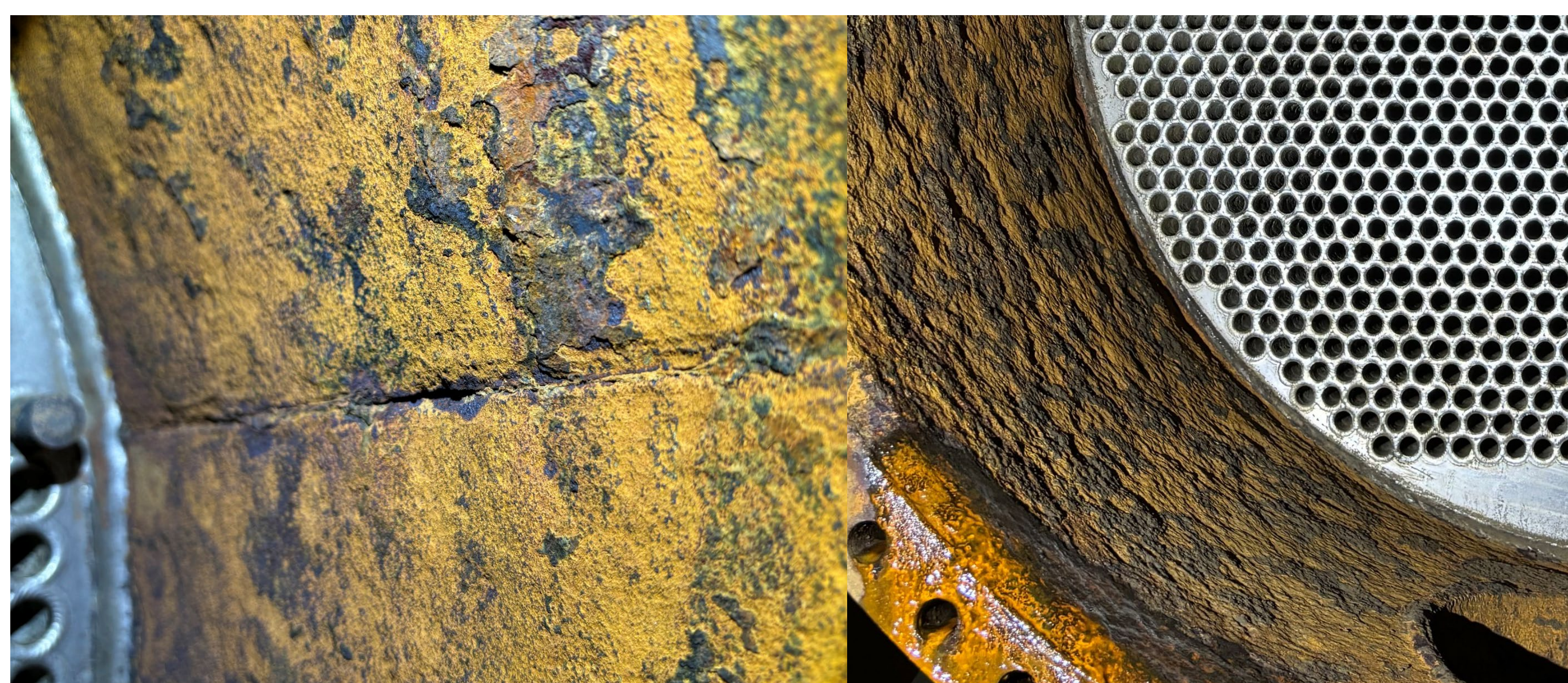


# Fitness For Service Assessment of a Corroded Heat Exchanger

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## ASME FFS-1/API 579 – Fitness For Service Application

The fitness for service standard was applied to assess the integrity of eight corroded heat exchangers that provide cooling to the Main Injector Accelerator at Fermilab. These heat exchangers comprise of Carbon Steel heads and Stainless-Steel tubes, tube sheets, and shell. The corrosion was reserved to the carbon steel surfaces. The assessments concluded that the heat exchangers could be returned to service safely at the design pressures and temperatures.

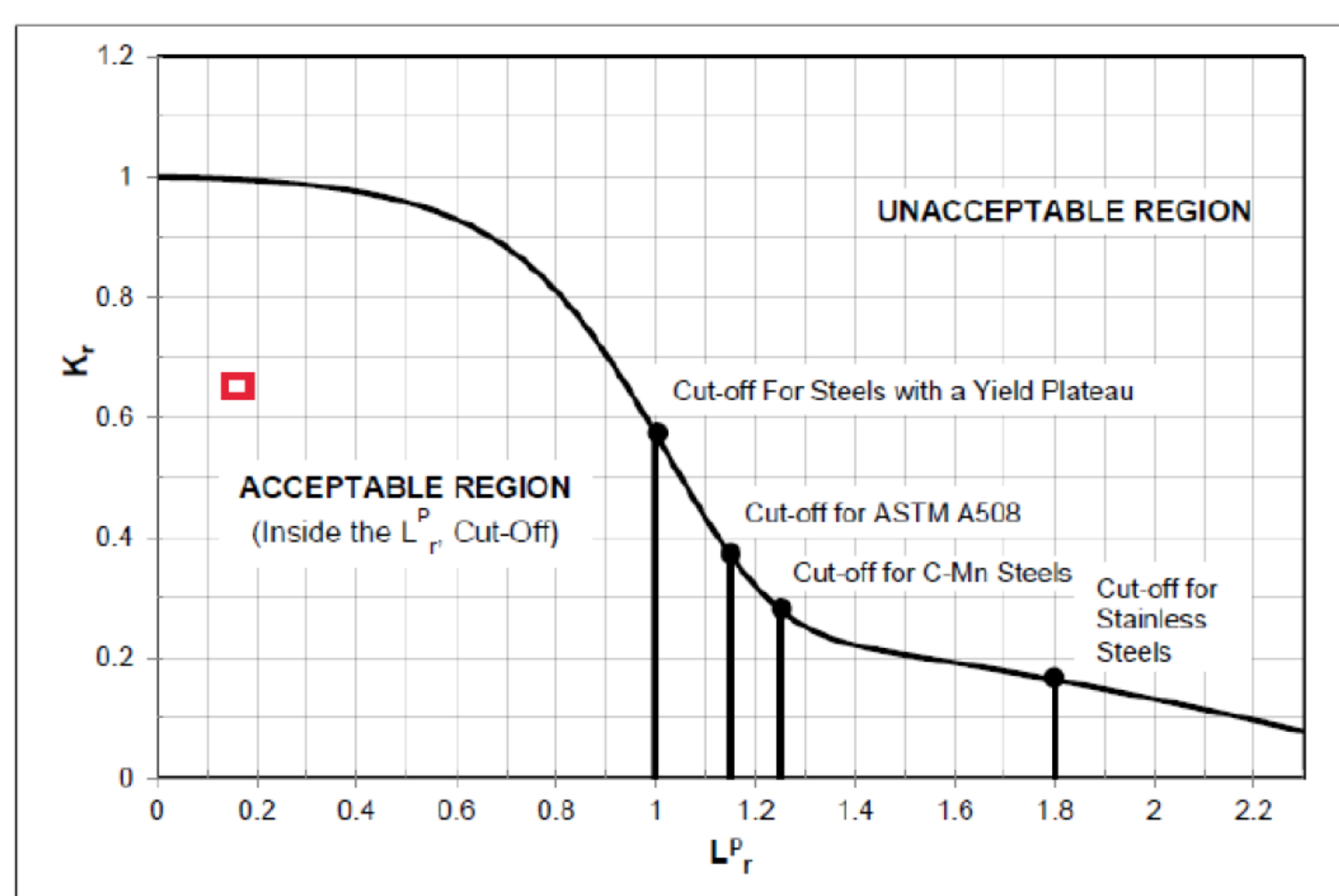
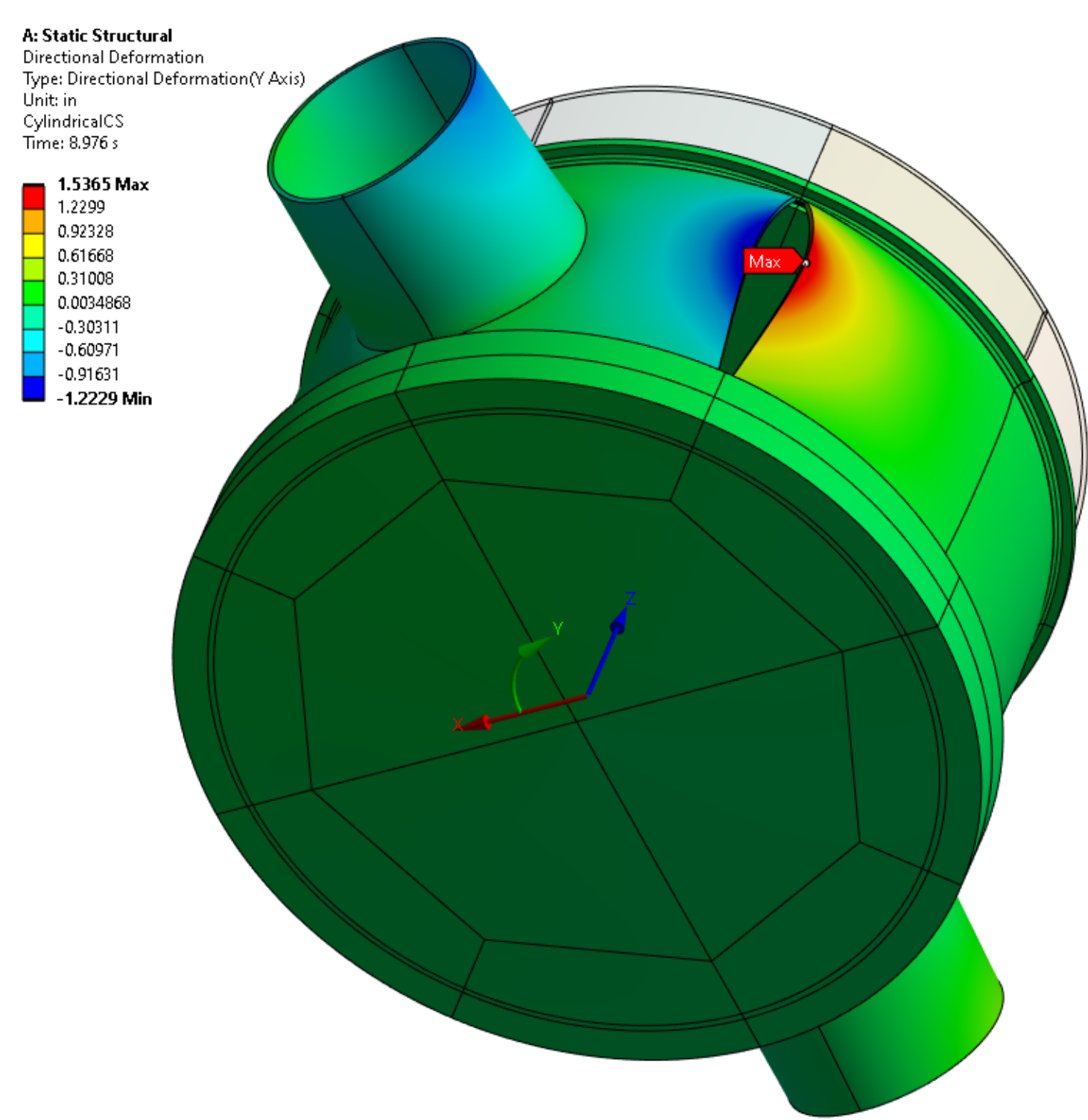


Corrosion on Longitudinal weld seam. Analyzed as crack-like flaw due to the sharp geometry of the corrosion.

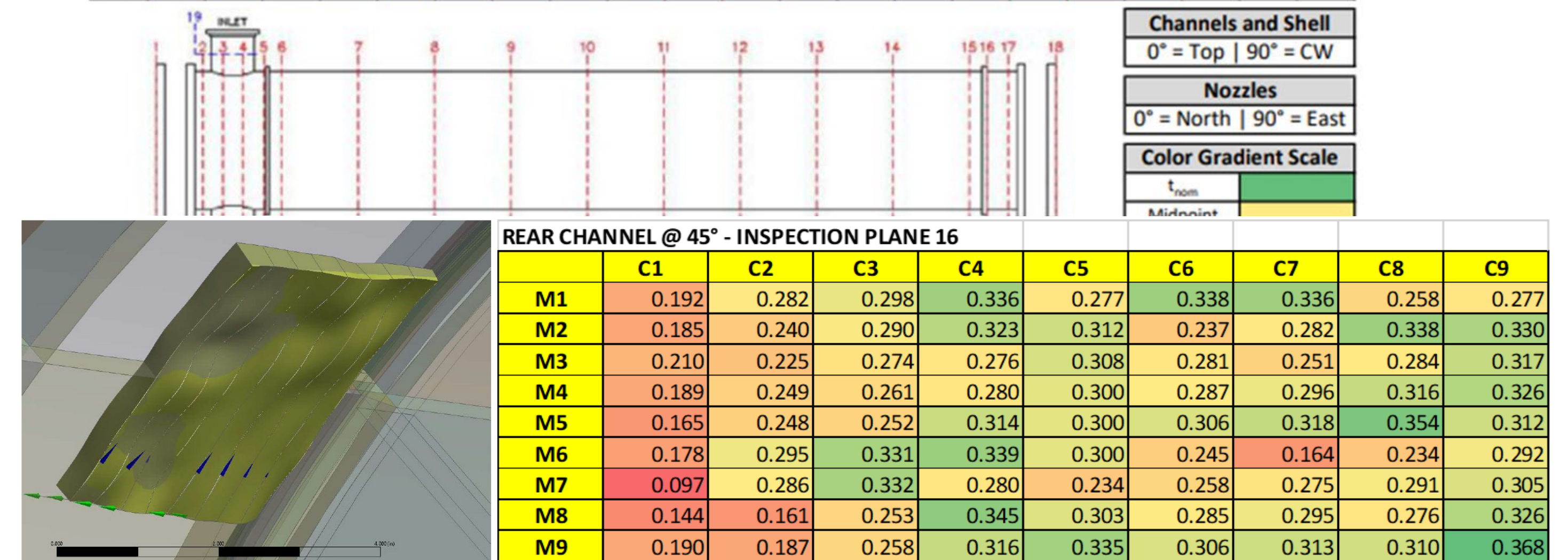
Corrosion of the base material on end channel. Characterized as General and Local metal loss.

## Part 9: Crack-Like Flaw

Fracture mechanics was used to determine the acceptability of a crack in the weld metal of the channel material. By graphing the calculated Load Ratio and Stress Intensity Ratios, the crack is defined as “acceptable” based on the Failure Assessment Diagram. Another assessment was done called “Leak Before Break” to determine leak rates if a crack should develop. FEA was utilized again to determine total deformation at failure pressure of 431psig. The COA was used to calculate theoretical leak rates. The leak rates were within an acceptable value, in the range of 10-30 GPM. The channel passes this assessment.



COVER	FRONT CHANNEL					SHELL										REAR CHANNEL			COVER		NOZZLES	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
0°	2.308	0.348	Obst	Obst	0.203	0.256	0.258	0.256	0.251	0.269	0.265	0.269	0.267	0.261	0.263	0.348	0.359	2.330	0.304	0.313		
45°	2.231	0.288	0.272	0.270	0.162	0.278	0.251	0.253	0.247	0.268	0.270	0.268	0.271	0.264	0.263	0.097	0.327	2.223				
90°	2.207	0.313	0.308	0.297	0.157	0.261	0.261	0.254	0.253	0.268	0.271	0.274	0.274	0.271	0.266	0.234	0.254	2.278	0.301	0.311		
135°	2.301	0.318	0.317	0.289	0.152	0.279	0.274	0.261	0.268	0.267	0.270	0.277	0.271	0.270	0.263	0.184	0.286	2.257				
180°	2.236	0.333	Obst	Obst	0.142	0.258	0.275	0.269	0.278	0.274	0.264	0.271	0.264	0.265	0.274	0.203	0.328	2.257	0.295	0.316		
225°	2.192	0.320	0.271	0.270	0.109	0.274	0.269	0.274	0.274	0.277	0.269	0.269	0.268	0.261	0.276	0.184	0.308	2.295				
270°	2.260	0.314	0.266	0.309	0.241	0.256	0.268	0.278	0.278	0.263	0.268	0.260	0.277	0.274	0.278	0.154	0.254	2.315	0.296	0.306		
315°	2.199	0.301	0.285	0.294	0.213	0.258	0.259	0.276	0.274	0.270	0.271	0.273	0.260	0.279	0.271	0.142	0.275	2.234				



Inspection data was used to generate a 3D model of the heat exchanger for the analysis. The locations on the heat exchanger experiencing the most corrosion were further inspected. A 4"x4" box of thickness measurements were used to create a Corrosion Thickness Profile (CTP) for more accurate results.

## FFS-1 Methodology

Level 1 and 2 assessments were not applicable due to the severity of corrosion, so Level 3 methods were used for all analyses which include the use of Finite Element Analysis to accurately assess each exchanger. Limitations of Level 1 & 2 assessments include location of corrosion and remaining wall thicknesses.

Table on the right shows the resultant values for a General and Local metal loss. All assessments were completed to ASME BPVC Sec. VIII Div 2 – Design by Analysis Methods. The extrapolated load factors are far higher than the code required load factors. The stiffness provided by the tube sheet and short length of material being analyzed, resulted in the remaining wall thickness being able to handle higher pressure than design, according to this analysis. The channel passes the General and Local Metal loss assessments.

Protection From Failure Type	ASME Section VIII Div. 2 Part 5 Elastic-Plastic Method	Material Model	Geometric Behavior	Code Requirements or Required Load Factor	Results vs Original 75 psi Design Pressure	Results / Requirements (Must be at least 1.0 to PASS FFS)	FFS Assessment Results (PASS/FAIL)
Plastic Failure	5.2.4	True SS Curve	Non-linear effects included	6.000	14.25	2.375	PASS
Local Failure	5.3.3	True SS Curve	Non-linear effects included	2.550	5.19	2.035	PASS
Buckling Failure	5.4.3	True SS Curve	Non-linear effects included	2.083	14.25	6.840	PASS
Failure from Cyclic Loading	5.5.7	Elastic-Perfectly-Plastic	Non-linear effects included	No Accumulation of Plastic Strain	Zero Plastic Strain	N/A (Meets Requirements)	PASS
Results of Numerical Analyses				Comment			
Plastic Failure Occurs @ LF:				14.250	= 1068.75 psi Internal Pressure		
Required Plastic Design Factor:				3.6	(4.0 * 0.9)		
MAWP Limit for Plastic Failure:				296.88	(psi)		
Rear Channel Local Failure Occurs @ LF:				8.7589	Bottom @ Tubesheet Connection Notch		
Front Channel Local Failure Occurs @ LF:				5.1902	Bottom @ Tubesheet Connection Notch		
Required Local Design Factor				1.53	(1.7 * 0.9)		
Minimum MAWP Limit for Local Failure:				254.42	(psi)		
Weld Efficiency Factor (WEF) (Using Global Method A)				0.6	Lowest Joint efficiency listed in ASME Sect. VIII Div. 1 Table UW-12 for corner joints or butt joints with zero radiography (lower than Original manufacturer value of 0.70)		
MAWP Limit for Plastic Failure * WEF:				178	psi		
MAWP Limit for Local Failure * WEF:				153	psi		
<b>FFS Limit for Channel MAWP</b>				<b>153</b>	<b>psi (Above Original 75 psi MAWP)</b>		

## Current Status of Heat Exchangers

The heat exchangers were returned safely, to operations for a period of 3 months, given the results of these assessments. Right now, repairs are underway to remove the corroded sections and weld new sections on.

