Repair and Retrofit of a Coke Drum Skirt Attachment Weld

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Problem Overview

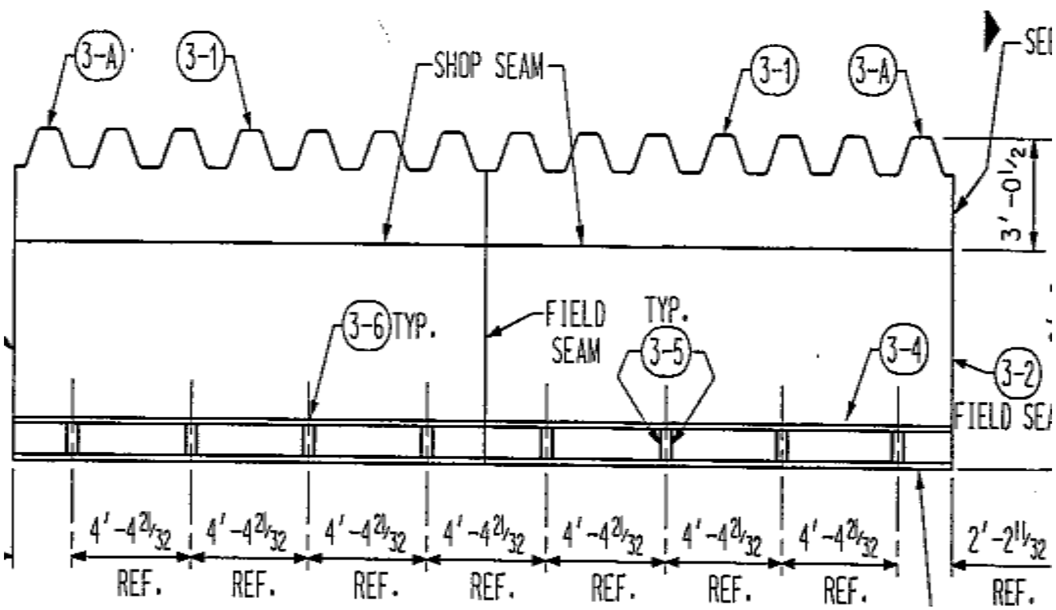
- Extensive cracking noted on skirt attachment weld of relatively young coke drums
- Needed to find a method to repair and extend the life of the skirt attachment to maximize the life of drums otherwise in very good condition
- Very short time frame to TA to analyze, design, fabricate, and implement solution (June-Sep)

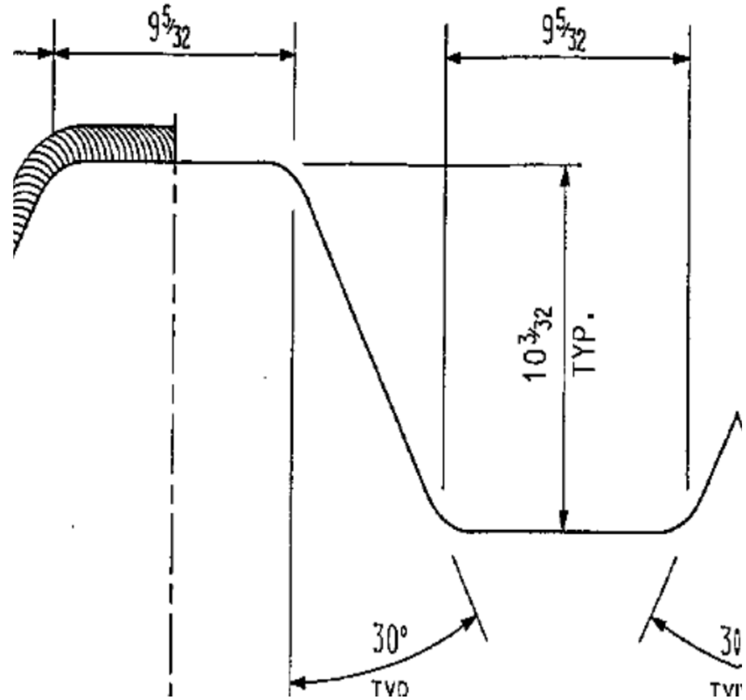
Presentation Overview

- Background
- Inspection of the cracked attachment welds
- Fitness-for-service assessment
- Retrofit plan
- Implementation of retrofit
- Subsequent re-inspection results

Background

- 1-1/4 Cr – ½ Mo drums installed in 2007
- Drums Dimensions: 22’ – 0” ID x 72’ – 4” TT
- The skirt-to-shell attachment incorporates a scallop type lap-joint design with a continuous full leg fillet weld

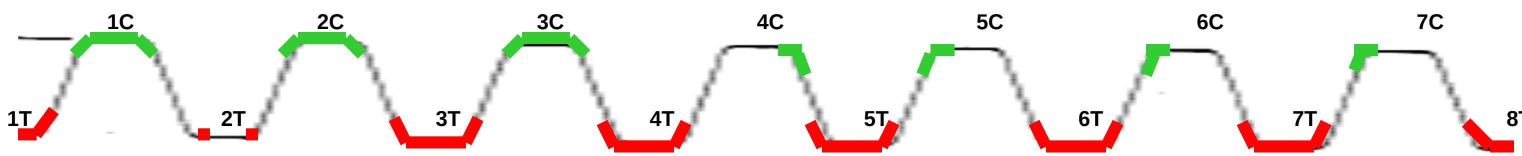




Background & Inspection

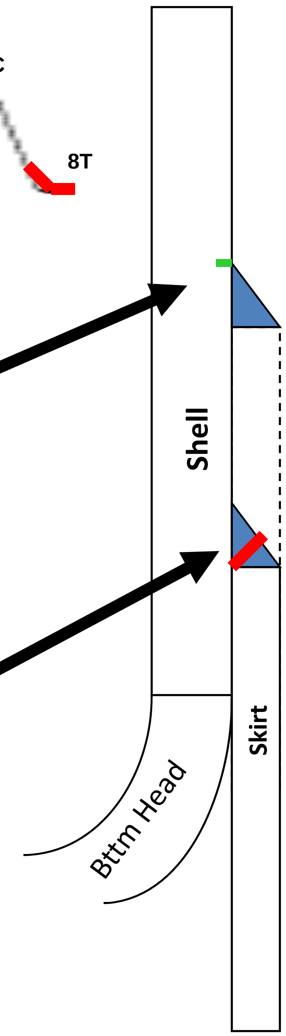
- Routine skirt attachment inspection scheduled prior to the Fall 2011 Turnaround
- Inspection was completed in June while the drums were in operation
- Extensive cracking noted during the inspection extending nearly full circumference of both drums
- Cracks were sized with dry, color contrast, MT and depths determined using UTPA
- The attachment weld was primarily cracked in two areas:
  - In the shell at the skirt attachment crown.
  - Through the throat of the trough fillet welds.

Skirt weld cracks

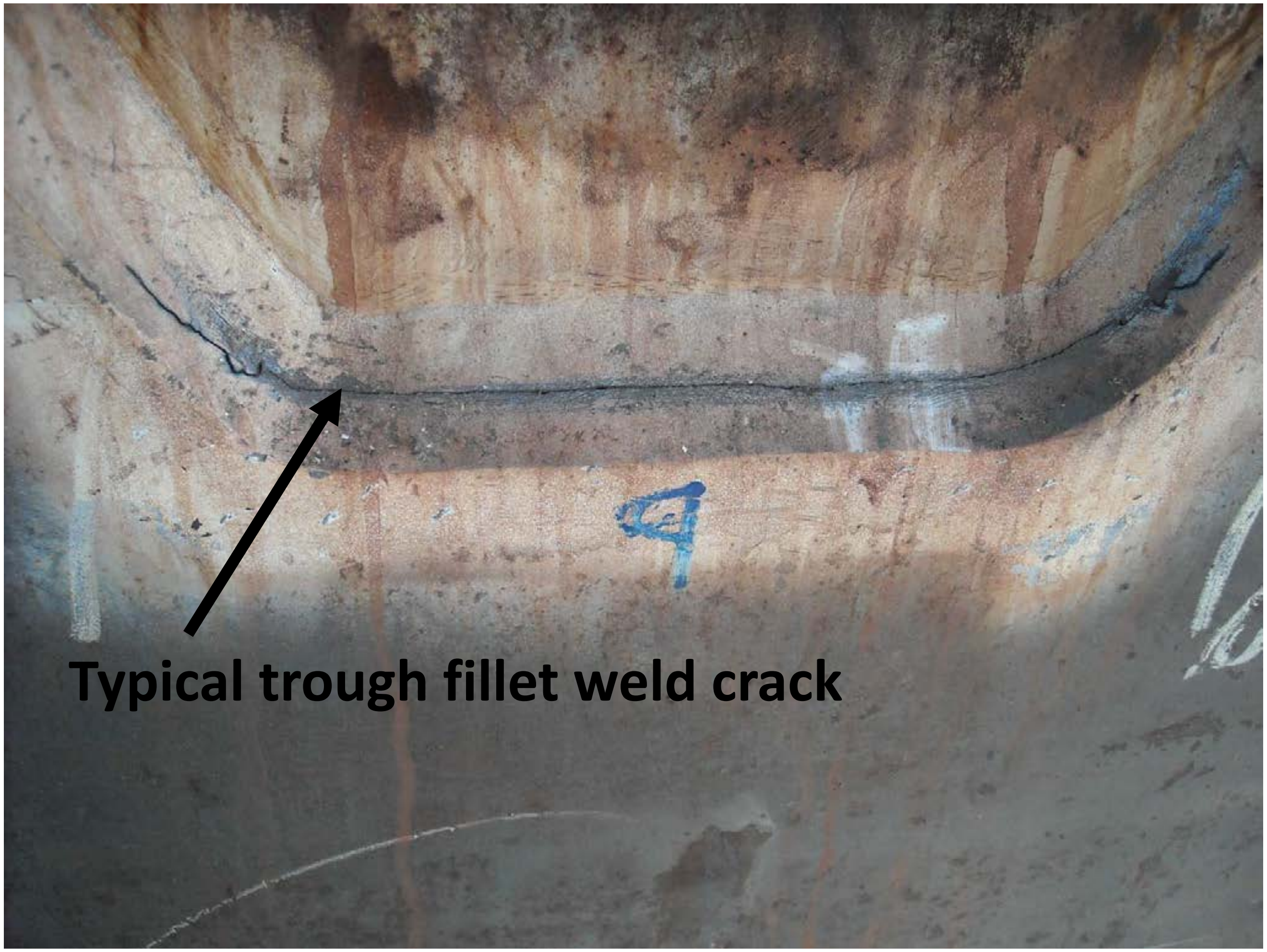


Peak cracks were at the toe of the fillet weld and in the base metal. Cracks were determined to be less than 0.10” deep.

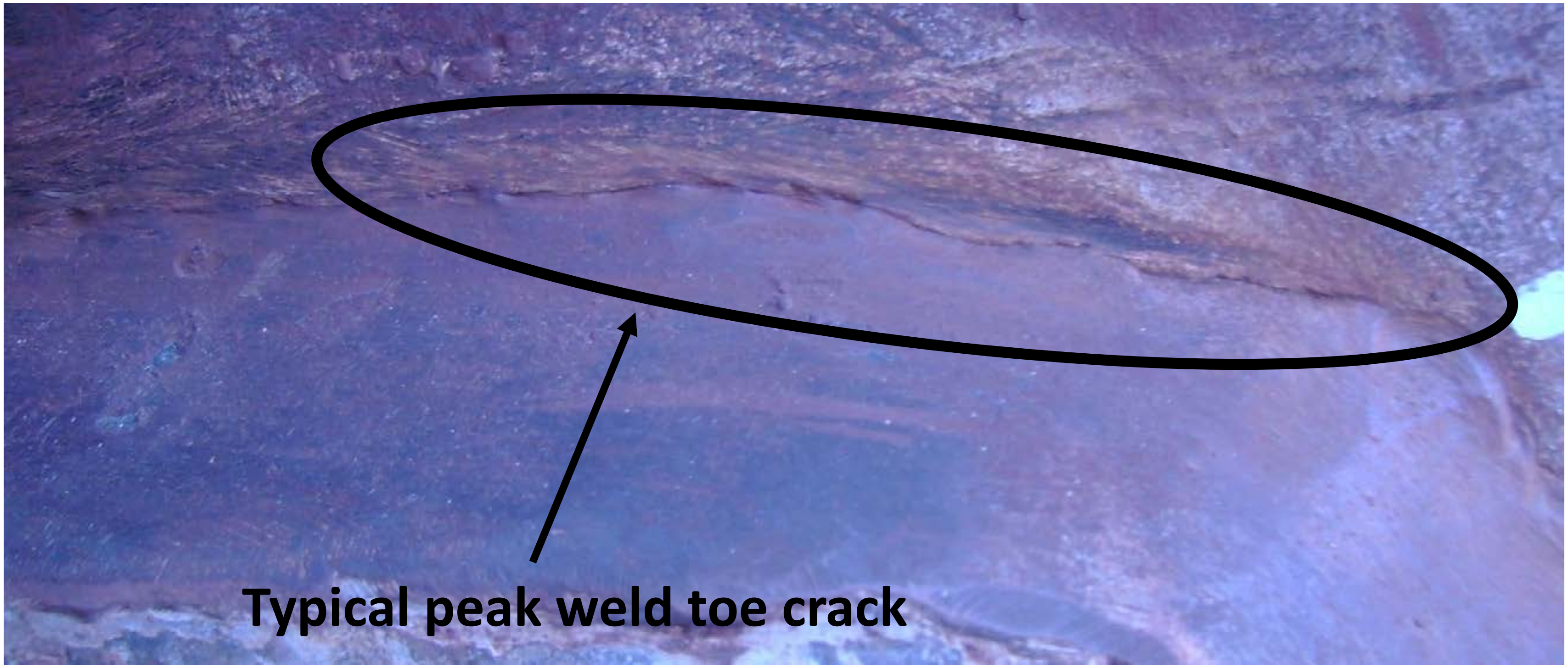
Trough cracks were in the fillet weld throat. Cracks which did not extend through the full weld thickness appeared to originate at the weld root.



Trough Cracks



Peak Cracks



CHS' Approach to the Problem

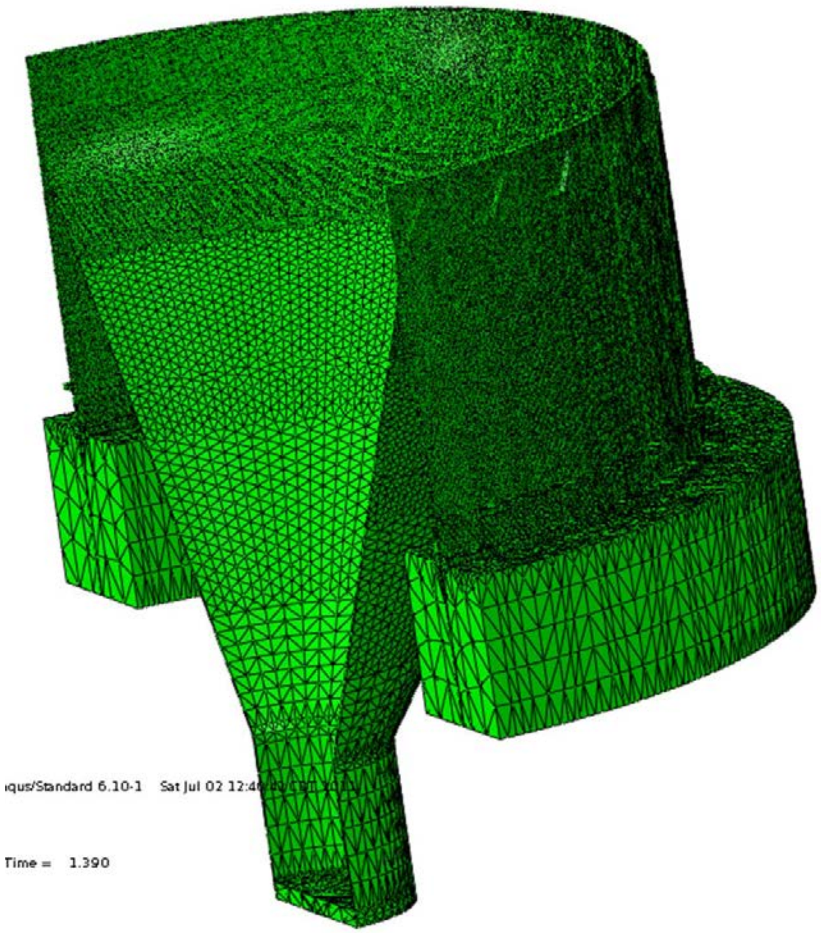
- Four main issues
  - Fitness-for-Service evaluation for continued operations
  - Repair plan if necessary to allow continued operation until the scheduled turnaround
  - Long term repair approach needed
  - Short timeframe of ~10 weeks (mid June – Early September)
    - Develop & evaluate design alternatives
    - Detailed design
    - Material procurement and prefab to support installation during TA
- Procurement, fabrication and installation handled directly by CHS.

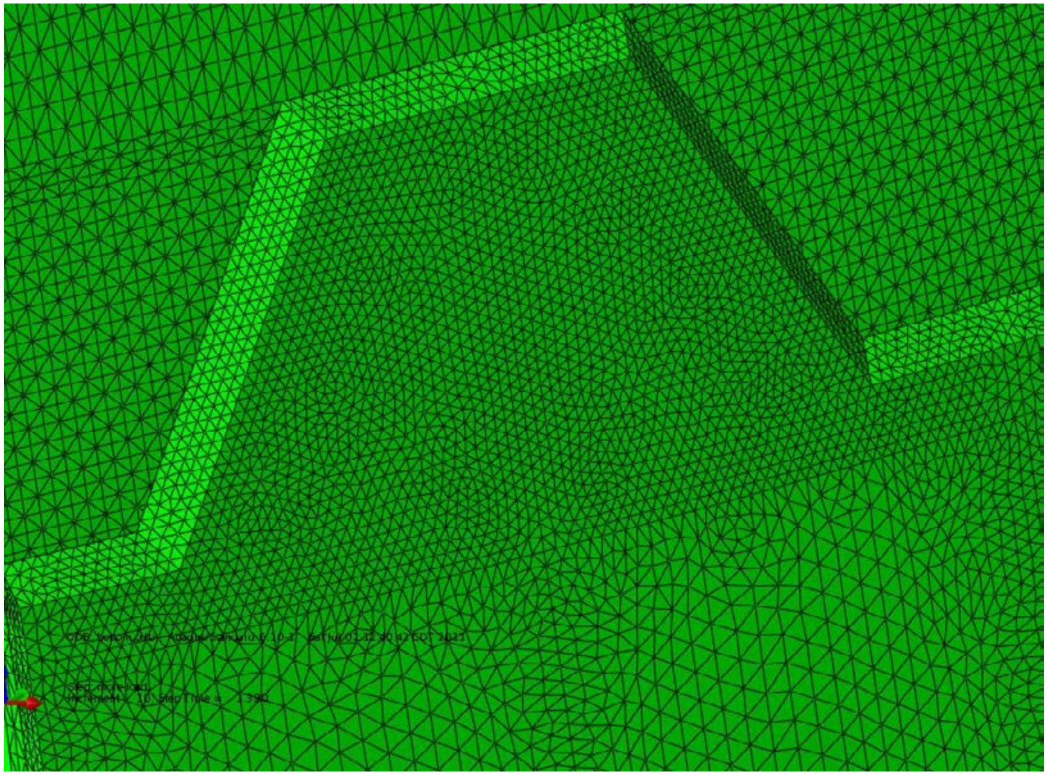
Fitness-For-Service Analysis

Fitness-For-Service Analysis of Skirt Stability

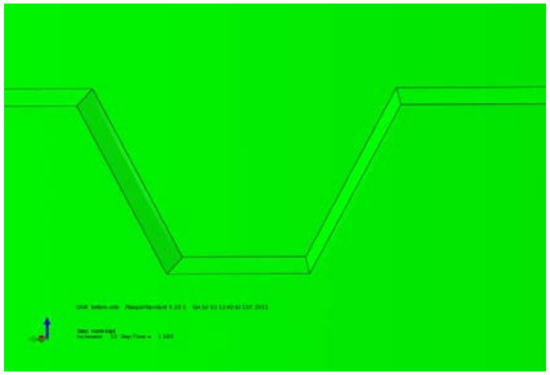
- Mechanical loads at operating and corroded condition:
  - Drum Weight
  - Seismic moment and shear force.
  - Wind moment and shear force.
- Thermal loads during typical filling and quenching temperature profiles.

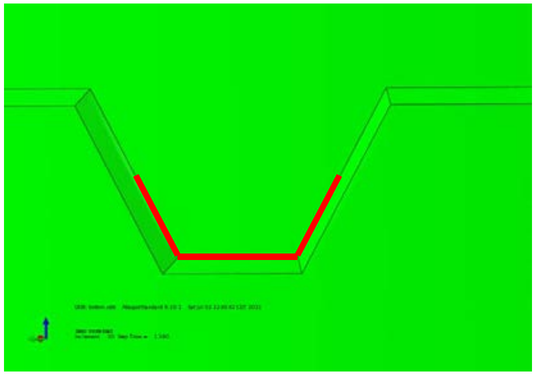
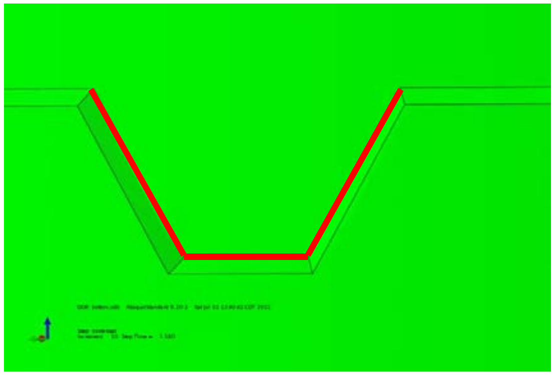
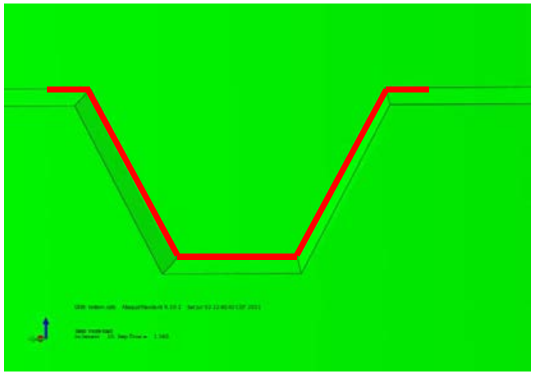
Finite Element Model





Model Cases 1 to 7



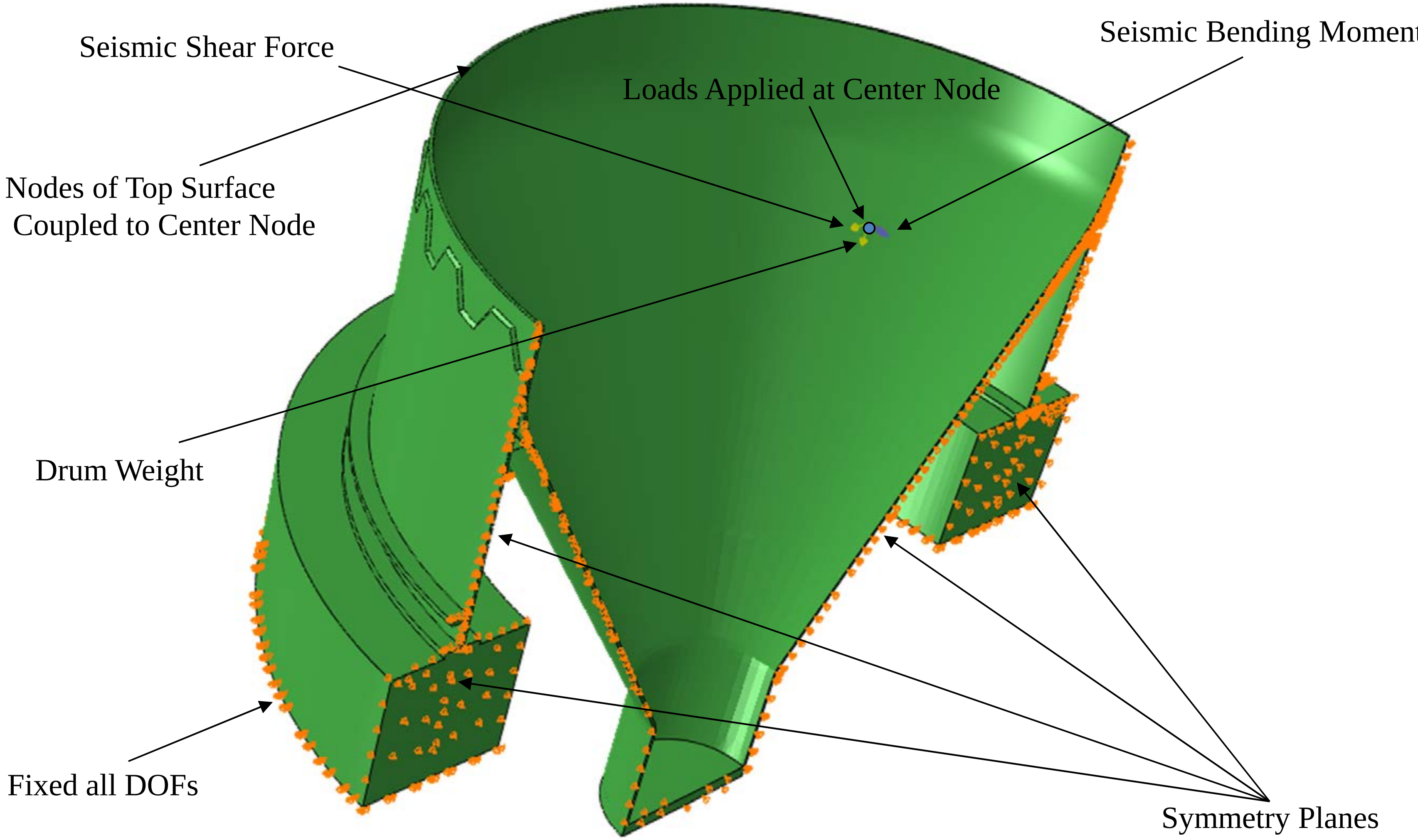
Model Case 1 : Fill, ASME Load Combination 5 , No Weld Crack.
Model Case 2 : Fill, ASME Load Combination 5 , Crack Size of 9.16 "
Model Case 3 : Fill, ASME Load Combination 5 , Crack Size of 20.81 "
Model Case 4 : Fill, ASME Load Combination 5 , Crack Size of 32.47 "
Model Case 5 : Fill, ASME Load Combination 5 , Crack Size of 37.05 "
Model Case 6 : Fill, ASME Load Combination 1, Crack Size of 37.05 "
Model Case 7 : Quench, ASME Load Combination 1, Crack Size of 37.05 "

Load combinations of the 2007 edition of API 579/ ASME FFS:

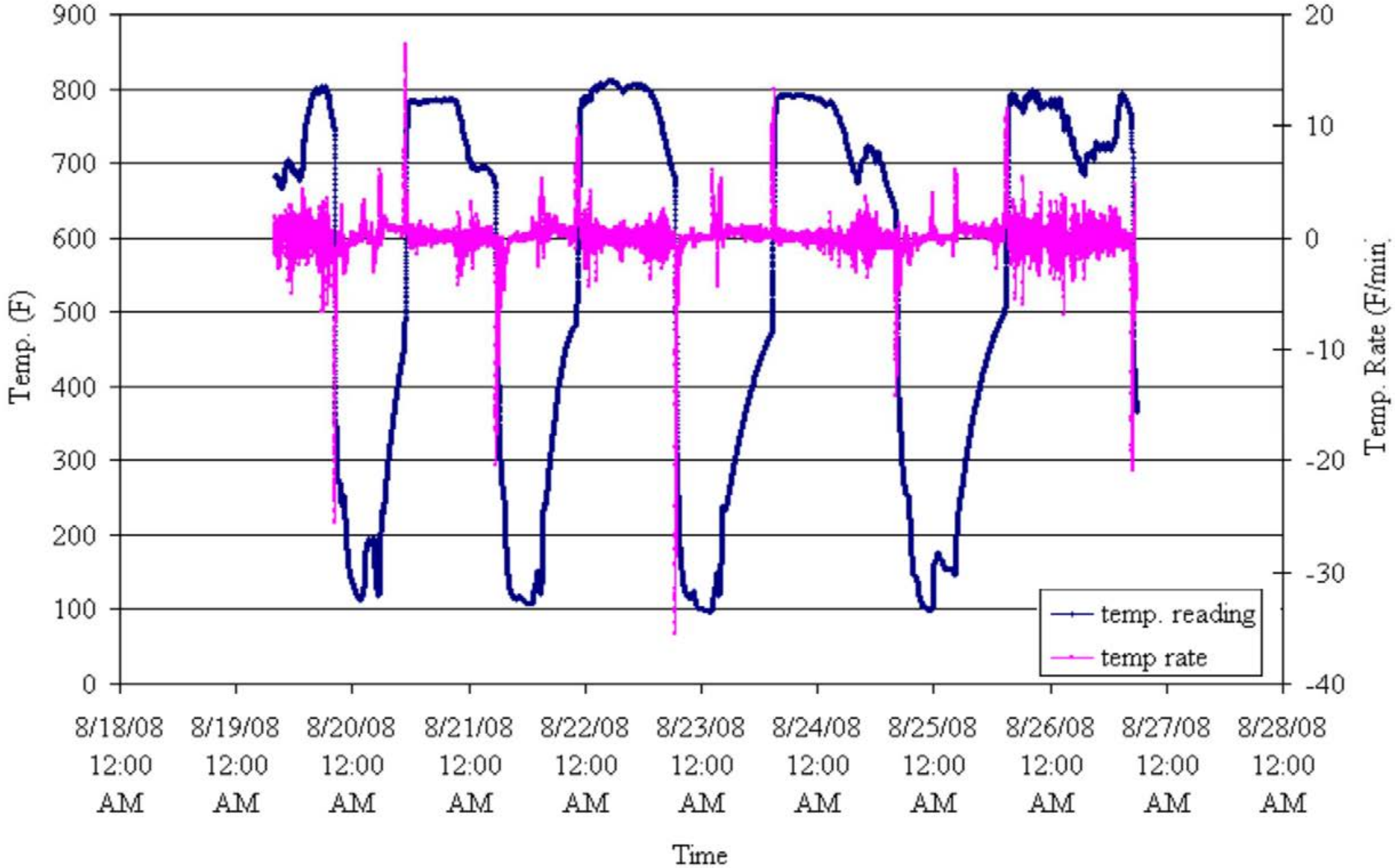
- Load combination 1: βD , where D is drum weight and β equals 3.15.
- Load combination 5: 0.86βD +0.71βE, where E is the seismic loads.

Loads

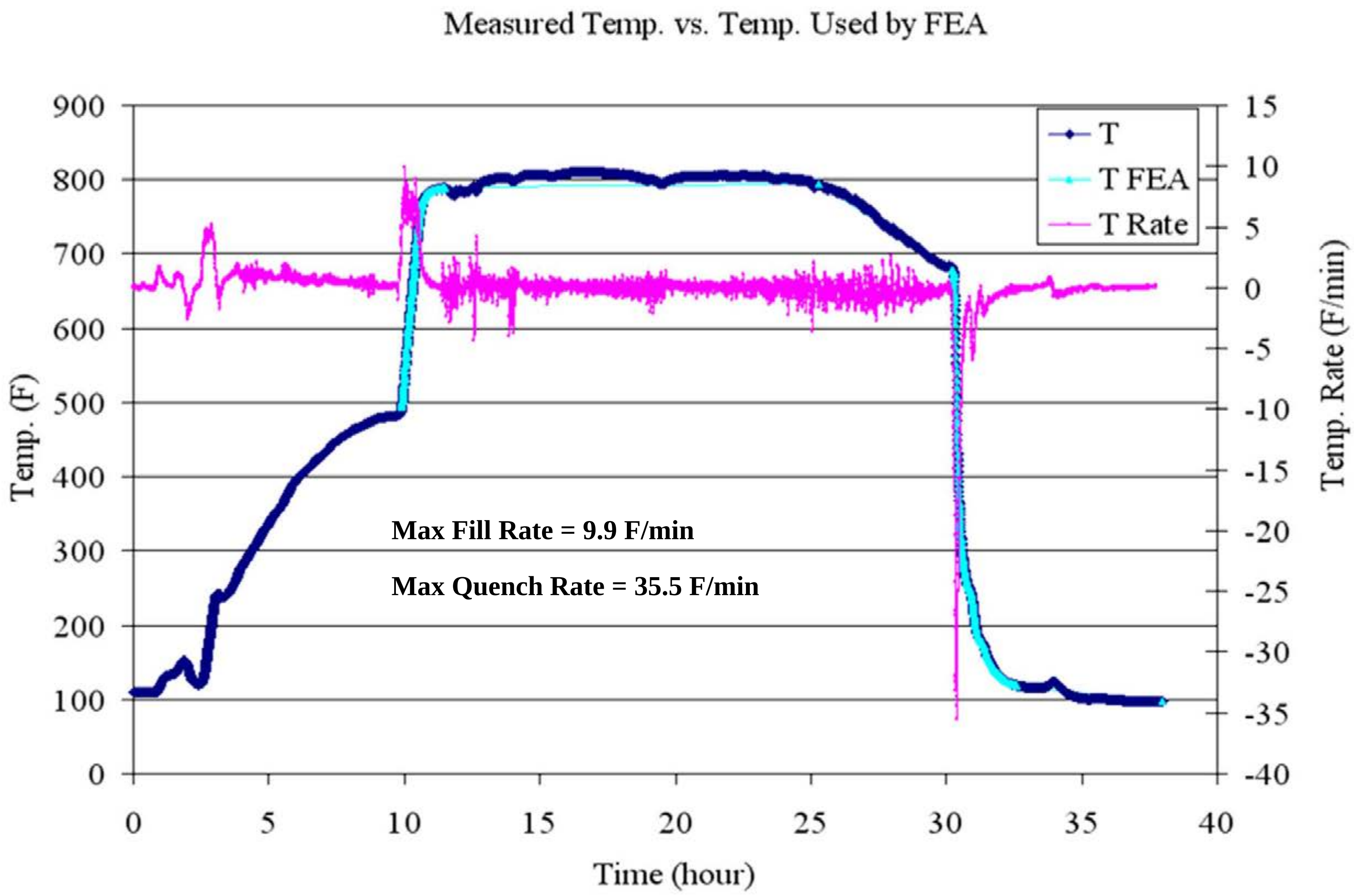
Mechanical Loads and Boundary Conditions



Operational Temperatures Provided by CHS

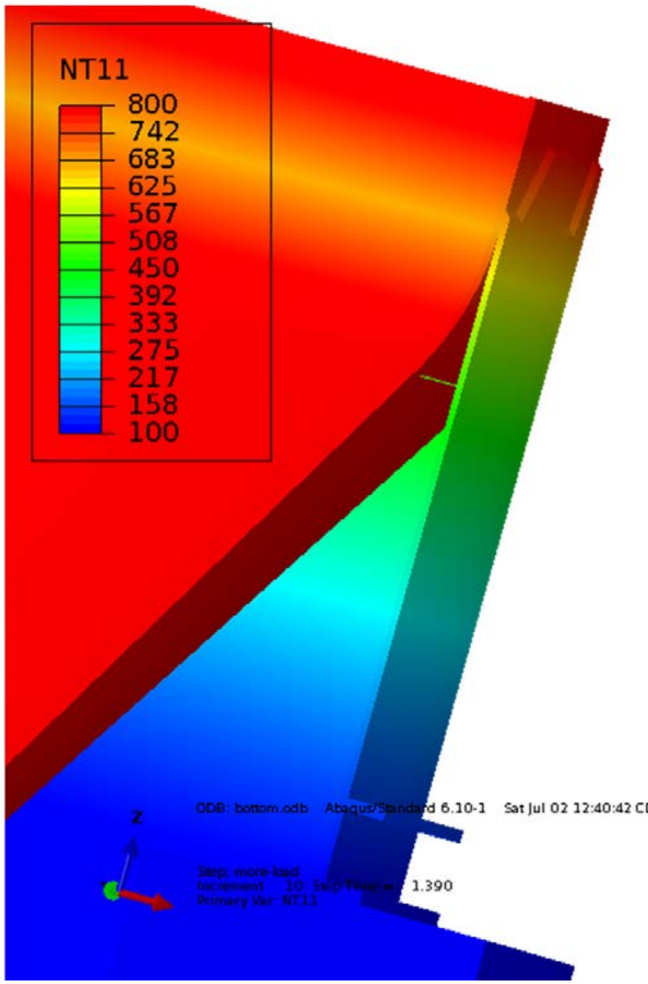


Representative Cycle

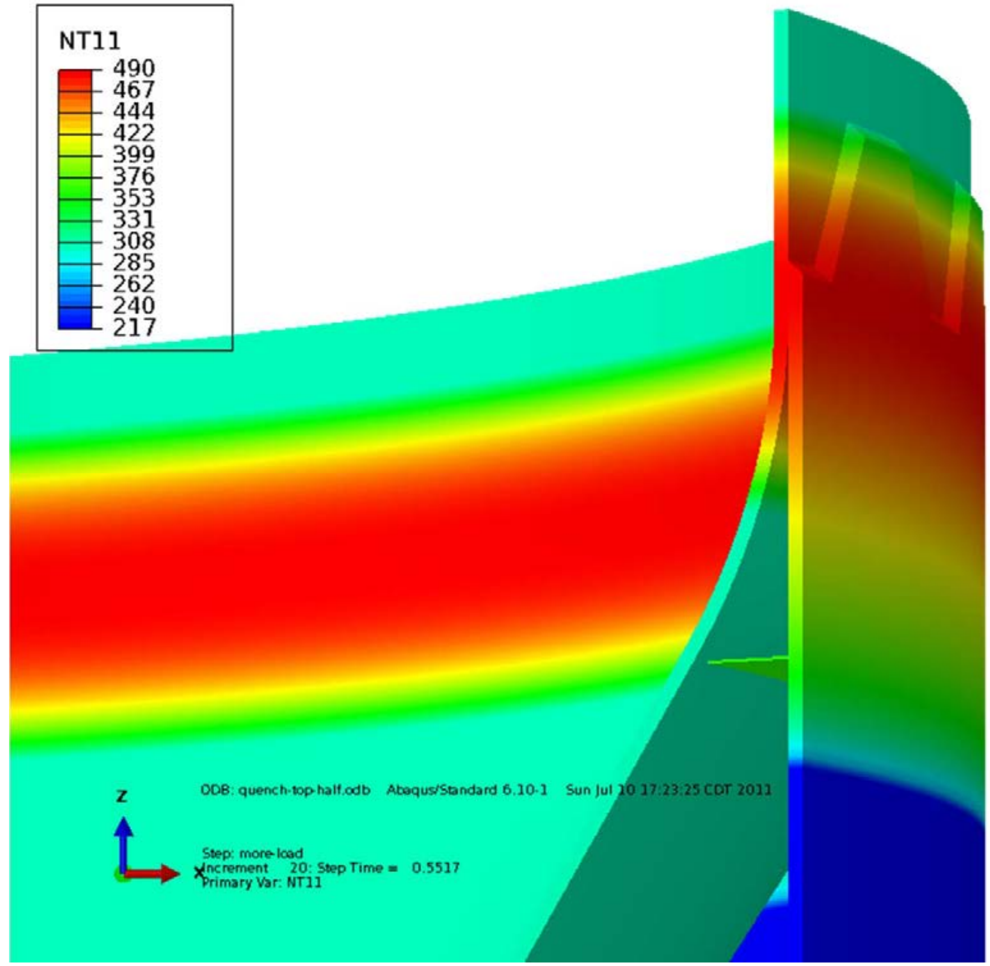


Thermal Loads

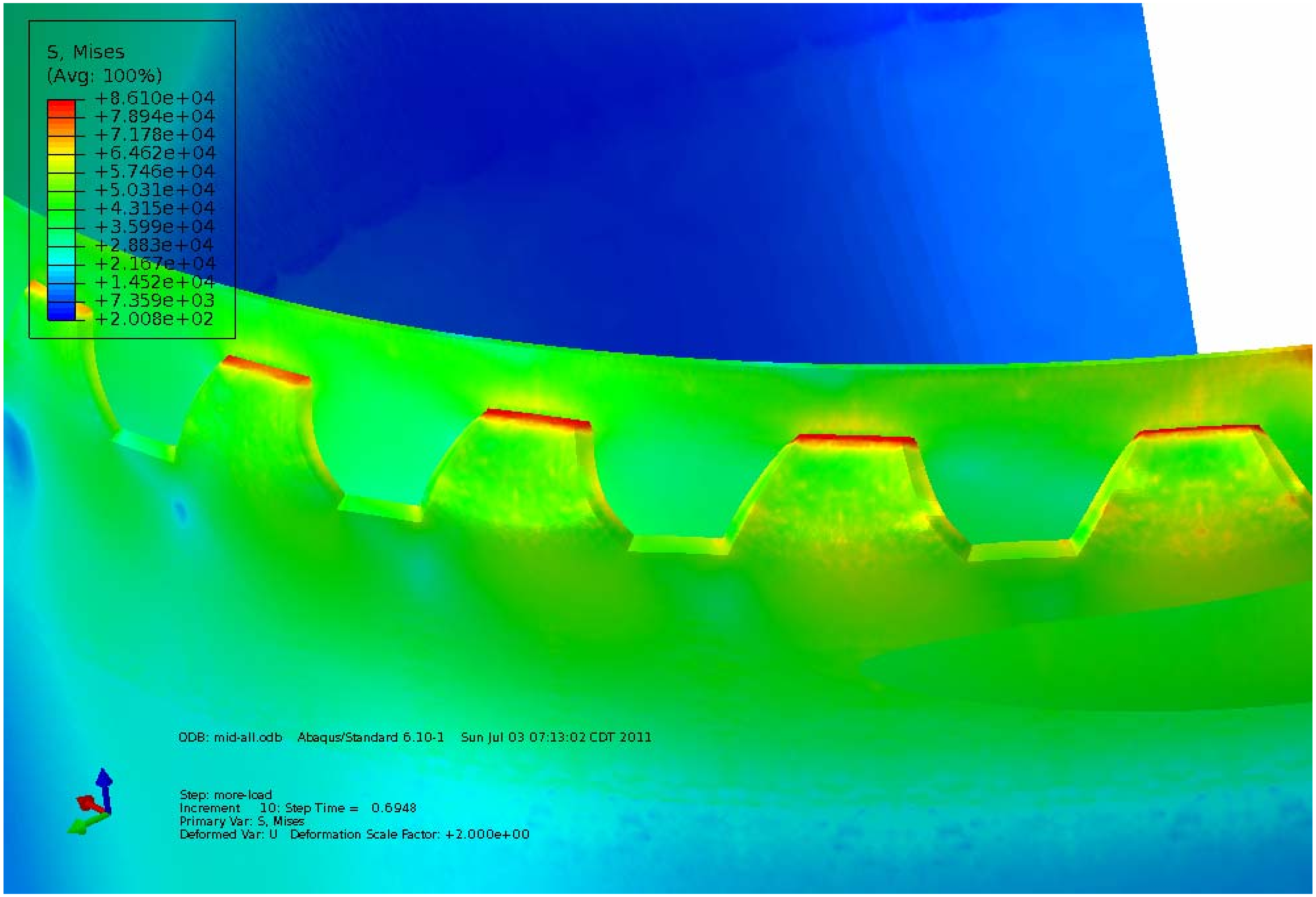
Fill



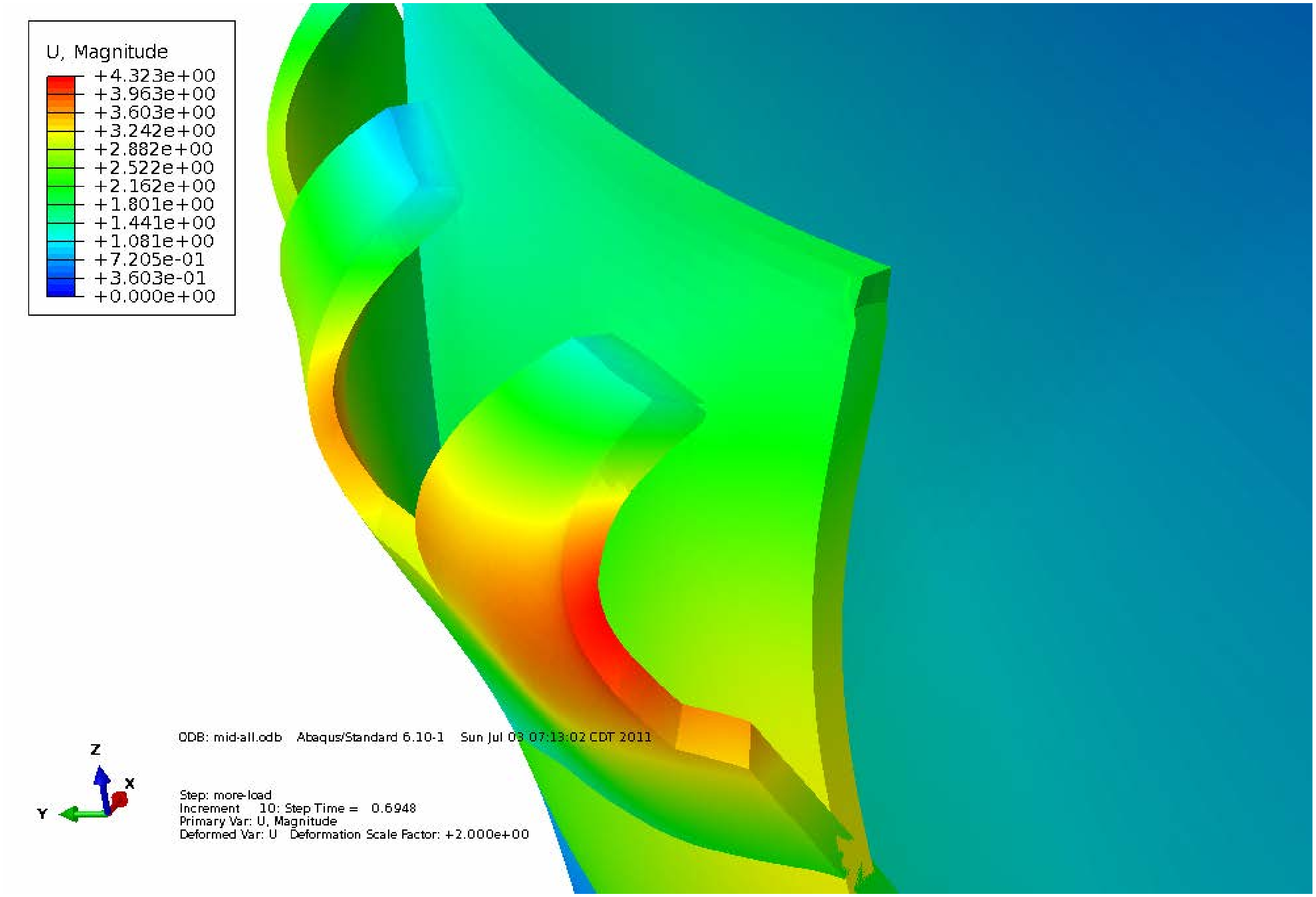
Quench



Von Mises Stress @ Collapse (Case 4)

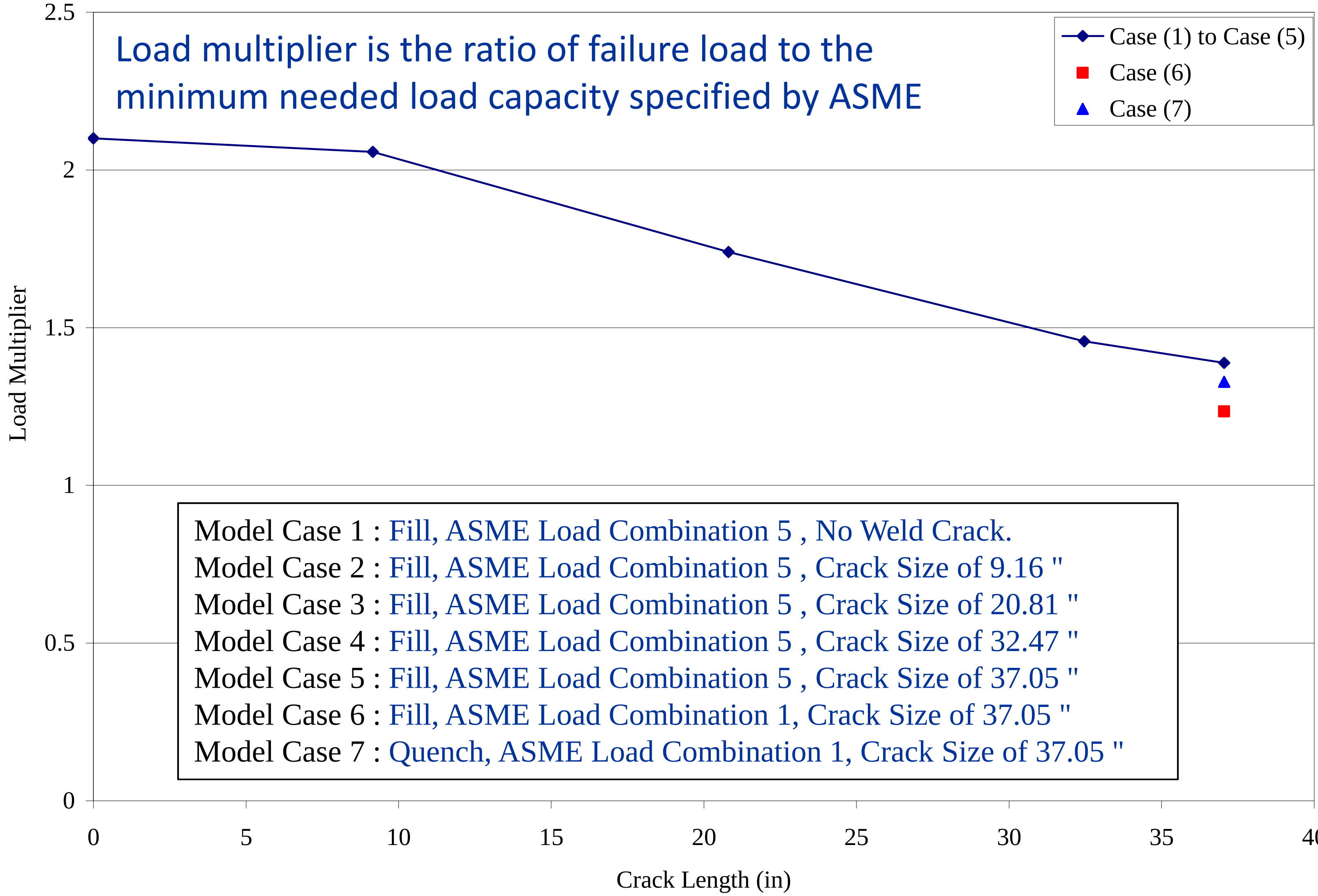


Displacement Magnitude @ Collapse (Case 4)



Summary of Results

Load Multiplier vs. Crack Length Under Seven Model Cases

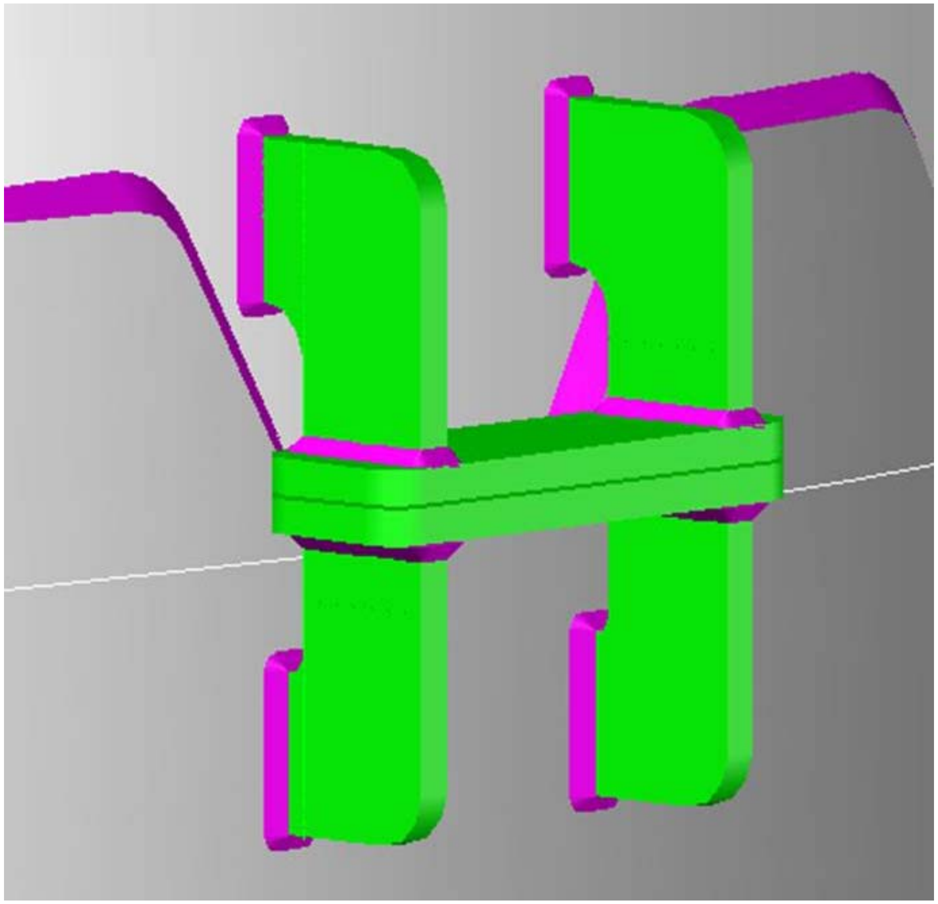


Summary of FFS Analysis

- For the longest crack of 37.05", the minimum load multiplier was 1.23. This means that the remaining ligament of the weld (half of the top weld attachment) had 23% more strength than that required by API-579/ ASME-FFS.
- The combination of drum weight and filling temperature profile was the worst load case.
- Skirt should remain stable with sufficient margin as long as one half of the peak of the scallop remains intact.
- In lieu of complex fracture mechanics study, frequent inspections used to monitor crack propagation until TA.

Long Term Repair Approach

- Install sliding brackets for load transfer
- Allow through-throat cracks in scallop troughs to continue to propagate
- Manage crack propagation at scallop peaks by crack removal and addition of planned notches

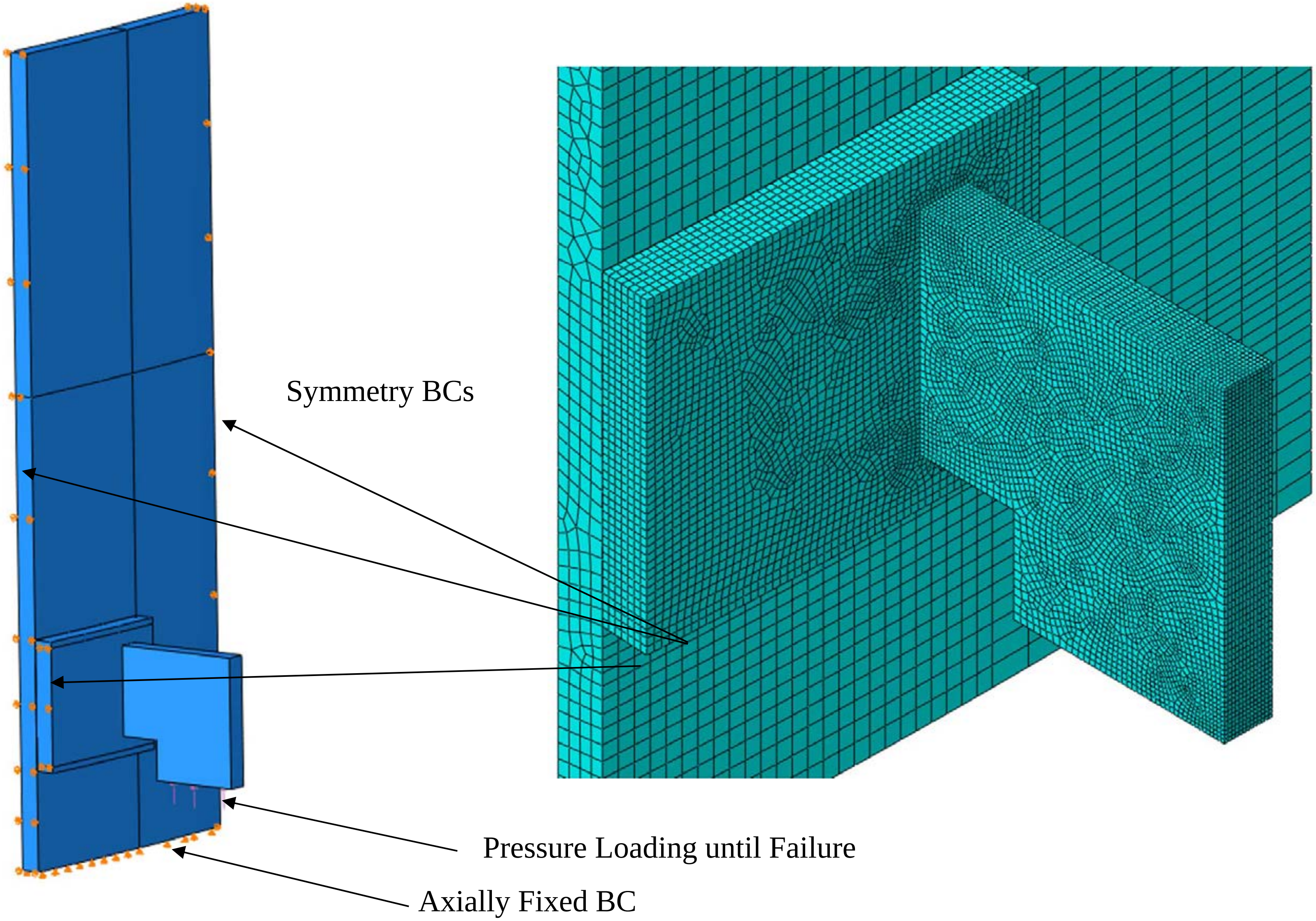


28 brackets per drum

Retrofit Details

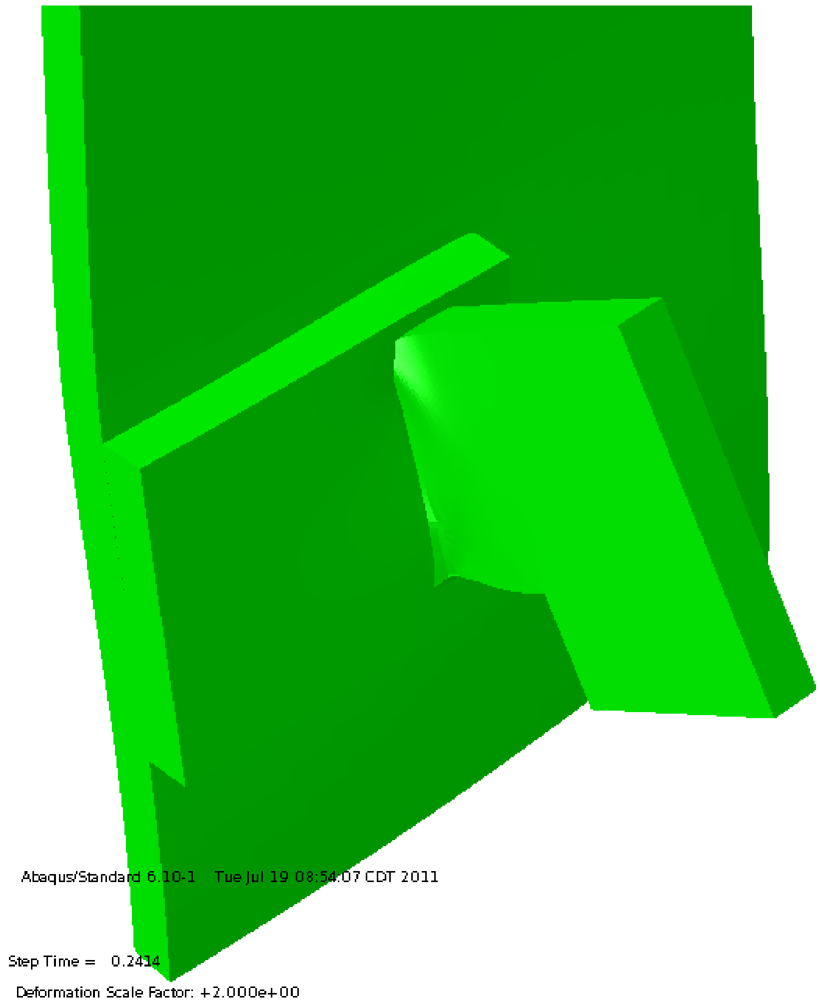
- Bracket fabricated from 1-1/4 Cr – ½ Mo
- Inconel 625 temper-bead welding
- Corners rounded and welds ground smooth.
- Matching sliding plates pre-loaded prior to welding.
- Nitronic 60 insert plates used to minimize galling.
- Brackets located to maximize access to scallop peaks for future repairs.

Model

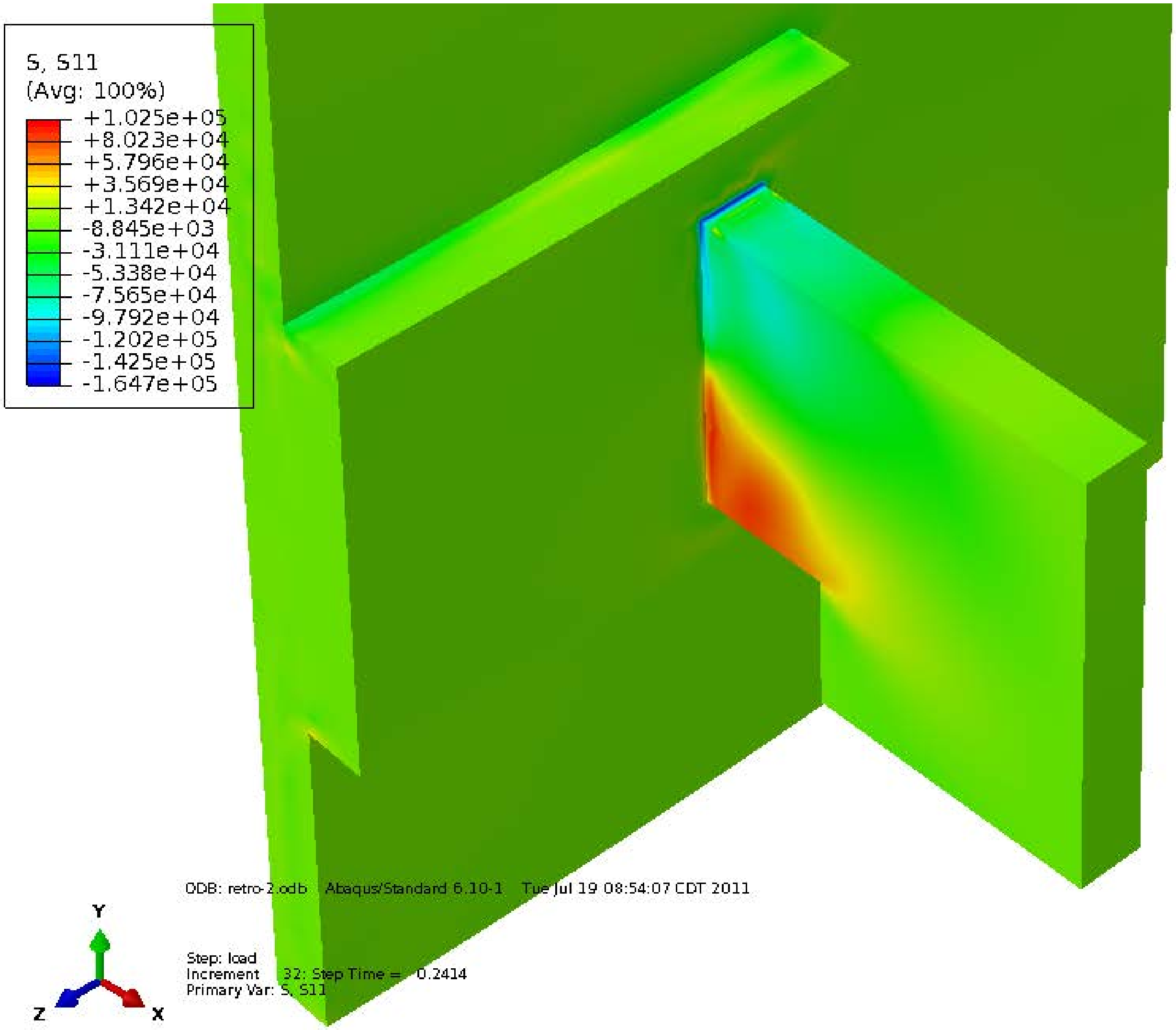

Symmetry BCs
Pressure Loading until Failure
Axially Fixed BC

Deformed Shape @ Collapse

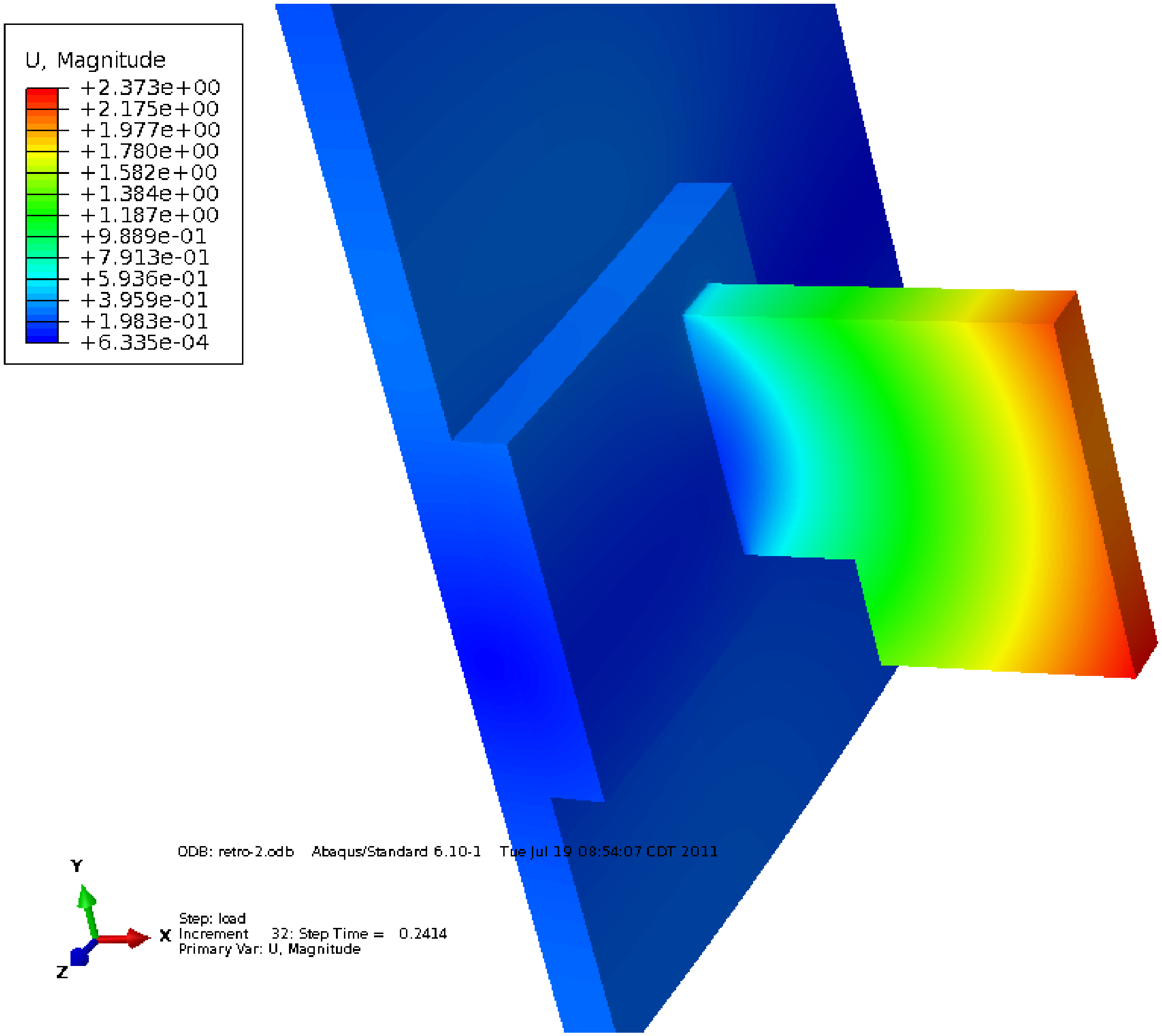
Scale Factor of 1



Stress along X Direction @ Collapse



Displacement Magnitude @ Collapse



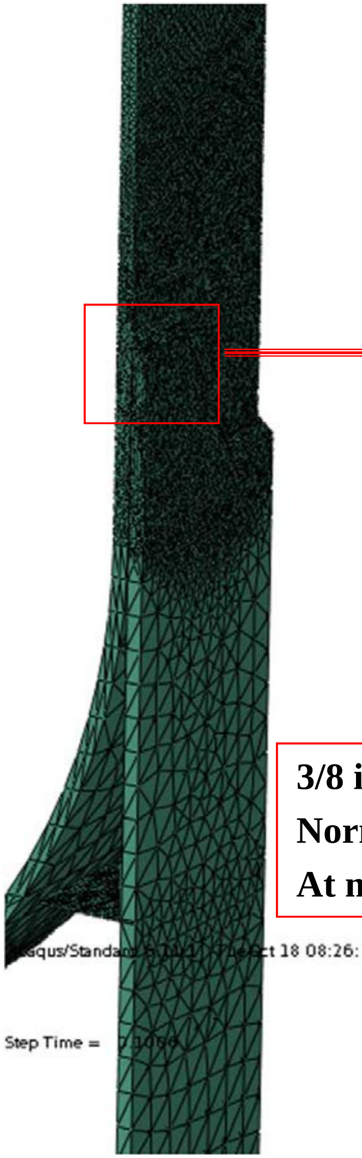
Summary of Retrofit Analysis

- Retrofit replacement model plastically collapsed at 3.667 times the operating weight of the drum.
- Using API-579/ ASME-FFS Standard of 2007 which requires a factor of 3.15, this bracket has adequate strength to resist nominal loads
- The repad (or filler plate) is an option that can potentially improve the logistics of field implementation. Its inclusion does not materially impact the safety margin of the retrofit which is controlled by the bending capacity of the bracket plate.

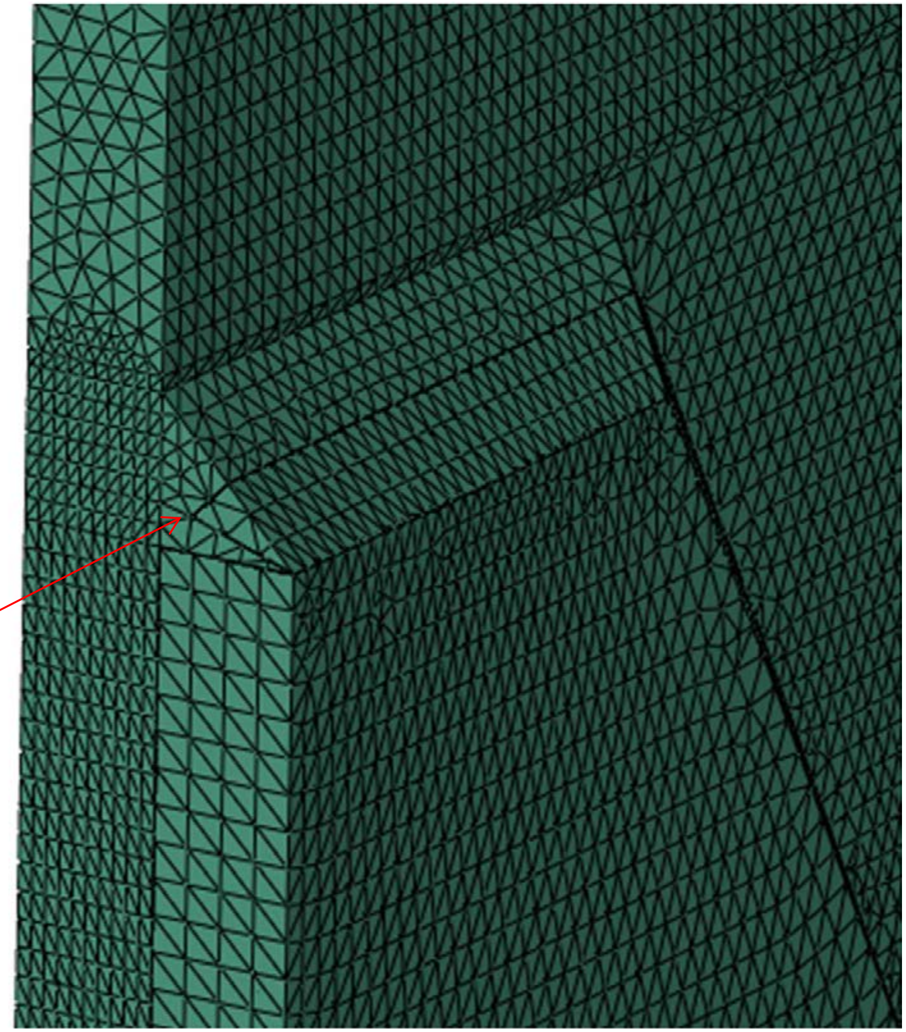
Analysis of Slotting Effect

- Examine the effectiveness of adding slots in "steering" cracks away from pressure boundary material & into fillet weld
- Approach
  - Simulate ~3/8" deep slots in the fillet attachment throat of scallop peaks
  - Consider mechanical and thermal transient loads
  - Exclude retrofit brackets (not expected to redistribute stresses until after significant cracking /unloading occur).
  - The bottom of the scallop weld is cracked half way up.
  - Determine impact of slots on fatigue life of drum side of fillet attachment per ASME 2004 elastic analysis.

Finite Element Model



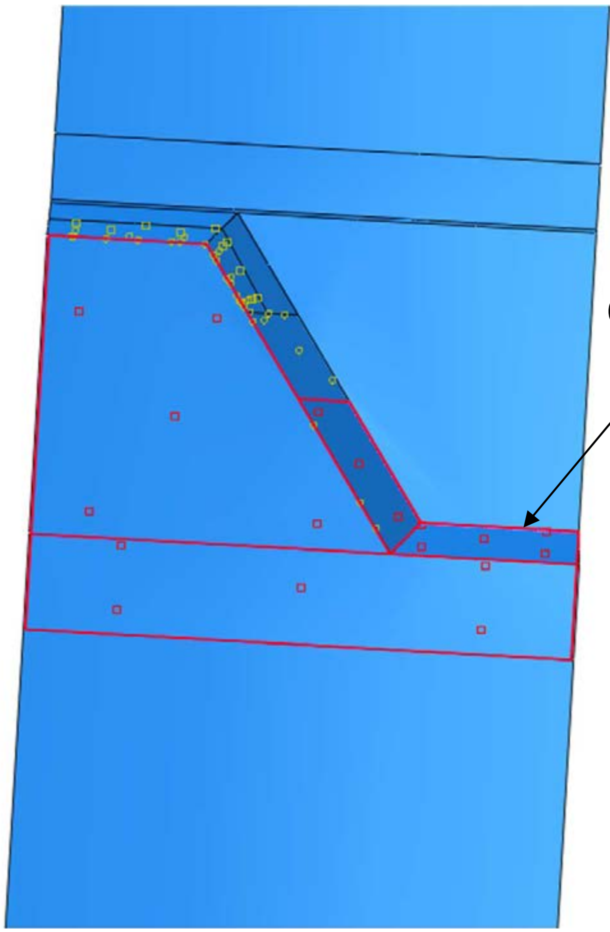
3/8 in. deep slot
Normal to weld surface
At middle of the weld



Two Configurations

Base Model

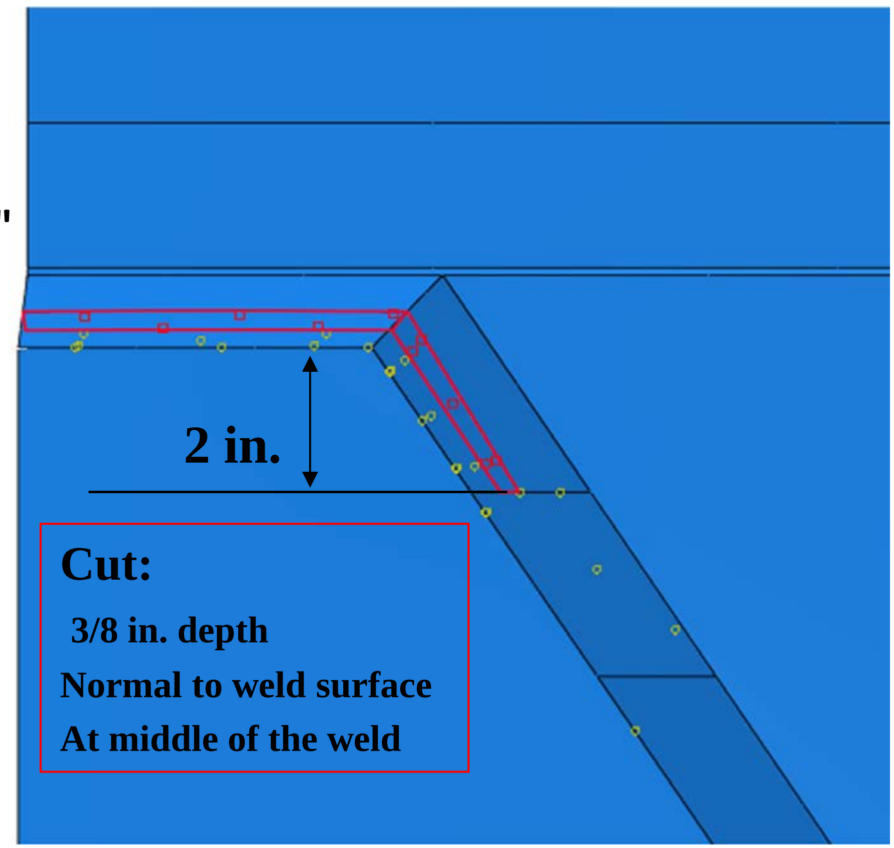
no slot



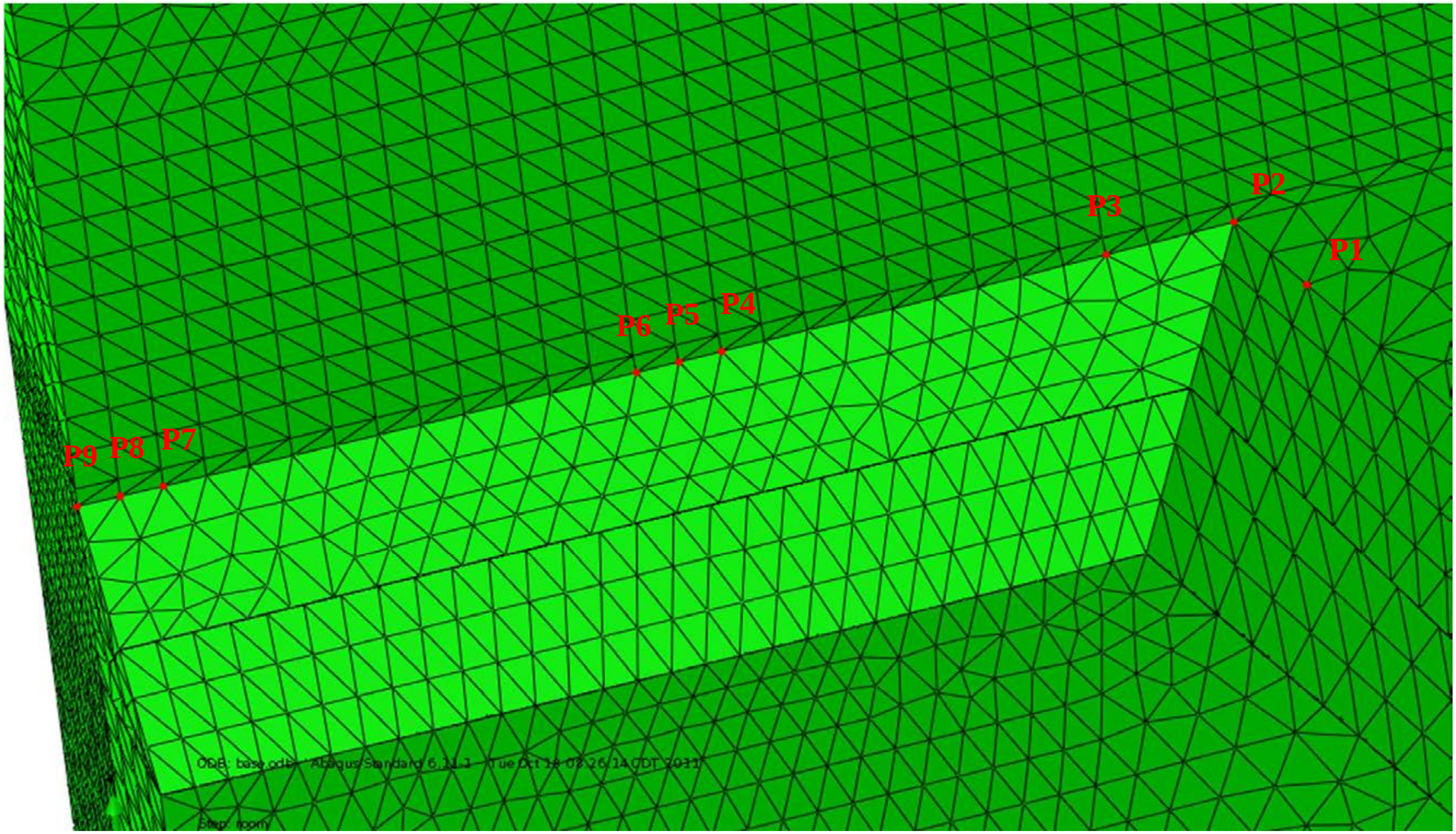
Crack Size of 10.4"

Slot Model

Same as Base Model + a slot cut across the peak of the scallop weld



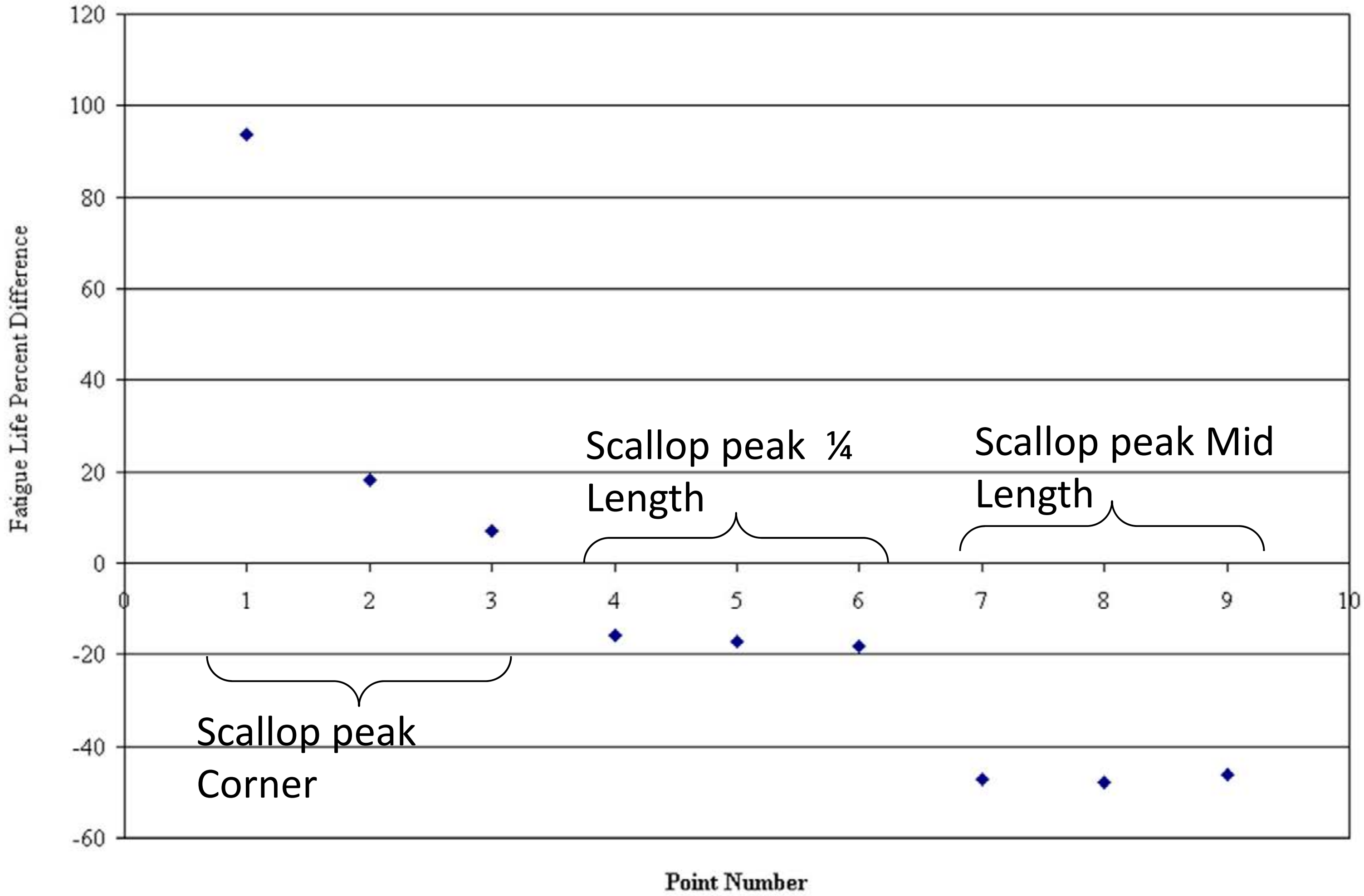
Fatigue Calculations Points <u>at</u> Weld Toe



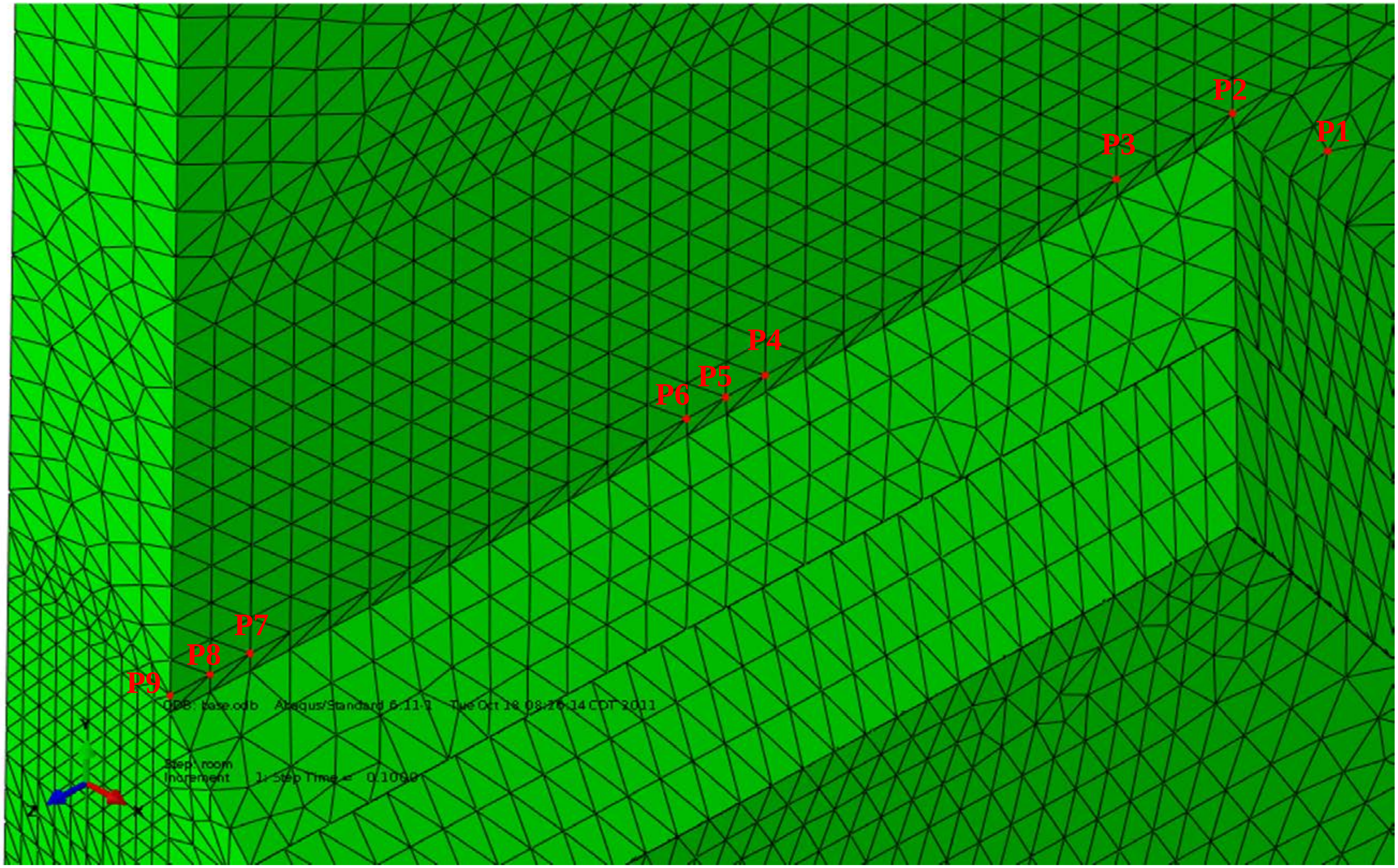
Fatigue Life at Weld Toe

Point	Base		Groove		
	Stress Amplitude (psi)	Fatigue Life (Cycles)	Stress Amplitude (psi)	Fatigue Life (Cycles)	%Difference
1	10856	3401708	10503	6584603	94
2	14792	226513	14196	267372	18
3	16195	159591	15911	170679	7
4	13024	391223	13519	329184	-16
5	12639	456694	13120	377636	-17
6	12474	492140	12949	402436	-18
7	10729	4301136	11077	2273692	-47
8	10414	7809470	10757	4083402	-48
9	10718	4394834	11056	2361558	-46

Fatigue Life % Difference at Weld Toe



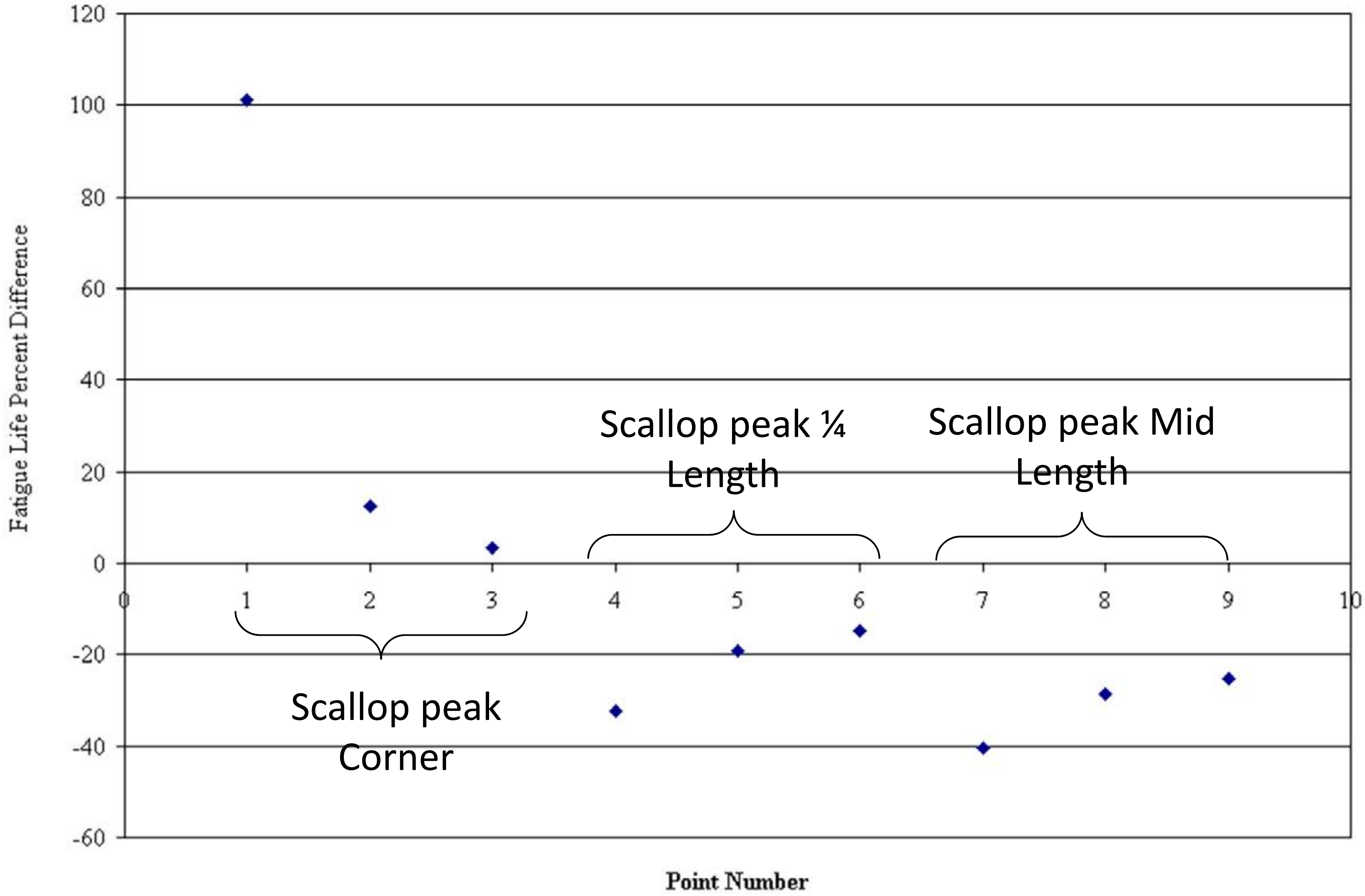
Fatigue Calculations Points Next to Weld Toe



Fatigue Life next to Weld Toe

Point	Base		Groove		
	Stress Amplitude (psi)	Fatigue Life (Cycles)	Stress Amplitude (psi)	Fatigue Life (Cycles)	%Difference
1	10351	***8826145***	9995	***17757422***	101
2	15065	***210782***	14625	***237007***	12
3	15645	***182055***	15516	***187945***	3
4	11505	***1065580***	11845	***719568***	-32
5	11988	***647051***	12348	***523575***	-19
6	12597	***465270***	12993	***395855***	-15
7	11332	***1442219***	11655	***859536***	-40
8	11546	***979970***	11882	***698811***	-29
9	11659	***855897***	12004	***639757***	-25

Fatigue Life % Difference next to Weld Toe



Summary of Slot Analysis

- The simulated slots cause fatigue life to increase at the scallop corner and decrease along the middle of the scallop peak. Therefore, fatigue life increases where it matters most (i.e. where life is shortest at the corner).
- For a life that is over 100,000 cycles which is an order of magnitude longer than the life of a typical drum, The peaks of cracked scallop welds in the skirt-to-drum attachment weld are expected to have a long fatigue life with and without specified slots.
- The slots are expected to direct a crack that starts at the root of the scallop peak weld to propagate along the throat and away from the pressure boundary.

Implementation of Retrofit

Implementation of Retrofit

- Cracks at toe in fillet weld into pressure boundary repaired
- Cracks through the fillet attachment throat were not repaired
- Preheat maintained via heating elements inside the drum
- Planned 15 days mechanical duration met for installation
- Preload to sliding plates applied using a press and welding hold tabs in place
- Slots were added in half of scallop peaks
- Challenge implementing required weld quality
- Fabrication tolerance challenge

Subsequent Inspection

- A re-inspection of sliding brackets and skirt attachment weld cracking was completed in August 2012.
- Inspection Results
  - No cracking noted in attachment fillet weld connections using dry MT
  - Brackets had no distortion or notable movement
  - Fillet welds in scallop valleys are continuing to propagate along the weld throat
  - Repaired cracking at the toe of the scallop peak fillet attachments have not re-initiated in this area.
  - No cracks found in slotted and un-slotted scallop peaks

Photos of Retrofit Skirt at Re-inspection