Design Methods for Metallic Components

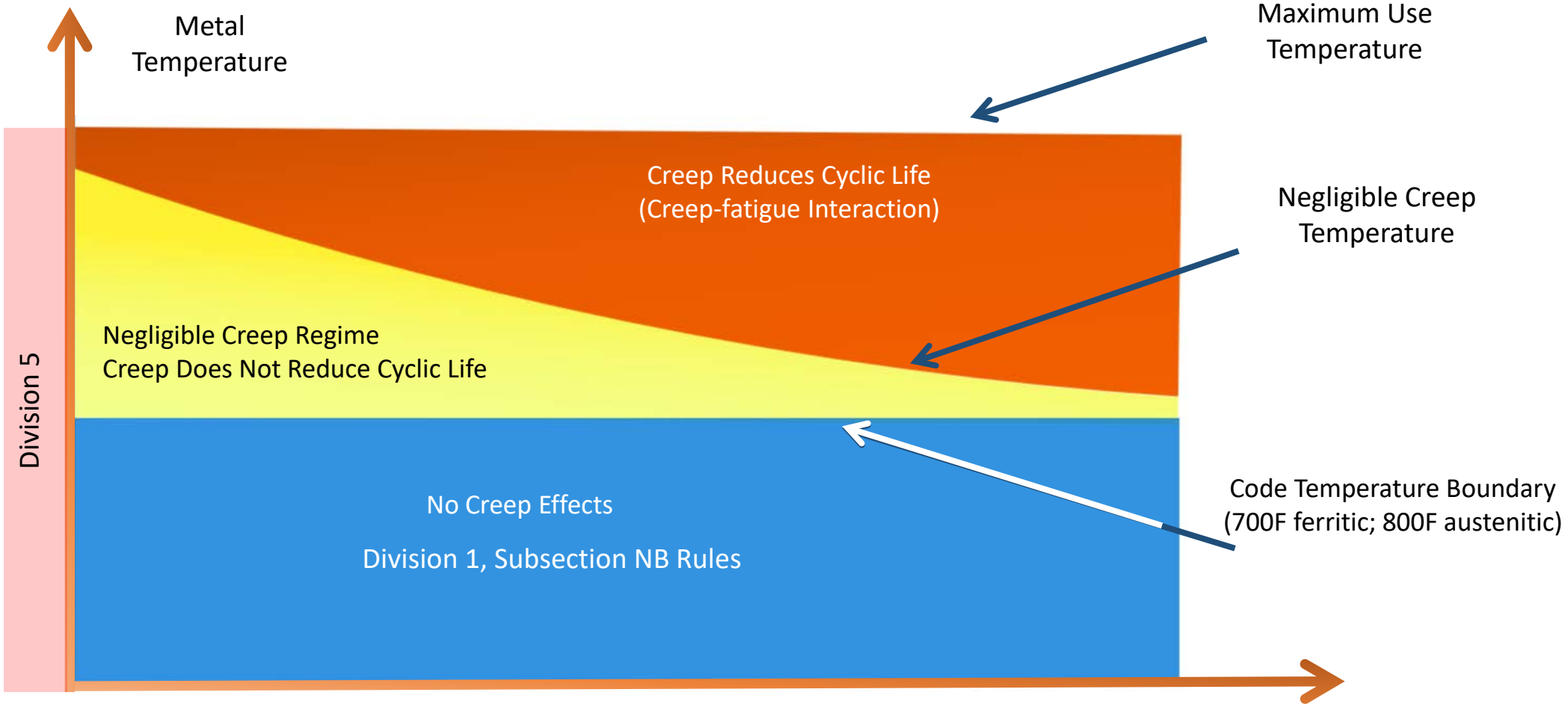
ASME BPV III Division 5 Workshop
On High Temperature Reactors
November 8 & 9, 2020 • Virtual Meetings

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Section III, Division 5 Overview

Class	Subsection	Subpart	Subsection ID	Title	Scope
General Requirements					
Class A, B, & SM	HA	A	HAA	Metallic Materials	Metallic
Class SN		B	HAB	Graphite and Composite Materials	Nonmetallic
Class A Metallic Pressure Boundary Components					
Class A	HB	A	HBA	Low Temperature Service	Metallic
Class A		B	HBB	Elevated Temperature Service	Metallic
Class B Metallic Pressure Boundary Components					
Class B	HC	A	HCA	Low Temperature Service	Metallic
Class B		B	HCB	Elevated Temperature Service	Metallic
Class A and Class B Metallic Supports					
Class A & B	HF	A	HFA	Low Temperature Service	Metallic
Class SM Metallic Core Support Structures					
Class SM	HG	A	HGA	Low Temperature Service	Metallic
Class SM		B	HGB	Elevated Temperature Service	Metallic
Class SN Nonmetallic Core Components					
Class SN	HH	A	HHA	Graphite Materials	Graphite
Class SN		B	HHB	Composite Materials	Composite

Temperature Boundaries



Design rules and negligible creep criteria vary based on component classification

Border Between High and Low Temperature rules

Table HAA-1130-1
Values of T_{max} for Various Classes of Permitted Materials

Materials	T_{max}, °F (°C)
Carbon steel	700 (370)
Low alloy steel	700 (370)
Martensitic stainless steel	700 (370)
Austenitic stainless steel	800 (425)
Nickel–chromium–iron	800 (425)
Nickel–copper	800 (425)

Class A Components

Class SM rules are very similar

HBB overview

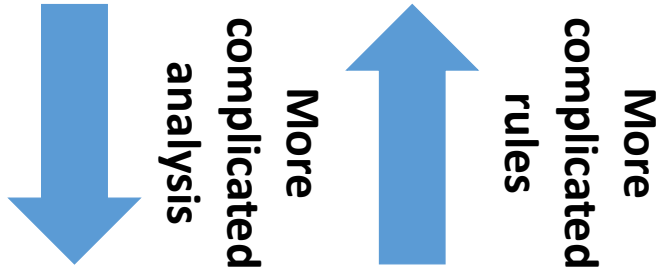
- ***What HBB tries to prevent***
  - Plastic collapse
  - Creep rupture
  - Creep-fatigue
  - Gross distortion (strain limits, ratcheting)
  - Time independent buckling
  - Time dependent buckling

Primary load design

Deformation-controlled quantities, Nonmandatory Appendix HBB-T

Some guidance
Procedure for a limited set of design situations

- ***Analysis method options:***
  - Elastic
  - Elastic perfectly plastic (EPP, Code Cases)
  - Full inelastic

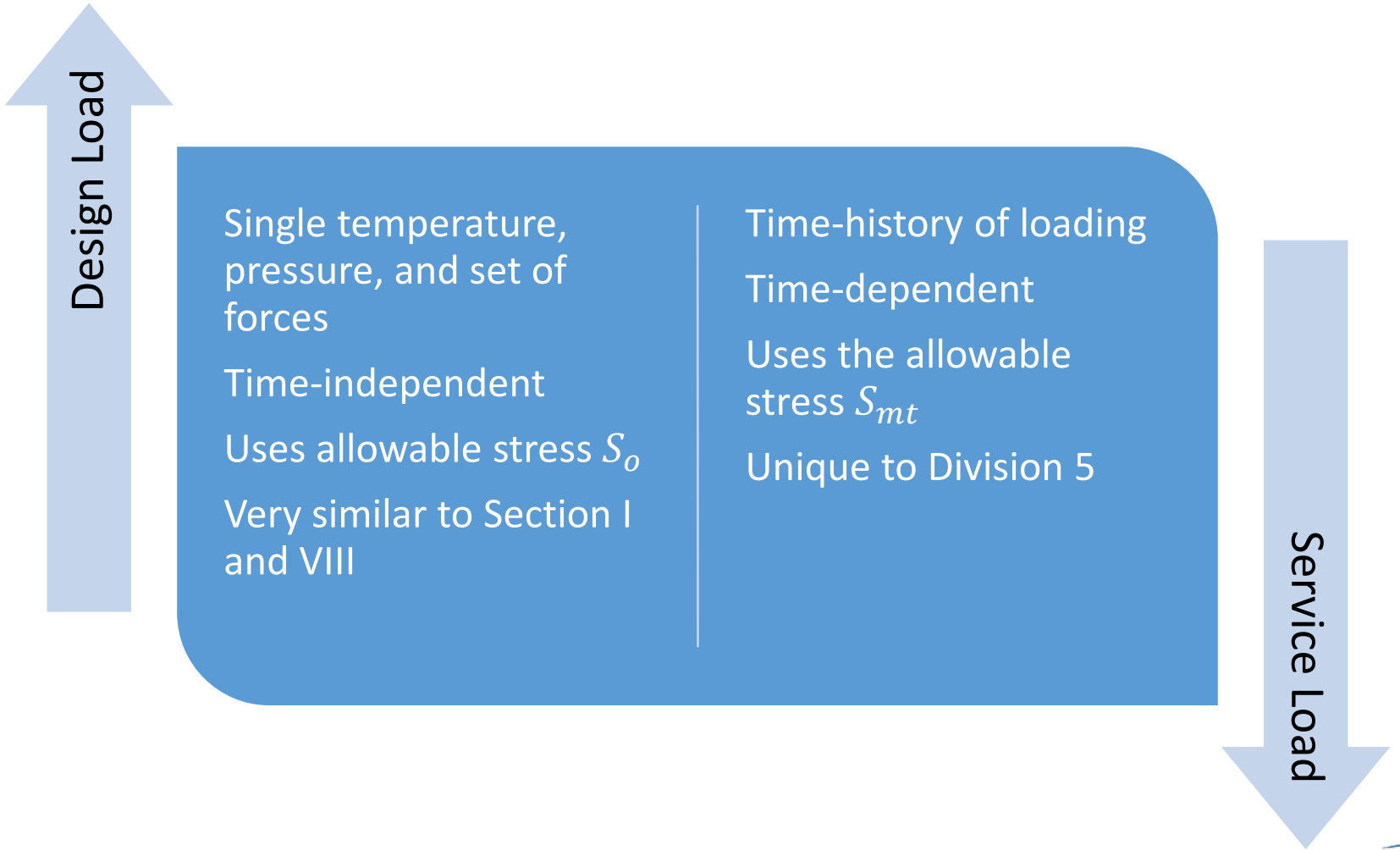


Order of conservatism?

Primary load design

- Allowable stress intensities based on combination of yield, ultimate, rupture stress, and creep criteria
- Based on elastic analysis *(EPP in progress)*
- ***Need to do stress classification and linearization***
  - *How I think about high temperature stress classification*: secondary stresses relax away during creep, primary stresses don't
  - *How I think about linearization*: back when this was written they only had axisymmetric frame-type elements
- Two checks:
  - S_{mt} with service loads and a life-fraction summation over the different load cases
  - S_o with a design condition (basically to ensure that nothing passes Division 5 that would fail Section VIII, Division 1)
- Accounts for thermal aging effects with factors
- **Welds**: same sort of check but with a stress rupture factor reducing allowables
- Simplified rules that avoid stress classification/linearization are in progress (R13-252)

Design versus service Loads



“Deformation controlled quantities”

- **A subset of the design limits:**
  - Strain accumulation
  - Creep-fatigue
  - Buckling
- Presumably called “deformation controlled” because they typically are driven by secondary (self limiting) stresses
- The Code requires the designer evaluate the component against these limits. The designer has several options:
  - HBB-3251 permits the designers to use a nonmandatory appendix (HBB-T), which provides two methods for evaluating these design limits (design by elastic and design by inelastic analysis)
  - Code Cases N-861 and N-862 provide an alternative method for a subset of the HBB Class A materials
  - The Design Specification may provide alternative methods for evaluating these design limits, with the approval of the Owner and documentation in the Design Report

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Options for evaluating deformation limits

Elastic analysis

- All Class A materials
- Rules found in Nonmandatory Appendix HBB-T
- Bounding analysis

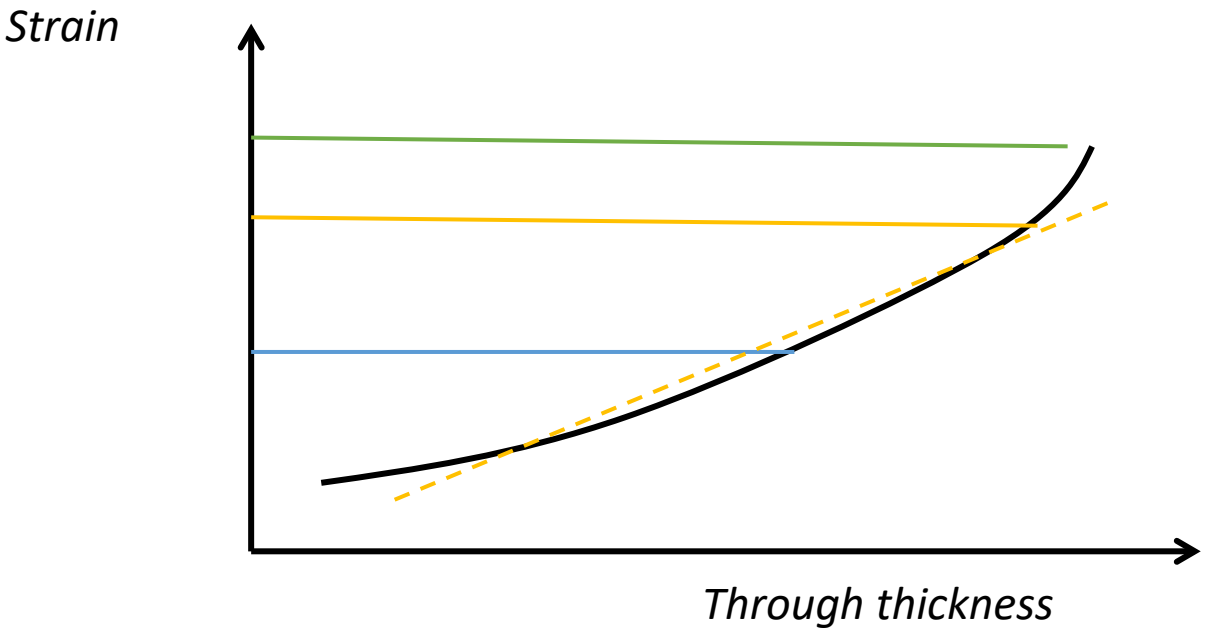
Inelastic analysis

- All Class A materials
- Rules found in NMA HBB-T
- But no material models in Code (currently)
- “Exact” analysis

Elastic perfectly-plastic analysis (EPP)

- Subset of materials (304 and 316 SS, A617, soon to be Grade 91)
- Rules in N-861 and N-862
- Bounding analysis

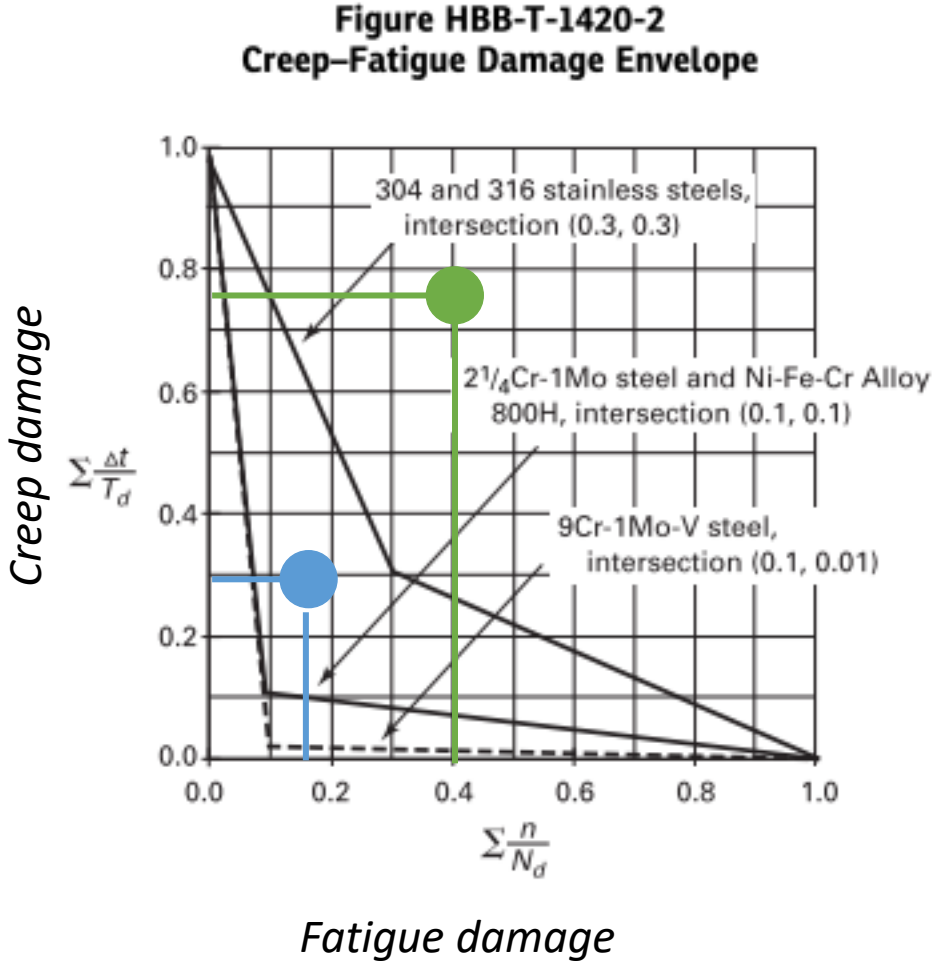
Strain limits



- ***General limits (done by sections):***
  - 1% average strain
  - 2% linearized bending
  - 5% maximum strain
- **Elastic analysis**
  - Basically O'Donnell & Porowski
  - Based on a Bree-type analysis but the Code extends it to general structures
- **EPP**
  - Bounding theorem based on isochronous stress-strain curve values
- **Inelastic analysis**
  - Run the simulation, check strain limits!
- **Welds**: lower strain limits (factor of 2)

Creep-fatigue

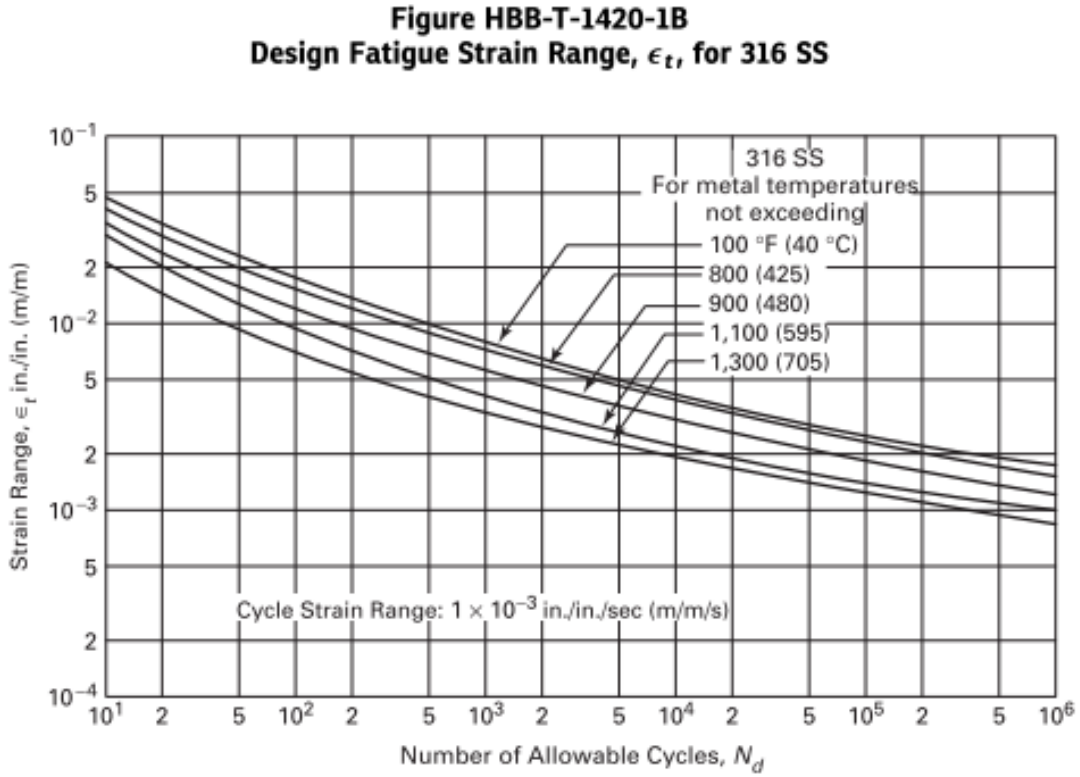
- **Basically:**
  1. Compute creep damage based on life fraction: D_c
  2. Compute fatigue damage based on a cyclic life fraction: D_f
  3. Consult interaction diagram for pass/fail
- **Welds:** same interaction diagram, factors on damage



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Fatigue Damage

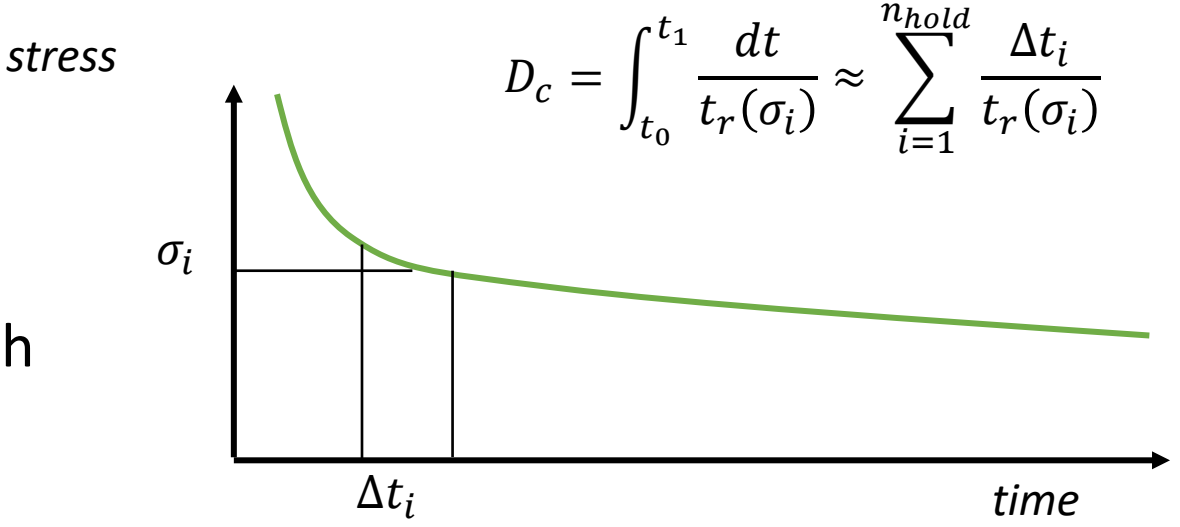
- Division 5 fatigue curves are strain-based, so you need a strain range to figure out allowable life
- **Analysis methods:**
  - *Elastic*: calculate elastic strain range, "hack up" to account for creep and plasticity
  - *EPP*: direct from model
  - *Inelastic*: direct from model
- Summing damage: $D_f = \sum_{i=1}^{n_{types}} \frac{N_i}{N_{d,i}}$
- **Welds**: factor of 2 on design cycles



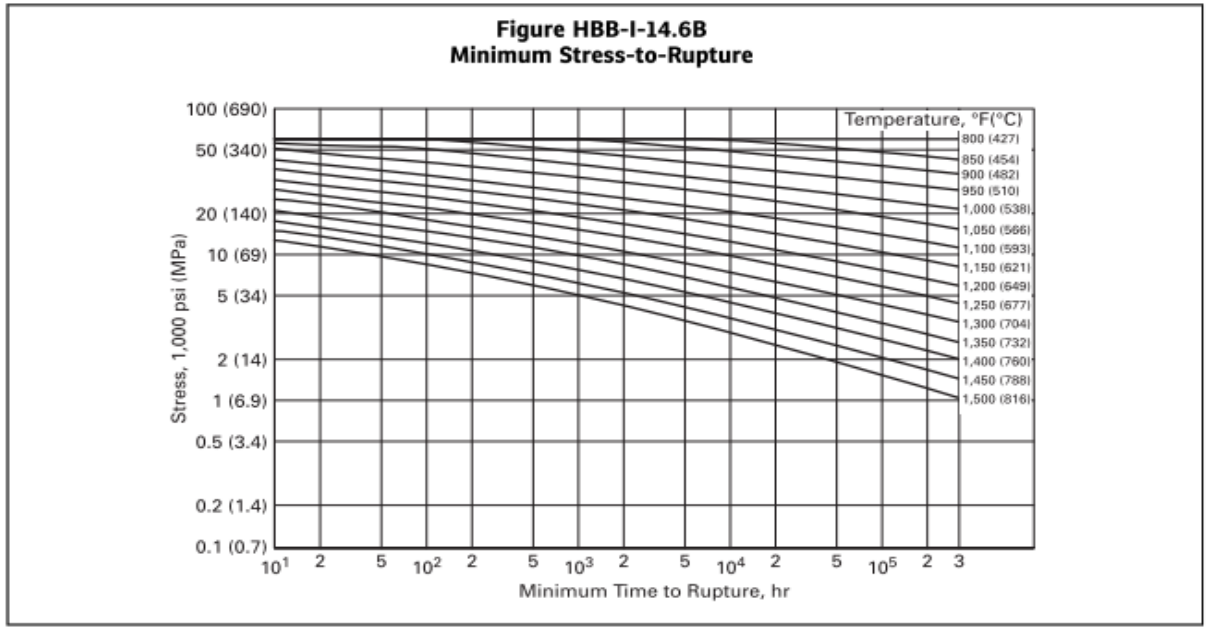
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Creep damage

- You need to construct a stress relaxation curve for each hold in each cycle type
- **Analysis methods:**
  - *Elastic*: several complicated methods
  - *Inelastic*: direct from analysis results
- *EPP* does something completely different (bounds life directly)
- Sum damage with a time fraction rule $D_c = \sum_{i=1}^{n_{hold}} \frac{t_i}{t_{r,i}}$
- Welds: stress rupture factors



$$D_c = \int_{t_0}^{t_1} \frac{dt}{t_r(\sigma_i)} \approx \sum_{i=1}^{n_{hold}} \frac{\Delta t_i}{t_r(\sigma_i)}$$

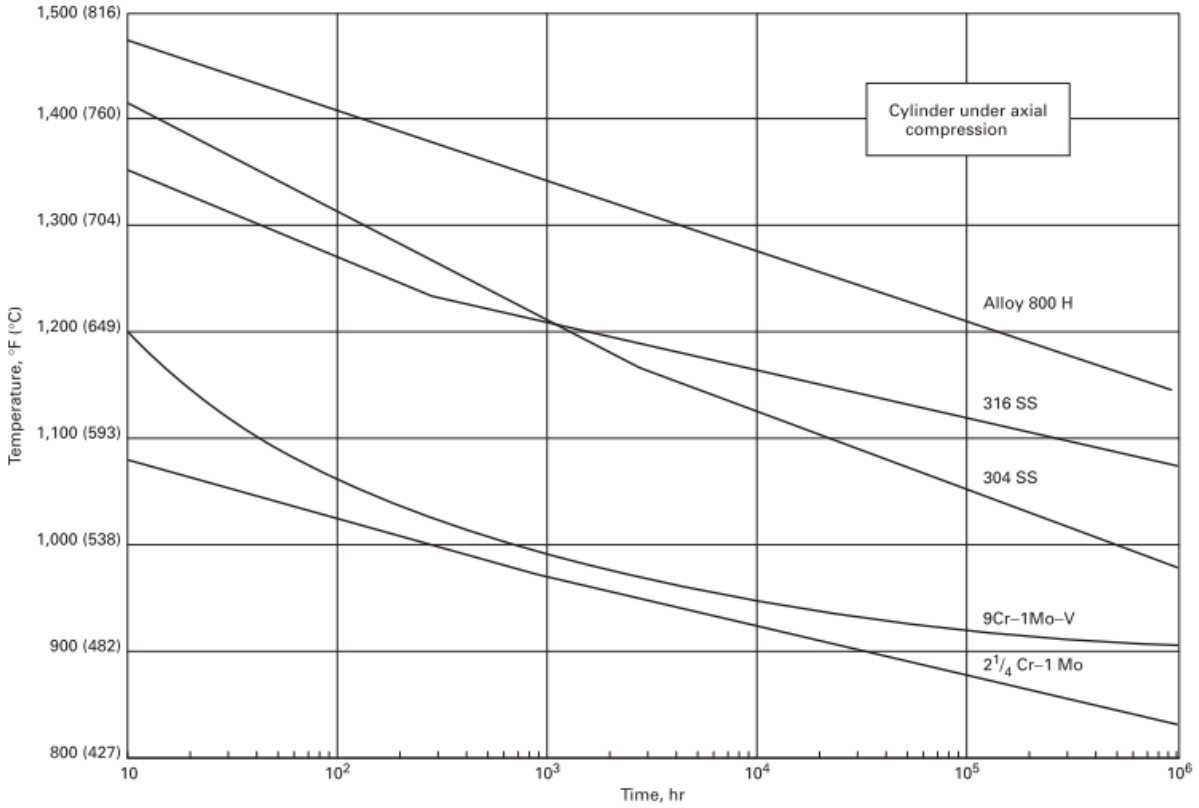


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Buckling

- **If** (factored) time independent buckling will occur before (factored) creep buckling you can use the Section II buckling diagrams and skip the time dependent check
  - Code provides charts showing this region for several simple geometries
- **If not**: load factors provided but no guidance on how to do the buckling check

Figure HBB-T-1522-1
Time–Temperature Limits for Application of Section II External Pressure Charts



Class B Components

Several options, depending on temperature

Wider range of materials, less rigorous design criteria

- **Low temperatures:** Division 1, Subsection NC with minor alterations
- **High temperatures:**
  - *Option 1:* Division 1, Subsection NC with substantial modifications:
    - Division 5 provides a route to appropriate allowable stresses including or excluding (as appropriate) creep, thermal aging, and weld strength reduction factors
    - Modification to use allowable stresses to evaluate Service Loadings
    - Additional checks for creep buckling
    - Various changes to detailed construction rules
    - Piping rules that include thermal gradients analogous to B31
  - *Option 2:* Use the Class A rules in their entirety (per HCB-1120). Component is still stamped as Class B.