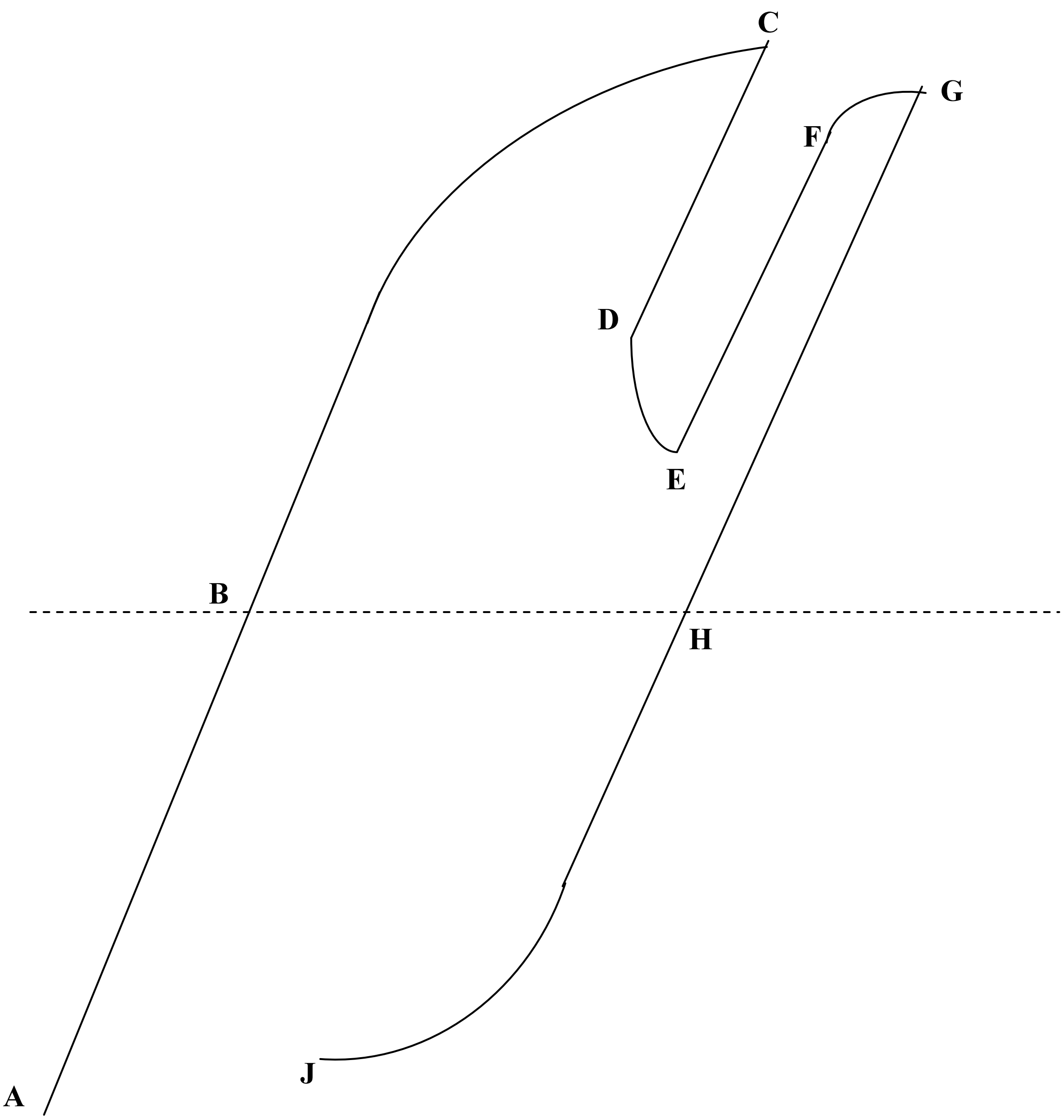
Hysteresis Cycle Construction Methodology for Interacting Cycles



A.1 NOTATION

Elastic stresses and strains are denoted by the subscript $_{el}$.

In the absence of this subscript the stress or strain in question is elastic-plastic.

In the definitions below, the subscript $_i$ denotes the i[th] load cycle.

The elastic stresses vary between cycles due to, (i)metal losses, (ii)random sampling of peak start-up and peak trip thermal system loads, (iii)varying shutdown conditions.

The stresses and strains below all refer to the same point on the same bifurcation or tube. Elastic stresses and stress ranges are Mises equivalents, but elastic-plastic stresses are generally <u>signed</u> Mises equivalents. Stresses refer to the total stress under the prevailing conditions (i.e., deadweight and thermal system loads and pressure load).

For weldment/HAZ it is assumed that any required SCF is included in the elastic stresses.

$\sigma_{i,el}^{SU}$ peak elastic start-up stress (not less than $\sigma_{i,el}^{NO}$)

$\sigma_{i,el}^{NO}$ normal operating elastic stress (must be positive)

$\sigma_{i,el}^{trip}$ peak elastic trip stress (not less than $\sigma_{i,el}^{NO}$)

$\sigma_{i,el}^{SD}$ elastic stress when shutdown at end of ith cycle (will be larger for hot shutdowns than cold shutdowns, the latter is deadweight only). Set $\sigma_{0,el}^{SD}$ to cold shutdown (deadweight) value.

Note: In all differences between Mises stresses of the form $\sigma_1 - \sigma_2$ below this should be interpreted to mean the Mises stress formed by the difference of the stress components, not literally the difference of the two Mises stresses.

$\Delta\sigma_{i,el}^{SD-SU} = \sigma_{i,el}^{SU} - \sigma_{(i-1),el}^{SD}$ elastic stress range from the *previous* shutdown condition to the start-up peak of the ith cycle (>0)

$\Delta\sigma_{i,el}^{SU-NO} = \sigma_{i,el}^{SU} - \sigma_{i,el}^{NO}$ elastic stress range from start-up peak to normal operation (≥0)

$\Delta\sigma_{i,el}^{NO-trip} = \sigma_{i,el}^{trip} - \sigma_{i,el}^{NO}$ elastic stress range from normal operation to trip peak (≥0)

$\Delta\sigma_{i,el}^{trip-SD} = \sigma_{i,el}^{trip} - \sigma_{(i-1),el}^{SD}$ elastic stress range from the *previous* shutdown condition to the trip peak of the ith cycle (>0)

$\Delta\tilde{\sigma}_{i,el}^{SD-SU} = \sigma_{i,el}^{SU} - \sigma_{i,el}^{SD}$ elastic stress range from the start-up peak of the ith cycle to the *following* shutdown condition (>0)

$\Delta\tilde{\sigma}_{i,el}^{trip-SD} = \sigma_{i,el}^{trip} - \sigma_{i,el}^{SD}$ elastic stress range from the trip peak of the ith cycle to the *following* shutdown condition (>0)

$\Delta\sigma_{i,el}^{reload} = MAX\left(\Delta\sigma_{i,el}^{SD-SU}, \Delta\sigma_{i,el}^{trip-SD}\right)$ elastic stress range from the previous shutdown to the peak of ith cycle (>0)

$\Delta\sigma_{i,el}^{unload} = MAX\left(\Delta\tilde{\sigma}_{i,el}^{SD-SU}, \Delta\tilde{\sigma}_{i,el}^{trip-SD}\right)$ elastic stress range from the cycle peak to the following shutdown condition at the end of the ith cycle (>0)

σ_i^{rev} reverse stress datum for the ith cycle (defined as a positive quantity but representing a compressive state of stress);

σ_i^{for} forward stress datum for the ith cycle;

$\left(K_s S_y\right)_{i,hot}$ Value of $K_S S_y$ at the highest temperature of the ith cycle (probably the trip peak)

$\left(K_s S_y\right)_{i,SD}$ Value of $K_S S_y$ at the temperature of the shutdown at the end of the ith cycle. Note that for hot standby or boiler disconnection this may be up to nearly 300^{o}C. For $i = 0$ treat as cold (20^{o}C).

$$\Delta\left(K_S S_y\right)_i^{reload} = \left(K_s S_y\right)_{(i-1),SD} - \left(K_s S_y\right)_{i,hot}$$

$\Delta\left(K_S S_y\right)_i^{unload} = \left(K_s S_y\right)_{i,SD} - \left(K_s S_y\right)_{i,hot}$

$\Sigma\left(K_S S_y\right)_i^{reload} = \left(K_s S_y\right)_{(i-1),SD} + \left(K_s S_y\right)_{i,hot}$

$\Sigma\left(K_S S_y\right)_i^{unload} = \left(K_s S_y\right)_{i,SD} + \left(K_s S_y\right)_{i,hot}$

$\overline{E} = \dfrac{3E}{2(1+\nu)}$ used throughout (for both plastic and creep steps)

flag set to PR (primary reset) if unloading following trip on the *previous* cycle was elastic-plastic, i.e., involving reverse plasticity, otherwise if the last cycle unloaded elastically, set to CH (continuous hardening). For this purpose "elastic" is defined as a plastic strain range <0.05%.

Other quantities are defined in the text below. In particular the absence of the subscript $_{el}$ relates to the corresponding elastic-plastic stress or strain.

The presence of the subscript $_{weld}$ indicates a quantity which has been corrected to apply to the weldment, e.g., HAZ, usually by factoring the strain by an appropriate weld strain enhancement factor (WSEF).

A.2 ABSOLUTE CYCLE POSITIONING (REVERSE STRESS DATUM)

The absolute hysteresis cycle position along the stress axis will be defined via the reverse stress datum σ_i^{rev} which is the (magnitude of the) elastic-plastic stress at the bottom of the cycle, i.e., the shutdown condition (which may be cold shutdown or hot standby). The reverse stress datum for the ith cycle is not determined by the ith cycle alone but also depends upon the preceding cycles. The suggested algorithm is,

Step 1: "Symmetrised" Reverse Stress Datum

Parent Features

The elastic stress ranges $\Delta\sigma_{i,el}^{reload}$ and $\Delta\sigma_{i,el}^{unload}$ are converted to elastic-plastic stress ranges $\Delta\sigma_i^{reload}$ and $\Delta\sigma_i^{unload}$ using the Neuber construction and the unmodified Ramberg-Osgood equation as follows,

$$\Delta\sigma_i^{reload}\Delta\varepsilon_i^{reload} = \frac{\left(\Delta\sigma_{i,el}^{reload}\right)^2}{\overline{E}}, \text{ where, } \Delta\varepsilon_i^{reload} = \frac{\Delta\sigma_i^{reload}}{\overline{E}} + \left(\frac{\Delta\sigma_i^{reload}}{A}\right)^{1/\beta} \quad (C.1)$$

$$\Delta\sigma_i^{unload}\Delta\varepsilon_i^{unload} = \frac{\left(\Delta\sigma_{i,el}^{unload}\right)^2}{\overline{E}}, \text{ where, } \Delta\varepsilon_i^{unload} = \frac{\Delta\sigma_i^{unload}}{\overline{E}} + \left(\frac{\Delta\sigma_i^{unload}}{A}\right)^{1/\beta} \quad (C.2)$$

Throughout, material constants like $\overline{E}$, A and S_y may be randomly sampled for the tube being assessed, but are constant for the whole trial at this location ***except*** as regards their temperature dependence. In (C.1), (C.2) the maximum temperature of the cycle (probably the trip peak) is used to determine the parameter A.

The volumetric strain range correction, $\Delta\varepsilon_{vol}$, is then found following R5V2/3 Section 7.4.2, Equations (7.13-16).

For parent features the symmetrised reverse stress datum for the ith cycle is given by, If $\Delta\sigma_i^{reload} > \Sigma\left(K_s S_y\right)_i^{reload}$ then $\sigma_i^{rev1} = \frac{1}{2}\left(\Delta\sigma_i^{reload} + \Delta\left(K_s S_y\right)_i^{reload}\right)$ (C.3)

else $\sigma_i^{rev1} = \left(K_s S_y\right)_{(i-1),SD}$ (C.4)

If $\Delta\sigma_i^{unload} > \Sigma\left(K_s S_y\right)_i^{unload}$ then $\sigma_i^{rev2} = \frac{1}{2}\left(\Delta\sigma_i^{unload} + \Delta\left(K_s S_y\right)_i^{unload}\right)$ (C.5)

else $\sigma_i^{rev2} = \left(K_s S_y\right)_{i,SD}$ (C.6)

Finally, the "symmetrised" reverse stress datum for the ith cycle is given by,

$$\sigma_i^{rev,sym} = \left(\sigma_i^{rev1} + \sigma_i^{rev2}\right)/2 \quad \text{(C.7)}$$

Weldment/HAZ Features

For weldment/HAZ the parent stress and strain ranges are corrected using the appropriate weld strain enhancement factor (WSEF) from O'Donnell's report, Ref.[5], or the draft revision of R5V2/3 Appendix A4. The procedure for undressed weldments based on linearised elastic stresses is used. The elastic-plastic strain range for the weldment is found from,

$$\Delta\varepsilon_{i,weld}^{reload} = WSEF\left(\Delta\varepsilon_i^{reload} + \Delta\varepsilon_{vol}\right) \quad \text{(C.8)}$$

$$\Delta\varepsilon_{i,weld}^{unload} = WSEF\left(\Delta\varepsilon_i^{unload} + \Delta\varepsilon_{vol}\right) \quad \text{(C.9)}$$

The corresponding elastic-plastic stress range for the weldment is then found by solving,

$$\frac{\Delta\sigma_{i,weld}^{reload}}{\overline{E}} + \left(\frac{\Delta\sigma_{i,weld}^{reload}}{A}\right)^{1/\beta} = \Delta\varepsilon_{i,weld}^{reload} \quad \text{(C.10)}$$

$$\frac{\Delta\sigma_{i,weld}^{unload}}{\overline{E}} + \left(\frac{\Delta\sigma_{i,weld}^{unload}}{A}\right)^{1/\beta} = \Delta\varepsilon_{i,weld}^{unload} \quad \text{(C.11)}$$

These weldment/HAZ stress ranges are then used in Equs.(C.3-C.7) in order to derive the "symmetrised" reverse stress datum for the weldment/HAZ, $\sigma_{i,weld}^{rev,sym}$.

Part 2: Adjustment for Prior Cycling History

Throughout this Part either parent or weldment/HAZ quantities are used as appropriate.

In this Part the derived forward stress datum is used only as an intermediate step in finding the reverse stress datum. The reverse stress datum is used to position the cycle in the subsequent methodology. The forward stress datum derived here is not used again.

For the first cycle, $i = 1$, there is no adjustment hence set,

$$\sigma_1^{rev} = \sigma_1^{rev,sym} \quad \text{(C.12)}$$

The forward stress datum for the first cycle is

$$\sigma_1^{for} = MAX\left(\Delta\sigma_1^{reload}, \Delta\sigma_1^{unload}\right) - \sigma_1^{rev} \quad \text{(C.13)}$$

For subsequent cycles the "symmetrised" forward stress datum is,

$$\sigma_i^{for,sym} = MAX\left(\Delta\sigma_i^{reload}, \Delta\sigma_i^{unload}\right) - \sigma_i^{rev,sym} \quad \text{(C.14)}$$

There are two Options…

Cycle Positioning Option 1

This option assumes that successive cycles are linked at the forward stress datum, but with a gradual tendency to symmetrise. The forward stress datum is defined by a linear interpolation between the forward stress datum of the previous cycle and the symmetrised forward stress datum:-

$$\sigma_i^{for} = \alpha\sigma_{i-1}^{for} + (1-\alpha)\sigma_i^{for,sym} \quad \text{(C.15)}$$

The value of α is to be decided. For $\alpha \to 1$ the forward stress datum is the same as that of the preceding cycle. If the first cycle had a very large stress range, this would be conservative. However, if the first cycle has a small stress range (more likely) then this will be non-conservative. The opposite extreme, $\alpha = 0$, symmetrises all cycles and hence the result of this option is independent of cycle order. With this option the reverse stress datum is defined from the forward stress datum as,

$$\sigma_i^{rev} = MAX\left(\Delta\sigma_i^{reload}, \Delta\sigma_i^{unload}\right) - \sigma_i^{for} \quad \text{(C.16)}$$

Cycle Positioning Option 2

This option assumes that successive cycles are linked at the reverse stress datum, but with a gradual tendency to symmetrise. The reverse stress datum is defined by a linear interpolation between the reverse stress datum of the previous cycle and the symmetrised reverse stress datum:-

$$\sigma_i^{rev} = \alpha\sigma_{i-1}^{rev} + (1-\alpha)\sigma_i^{rev,sym} \quad \text{(C.17)}$$

And then

$$\sigma_i^{for} = MAX\left(\Delta\sigma_i^{reload}, \Delta\sigma_i^{unload}\right) - \sigma_i^{rev} \quad \text{(C.18)}$$

For $\alpha = 0$ the two options are the same (individual cycle symmetrisation).

If $\alpha \to 1$ this option will give conservative results if the first cycle has a small stress range, but non-conservative results if the first cycle has a particularly large stress range.

If the weldment/HAZ procedure has been used then this procedure produces the quantities $\sigma_{i,weld}^{rev}$ and $\sigma_{i,weld}^{for}$.

Note that the attempt to ensure conservatism by changing between options 1 and 2 cycle by cycle will lead to an unbounded drift of the hysteresis cycle upwards and is not workable.

Either option will lead to cycles being symmetrised on average, in the sense that $\sum_i \sigma_i^{rev} = \sum_i \sigma_i^{rev,sym}$.

A.3 HYSTERESIS CYCLE CONSTRUCTION

A single hysteresis cycle is shown in Figure 10, with salient points denoted A, B, C, D, E, F, G, H, J. This represents any of the cycles in the plant's history, which will differ. Unlike a conventional R5 hysteresis cycle, that of Figure 10 is not even intended to be closed. Point A is the shutdown condition prior to start-up. Point J is the shutdown condition after trip. The cycle does not close because the loading and temperature conditions at A and J may differ. The difference will be greatest when one is a cold shutdown and the other is a hot standby condition. However significant differences will occur between two different hot standby conditions as well.

The algebraic details of the hysteresis cycle construction are specified in §C.3.1 to §C.3.5 below. The overview is,

- The absolute position of point A is the reverse stress datum derived in §C.2;
- Construct part-cycle ABC using the Neuber rule and the unmodified Ramberg-Osgood equation – hence find point C;
- Unload elastically to point D (start of dwell);
- Use integration of the RCC-MR strain rate with an appropriate Z and ζ to calculate the stress relaxation and increment of creep strain, hence find point E (end of dwell);
- Construct point G. Depending upon the magnitude of the peak trip stress this may involve linear elastic loading from E to G, with F identified with G, or construction of the half-cycle ABCFG using the Neuber rule and the *modified* Ramberg-Osgood equation;
- Finally, construct half-cycle GHJ using the Neuber rule and the unmodified Ramberg-Osgood equation – hence define point J. For the more benign hot standby conditions GHJ may be almost elastic unloading (i.e., with a reverse plastic strain below a certain small threshold value, taken here as 0.01%). If so, this fact must be flagged since it will affect the manner in which the creep damage increment is calculated in the next cycle.

A.3.1 Part-Cycle ABC

Here we follow the procedure of R5V2/3 Appendix A7, Section A.7.5.3.1. The relevant elastic Mises stress range is $\Delta\sigma_{i,el}^{SD-SU}$. The unmodified Ramberg-Osgood expression is used to represent the cyclic strain range in terms of the cyclic stress range with A defined at the start-up peak temperature. Hence the elastic-plastic strain range and stress range is found from the Neuber construction as follows,

$$\Delta\sigma_i^{ABC}\Delta\varepsilon_i^{ABC} = \frac{\left(\Delta\sigma_{i,el}^{SD-SU}\right)^2}{\bar{E}}, \text{ where, } \Delta\varepsilon_i^{ABC} = \frac{\Delta\sigma_i^{ABC}}{\bar{E}} + \left(\frac{\Delta\sigma_i^{ABC}}{A}\right)^{1/\beta} \quad \text{(C.19a)}$$

This is consistent with R5V2/3 Appendix A7, Equations (A7.13) and (A7.14) in the case that $\sigma_D = 0$ and $\sigma_N = \Delta\sigma_i^{ABC}$.

The volumetric strain range correction, $\Delta\varepsilon_{vol}$, is then found following R5V2/3 Section 7.4.2, Equations (7.13-16). This volumetric correction is added to the previous estimate of the elastic-plastic strain range,

$$\Delta\varepsilon_i^{ABC} \rightarrow \Delta\varepsilon_i^{ABC} + \Delta\varepsilon_{vol} \quad \text{(C.19b)}$$

Where relevant, the stress and strain ranges are corrected so as to apply for the undressed weldment, specifically in the weld toe region for which a weld strain enhancement factor (WSEF) applies. The procedure for undressed weldments based on linearised elastic stresses is used, see Ref.[5]. The elastic-plastic strain range for the weldment is found from,

$$\Delta\varepsilon_{i,weld}^{ABC} = WSEF \times \Delta\varepsilon_i^{ABC} \quad \text{(C.20)}$$

The corresponding elastic-plastic stress range for the weldment is then found by solving,

$$\frac{\Delta\sigma_{i,weld}^{ABC}}{\overline{E}} + \left(\frac{\Delta\sigma_{i,weld}^{ABC}}{A}\right)^{1/\beta} = \Delta\varepsilon_{i,weld}^{ABC} \quad \text{(C.21)}$$

The stress at point C on Figure 10 is thus estimated to be,

$$\sigma_i^C = \Delta\sigma_i^{ABC} - \sigma_i^{rev} \quad \text{or} \quad \sigma_i^C = \Delta\sigma_{i,weld}^{ABC} - \sigma_{i,weld}^{rev} \quad \text{(C.22)}$$

A.3.2 The Creep Dwell and Creep Damage

The elastic stress decrease from the start-up stress peak to normal operation is $\Delta\sigma_{i,el}^{SU-NO}$. Assuming elastic unloading the start-of-dwell stress is therefore,

$$\sigma_i^D = MAX\left(\sigma_i^C - \Delta\sigma_{i,el}^{SU-NO}, \sigma_{ref}^R\right) \quad \text{(C.23)}$$

where σ_{ref}^R is the rupture reference stress based on the primary loads alone. Equ.(C.23) reflects the R5 requirement that the start of dwell stress is not allowed to be less than the rupture reference stress. (This is due to the uncertainty of what happens physically during the creep dwell if the initial stress is less than the primary rupture reference stress).

The calculation of relaxation and creep damage follows §11.4, with the start of dwell stress being given by (C.23). In applying §11.4 recall that primary creep reset is employed if the last unloading produced a plastic strain in excess of the User input limit (taken here as 0.01%). Otherwise continuous hardening is employed and this may involve the accumulation of creep strain over many cycles (until the next significant reverse plastic strain). If continuous hardening is assumed in the integrations of equations (11.2) then ζ is set to unity.

When the assessed location lies in HAZ material, R5V2/3 Appendix A4, Section A4.6.2.2 calls for the dwell stress to be increased by the ratio of the HAZ to parent yield strengths at the relevant strain range, i.e., by the factor $\sigma_{\Delta\varepsilon}^{HAZ} / \sigma_{\Delta\varepsilon}^{parent}$. In the present application the HAZ will be taken to have the same cyclic stress-strain behaviour as parent so this factor is unity.

A.3.3 Construction of Point G

If $\Delta\sigma_{i,el}^{NO-trip} \le \sigma_i^C - \sigma_i^E$ then EFG is simply elastic loading and the points F and G are identified, and are at a stress of,

$$\sigma_i^F = \sigma_i^G = \sigma_i^E + \Delta\sigma_{i,el}^{NO-trip} \quad \text{(C.29a)}$$

$$\sigma_i^{peak} = \sigma_i^C \tag{C.29b}$$

Alternatively, if $\Delta\sigma_{i,el}^{NO-trip} > \sigma_i^C - \sigma_i^E$ then EFG involves additional plastic straining. Here we follow the procedure of R5V2/3 Appendix A7, Section A.7.5.6.2, noting that the creep dwell decreases the stress range (and increases the strain range). This involves the use of R5 V2/3 App.A7 Equ.(A7.13) to evaluate the whole of the half-cycle ABCFG. Since this is interrupted by creep, the modified Ramberg-Osgood curve is used.

The relevant elastic Mises stress range is that between points A and G, $\Delta\sigma_{i,el}^{trip-SD}$. The Neuber construction to find the elastic-plastic stress at point G, σ_i^G, is the solution to,

$$\left(\sigma_i^{rev} + \sigma_i^G\right)\Delta\varepsilon_i^{ABCFG} = \frac{\left(\Delta\sigma_{i,el}^{trip-SD}\right)^2}{\overline{E}}, \text{ where, } \Delta\varepsilon_i^{ABCFG} = \frac{\sigma_i^{rev} + \sigma_i^G}{\overline{E}} + \left(\frac{2\sigma_i^G}{A}\right)^{1/\beta} \tag{C.30}$$

The volumetric strain range correction, $\Delta\varepsilon_{vol}$, is then found following R5V2/3 Section 7.4.2, Equations (7.13-16) and added to the previous estimate of the elastic-plastic strain range, thus,

$$\Delta\varepsilon_i^{ABCFG} \rightarrow \Delta\varepsilon_i^{ABCFG} + \Delta\varepsilon_{vol} \tag{C.31}$$

In the case of weldment/HAZ, the strain range is adjusted as follows,

$$\Delta\varepsilon_{i,weld}^{ABCFG} = WSEF \times \Delta\varepsilon_i^{ABCFG} \tag{C.32}$$

The corresponding elastic-plastic stress for the weldment at trip peak, $\sigma_{i,weld}^G$, is then found by solving,

$$\frac{\sigma_i^{rev} + \sigma_{i,weld}^G}{\overline{E}} + \left(\frac{2\sigma_{i,weld}^G}{A}\right)^{1/\beta} = \Delta\varepsilon_{i,weld}^{ABCFG} \tag{C.33}$$

The peak stress of the cycle is,

$$\sigma_i^{peak} = \sigma_i^G \quad \text{or} \quad \sigma_i^{peak} = \sigma_{i,weld}^G \tag{C.34}$$

A.3.4 Construction of Half-Cycle GHJ

The relevant elastic stress range between the peak of the cycle (either point C or point G) and point J is $\Delta\sigma_{i,el}^{unload}$. The Neuber construction uses the unmodified Ramberg-Osgood equation since there is no creep in this half-cycle. Hence the elastic-plastic stress range over GH J is found by solving,

$$\Delta\sigma_i^{GHJ}\Delta\varepsilon_i^{GHJ} = \frac{\left(\Delta\sigma_{i,el}^{unload}\right)^2}{\overline{E}}, \text{ where, } \Delta\varepsilon_i^{GHJ} = \frac{\Delta\sigma_i^{GHJ}}{\overline{E}} + \left(\frac{\Delta\sigma_i^{GHJ}}{A}\right)^{1/\beta} \tag{C.35}$$

If $\Delta\varepsilon_i^{GHJ} \leq 0.01\%$ then the degree of reverse plasticity is deemed insufficient to reset primary creep on the following cycle and *flag* is set to *CH* for the next dwell. (Note that the 0.01% reverse plastic strain threshold can be changed by the User in BIFINIT-RB).

If $\Delta\varepsilon_i^{GHJ} > 0.01\%$ then the degree of reverse plasticity is deemed sufficient to reset primary creep on the following cycle and *flag* is set to *PR* for the next dwell. (Note that the 0.01% reverse plastic strain threshold can be changed by the User in BIFINIT-RB).

The volumetric strain range correction, $\Delta\varepsilon_{vol}$, is then found following R5V2/3 Section 7.4.2, Equations (7.13-16) and the elastic-plastic strain range increased by this amount,

$$\Delta\varepsilon_i^{GHJ} \rightarrow \Delta\varepsilon_i^{GHJ} + \Delta\varepsilon_{vol} \tag{C.36}$$

For weldment/HAZ, the parent strain range is adjusted as follows,

$$\Delta\varepsilon_{i,weld}^{GHJ} = WSEF \times \Delta\varepsilon_i^{GHJ} \tag{C.37}$$

The corresponding elastic-plastic stress range for the weldment/HAZ is found by solving,

$$\frac{\Delta\sigma_{i,weld}^{GHJ}}{\overline{E}} + \left(\frac{\Delta\sigma_{i,weld}^{GHJ}}{A}\right)^{1/\beta} = \Delta\varepsilon_{i,weld}^{GHJ} \tag{C.38}$$

The Mises stress at point J is therefore given by,

$$\sigma_i^J = \Delta\sigma_i^{GHJ} - \sigma_i^{peak} \quad \text{or} \quad \sigma_{i,weld}^J = \Delta\sigma_{i,weld}^{GHJ} - \sigma_{i,weld}^{peak} \tag{C.39}$$

noting that this positive quantity represents a compressive state of stress. However (C.39) plays no part in the assessment since the reverse stress datum for the next cycle is based on §C.2 rather than (C.39) in order to incorporate the effects of all the previous cycling.

A.3.5 Fatigue Strain range

The strain range to be used for the assessment of fatigue damage is,

$$\Delta\varepsilon_i^{fatigue} = MAX\left(\Delta\varepsilon_i^{ABCFG} + \Delta\varepsilon_{i,c}, \Delta\varepsilon_i^{GHJ}\right) \tag{C.40}$$

or the equivalent for weldment/HAZ,

$$\Delta\varepsilon_{i,weld}^{fatigue} = MAX\left(\Delta\varepsilon_{i,weld}^{ABCFG} + \Delta\varepsilon_{i,c}, \Delta\varepsilon_{i,weld}^{GHJ}\right) \tag{C.41}$$