

Extending the Creep Life of a High Temperature Refinery Reactor

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FCC



Me

Topics Covered in this Presentation

- Fluidized bed Catalytic Cracking (FCC) reactor
- Background of the first creep crack and 2006 repairs
- Inspections in 2008 and the new repair technique
- 2010 shut-down inspections and repairs
- 2010 creep testing of the 2008 weld overlays
- Analysis of vessel distortion and the large nozzle
- 2012 cracking away from welds and repairs
- 2014 weld overlay cracking and repairs
- Conclusions and recommendations

Lemont Refinery Catalytic Cracking Unit

Regenerator

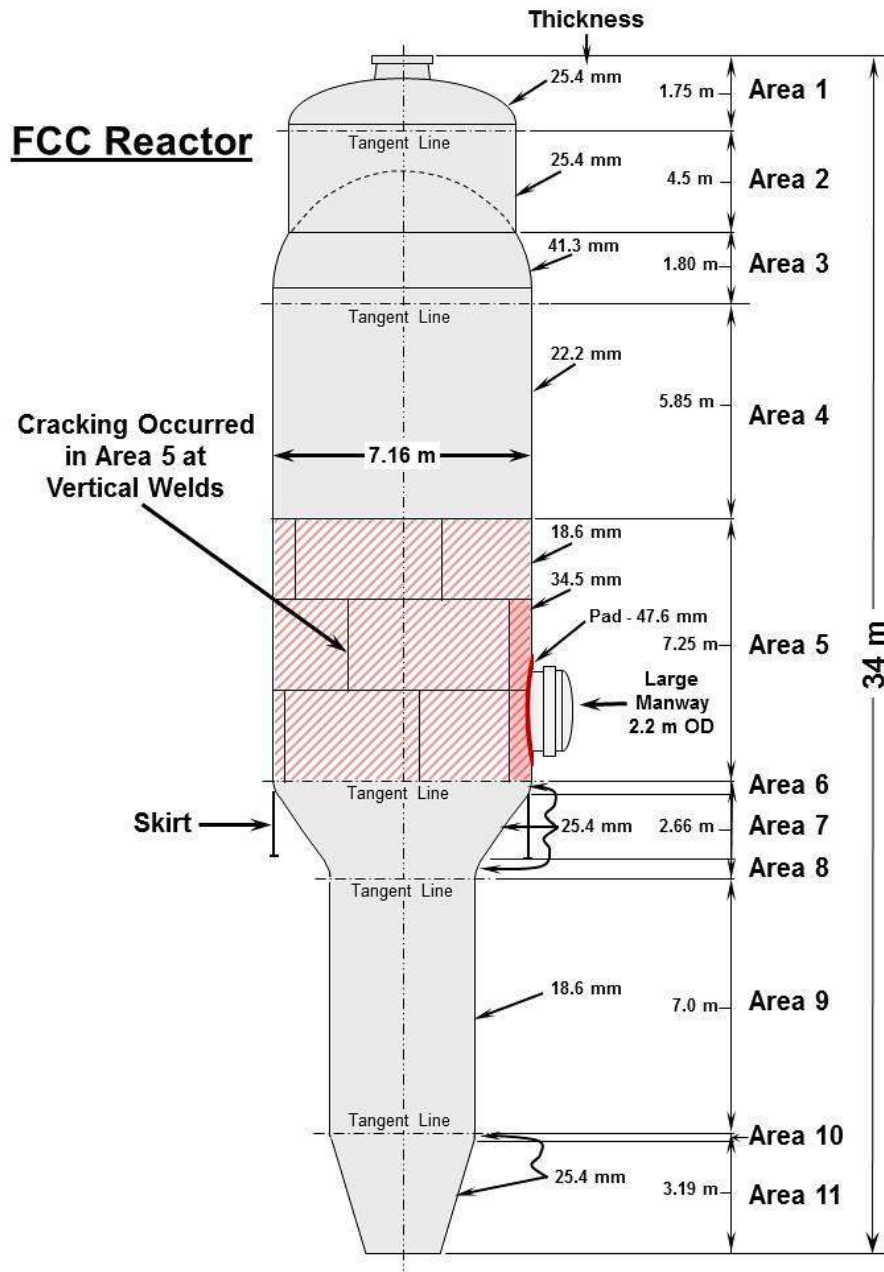
Fractionator

Reactor

This photograph
is from the 2010
Shut Down

Boiler



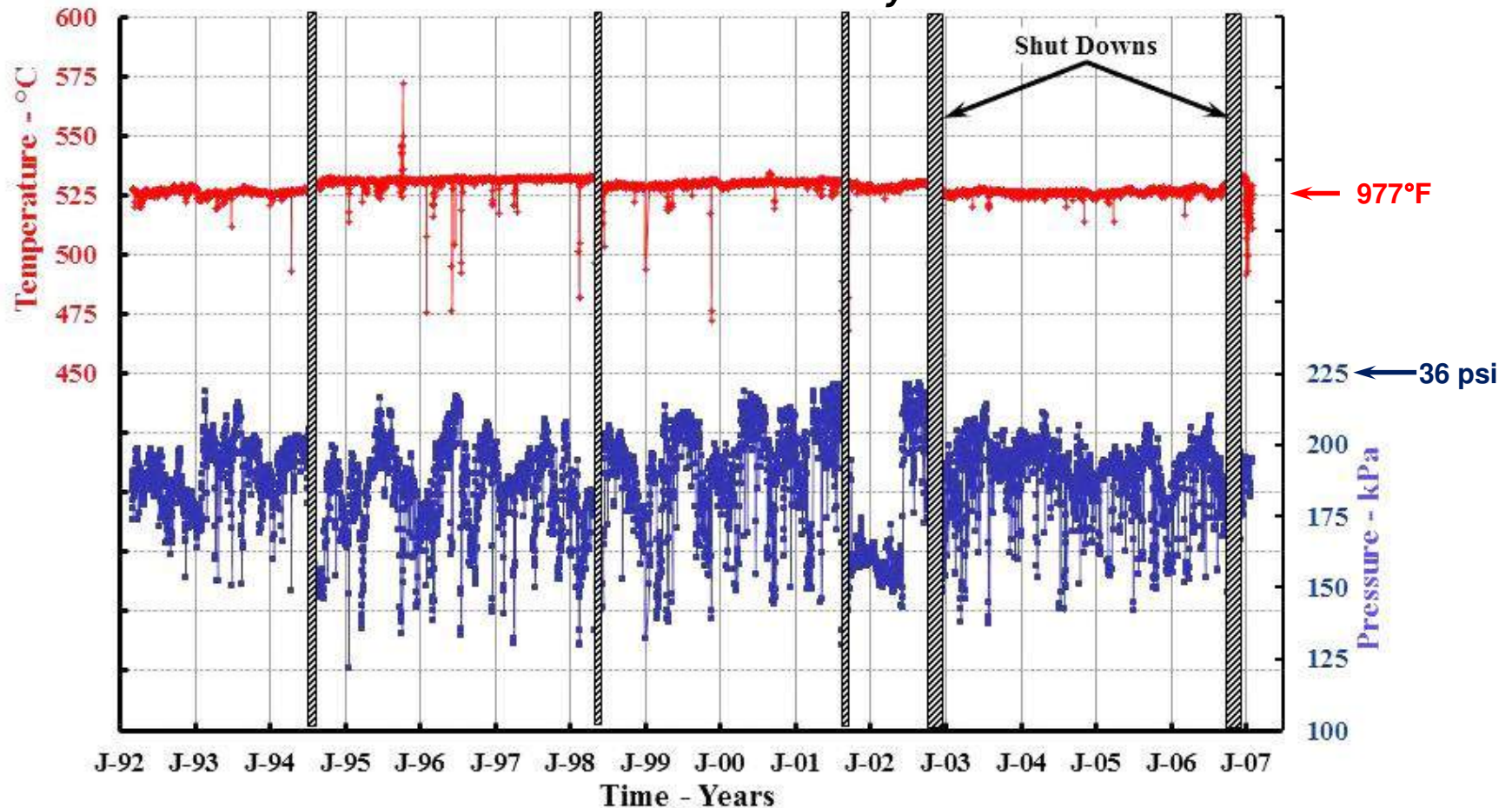


The Reactor

- Thickness varies with stress in the vessel wall
- Areas 1-4 installed in 1994
- Lower areas installed in 1968
- All creep cracking occurred in Area 5
- Area 5 is made of
K11757 (1Cr- $\frac{1}{2}$ Mo)
- Areas 1-4 are made of
K11789 (1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo)
- ASME allowable stresses were higher in 1968

The Process

Daily Average Reactor Temperature and Pressure From March 1992 to January 2007

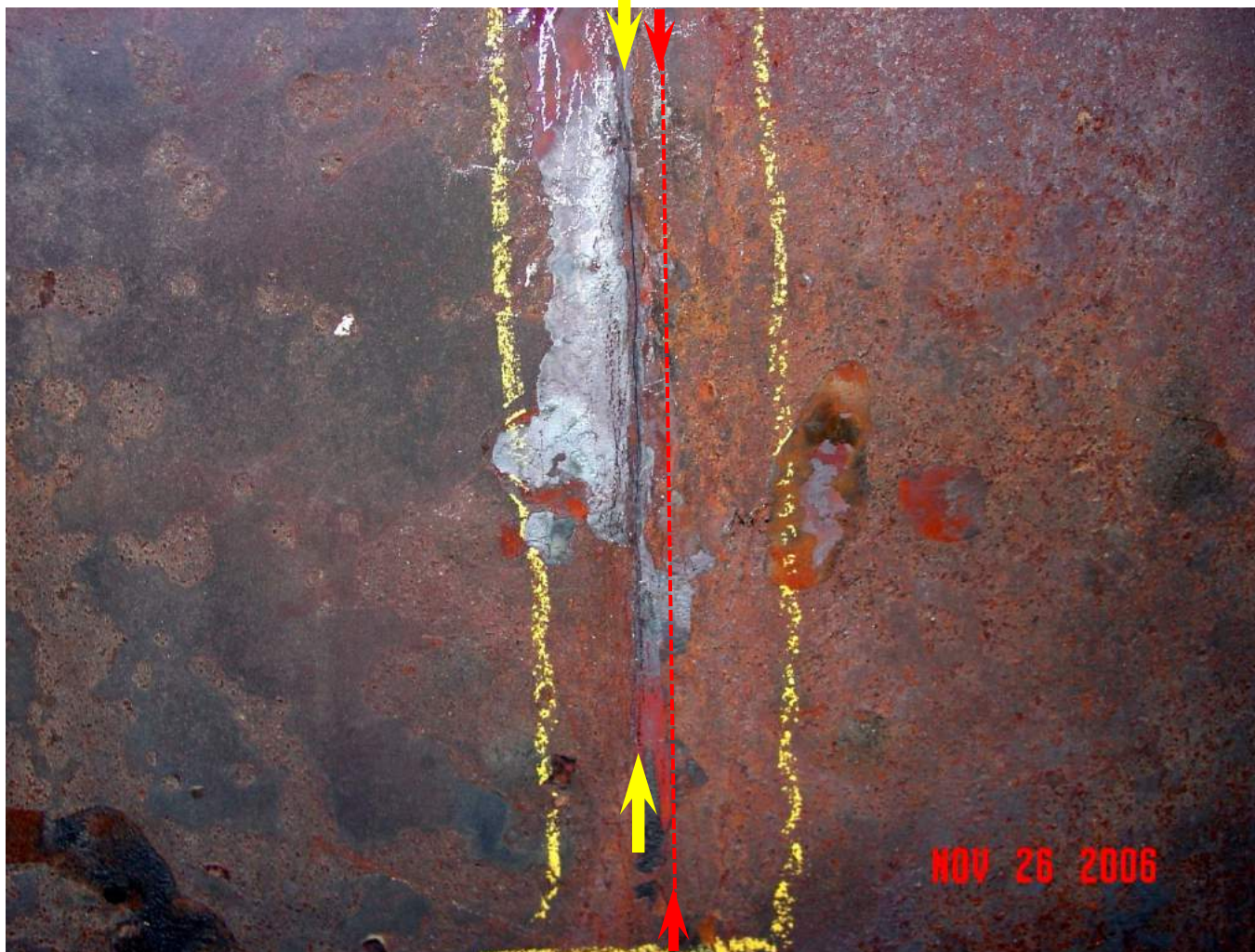


The pressure changes introduce the possibility that fatigue could influence creep life.

The 2006 Crack Along the Weld Toe

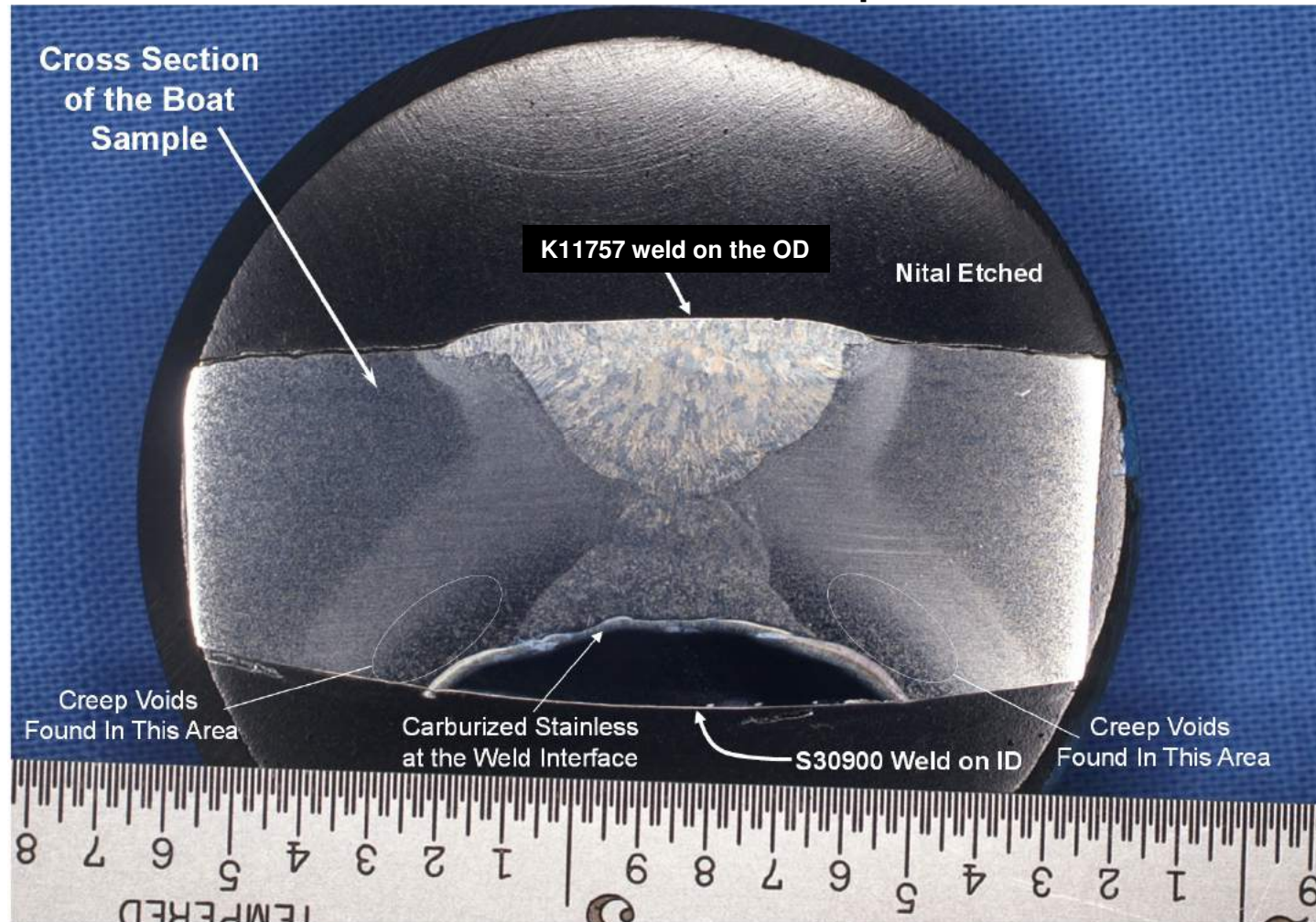
The creep crack is between
the yellow arrows

The weld center line is at the dashed
red line between the red arrows



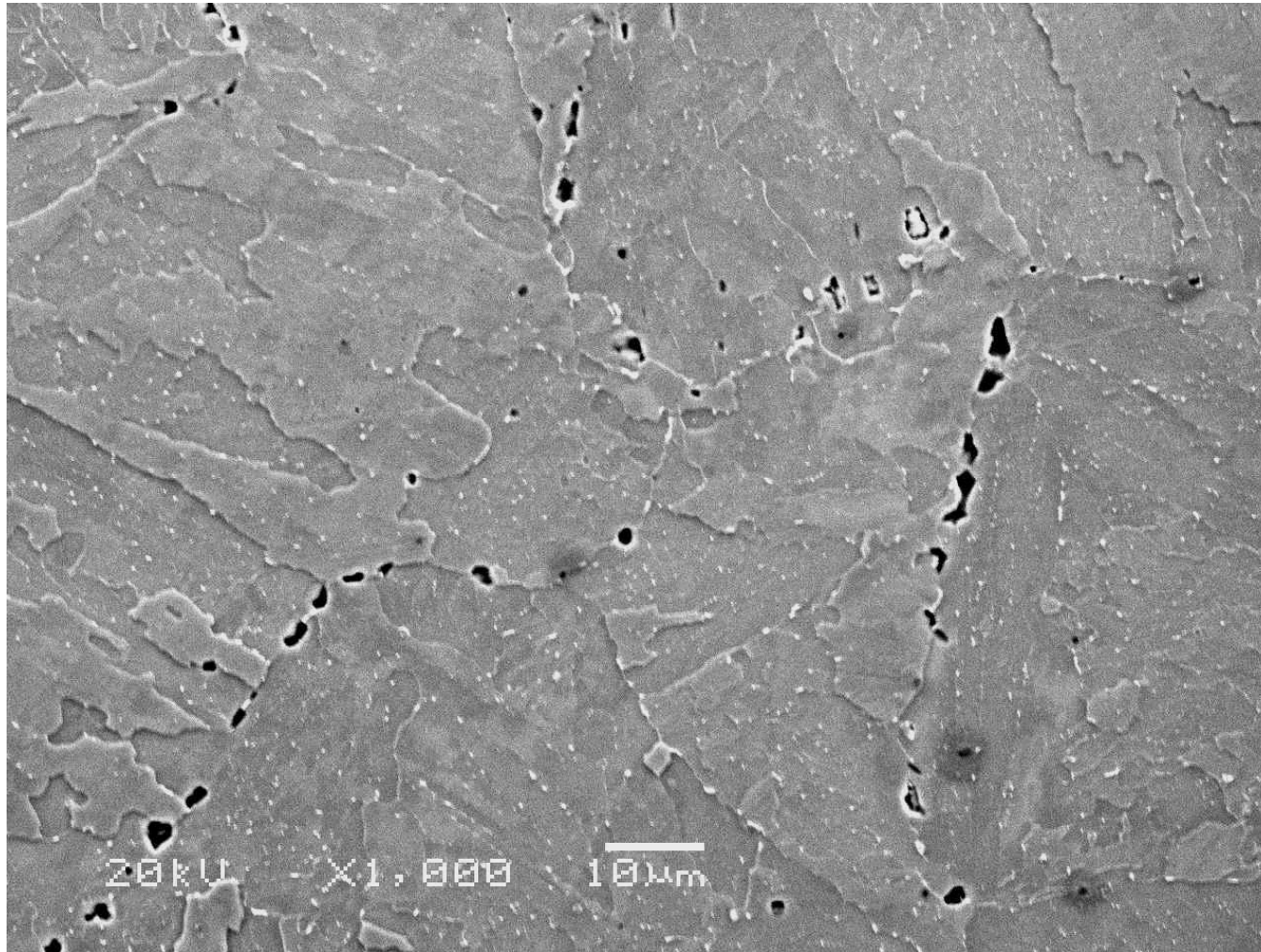
Vertical Weld Seam Boat Sample

Located 1.5 m from the rupture



The S30900 stainless on the ID was thicker than it should have been.

Creep Voids Beginning to Form Cracks



The 2006 Inspections and Repairs

- All vertical seams were UT shearwave inspected
- Defects and cracks were present all along the ruptured seam
- No defects were found in other weld seams
- Cracks were ground out.
- The cracked seam was rewelded with N06625
- GTAW process - temper bead technique
- No post weld heat treatment

The 2008 Shut Down and Repairs

- In 2008 the unit was shut down due to regenerator problems making the reactor available
- UT inspections found defects in three vertical seams
- The defects had characteristics indicating they were creep cracks – indicating near end of life
- New repair technique tested - weld overlaying with N06625 – Inconel 625
- Weld overlay repairs:
 - SMAW process
 - Temper bead technique
 - No post weld heat treatment

Weld Overlay Repairs in 2008



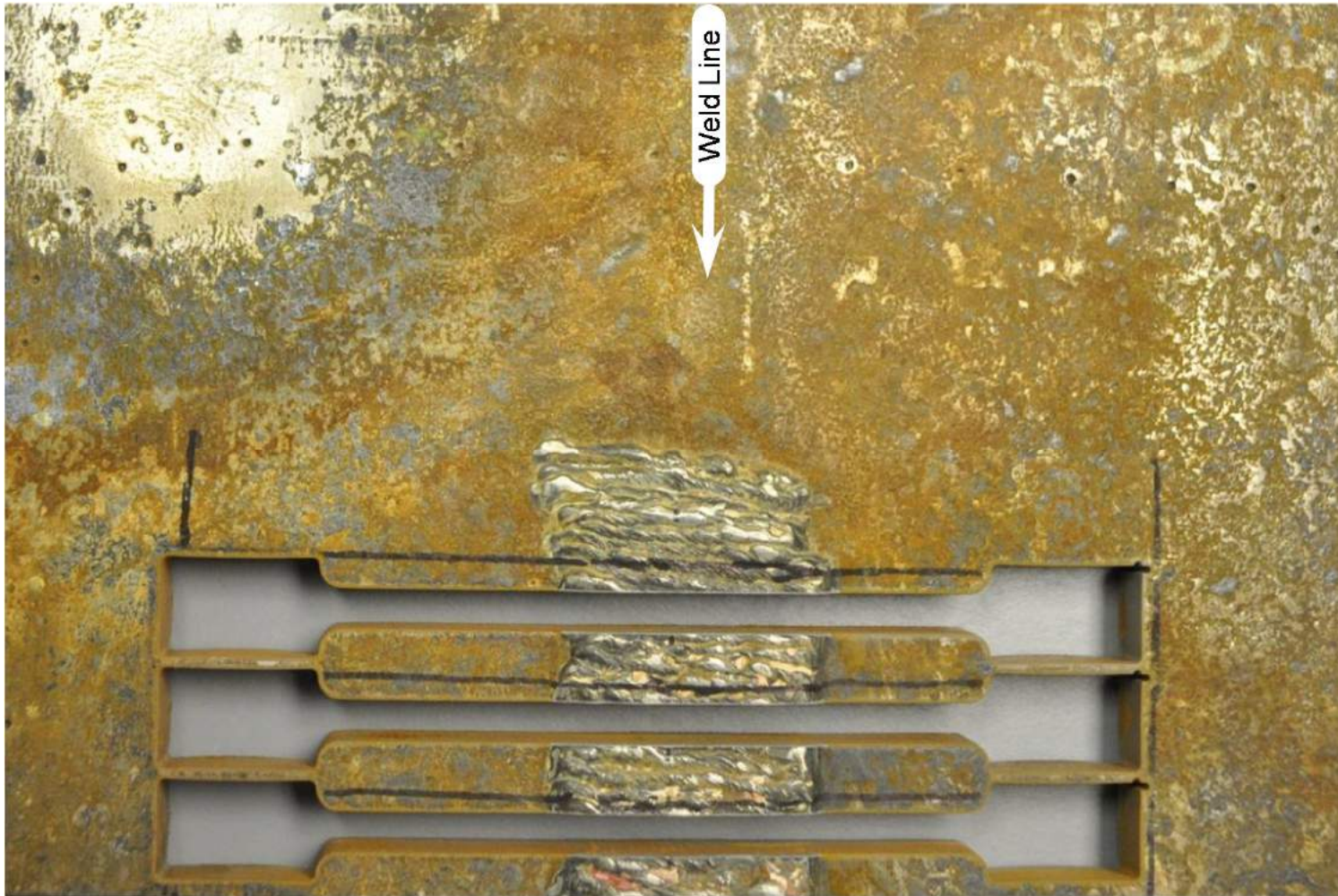
2010 Inspections, Repairs, and Testing

- All the welds UT shearwave inspected
- Samples of repaired welds and distorted areas were cut out for creep testing
- Vertical seam welds were arc gouged out including weld heat affected zones
- Vertical seams were rewelded with N06625
- GMAW, temper bead technique, no post weld heat treat – weld beads in the vertical direction.
- Existing weld tee junctions were also rewelded

Results of 2010 Inspections and Testing

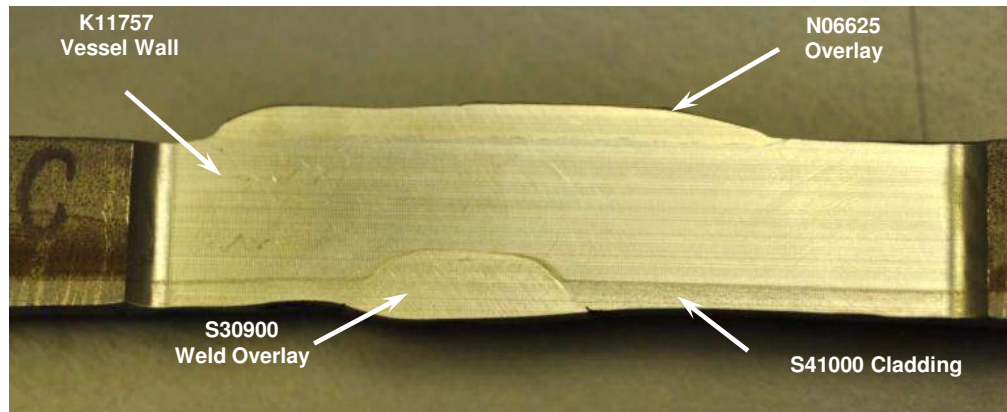
- 2008 weld overlay repairs were cut out, UT inspected, and creep tested
- Existing cracks had not grown in 2 years
- Weld overlay repairs had increased creep life relative to wall samples
- Creep specimens failed outside of the overlays
- Samples of distorted areas were cut out, inspected and creep tested
- Bulged and flattened areas had lower remaining life than undistorted wall

Creep Samples Cut Through the Weld Repairs



The Results of Creep Testing

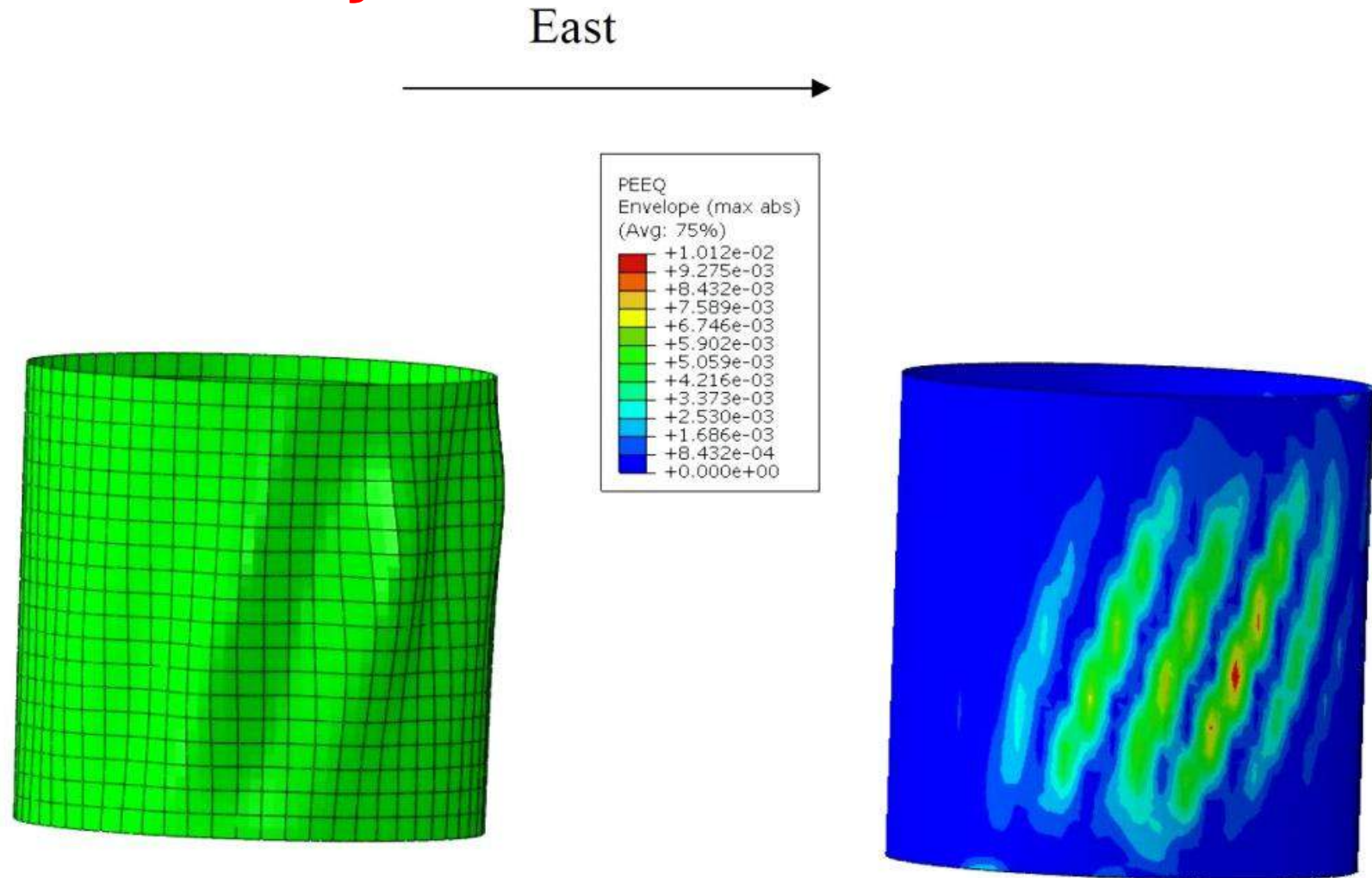
Before Creep Testing



After Creep Testing

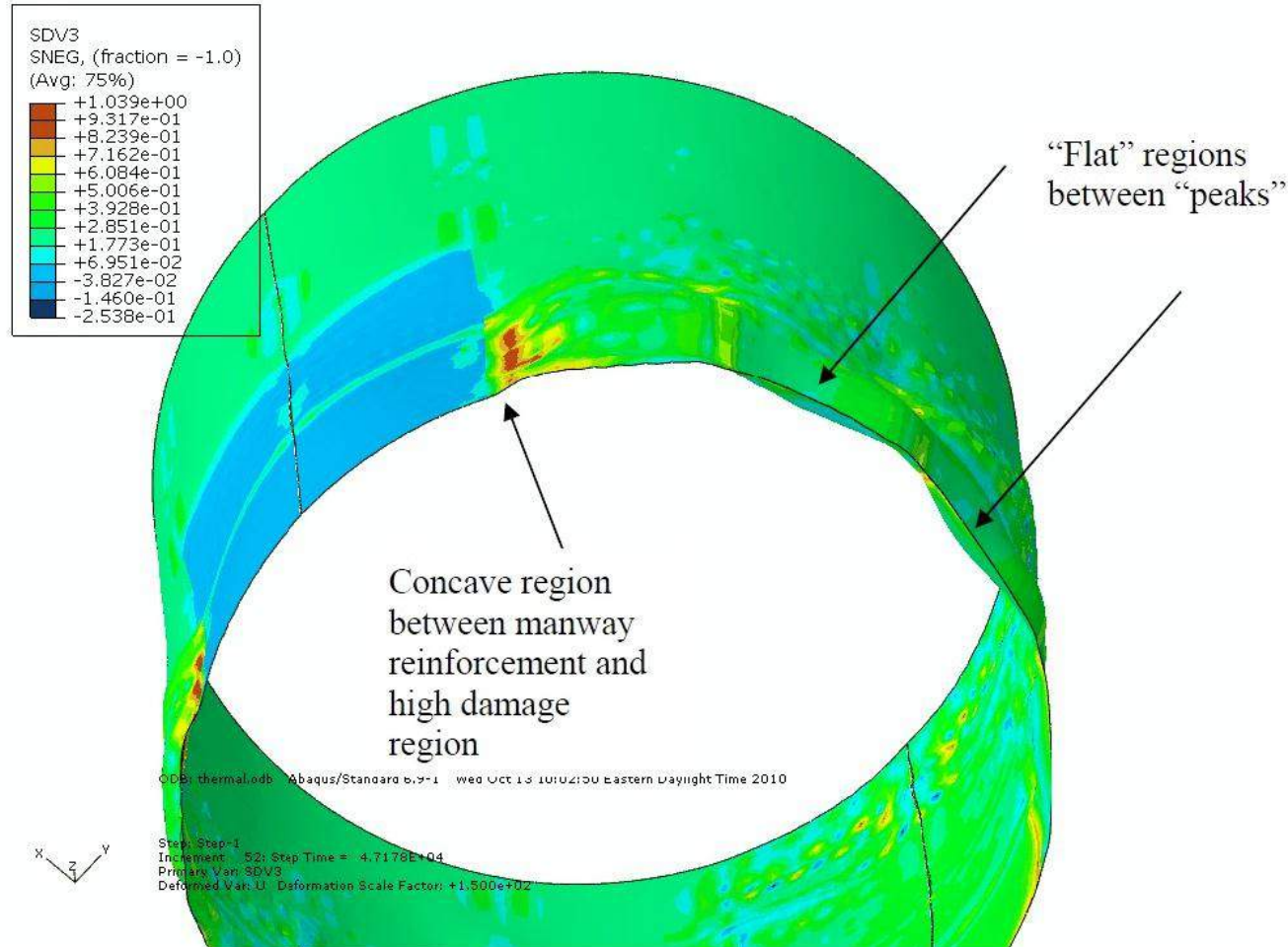
All of the weld overlaid samples fractured outside of the weld overlaid areas.

Analysis of Vessel Distortion



3D finite element analysis modeling revealed that minor bulges and flat areas were caused by the applied weight and wind loads.

Localized Distortion Caused by Insulation Removal

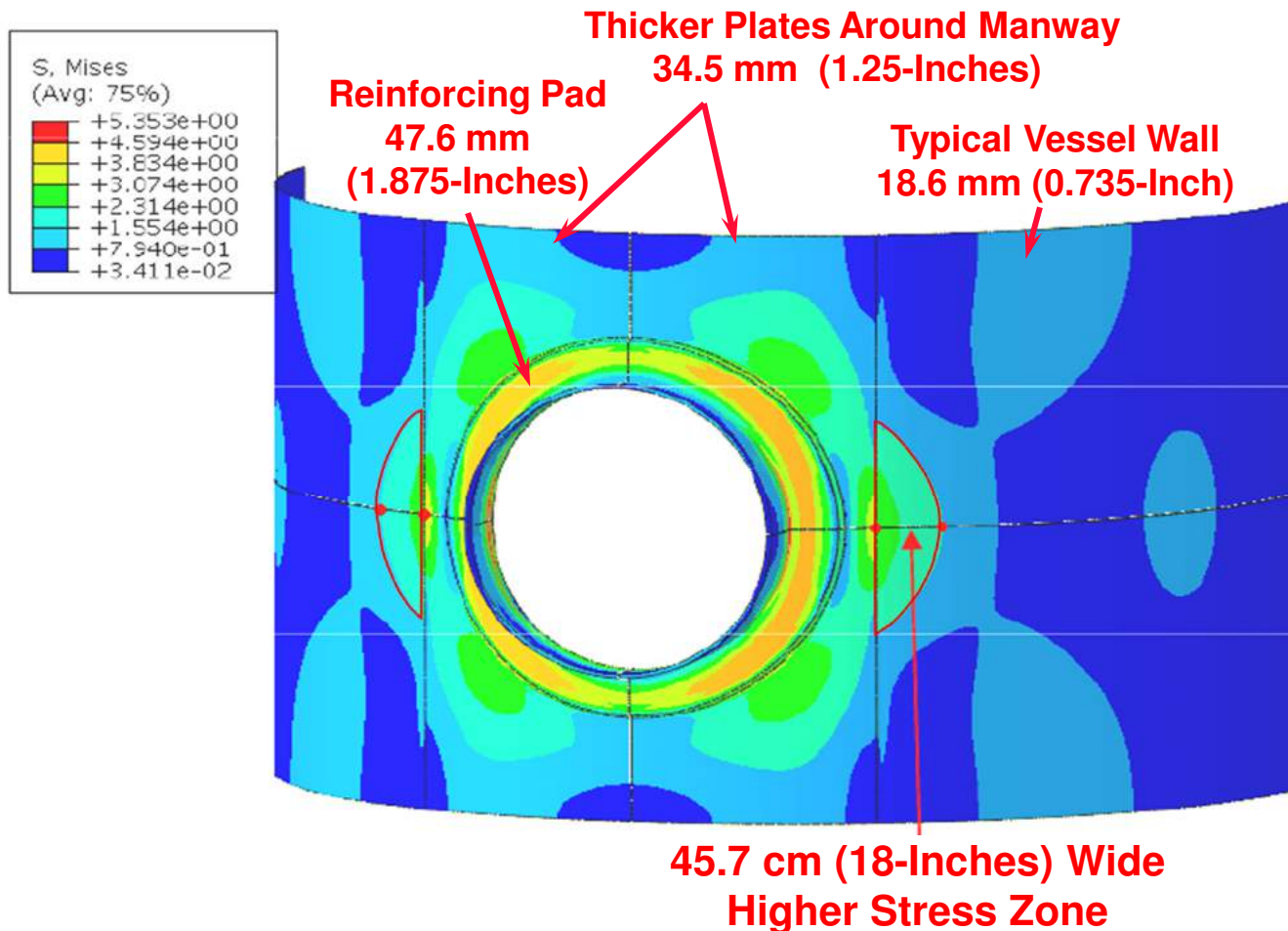


Larger flat areas and bulges were caused by rapid removal of insulation that occurred in 2008 and 2010. The highest stress was near the manway.

2012 Cracking and Repairs

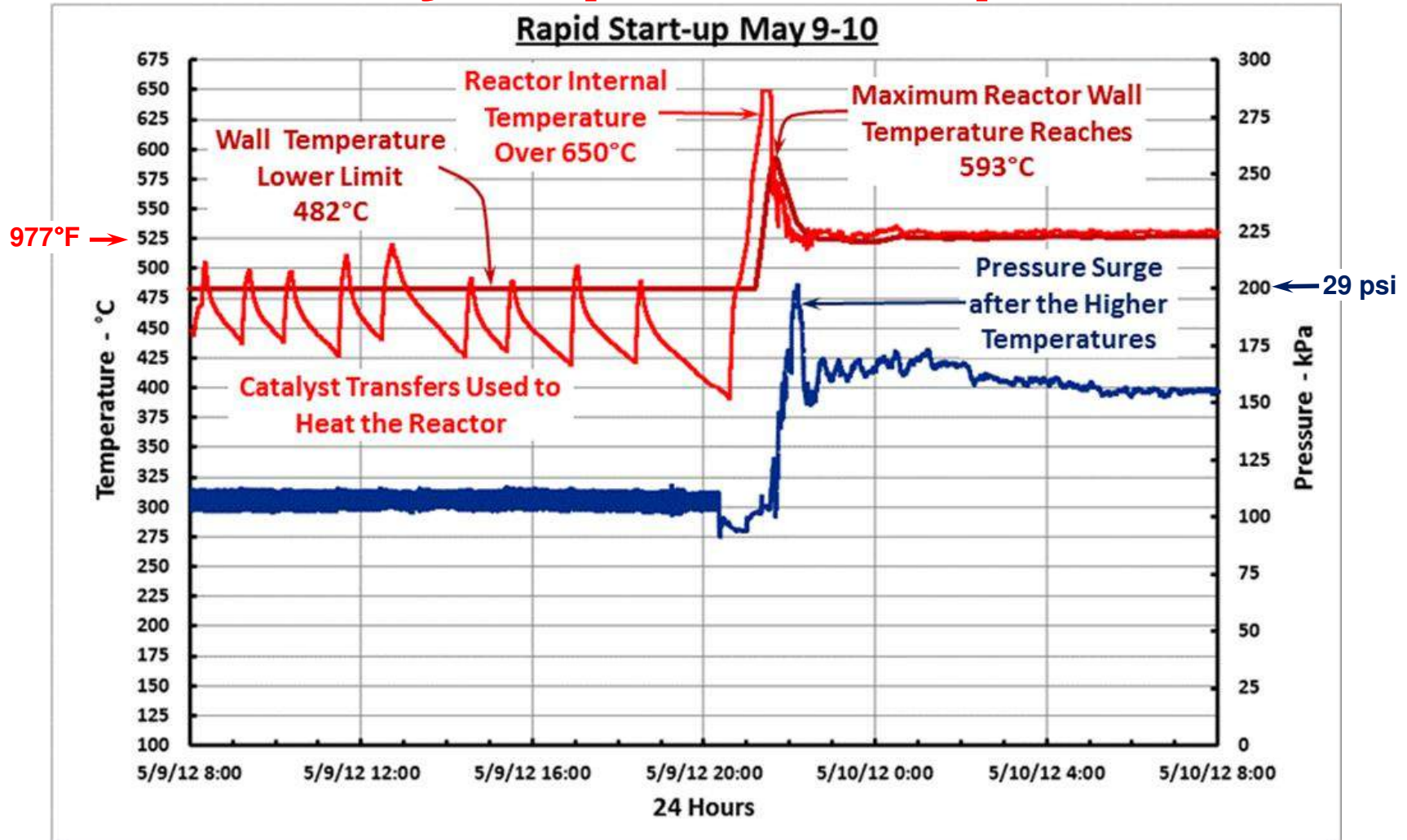
- Creep cracking occurred for the first time away from welds
- Crack locations indicated the cracks were related to vessel geometry.
- Finite element analysis revealed additional stress was introduced due to rapid temperature changes.
- Reviews of process information identified very rapid start-ups sometimes occur
- Process improvements were made to slow the heating rate
- Cracks were repaired by installing an insert plate
- Vertical seams were reinforced with weld overlays
- Analysis was conducted to determine the vessel remaining life
- The reactor could make it to the 2015 turnaround date

Thermal Stresses Around the Manway During Rapid Start-ups



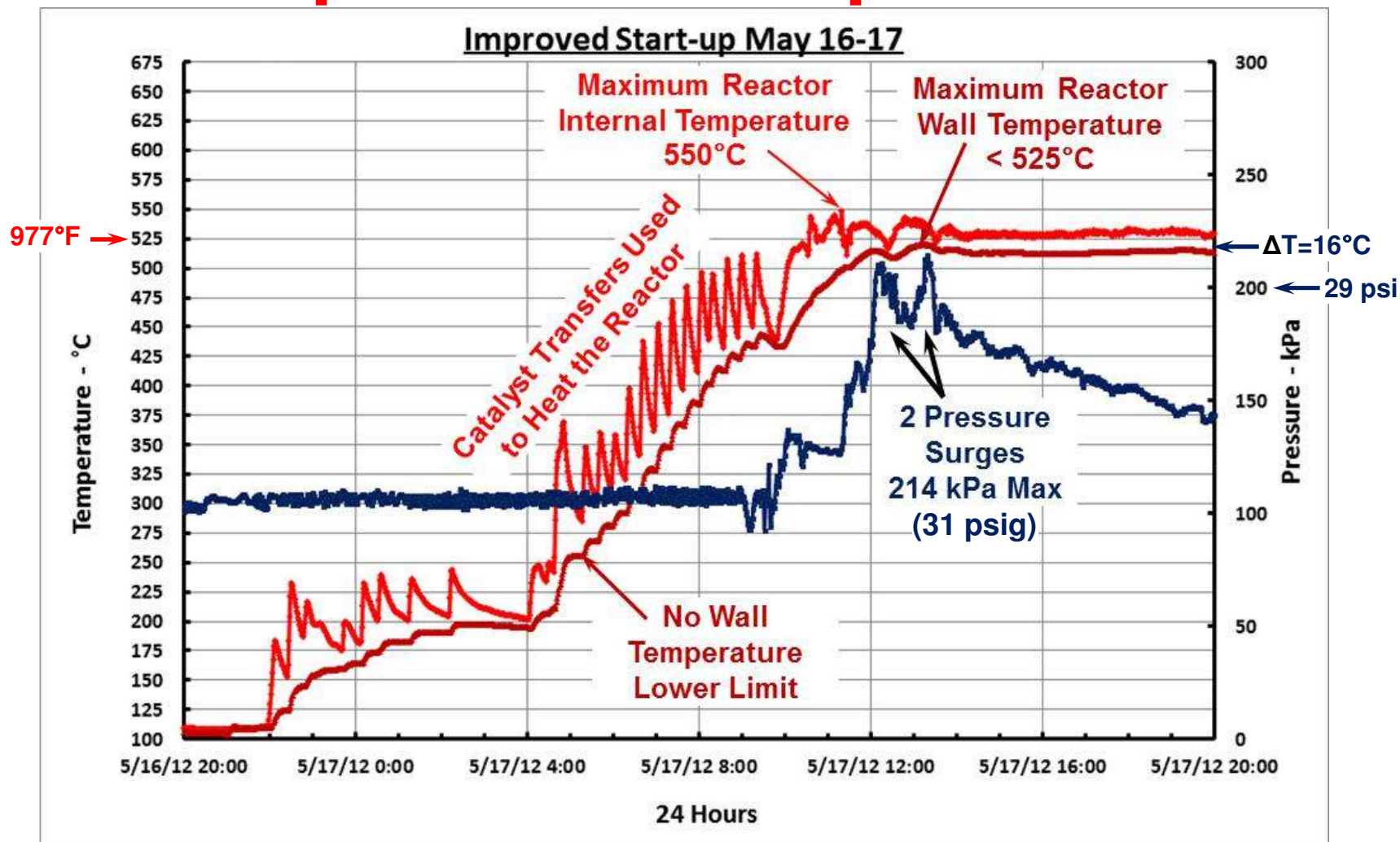
3D finite element analysis indicated that rapid heating could produce 15.9-26.2 MPa (2.3-3.7 ksi) higher stress in zones adjacent to the manway reinforcing plates.

Unusually Rapid Start-up in 2012



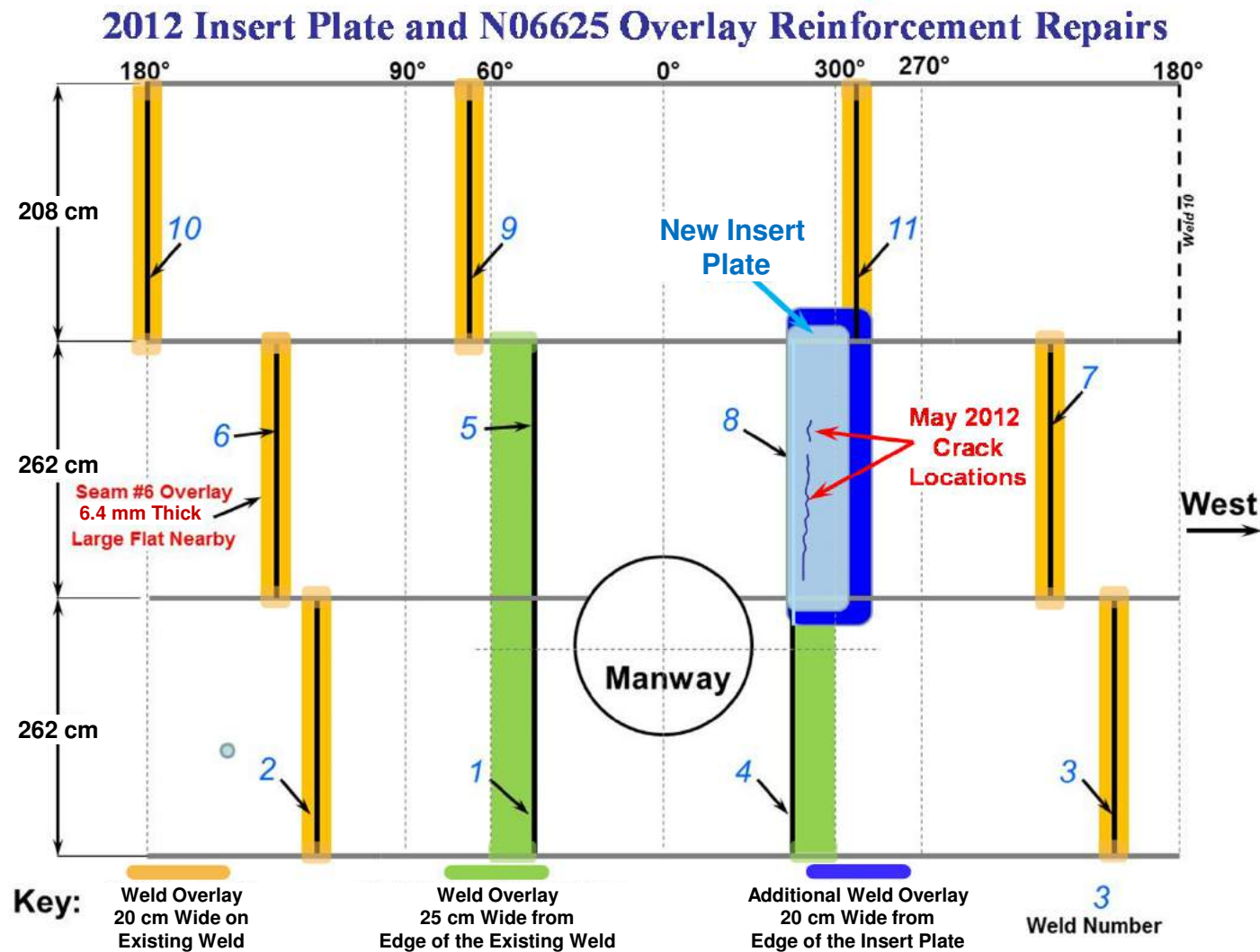
Past rapid start-ups resulted in cracking 6-15 cm (2-6 Inches) away from the welds in the high stress zones surrounding the manway reinforcing plate.

Improved Start-up in 2012

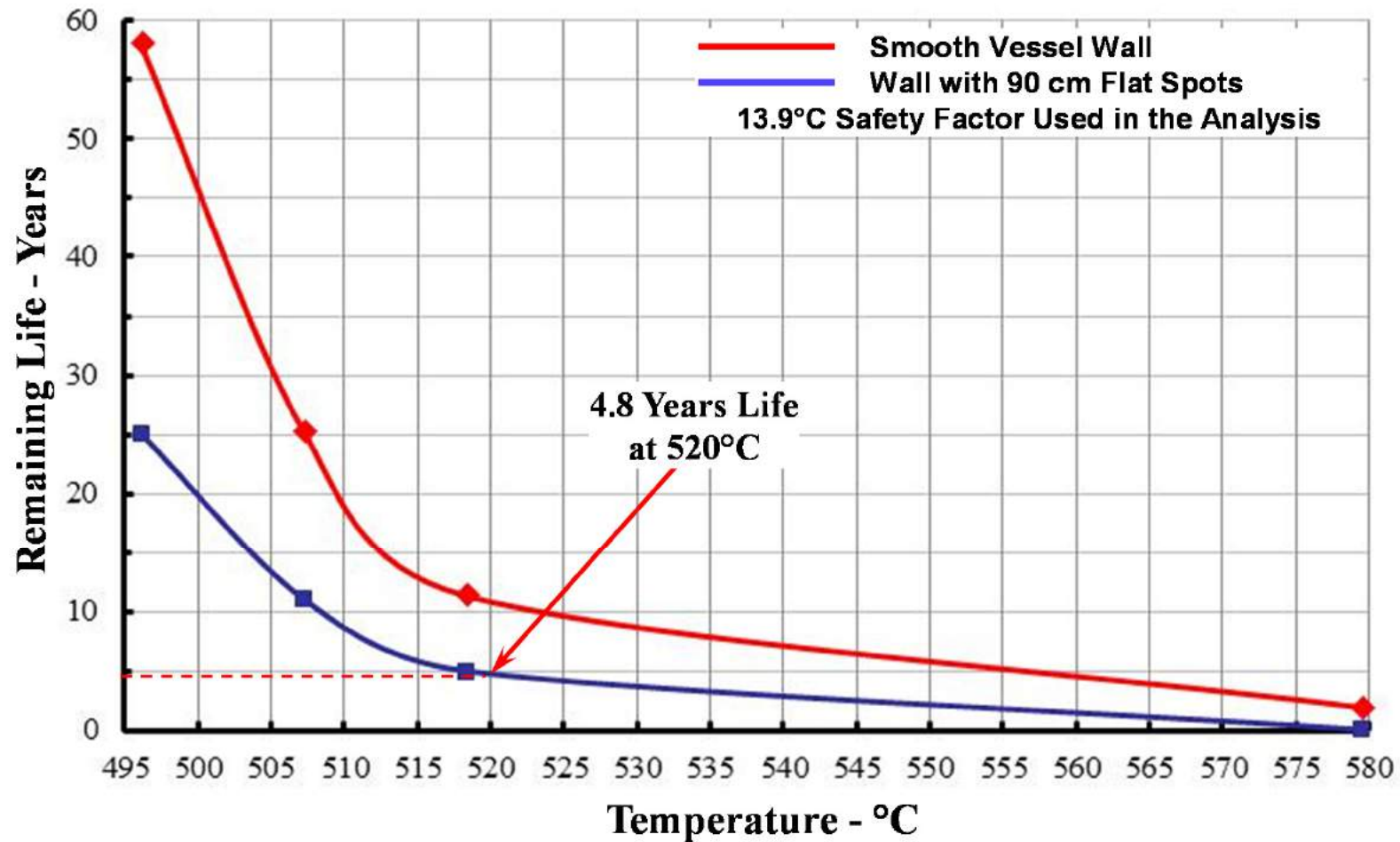


Improvements: Wall temperature was available to operators over the entire start-up
Insulation was changed so that there is a 16°C ΔT internal vs. surface

2012 Weld Overlay Repairs and Insert Plate Repair



Remaining Life of the Reactor Based Upon 2012 Creep Tests



2014 Weld Overlay Cracking and Repairs

- A different type of creep cracking occurred in January 2014 in the weld overlay
- Cracking was caused by residual stress in the Inconel 625 welds
- On-line repairs were made to keep the FCC operating in January
- First repairs involved installing a 10-Inch pipe cap over the crack following ASME PCC-2 guidelines – Article 2.4 “Welded Leak Box Repair”
- FEA analysis indicated the crack would be in compression and crack propagation would stop
- Critical creep crack size was 41-Inches – much larger than the cap size
- Acoustic emission monitoring was considered for monitoring cracks inside leak box repairs – this wasn’t done since the critical size was large
- FEA analysis and Omega creep life analysis indicated the vessel wall creep life would be greater than 3 years with the leak box repairs

The 4.5-Inch Crack in a Vertical Weld Seam



This crack was tight, and it was easily peened to stop the leak until the pip cap was installed.

The Weld Seam After the Repair

10-Inch Schedule 160
Carbon Steel
Pipe Cap
1 1/8-Inches Thick

Valves to
Control Argon
Purge Gas Flow
During Welding

*3 more repairs
like this were
made in 2014*

Conclusions

- Weld overlaying the vessel weld seams with UNS 06625 stopped creep crack propagation.
- Creep testing of welds that had been weld overlay repaired indicated that the repaired welds had more remaining life than the vessel wall without welds.
- Analyses revealed that large nozzles and changes in vessel wall thickness can create zones of higher stress if the vessel experiences significant changes in operating temperature. These zones can lead to creep failures.
- Insulation removal from a vessel while the vessel is at elevated temperature should be avoided. Safe insulation removal temperatures need to be developed based upon the vessel and insulation design.

Conclusions

- The cyclic operating pressure that this vessel experienced probably contributed to the creep cracking. Cyclic stress in a vessel should be taken into account in vessel design. API 579 includes this in creep fitness-for-service analysis.
- ASME PCC-2 welded leak box repairs were made while this vessel was operating, and those repairs stopped or significantly reduced creep crack propagation – we will know soon.
- The creep properties of UNS 06625 weld overlays need to be analyzed including the residual stresses from welding. High level of residual stress that can lead to creep cracking when the temperature is near 510°C. Inconel 625 has a temperature range where it is creep brittle.

Recommendations

- It is recommended that procedures be developed by industry for repairing equipment containing creep cracks with external weld overlays.
- It is recommended that ASME develop guidelines for including the effects of large nozzles and changes in vessel wall thickness in remaining life calculations for equipment that experiences rapid changes in temperature.

Acknowledgements:

The author thanks Peter Carter of Stress Engineering Services for his help with the analyses of this reactor vessel.

Also thanks to the WSI /AZZ welders who made the on-line repairs while the vessel wall was at 515°C.

Questions?

