultimate true plastic strain is

$$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.2588$$

C.8 Material A-36 (head seatbar)

This material is a C-Mn-Si steel with maximum carbon content of 0.28 % (ASME code Section II part A, page 111). From ASME code Table TM-1 :

$$T := \begin{bmatrix} 70 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix}\cdot°F \qquad E := \begin{bmatrix} 29.5\cdot10^6 \\ 28.8\cdot10^6 \\ 28.3\cdot10^6 \\ 27.7\cdot10^6 \\ 27.3\cdot10^6 \\ 26.7\cdot10^6 \end{bmatrix}\cdot psi \qquad C \le 0.3\%$$

$E_a := \text{linterp}(T, E, 544\cdot°F)$

The interpolated value of E @ 544 ° F $\quad E_a = 2.7036\cdot10^7 \cdot psi$

From ASME code Table Y-1 (page 460) :

$$T := \begin{bmatrix} 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot {}^{\circ}F \qquad Sy := \begin{bmatrix} 36.0 \cdot 10^3 \\ 32.8 \cdot 10^3 \\ 31.9 \cdot 10^3 \\ 30.8 \cdot 10^3 \\ 29.1 \cdot 10^3 \\ 26.6 \cdot 10^3 \end{bmatrix} \cdot psi$$

$Sy_a := \text{linterp}(T, Sy, 544 \cdot {}^{\circ}F)$

The interpolated value of Sy @ 544 ° F $\quad Sy_a = 28000 \cdot psi$

The yield strain $\quad \varepsilon_y := \dfrac{Sy_a}{E_a} \qquad \varepsilon_y = 0.00104$

Su for this material is not listed in ASME code Table U. However, Table Y-1 indicates that the minimum Su is 58 ksi, and Su for most carbon steel remains the same for temperature up to 700°F, the minimum Su is used :

$$Su := 58000 \cdot psi$$

Form ASME code Section II part A page 111 : $\qquad \varepsilon_u := 20 \cdot \%$

Let $\quad \sigma_{eng} := Su \qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$$\sigma_{true} := \sigma_{eng} \cdot \left(1 + \varepsilon_{eng}\right) \qquad \sigma_{true} = 69600 \cdot psi$$

$$\varepsilon_{true} := \ln\left(1 + \varepsilon_{eng}\right) \qquad \varepsilon_{true} = 0.1823$$

The ultimate true plastic strain is

$$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.1797$$

<u>C.9 Material E7018-A1</u> <u>(head seatbar weld)</u>

This material is a C-1/2Mo (0.12C-0.9Mn-0.5Mo) steel electrode (ASME code Section II part C, SFA 5.5, page 103). From ASME code, Section II, part D, Table TM-1 :

$$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot {}^{\circ}F \qquad E := \begin{pmatrix} 27.0 \cdot 10^6 \\ 26.4 \cdot 10^6 \end{pmatrix} \cdot psi$$

$E_a := \text{linterp}(T, E, 544\cdot°F)$

The interpolated value of E @ 544 ° F $E_a = 2.6736\cdot10^7\ \cdot\text{psi}$

From ASME code Section II part C page 109, the minimum Sy and Su at room temperature for this material are :

$Sy := 57000\cdot\text{psi}$ $\quad\quad$ $Su := 70000\cdot\text{psi}$

This material has the same Su as SA-204 Gr B and is similar to SA-204 Gr B (0.2C-0.9Mn-0.5Mo) in chemical composition. Yield stresses of SA-204 Gr B were used to established the yield stress of this material at 544°F as in the following :

$$T := \begin{pmatrix} 70 \\ 500 \\ 600 \end{pmatrix}\cdot°F \qquad Sy := \begin{bmatrix} 40.0\cdot10^3 \\ 32.5\cdot10^3 \\ 31.4\cdot10^3 \end{bmatrix}\cdot\text{psi}$$

for SA-204 Gr B, Table Y-1 page 472

$Sy_a := \text{linterp}(T, Sy, 544\cdot°F)$ $\quad\quad$ $Sy_a = 32016\cdot\text{psi}$

Prorate Sy_a by the room temperature yield stresses of the two materials : $Sy_a := Sy_a\cdot\frac{57}{40}$

Sy @ 544 ° F for the weld is : $\quad$ $Sy_a = 45623\cdot\text{psi}$

The yield strain $\quad \varepsilon_y := \frac{Sy_a}{E_a}$ $\quad\quad$ $\varepsilon_y = 0.00171$

From ASME code Section II part C page 109 : $\quad$ $Su := 70000\cdot\text{psi}$

Form ASME code Section II part C page 109 : $\quad$ $\varepsilon_u := 25\cdot\%$

Let $\quad \sigma_{eng} := Su \qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$\sigma_{true} := \sigma_{eng}\cdot(1 + \varepsilon_{eng})$ $\quad\quad$ $\sigma_{true} = 87500\cdot\text{psi}$

$\varepsilon_{true} := \ln(1 + \varepsilon_{eng})$ $\quad\quad$ $\varepsilon_{true} = 0.2231$

The ultimate true plastic strain is

$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a}$ $\quad\quad$ $\varepsilon_f = 0.2199$

C.10 Material SA516 Gr. 70 (head)

This material is a C-Mn-Si steel. The primary head is 3.75" thick, therefore the maximum carbon content is 0.30 % (ASME code Section II part A, page 799). From ASME code, Section II, part D, Table TM-1 :

$$T := \begin{bmatrix} 70 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot {}^\circ F \qquad E := \begin{bmatrix} 29.5 \cdot 10^6 \\ 28.8 \cdot 10^6 \\ 28.3 \cdot 10^6 \\ 27.7 \cdot 10^6 \\ 27.3 \cdot 10^6 \\ 26.7 \cdot 10^6 \end{bmatrix} \cdot psi \qquad C \le 0.3\%$$

$E_a := \text{linterp}(T, E, 544 \cdot {}^\circ F)$

The interpolated value of E @ 544 ° F $E_a = 2.7036 \cdot 10^7 \cdot psi$

From ASME code Table Y-1 (page 460) :

$$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot {}^\circ F \qquad Sy := \begin{pmatrix} 30.7 \cdot 10^3 \\ 28.1 \cdot 10^3 \end{pmatrix} \cdot psi$$

$Sy_a := \text{linterp}(T, Sy, 544 \cdot {}^\circ F)$

The interpolated value of Sy @ 544 ° F $Sy_a = 29556 \cdot psi$

The yield strain $\varepsilon_y := \dfrac{Sy_a}{E_a}$ $\qquad \varepsilon_y = 0.00109$

From ASME code Table U (page 424) : $Su := 70000 \cdot psi$

Form ASME code Section II part A page 799 : $\varepsilon_u := 17 \cdot \%$

Let $\sigma_{eng} := Su$ $\qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$$\sigma_{true} := \sigma_{eng} \cdot (1 + \varepsilon_{eng}) \qquad \sigma_{true} = 81900 \cdot psi$$

$$\varepsilon_{true} := \ln(1 + \varepsilon_{eng}) \qquad \varepsilon_{true} = 0.157$$

The ultimate true plastic strain is

$$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.154$$

C.11 Material A-325 (5/8" 11UNC-2A BOLTS)

This material is a plain carbon steel with carbon content of 0.13 to 0.58% (ASME code 1992 edition, Section II, part A, page 418). The E values for high carbon steel (C > 0.3%), which is lower than those of low carbon steel, from ASME code Table TM-1 was used :

$$T := \begin{bmatrix} 70 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot °F \qquad E := \begin{bmatrix} 29.3 \cdot 10^6 \\ 28.6 \cdot 10^6 \\ 28.1 \cdot 10^6 \\ 27.5 \cdot 10^6 \\ 27.1 \cdot 10^6 \\ 26.5 \cdot 10^6 \end{bmatrix} \cdot psi \qquad C > 0.3\%$$

$E_a := \text{linterp}(T, E, 544 \cdot °F)$

The interpolated value of E @ 544 ° F $\quad E_a = 2.6836 \cdot 10^7 \cdot psi$

From ASME code 1995 editition Table Y-1 page 468

$$T := \begin{bmatrix} 70 \\ 200 \\ 300 \\ 400 \end{bmatrix} \cdot °F \qquad Sy := \begin{bmatrix} 81.0 \cdot 10^3 \\ 73.9 \cdot 10^3 \\ 71.6 \cdot 10^3 \\ 69.3 \cdot 10^3 \end{bmatrix} \cdot psi$$

$Sy_a := \text{linterp}(T, Sy, 544 \cdot °F)$

The extrapolated value of Sy @ 544 ° F $\quad Sy_a = 65988 \cdot psi$

:According to ASME code 1995 editition Table Y-1 page 468, for bolt 0.5" to 1.5", the room temperature minimum Sy and Su is 81 ksi and 105 ksi respectively. However, the 1992 code (Section II part A page 419) indicates that these values are actually for bolt size of 1.125" to 1.5". For bolt 0.5" to 1.0", the minimum Sy and Su is 92 ksi and 120 ksi respectively. Since the divider plate bolts are 5/8" bolt, a more realistic Sy_a is to prorate the Sy_a calculated above by the ratio of yield stresses of the 2 bolt sizes :

$Sy_a := Sy_a \cdot \frac{92}{81} \qquad Sy_a = 74949 \cdot psi$

The yield strain $\quad \varepsilon_y := \frac{Sy_a}{E_a} \qquad \varepsilon_y = 0.00279$

From ASME code 1992 edition Section II part A page 419 : $\quad Su := 120000 \cdot psi$

Form ASME code 1992 edition Section II part A page 419 : $\quad \varepsilon_u := 14 \cdot \%$

Let $\quad \sigma_{eng} := Su \qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$\sigma_{true} := \sigma_{eng} \cdot (1 + \varepsilon_{eng})$ $\sigma_{true} = 136800 \cdot psi$

$\varepsilon_{true} := \ln(1 + \varepsilon_{eng})$ $\varepsilon_{true} = 0.131$

The ultimate true plastic strain is

$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a}$ $\varepsilon_f = 0.1259$

Density of the bolt elements were increased based on the element size such that they do not severely limit the analysis time step

$11 \cdot 0.000722 = 0.007942$

$5.5 \cdot 0.000722 = 0.003971$

$3.0 \cdot 0.000722 = 0.002166$

$1.3 \cdot 0.000722 = 0.000939$

C.12 Material SB-443 (sealing skin)

This material is a Nickel-Chromium-Molybdenum-Columbium alloy (UNS N06625). The sealing skin is 0.030" thick with a maximum carbon content is 0.10 % (ASME code Section II part B, page 502). From ASME code, Section II, part D, Table TM-4 :

$$T := \begin{bmatrix} 70 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot {}^\circ F \qquad E := \begin{bmatrix} 30.0 \cdot 10^6 \\ 29.3 \cdot 10^6 \\ 28.8 \cdot 10^6 \\ 28.5 \cdot 10^6 \\ 28.1 \cdot 10^6 \\ 27.8 \cdot 10^6 \end{bmatrix} \cdot psi \qquad C \le 0.1\%$$

$E_a := \text{linterp}(T, E, 544 \cdot {}^\circ F)$

The interpolated value of E @ 544 ° F $E_a = 2.7968 \cdot 10^7 \cdot psi$

From ASME code Table Y-1 (page 572) :

$$T := \begin{pmatrix} 500 \\ 600 \end{pmatrix} \cdot {}^\circ F \qquad Sy := \begin{pmatrix} 48.5 \cdot 10^3 \\ 47.2 \cdot 10^3 \end{pmatrix} \cdot psi$$

$Sy_a := \text{linterp}(T, Sy, 544 \cdot {}^\circ F)$

The interpolated value of Sy @ 544 ° F $Sy_a = 47928 \cdot psi$

The yield strain $\varepsilon_y := \dfrac{Sy_a}{E_a}$ $\qquad \varepsilon_y = 0.00171$

From ASME code Section II part B page 502 : $Su := 110000 \cdot psi$

Form ASME code Section II part B page 502 : $\varepsilon_u := 30 \cdot \%$

Let $\sigma_{eng} := Su$ $\qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$\sigma_{true} := \sigma_{eng} \cdot \left(1 + \varepsilon_{eng}\right)$ $\qquad \sigma_{true} = 143000 \cdot psi$

$\varepsilon_{true} := \ln\left(1 + \varepsilon_{eng}\right)$ $\qquad \varepsilon_{true} = 0.2624$

The ultimate true plastic strain is

$\varepsilon_f := \varepsilon_{true} - \dfrac{\sigma_{true}}{E_a}$ $\qquad \varepsilon_f = 0.2573$

C.13 Material SA-193-B7 (5/8" UNC x 1 1/2" BOLTS)

This material is a plain stainless steel (Chromium-Molybdenum) with carbon content of 0.37 to 0.49% (ASME code 1992 edition, Section II, part A, page 228). The E values for high carbon steel (C > 0.3%), which is lower than those of 1/2 - 2Cr steels, from ASME code Table TM-1 was used :

$$T := \begin{bmatrix} 70 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot {}^\circ F \qquad E := \begin{bmatrix} 29.3\cdot 10^6 \\ 28.6\cdot 10^6 \\ 28.1\cdot 10^6 \\ 27.5\cdot 10^6 \\ 27.1\cdot 10^6 \\ 26.5\cdot 10^6 \end{bmatrix} \cdot psi \qquad C > 0.3\%$$

$E_a := \text{linterp}(T, E, 544\cdot {}^\circ F)$

The interpolated value of E @ 544 ° F $\quad E_a = 2.6836\cdot 10^7 \cdot psi$

From ASME code 1995 edition Table Y-1 page 468

$$T := \begin{bmatrix} 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot {}^\circ F \qquad Sy := \begin{bmatrix} 105.0\cdot 10^3 \\ 98.0\cdot 10^3 \\ 94.1\cdot 10^3 \\ 91.5\cdot 10^3 \\ 88.5\cdot 10^3 \\ 85.3\cdot 10^3 \end{bmatrix} \cdot psi$$

$Sy_a := \text{linterp}(T, Sy, 544\cdot {}^\circ F)$

The interpolated value of Sy @ 544 ° F: $\quad Sy_a = 87092 \cdot psi$

The yield strain $\quad \varepsilon_y := \dfrac{Sy_a}{E_a} \qquad \varepsilon_y = 0.00325$

From ASME code 1992 edition Section II part A page 231 : $\quad Su := 125000\cdot psi$

Form ASME code 1992 edition Section II part A page 231 : $\quad \varepsilon_u := 16\cdot\%$

Let $\quad \sigma_{eng} := Su \qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$$\sigma_{true} := \sigma_{eng}\cdot\left(1 + \varepsilon_{eng}\right) \qquad \sigma_{true} = 145000 \cdot psi$$

$$\varepsilon_{true} := \ln\left(1 + \varepsilon_{eng}\right) \qquad \varepsilon_{true} = 0.1484$$

The ultimate true plastic strain is

$$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.143$$

C.14 Material SA-540-B22 Class 1 (5/8" UNC x 1 1/2" BOLTS)

This material is an alloy steel bolting material (Chromium-Molybdenum) with carbon content of 0.39 to 0.46% (ASME code 1995 edition, Section II, part A, page 845). The E values for high carbon steel (C > 0.3%), which is lower than those of 1/2 - 2Cr steels, from ASME code Table TM-1 was used :

$$T := \begin{bmatrix} 70 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot °F \qquad E := \begin{bmatrix} 29.3 \cdot 10^6 \\ 28.6 \cdot 10^6 \\ 28.1 \cdot 10^6 \\ 27.5 \cdot 10^6 \\ 27.1 \cdot 10^6 \\ 26.5 \cdot 10^6 \end{bmatrix} \cdot psi \qquad C > 0.3\%$$

$$E_a := \text{linterp}(T, E, 544 \cdot °F)$$

The interpolated value of E @ 544 ° F $\quad E_a = 2.6836 \cdot 10^7 \cdot psi$

From ASME code 1995 editition Table Y-1 page 480

$$T := \begin{bmatrix} 100 \\ 200 \\ 300 \\ 400 \\ 500 \\ 600 \end{bmatrix} \cdot °F \qquad Sy := \begin{bmatrix} 150.0 \cdot 10^3 \\ 140.1 \cdot 10^3 \\ 135.3 \cdot 10^3 \\ 131.7 \cdot 10^3 \\ 127.7 \cdot 10^3 \\ 103.7 \cdot 10^3 \end{bmatrix} \cdot psi$$

$$Sy_a := \text{linterp}(T, Sy, 544 \cdot °F)$$

The interpolated value of Sy @ 544 ° F: $\quad Sy_a = 117140 \cdot psi$

The yield strain $\quad \varepsilon_y := \frac{Sy_a}{E_a} \qquad \varepsilon_y = 0.00437$

From ASME code 1995 edition Section II part A page 846 : $\quad Su := 165000 \cdot psi$

Form ASME code 1995 edition Section II part A page 846 : $\quad \varepsilon_u := 10 \cdot \%$

Let $\quad \sigma_{eng} := Su \qquad \varepsilon_{eng} := \varepsilon_u$

The true stress and strain are

$$\sigma_{true} := \sigma_{eng} \cdot (1 + \varepsilon_{eng}) \qquad \sigma_{true} = 181500 \cdot psi$$

$$\varepsilon_{true} := \ln(1 + \varepsilon_{eng}) \qquad \varepsilon_{true} = 0.0953$$

The ultimate true plastic strain is

$$\varepsilon_f := \varepsilon_{true} - \frac{\sigma_{true}}{E_a} \qquad \varepsilon_f = 0.0885$$