Items for Discussion Related to the Div 2 Rewrite Master SN Method

BPVC Code Week

Atlanta, GA

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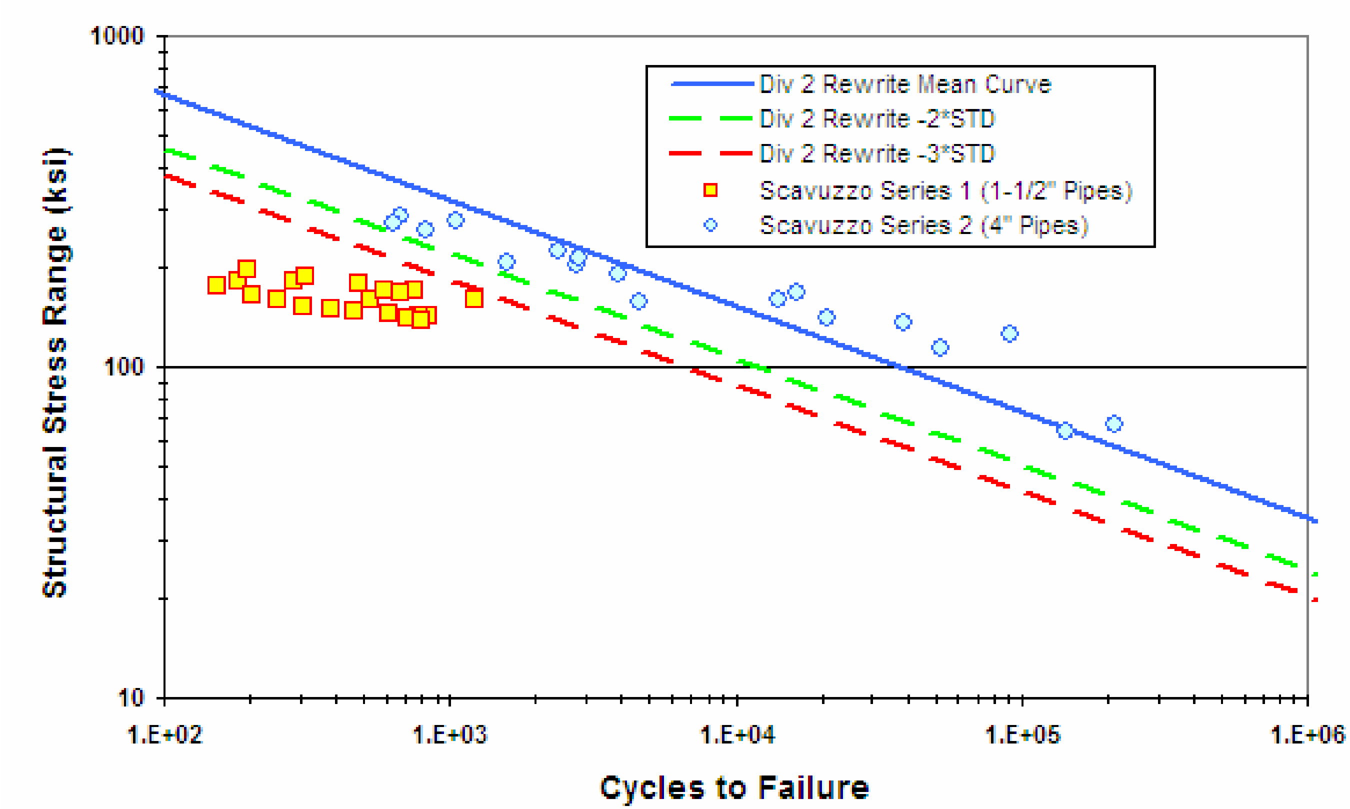
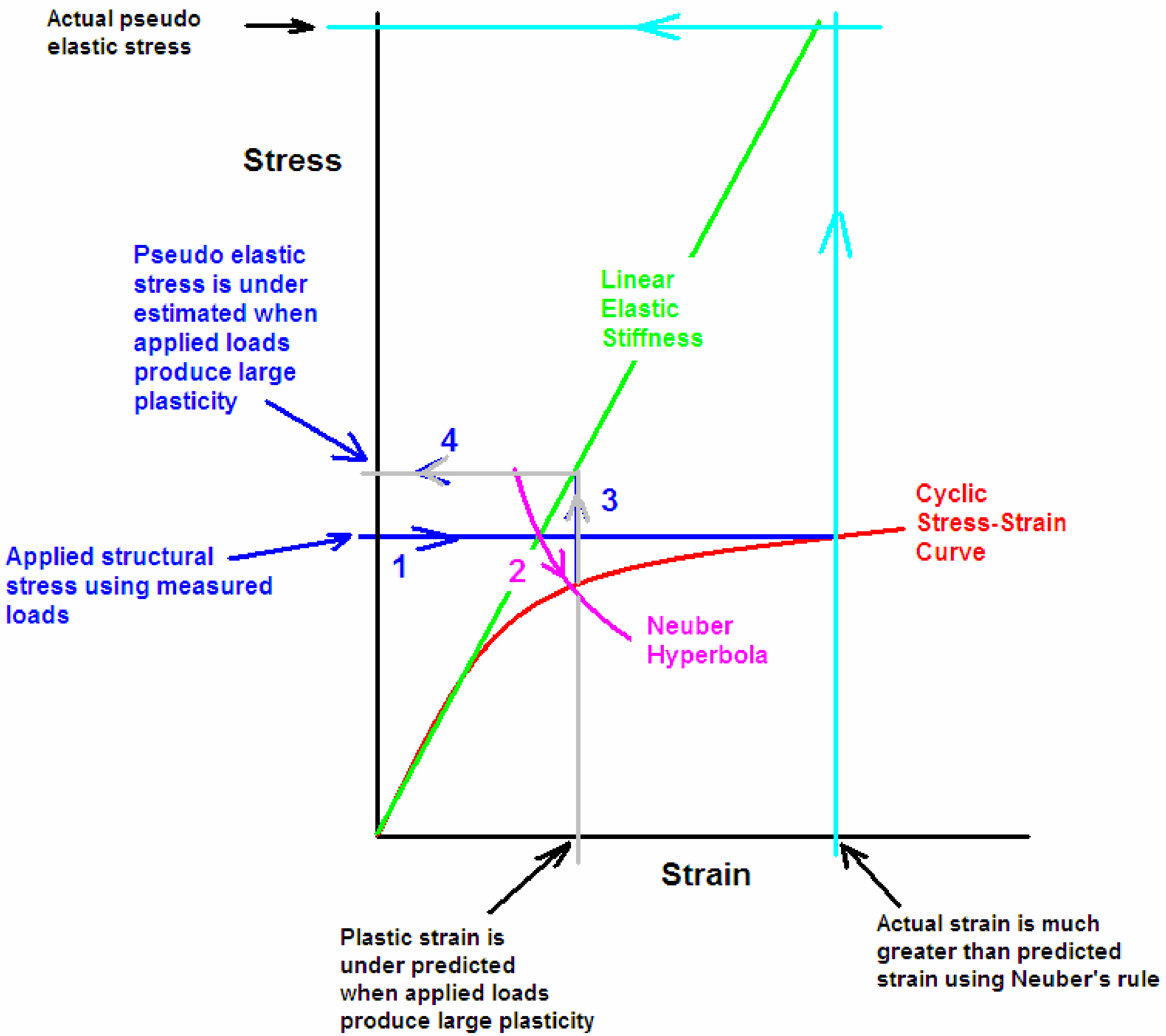
Item #1 – Non-Conservatism of Neuber's Rule

- **Neuber's rule is only valid when mild plasticity occurs.**
- **Validation can be performed by using measured load from low cycle fatigue tests.**
- **Large strains will cause Neuber's rule to under predict the actual pseudo elastic loads/stresses and can result in non-conservative designs when the measured (applied) loads are specified in the analysis.**



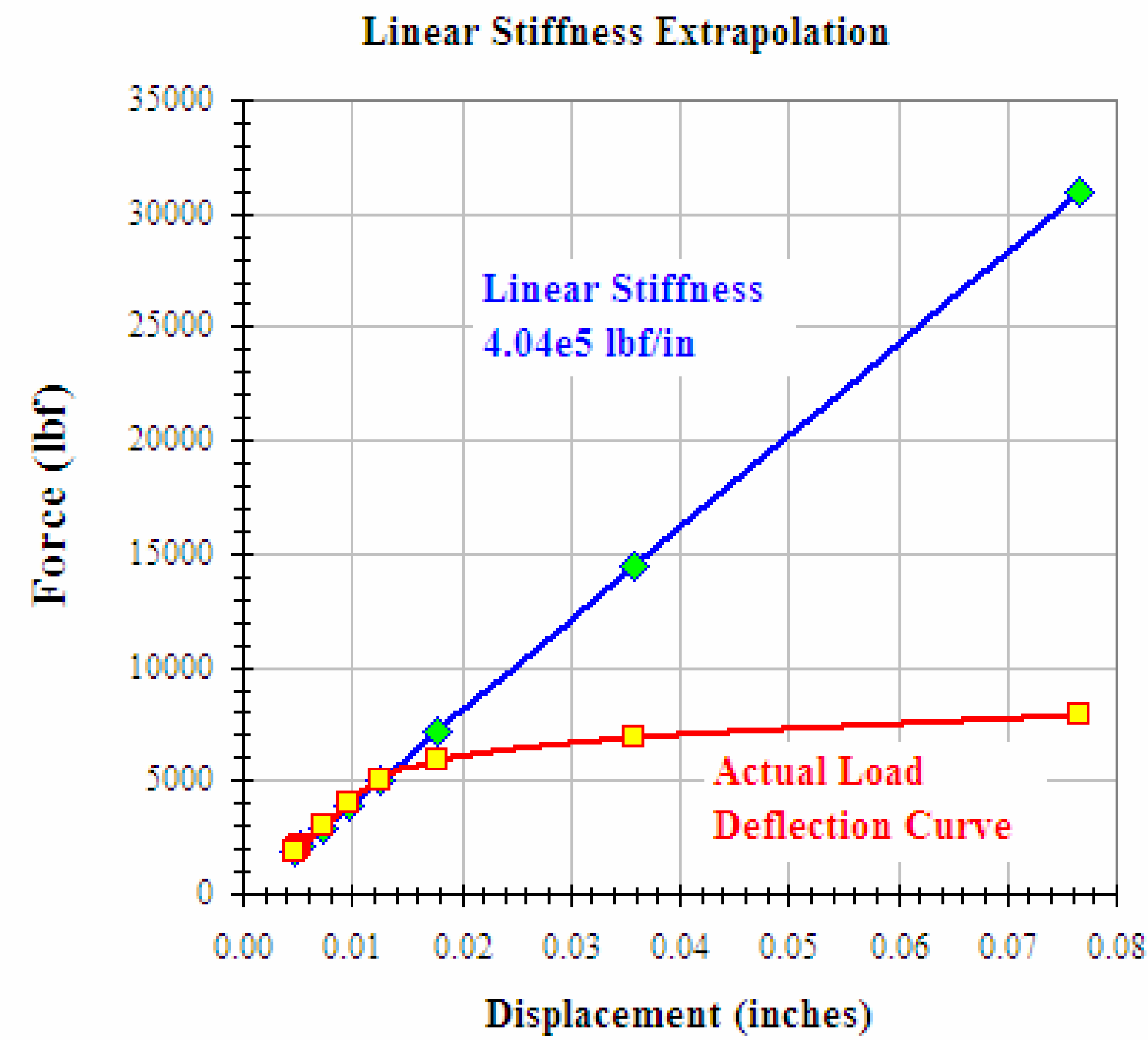
Item #2 – Non-Conservatism of Neuber's Rule

- Once the onset of plasticity begins, the pseudo elastic load increases rapidly with little increase in the measured load.



Item #2 – Non-Conservatism of Neuber's Rule

- **An example of a load-deflection diagram with large degree of plasticity**



Item #3 – Comparison of Code Methods

- **Fatigue design life charts for sets of applied loads have been prepared to compare fatigue methods.**
- **The curves shown charts are directly comparable since they represent the fatigue lives for an applied load.**

- **Calculations have used the stress definition required by each Code for the applied loads (peak stress, hot spot stress, extrapolated stress, etc)**
- **Plasticity correction factors have been used for all Codes were applicable**
- **An environmental factor of 4.0 is included in all as-welded Codes since it is inherently included in the ASME smooth bar design curves.**

- **These SN charts DO NOT imply one method predicts the actual failure life with any better accuracy than any other method. These are simply design life comparisons.**

Item #3 – Comparison of Code Methods

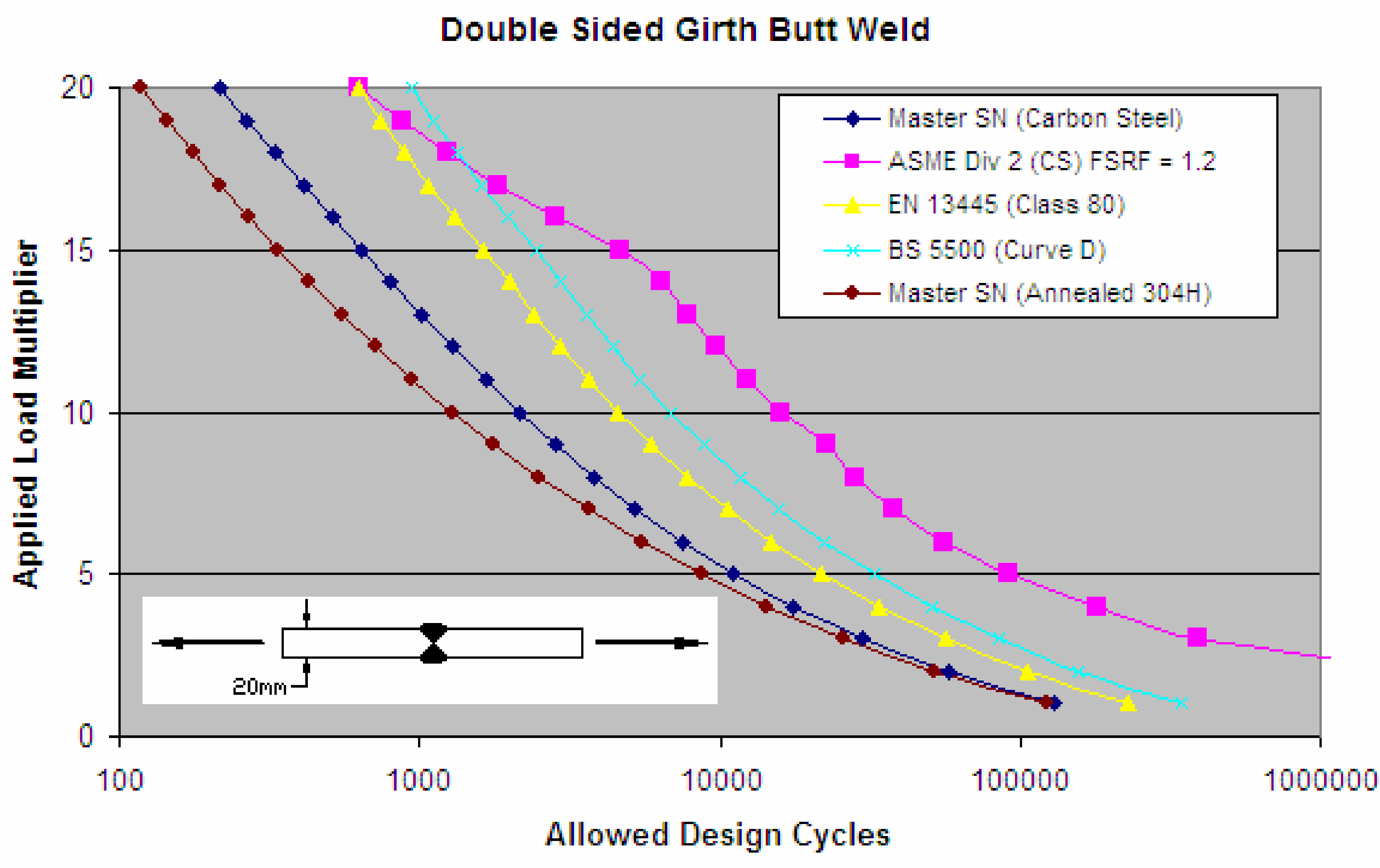
Some observations:

- **In comparison with existing ASME FSRF method the proposed Master SN method will result in:**
  - ***Decreased life for "good joints"***
  - ***Increased life for "bad joints"***

- **ASME FSRF method predicts 100,000 cycles for a girth butt weld, but the Master SN would only allow approximately 11,000 cycles for the same.**
- **ASME FSRF method predicts 10,000 cycles for fillet root failure, but the Master SN would allow almost 80,000 cycles for the same joint.**
- **Could be that the FSRF's from WRC 432 aren't sufficiently accurate.**

- **Master SN is not as sensitive as other Codes to joints where quality and constructability is poor. Considers applied stress and general geometric features.**

Item #3 – Comparison of Code Methods



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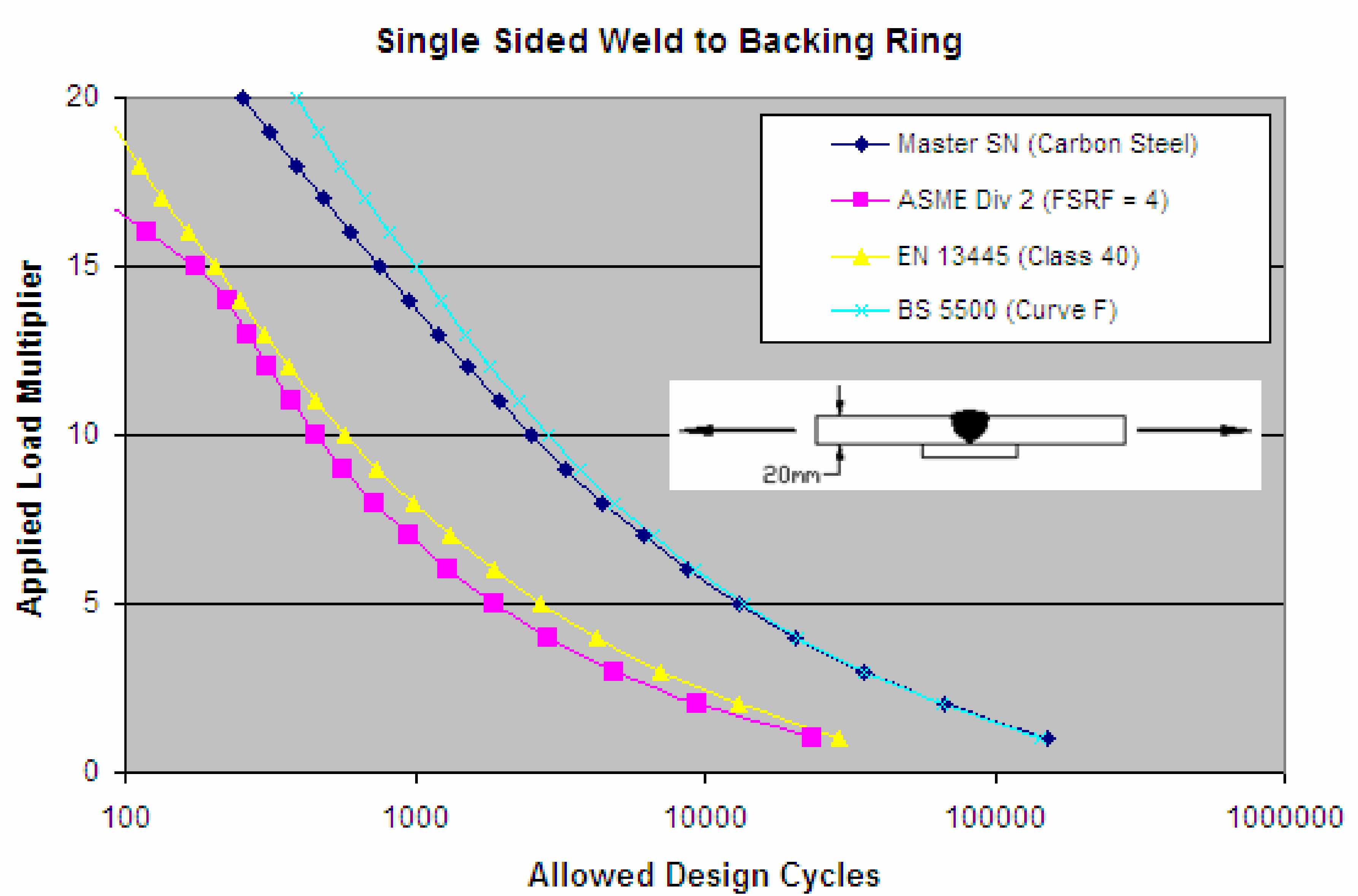

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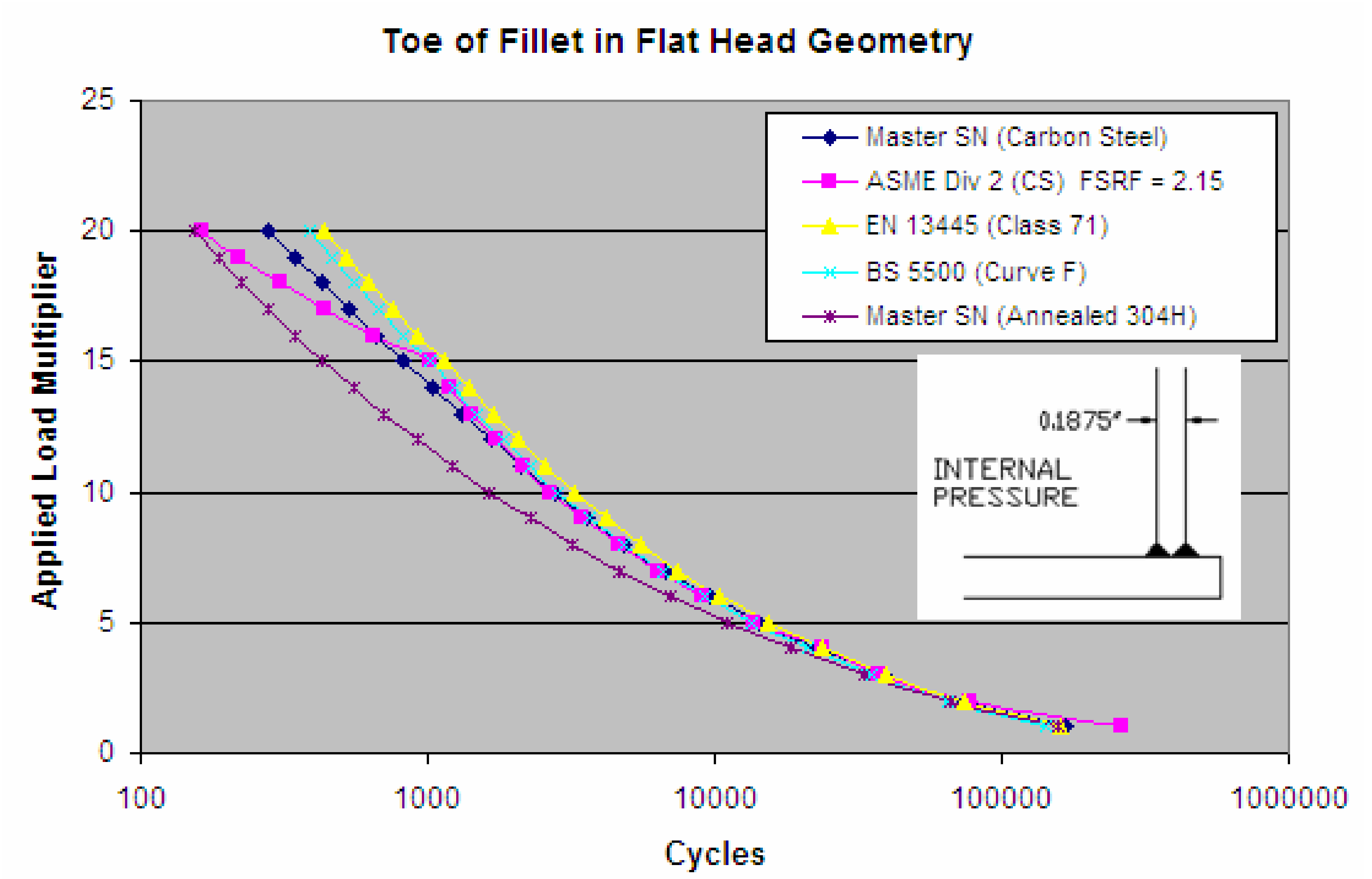

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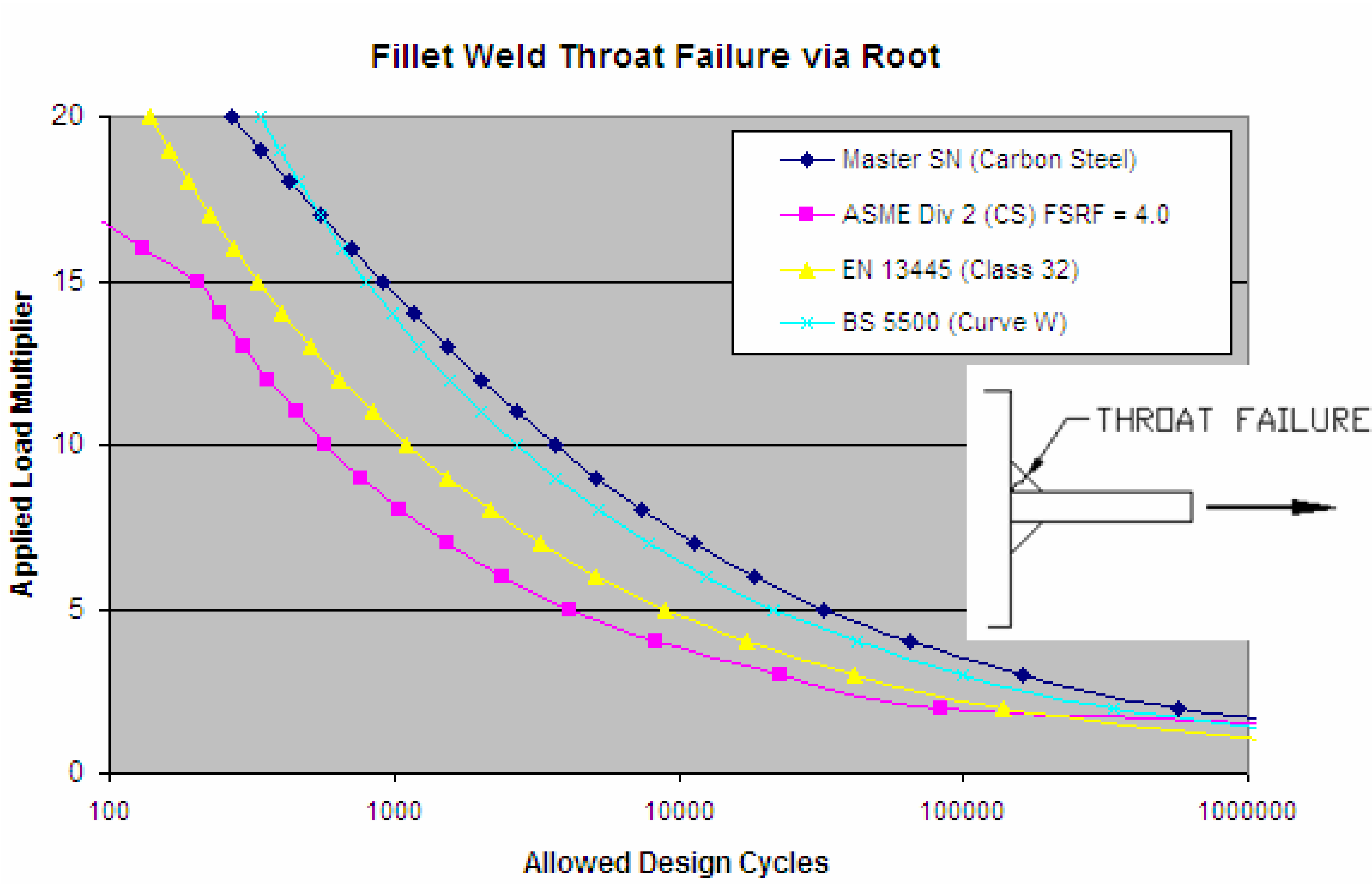
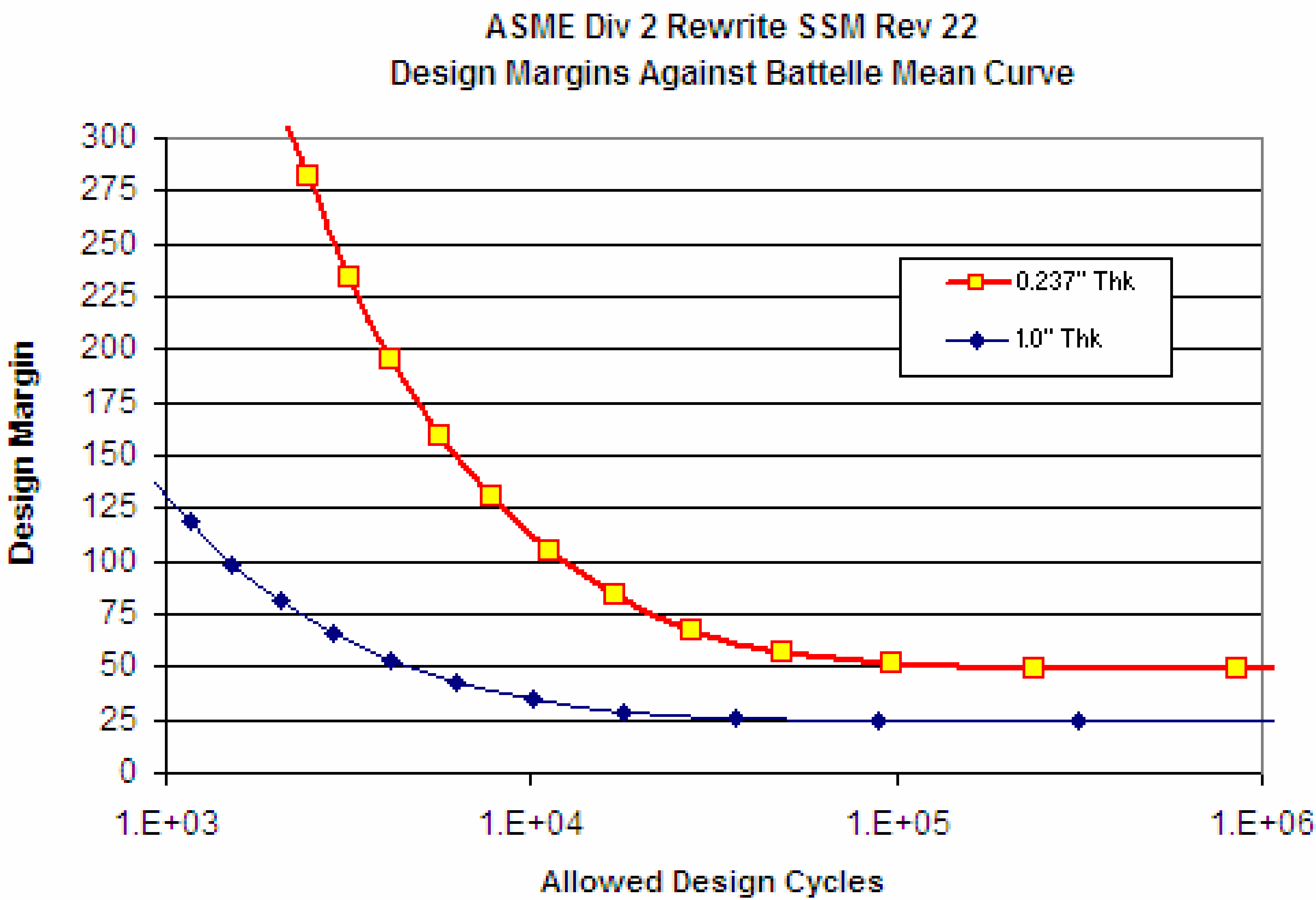


Item #4 – Margins against Battelle Database

- Margins can be large for typical PVP geometries used as validation.
- Margin in thicker plate is approximately fives times greater than the lower third standard deviation in the Battelle database.
- The Battelle lower third standard deviation provides a margin of 4 to 5 for 99% of test data contained in the database.
- Largest margins are due to a different definition of the equivalent structural stress.
- Are such large margins required to provide conservatism for PVP geometries?

- European codes implement their statistical based methods directly without alteration or manipulation of their databases or the stresses to be used with those fatigue curves.

Item #4 – Margins against Battelle Database



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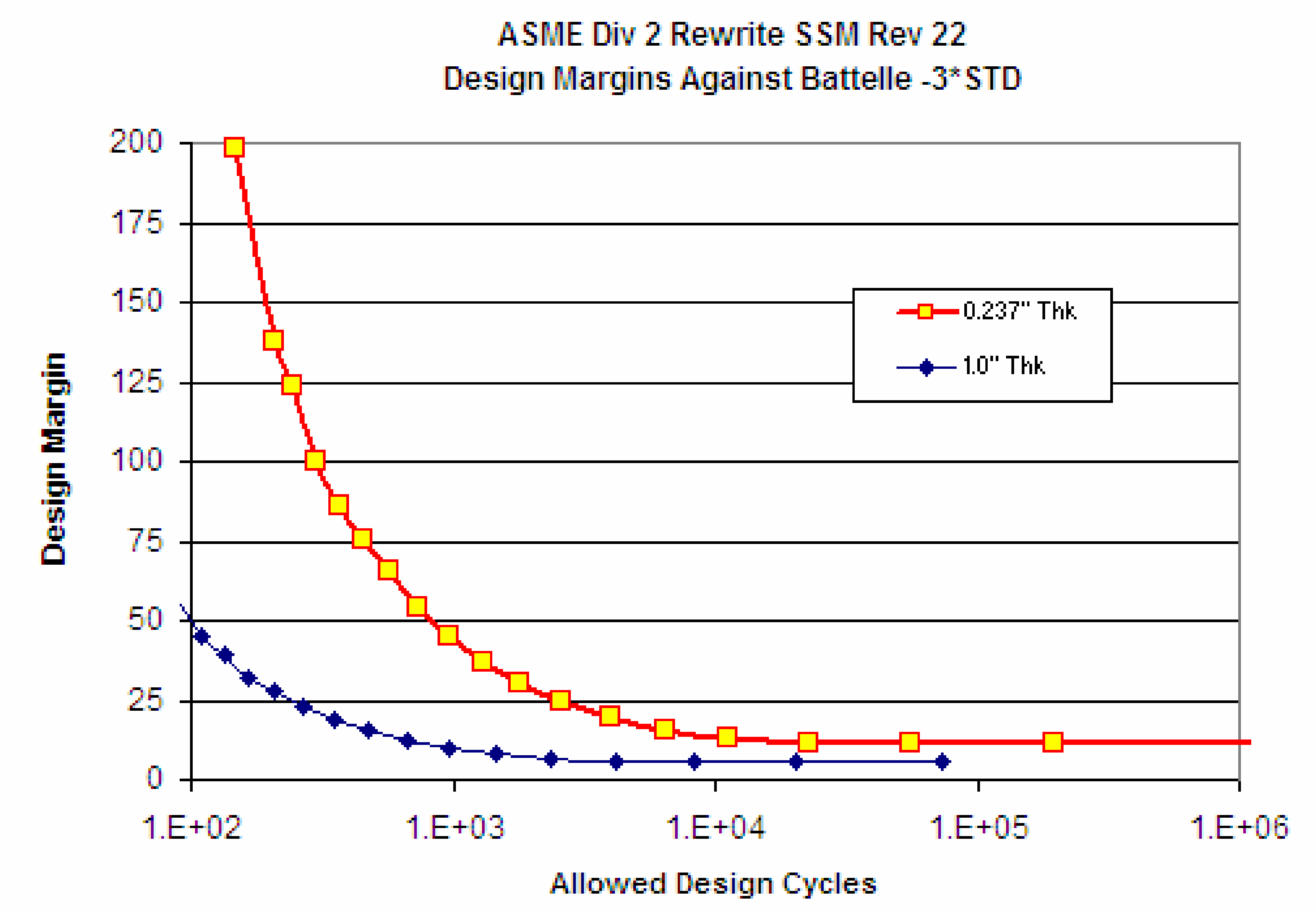
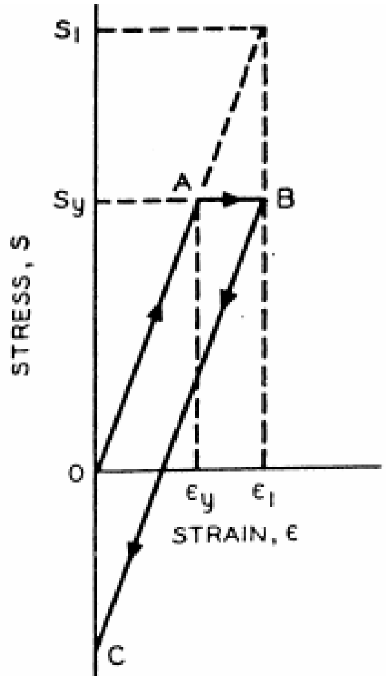


Item #5 – Neuber Adjustment within 2*Sy

- Div 2 Rewrite's implementation of Neuber's rule adjusts for plasticity in the structural stress, not local notch stress.
- Historically, it is assumed that stresses will shake down to elastic action if the range of stresses are within the limits of 2*Sy.
- Shakedown prevents structural stress plasticity if within 2*Sy and eliminates need for Neuber's adjustment.
- Notch stress certainly could see plasticity, but Battelle is using structural stress not the notch stress.



Item #6 – Neuber Adjustment Double Dipping

- **If Neuber's adjustment is applied to linear elastic solutions, then the solution will be inaccurate and grossly under predict the fatigue life. (predicted fatigue life is much lower than actual fatigue life)**

- **Linear elastic analysis of specified thermal strains or displacements are equivalent to the displacement controlled tests used for the as-welded fatigue curves.**

- **This concept has been used in the piping codes since their inception.**
- **B31 piping codes focus on thermal displacement range analysis and do not use any plasticity adjustments.**

Item #6 – Neuber Adjustment Double Dipping

- **Rodabaugh stated in NUREG 3243 that no adjustment is necessary:**

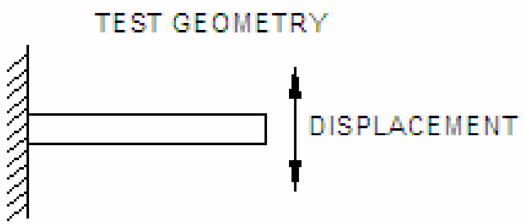
The test method is consistent with an elastic analysis of a piping system, even though calculated stresses may be above the material yield strength and some plastic deformation may occur. Accordingly, an adjustment analogous to the K_e used in Code 1 is not needed.

- **Pingsha Dong's presentation in Columbus, OH also supports the concept that Neuber's is not required when analyzing displacement controlled conditions:**

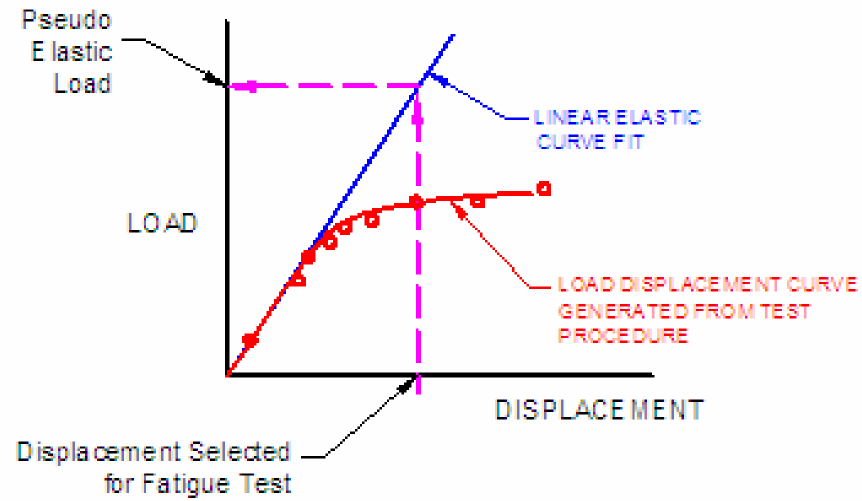
- The Neuber-based procedure for estimating pseudo elastic structural stress in low-cycle regime is only needed when performing linear FEA when pseudo elastic load or stress is not known

Item #6 - Testing with Controlled Displacement

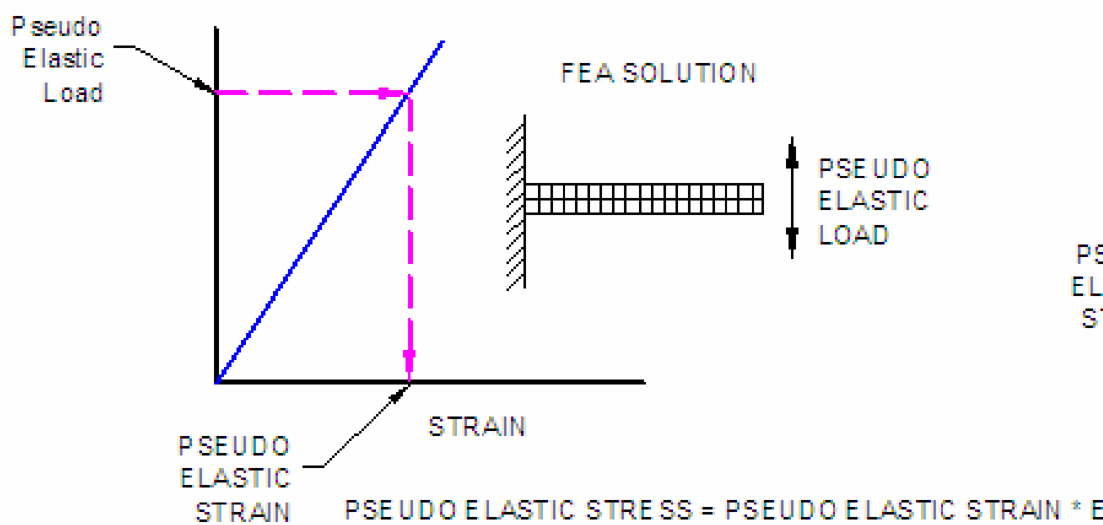
1\. CONDUCT LOAD-DEFLECTION TEST AND FATIGUE TEST OF GEOMETRY



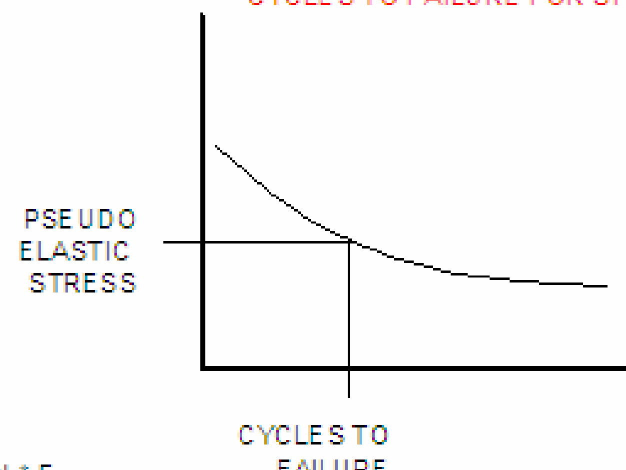
2\. DETERMINE PSEUDO ELASTIC LOAD TO BE USED IN CALCULATION OF PSEUDO ELASTIC STRESSES.



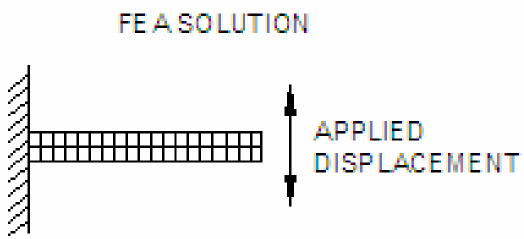
3\. CONSTRUCT FE MODEL OF GEOMETRY, APPLY PSEUDO ELASTIC LOAD, AND CALCULATE PSEUDO ELASTIC STRESS



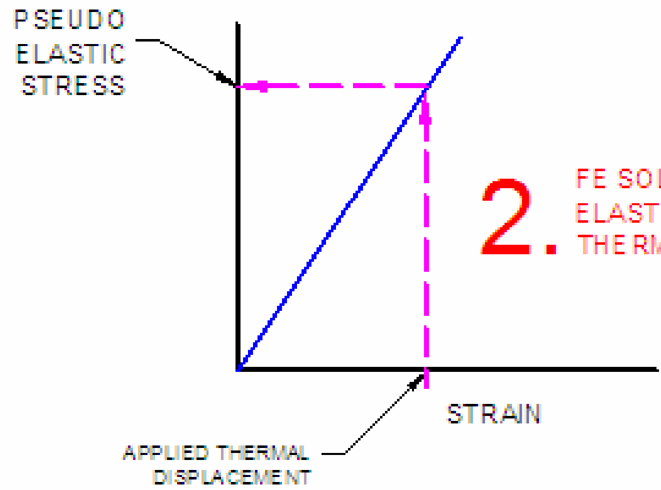
4\. PLOT DATA POINT INTO FATIGUE CHART USING PSEUDO ELASTIC STRESS AND CYCLES TO FAILURE FOR SPECIMEN



Item #6 - Designing with Displacement Conditions



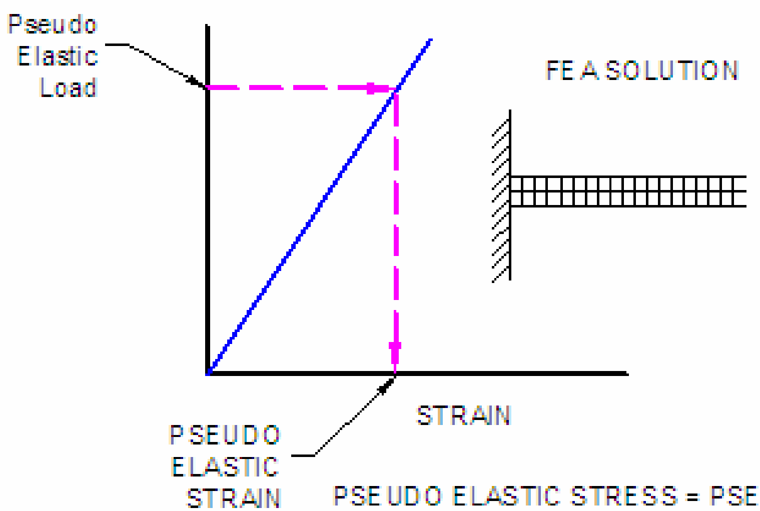
1. BEGIN FE ANALYSIS WITH A KNOWN THERMAL DISTRIBUTION



2. FE SOLVES FOR THE PSEUDO ELASTIC LOAD BASED ON SPECIFIED THERMAL DISPLACEMENT

3. CONSTRUCT FE MODEL OF GEOMETRY, APPLY PSEUDO ELASTIC LOAD, AND CALCULATE PSEUDO ELASTIC STRESS

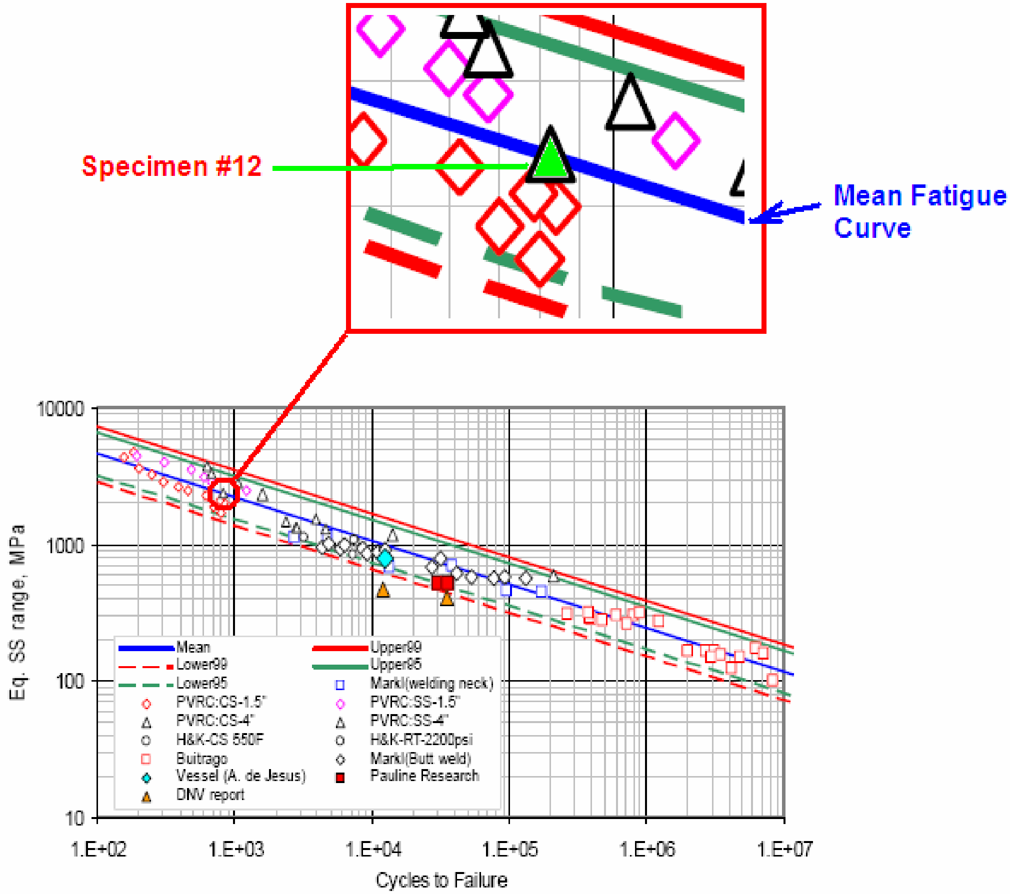
THE FE SOLUTION YIELDS SAME RESULT AS THE LINEAR EXTRAPOLATION PROCEDURE USED FOR TEST RESULTS.



PSEUDO ELASTIC STRESS = PSEUDO ELASTIC STRAIN * E

Item #6 - Designing with Displacement Conditions

- We should be able to specify displacements in an FE model and reproduce points which exist along the mean curve.
- Using Neuber's rule, the life is predicted at 5 cycles, the actual life is 222 cycles to failure.



Item #7 – Neuber's Implementation Affects Elastic Designs

- **Part 5.5.5 states that Neuber's is always applied and will not affect designs where stresses are wholly elastic.**
- **The implementation will produce errors on stress up to 10% or on life up to 35%.**

$$\Delta\sigma_k = \frac{E_{ya,k}\,\Delta\varepsilon_k^e}{\left(1-\nu^2\right)^2} \neq \frac{\Delta\varepsilon_k^e\,E_{ya,k}}{\left(1-\nu^2\right)}$$

The predicted stress will always be (1 / 0.91) = 109.8% greater than the elastic stress.

$$\Delta\sigma_k = \frac{\left(1-\nu^2\right)^{\frac{1}{2}}\,\Delta\sigma_k^e}{1-\nu^2} \neq \Delta\sigma_k^e$$

The predicted stress will always be 105% of the expected elastic stress.

$$\frac{\Delta\sigma_k}{\Delta\sigma_k^e} = \frac{\left(1-\nu^2\right)^{\frac{1}{2}}}{1-\nu^2}$$

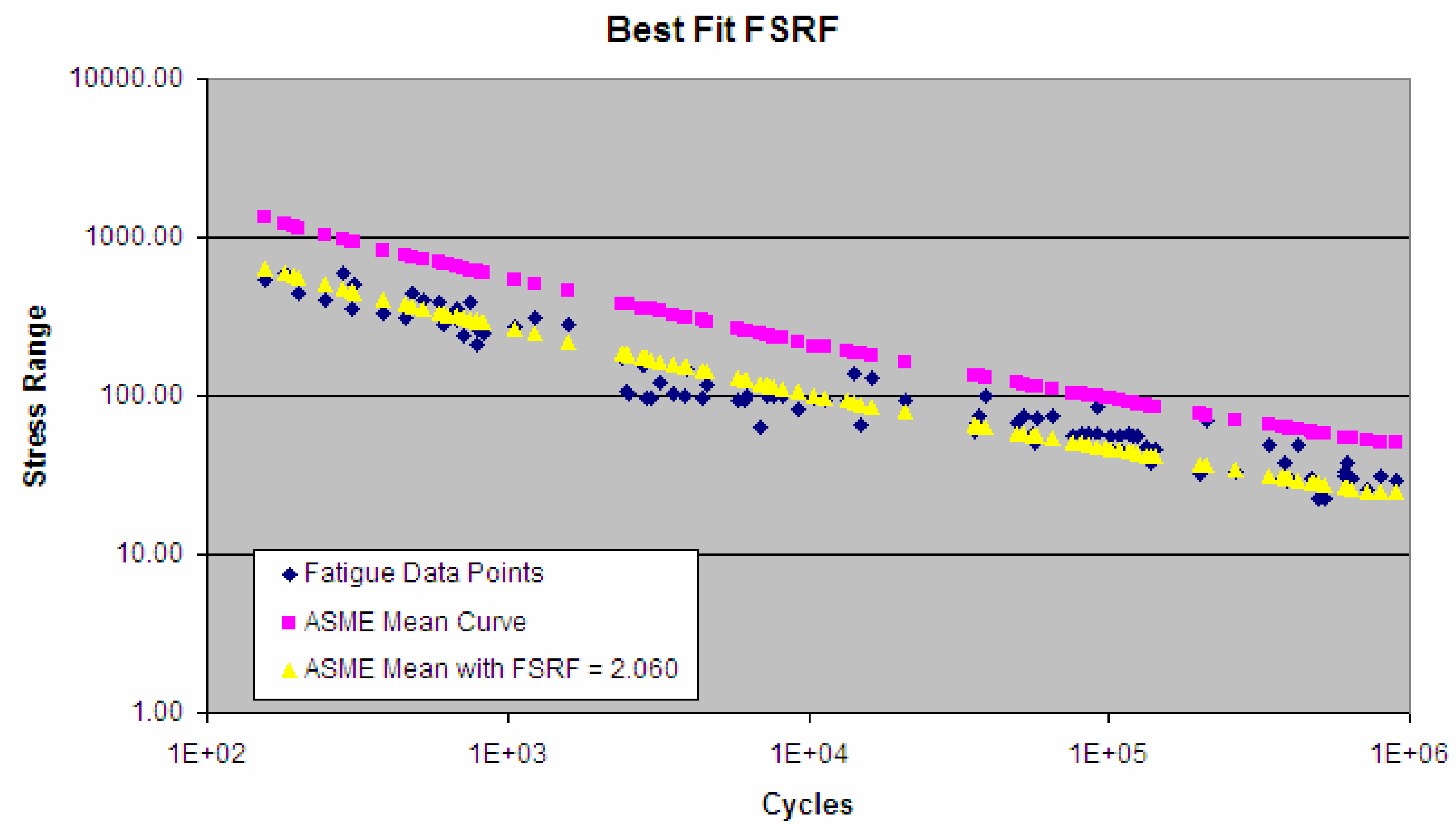
Why is Neuber's Used?

- Based on the issues raised here, Neuber's adjustment would not be required in the ASME Codes because of displacement controlled conditions and limited stress ranges for applied loads (sustained type loads).
- Neuber's was introduced to make test data match the Battelle database.
- The PVP industry is unique and different than automotive, aerospace, etc. Most industries don't have our unique loadings and stress limits.
- Although not technically required for the Div 2 Rewrite, the Master SN curve could produce non-conservative results for many recent fatigue tests including those by PRG, EPRI, DNV, and DeJesus if Neuber's rule was not implemented.

- If additional safety factor is desired, then why not implement something easier to use?
- Europeans have single equation similar to Ke factor, but used to modify the membrane plus bending stress range. It also differentiates between thermal loadings and mechanical loadings.

FSRF Values

- **Are the WRC 432 FSRF adequate for girth butt welds?**
- **WRC recommends FSRF of 1.2. Statistical analysis indicates an FSRF of 2.06 for girth butt welds used as validation for Master SN.**



FSRF Values

- **Data appears to indicate that FSRFs should be cycle dependent.**