Update on Fatigue Testing

at

Paulin Research Group

BPVC Code Week

Louisville, KY

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ASME Subgroup Design Analysis

(Revised with comments Nov. 6, 2006)

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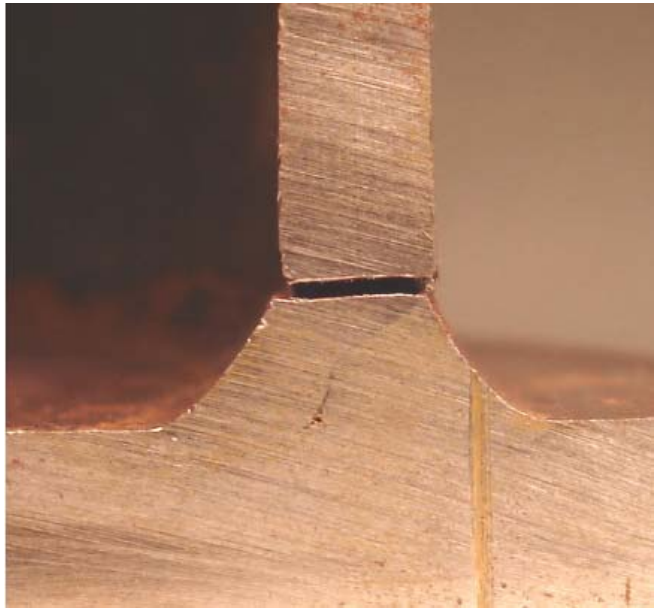
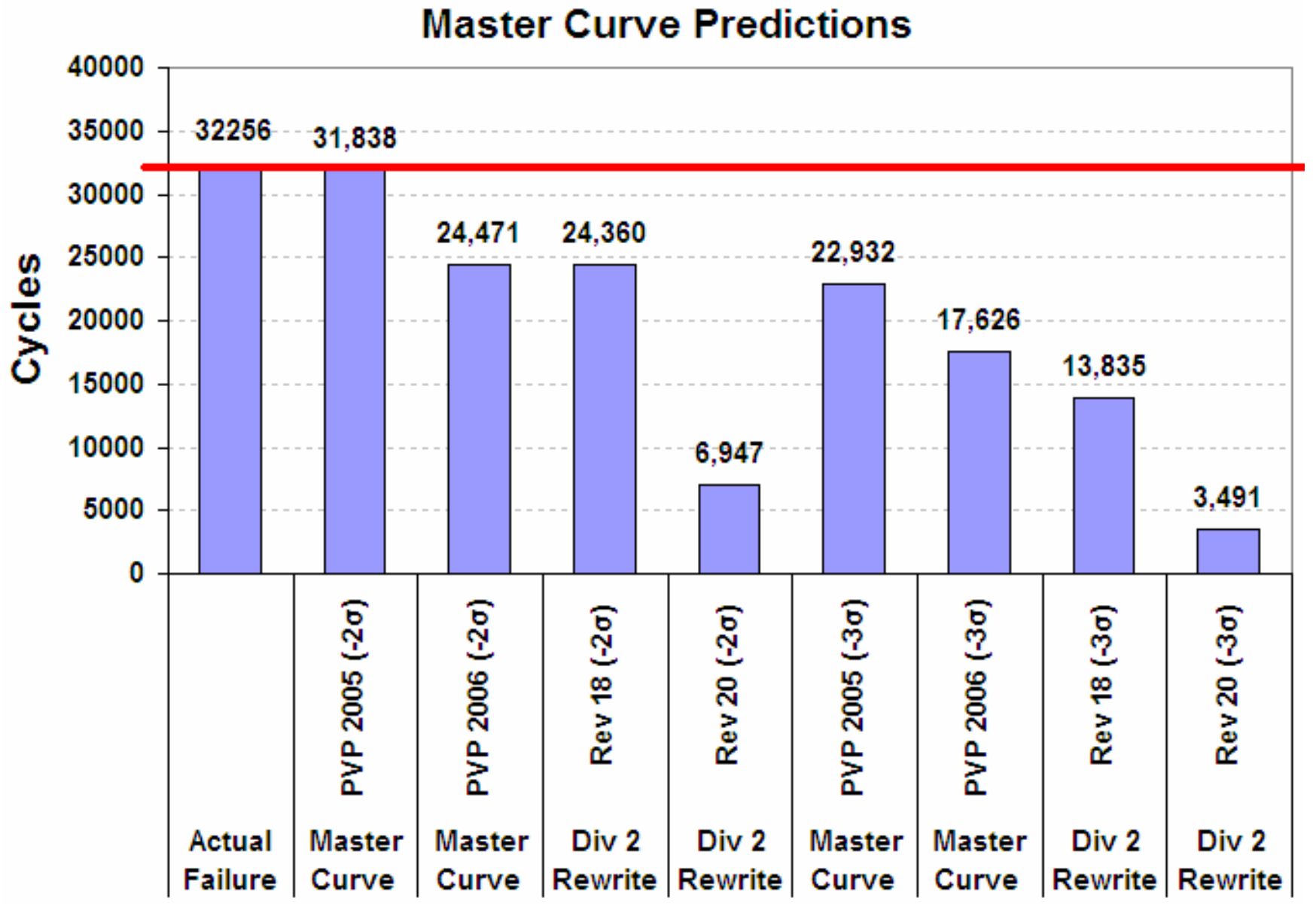
What has been done…

- Five tests presented at 2006 PVP conference in paper PVP2006-ICPVT11-93967.
- Two new tests have been conducted with 0.055” thickness to evaluate thickness correction term.
- Total of 25 failure points so far.
- Carbon steel and stainless steel included in testing.
- Two new tests have been fabricated for fatigue testing in air to evaluate environmental effects of Houston tap water.



Recent History of Master SN



Latest Work - Thin Tests (#6 and #7)

- **Tests completed to evaluate increase in allowable cycles provided by thin materials in Master Curve method.**
- **Similar flat head geometry as already tested.**
- **Shell thickness measured at 0.055”.**

PRG

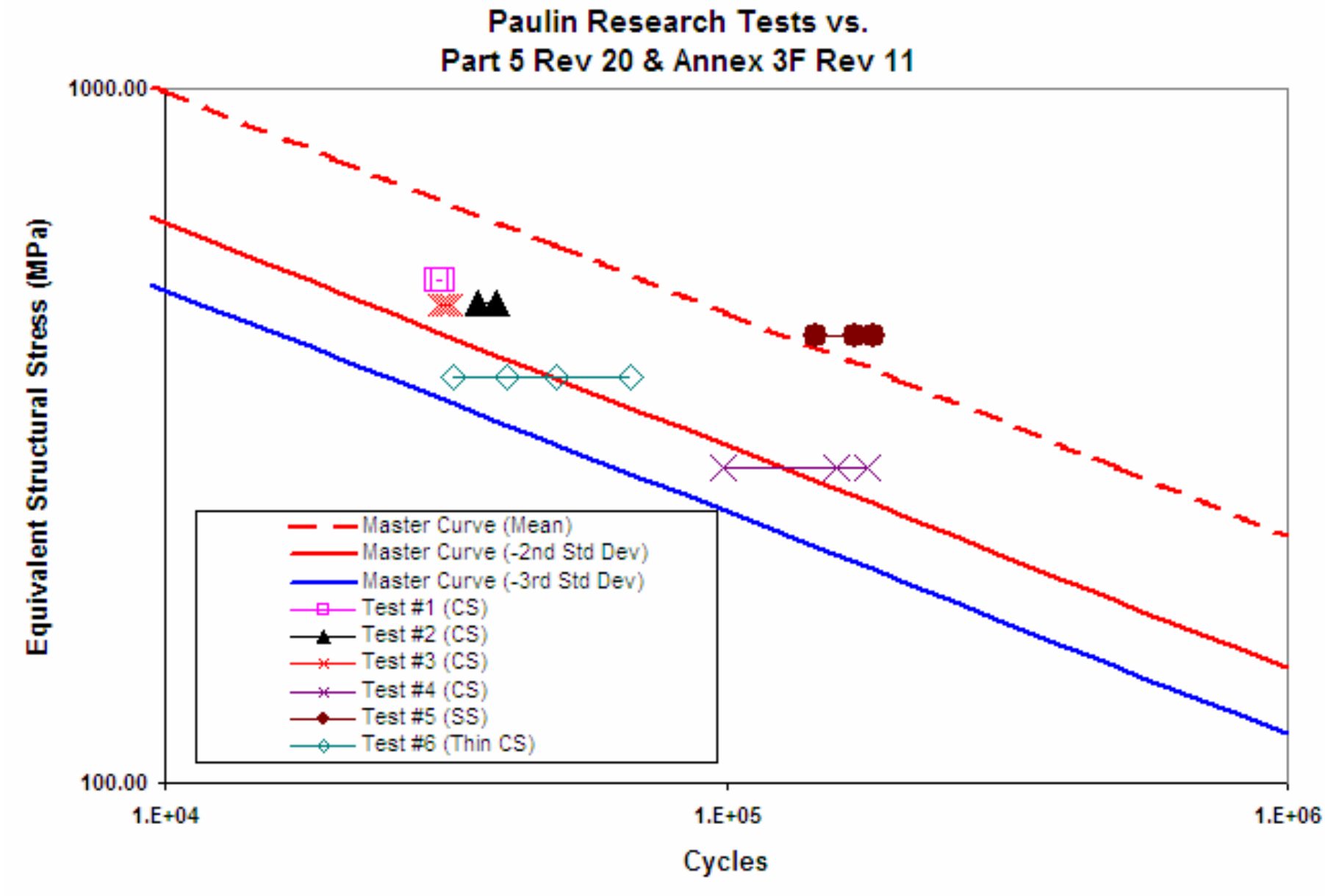
Latest Work - Thin Tests (#6 and #7)

- **Thickness correction indicates an increased life of 2.35 times original tests (or about 78,200 cycles). This is about 150% greater than test.**

Cycles to Failure Average = 51,483 cycles	32,276 40,703 49,739 67,348 67,348

	Mean	-2*STD	-3*STD
Master SN PVP 2005	230,263	74,267	53,492
Master SN PVP 2006	177,827	57,355	41,311
Div 2 Rewrite Rev 18	177,023	57,095	32,426
Div 2 Rewrite Rev 20	28,280	7,133	3,585

All Tests to Date



Upcoming Work - Air Tests (#8 and #9)

- Two new 20” flat head geometries will be tested in air.
- Filled with concrete castings to reduce cyclic volume (test specimens were protected by lining while concrete cured).
- Will establish an environmental factor for PRG tests conducted in Houston tap water.

Summary of Latest Work

- General trend for Master SN has been to produce lower design lives (increasing margin against failure).
- Original thickness correction factor appears overly aggressive in light of recent tests.
- Recent testing supports latest changes to thickness correction rule.
- Air test data is pending.

How Conservatism Has Been Achieved

- **Most recent revisions to Division Rewrite 2 Master Curve method have been able to achieve conservatism for PRG tests by implementing:**
  - ***Environmental factor (4.0)***
  - ***Neuber's correction (plasticity adjustment factor)***
  - ***Modified thickness correction term***
- **What will be shown is that the environmental factor for Houston tap water and plasticity effects are already included in the data scatter of the Master SN method.**
- **A fatigue point on the mean curve should be predicted to be on the mean curve when the design procedures are implemented.**
- **Although these changes make PRG tests match the mean curve, what happens to other geometries?**

Environmental Effects of Houston Tap Water

- **For not including an environmental factor for Houston tap water the following conclusion was drawn by "the Div 2 rewrite fatigue analysis team" at PVP 2006:**

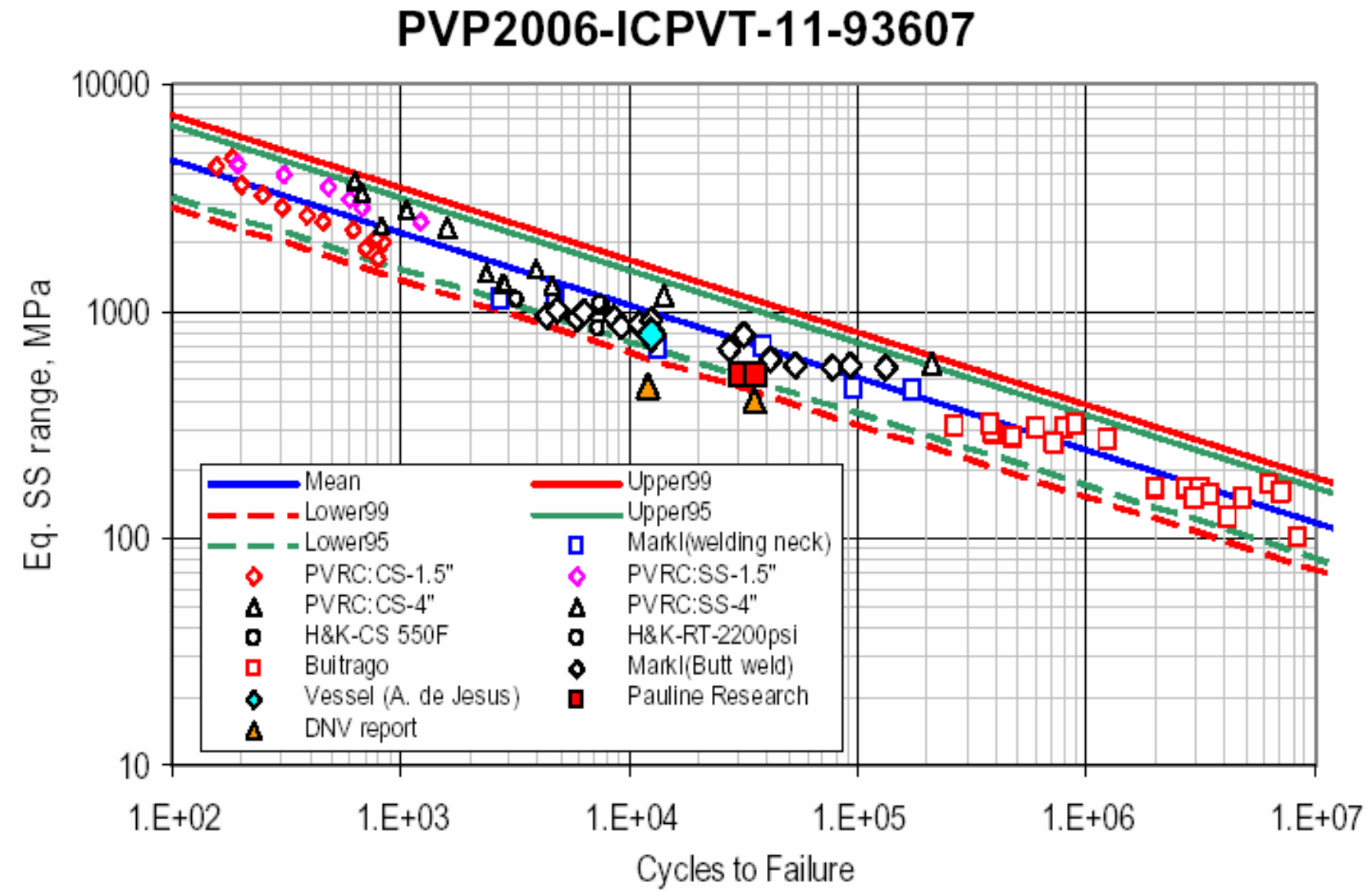
> ■ The Section VIII Div 2 Rewrite Fatigue Analysis team has reviewed the first paper and concluded that implementation of the Master S-N Curve method as reported contain fatal flaws that led to incorrect conclusions

- **"the first paper" (Hinnant 2006 PVP) did not include any Div 2 rewrite material or comparisons against the Div 2 rewrite procedure. Only the Master Curve Method was considered.**

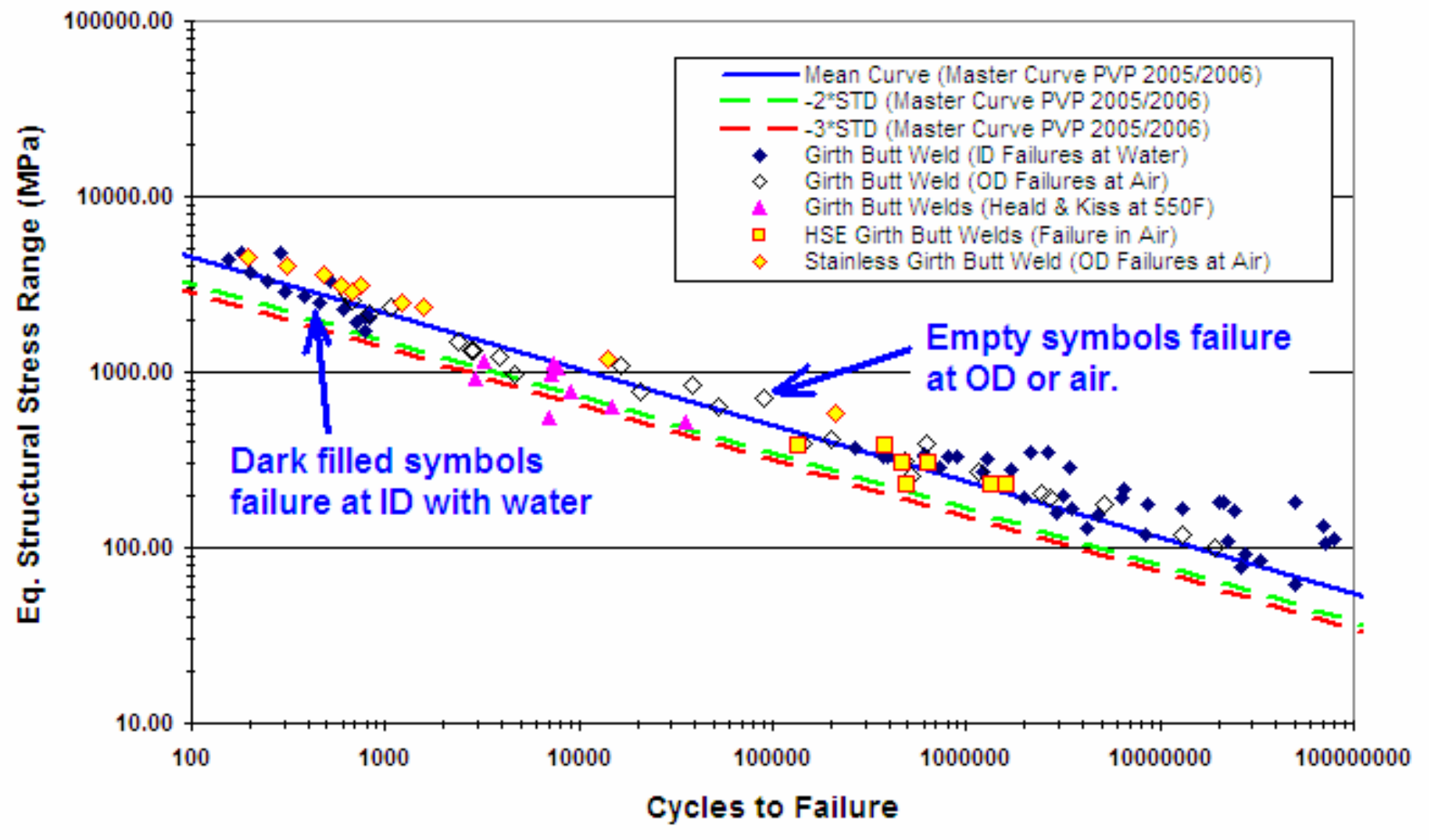
Master Curve Includes Tap Water Tests

- **All PVP data presented in Pingsha Dong's 2006 PVP paper included water inside the test specimens.**
  - **Buitrago, Scavuzzo, Markl, DNV, EPRI, PRG, DeJesus, Heald & Kiss**
- **At least 50% of the pressure vessel and piping geometries cited in the Master Curve PVP 2006 paper had failures originating at the wetted surface (inside).**
- **Of these tests in failing in water, approximately 70% are conducted in Houston tap water.**
- **Tests with failures at water can't be distinguished from tests in air.**

Master Curve Includes Tap Water Tests

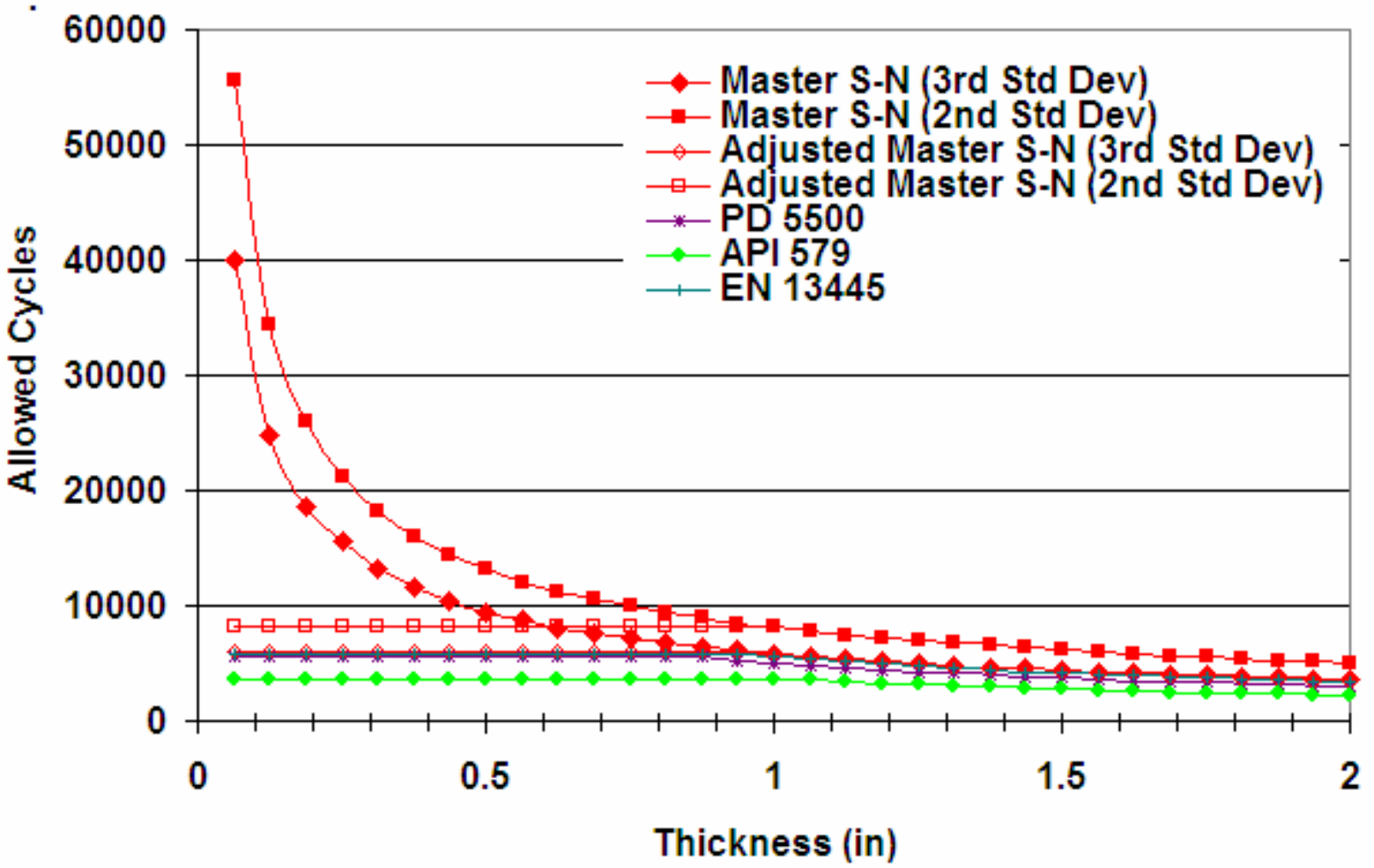


Master Curve Includes Tap Water Tests



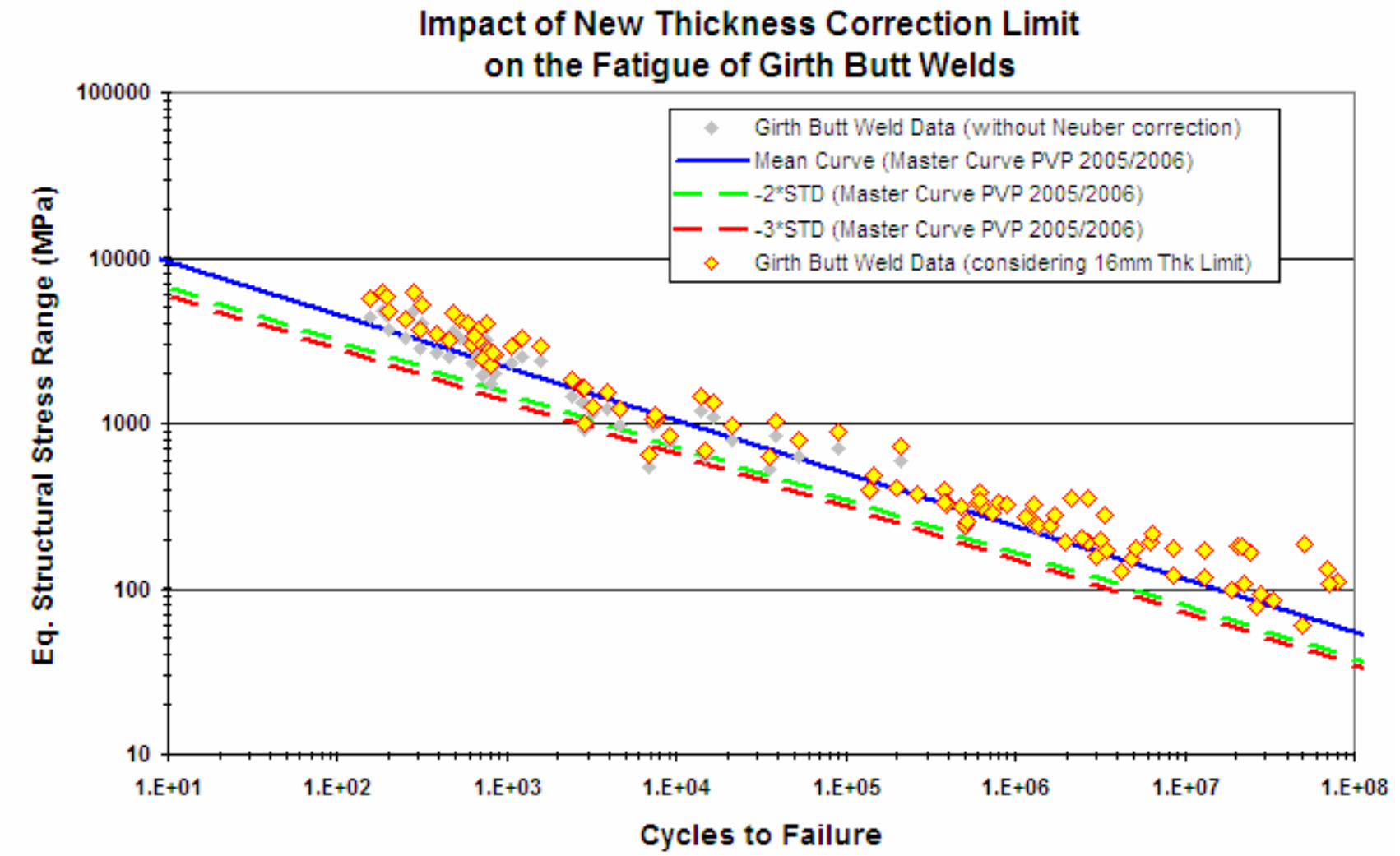
Part 5 Rev 20 Thickness Correction Rule

- **Thickness factor has been modified to eliminate the concept that very thin materials have significantly longer fatigue lives than thicker materials.**



New Thickness Correction Rule

- **The effect of the new thickness rule on PVP data is shown below:**



How significant is the new thickness rule?

- **Influence of new thickness rule on Master Curve predicted cycles on Scavuzzo 4” carbon steel “CS9” test (6mm thk) with 90,773 cycles to failure:**

- **With existing thickness rules (design margin of 11.9)**

```
Mean Cycles to Failure          = 32,876 cycles
-2 Std Dev Design Cycles        = 10,604 cycles
-3 Std Dev Design Cycles        = 7,637 cycles
```

- **With new thickness rules (design margin of 23.4)**

```
Mean Cycles to Failure          = 16,675 cycles
-2 Std Dev Design Cycles        = 5,378 cycles
-3 Std Dev Design Cycles        = 3,874 cycles
```

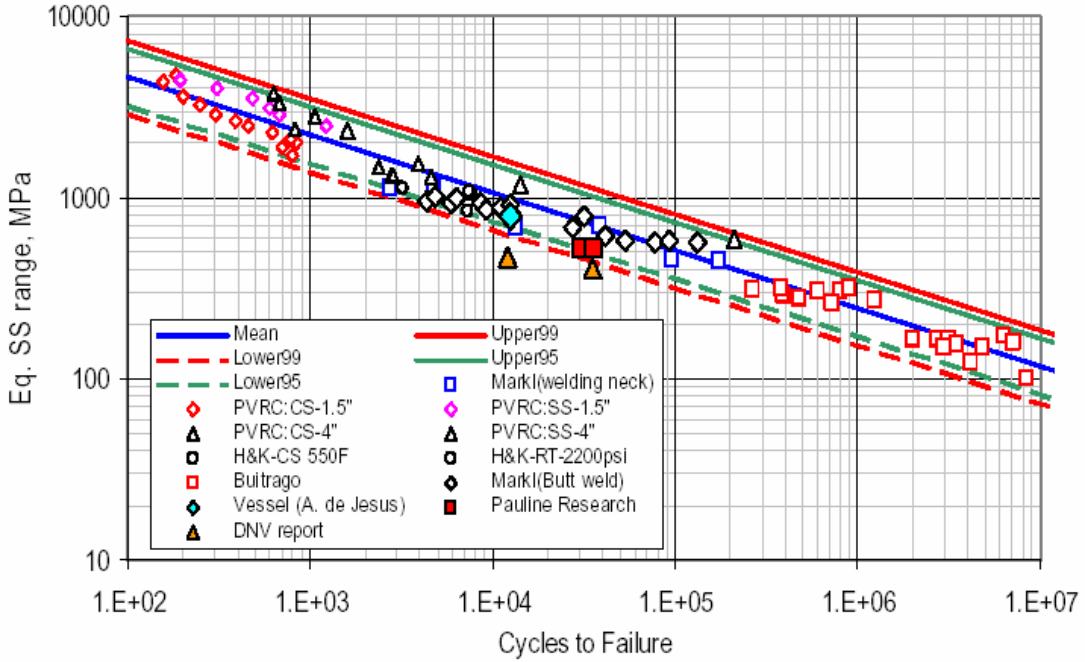
Neuber's Correction

- Every experimental data point already contains the true notch strain for that specific test.
- When a point is plotted on a fatigue curve, that point represents all the immeasurable quantities (notch strain, residual stresses, surface finish, mean stress, etc.) and is described by the stress on the Y-ordinate.
- Applying a LCF adjustment is "double dipping" on the notch strain which is already included in the experimental data.

- Conclusion – LCF (Neuber) adjustment is not required since the local strain is inherent in the test data.

Effect of Neuber Adjustment on Mean Curve

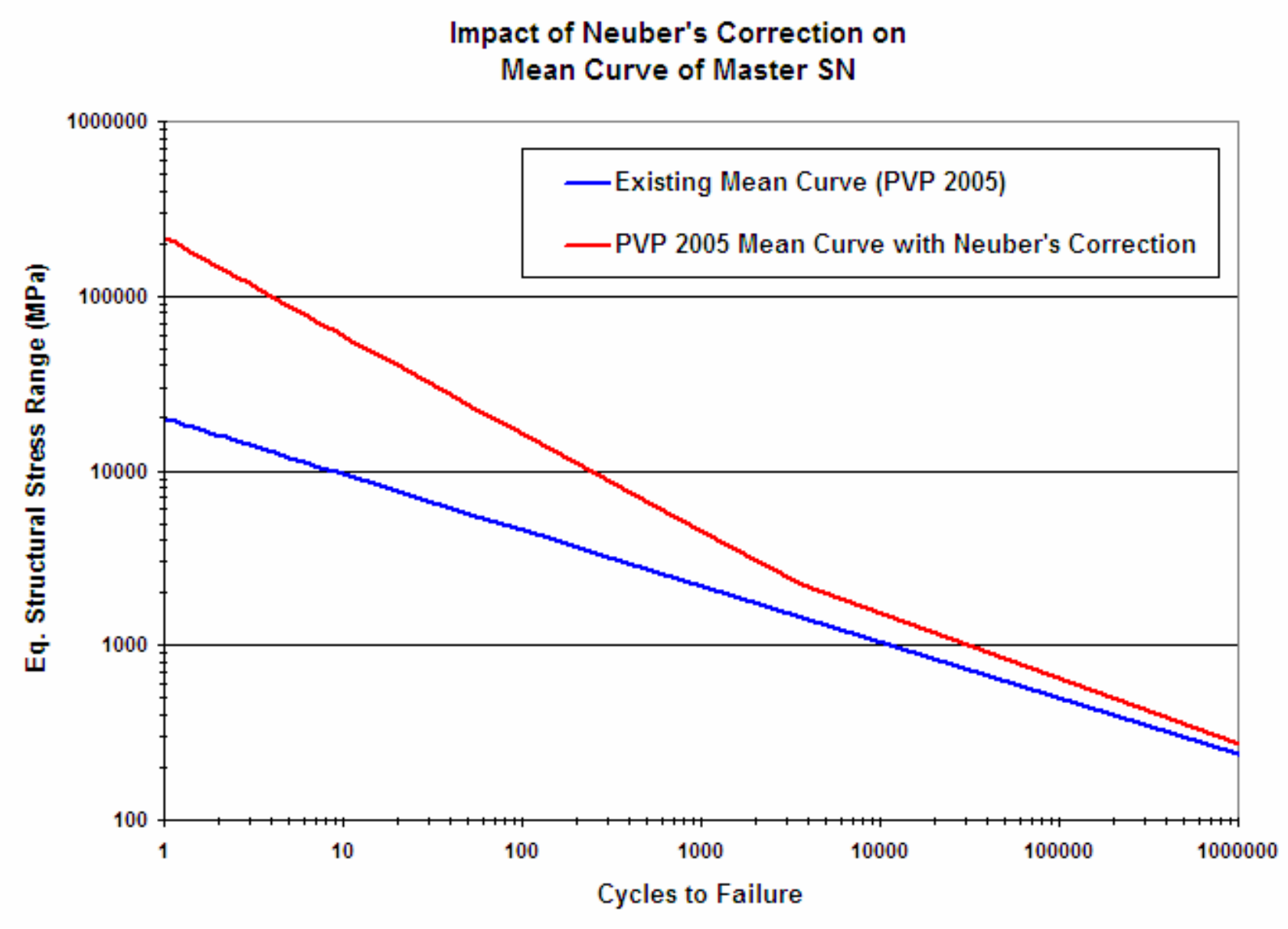
- **Why hasn't the Master Curve included the Neuber's adjustment into existing data to improve the Master Curve?**
- **Only selected data was adjusted in Pingsha Dong's 2006 PVP paper (PRG, EPRI, DeJesus, DNV but not Scavuzzo, Buitrago, or MarkI.)**
- **The Neuber's correction introduces a non-linear behavior into the log-log S-N curves.**
- **To date, all welded curves are straight lines, not curved lines.**



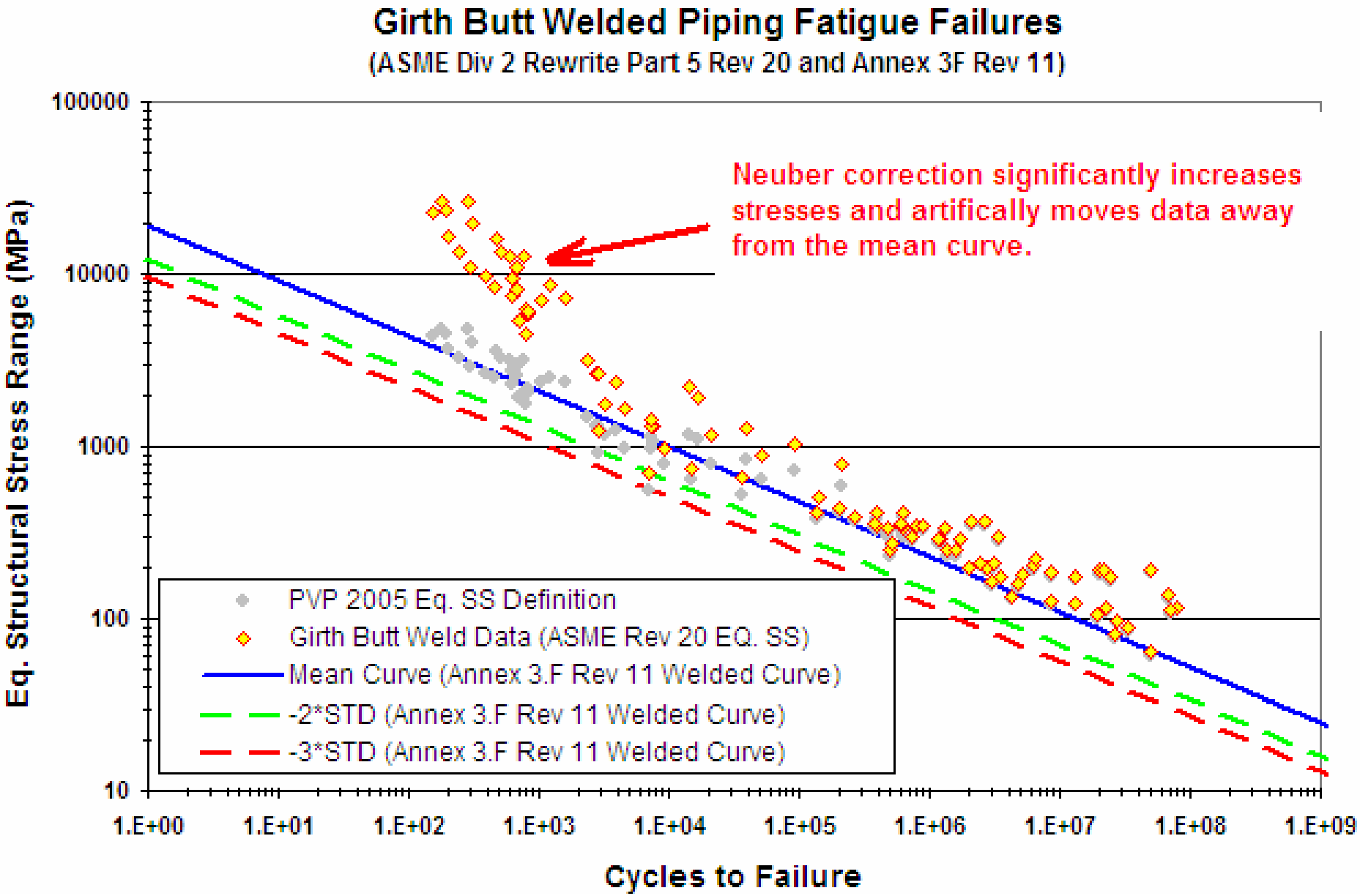
Neuber Adjustment

- Low Cycle Fatigue adjustment is material dependent.
- This is contradictory to the concept that all ferritic welded joints behave similarly (i.e. stainless and carbon steel have same fatigue life).
- Fatigue life is mildly sensitive to the selection of cyclic stress-strain curve parameters.
- For stainless 304H, the cycles permitted for PRG tests would be roughly half those permitted by carbon steel.

Effect of Neuber Adjustment on Mean Curve



Influence of Neuber Adjustment



Which is right - Straight or Curved?

- **Which is the right approach – straight or curved fatigue line? – BOTH**
- **Fatigue curves can be presented as pseudo elastic stress based on measured stiffness or based on measured strain.**
- **Both methods lead to the "correct" answer, so long as we don't mix-and-match the methods. The stress on the Y-ordinate must be consistent.**

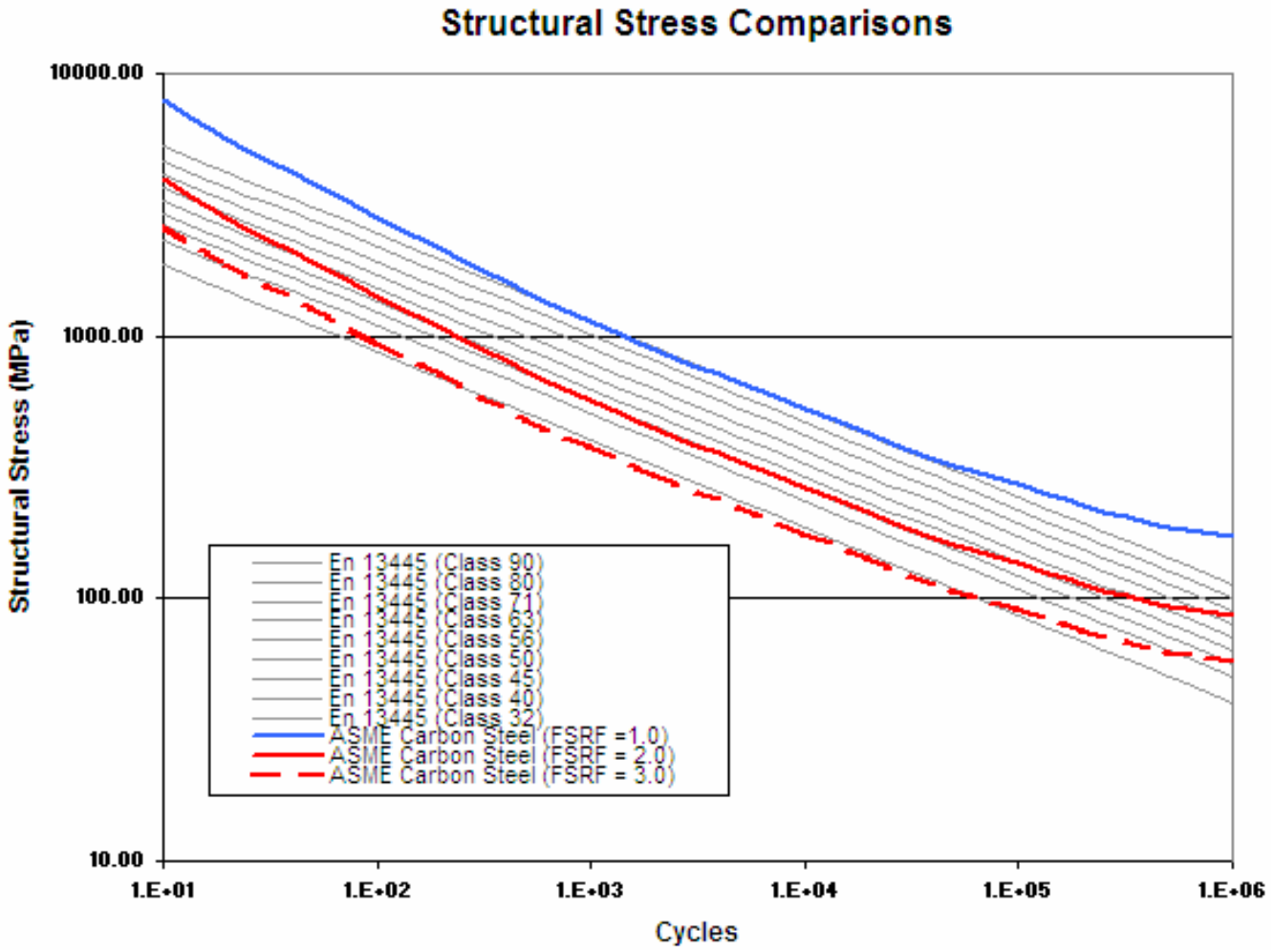
- **A common fault cited with FSRFs is that ASME fatigue plots are curved lines whereas welded fatigue plots are straight lines. Therefore, FSRFs must be a function of the fatigue life.**
- **BUT – this isn't based on an apples-to-apples comparison.**
  - **ASME Curves are pseudo elastic stress based on measured strain.**
  - **Welded curves are pseudo elastic stress based on extrapolated stiffness curves.**

Material Behavior

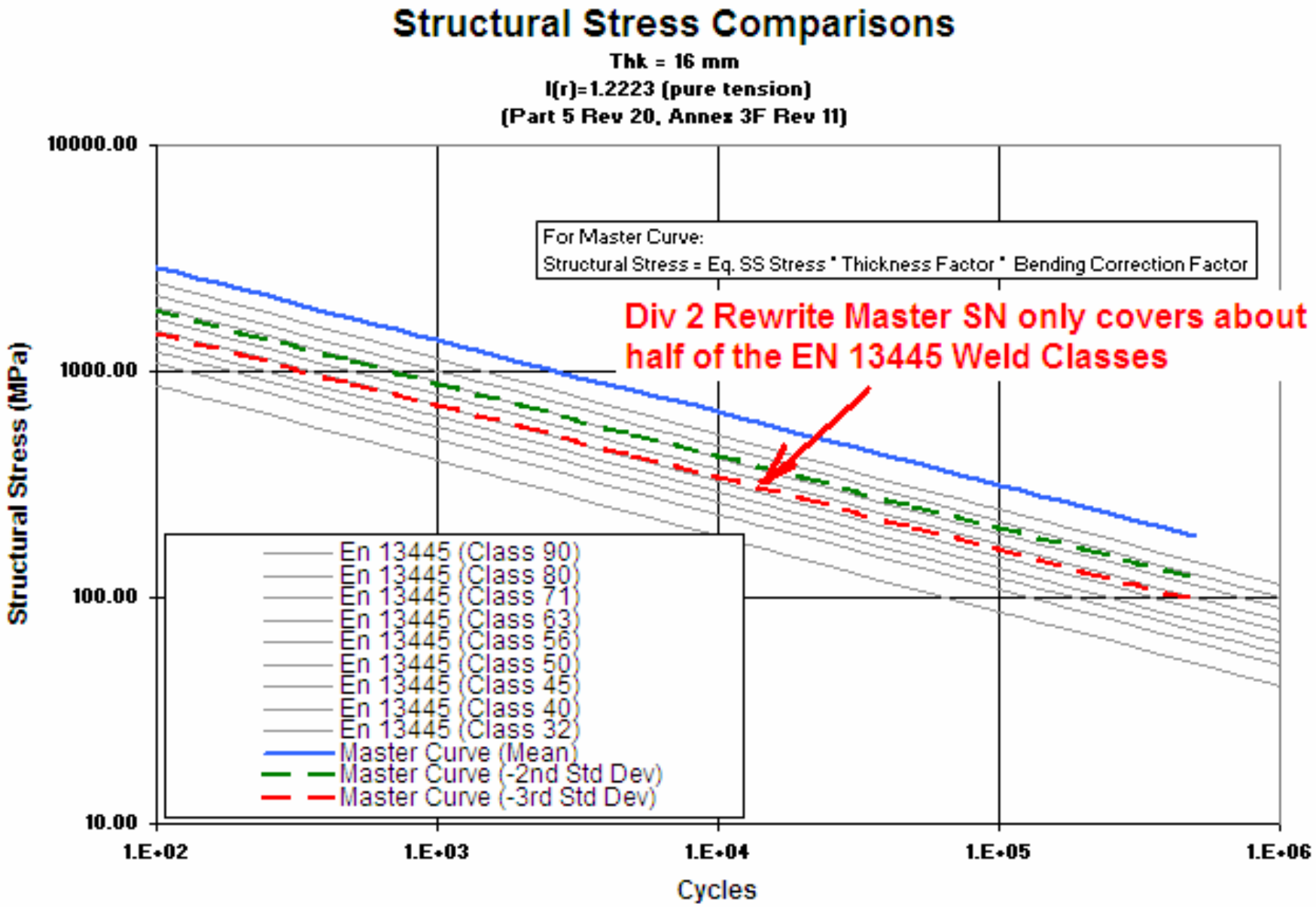
- The difference between the current ASME method and as-welded codes is significant for Stainless Steel vs. Carbon Steel.
- ASME smooth bar curves predict higher lives for welded Stainless steel geometries.
- As-welded codes treat Stainless steel and Carbon steel equally.
- These differences need to be resolved if two methods are to be approved for the Div 2 Rewrite.

FSRFs vs. Welded Curves (EN 13445)

- **FSRF's as recommended in Div 2 rewrite provide good match to existing welded codes.**
- **As shown below, FSRF values envelope EN 13445's welded curves.**



Master SN vs. Welded Curves (EN 13445)



Applying Latest Div 2 Rewrite to Documented Tests

- **Need to show consistency across many joint types and cycle ranges.**
- **Does the method produce good predictions for "bad" joints, but have significantly larger design margins for "good" tests?**
- **-3*STD for PRG test provides a design margin of 9.25.**
- **-3*STD for Scavuzzo's test "CS4" provides a design margin of 394.**
- ***Note that Scavuzzo's "CS4" test falls almost directly on Pingsha's PVP 2006 mean curve.***

	PRG Tests 1-3	Scavuzzo "CS4"
Cycles to Failure	32,256	394
Div 2 Rewrite Mean Life	27,543	6
Div 2 Rewrite -2*STD	6,974	<1
Div 2 Rewrite -3*STD	3,491	<1

Summary

- Latest revisions provides conservative margin against PRG test data.
- Latest revisions produces very conservative margins for girth butt weld joints in low cycle range.
- If “double dipping” on environmental and plasticity factors are eliminated, then margin against PRG tests is reduced.
- Margin is not consistent thru cycle range due to Neuber correction.
- Environmental factor for Houston tap water is not necessary since it is already included in scatter band.
- Neuber’s correction is not necessary since it is already included in scatter band.

- Master Curve needs to be reanalyzed using new definition of Equivalent Structural Stress per Part 5, Rev 20.

Summary

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