In-Service Aboveground Storage Tank Floor Inspection

NDT Payload Validation
API-653 Plate
Test Plan and Report

Two NDT sensor payloads, PEC and PAUT, are evaluated against a known plate machined to meet API-653 Annex G Qualification Standards. Results demonstrate each sensor's repeatability across mission data sets. PEC and PAUT results detect similar patterns of corrosion on the test plate. PAUT results were able to repeatedly detect each individual qualification. Thickness measurements generated by the PEC sensor are on average more than 30% greater than the actual thickness. PAUT prove-up results track actual values with an average difference of 3% WT loss. PEC demonstrates an ability to detect defects and is an option for bottom-scanning. PAUT demonstrates an ability to detect and size defects, meeting API-653 Qualification Standards, and is an option for bottom-scanning and prove-up using the robot's survey procedures.

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Executive Summary

A plate with known manufactured defects, as defined by API-653 Section G.5.1 Qualification Test Plates, was autonomously inspected using the two NDT technologies currently available on Square Robot in-service inspection robots. Pulsed Eddy Current (PEC) and Phased Array Ultrasonic Testing (PAUT) sensors have been integrated on the SR robot. These sensor technologies were evaluated in an environment simulating the robot's.

PEC results consistently measure greater %WT remaining when compared to PAUT data and the known thickness of the defects. The physics of the PEC system are such that isolated pits or defect clusters are averaged with their immediate surroundings, an area approximately 1" in diameter. This averaging effectively reduces the resolution of the measured data and generates results that underestimate a defect's wall loss; or equivalently overestimates a defect's remaining wall thickness. PEC does not meet API-653 Annex G Qualification Test Acceptance Standards for defect sizing/prove-up but is useful in identifying locations of defects and general corrosion.

The PAUT system meets API-653 Annex G Qualification Test Acceptance Standards for defect sizing/prove-up. All defect sizing results were within the allowable ±0.020 inches. The PAUT system can be used to measure and characterize the remaining thickness of a low-carbon steel tank floor and can be expected to meet API-653 standards using the robot's standard procedure for surveying. PAUT results are expected to agree with those of an out-of-service MFL inspection.

Figure 1 below depicts a summary of the results for each qualification defect, as a function of % Wall Thickness remaining

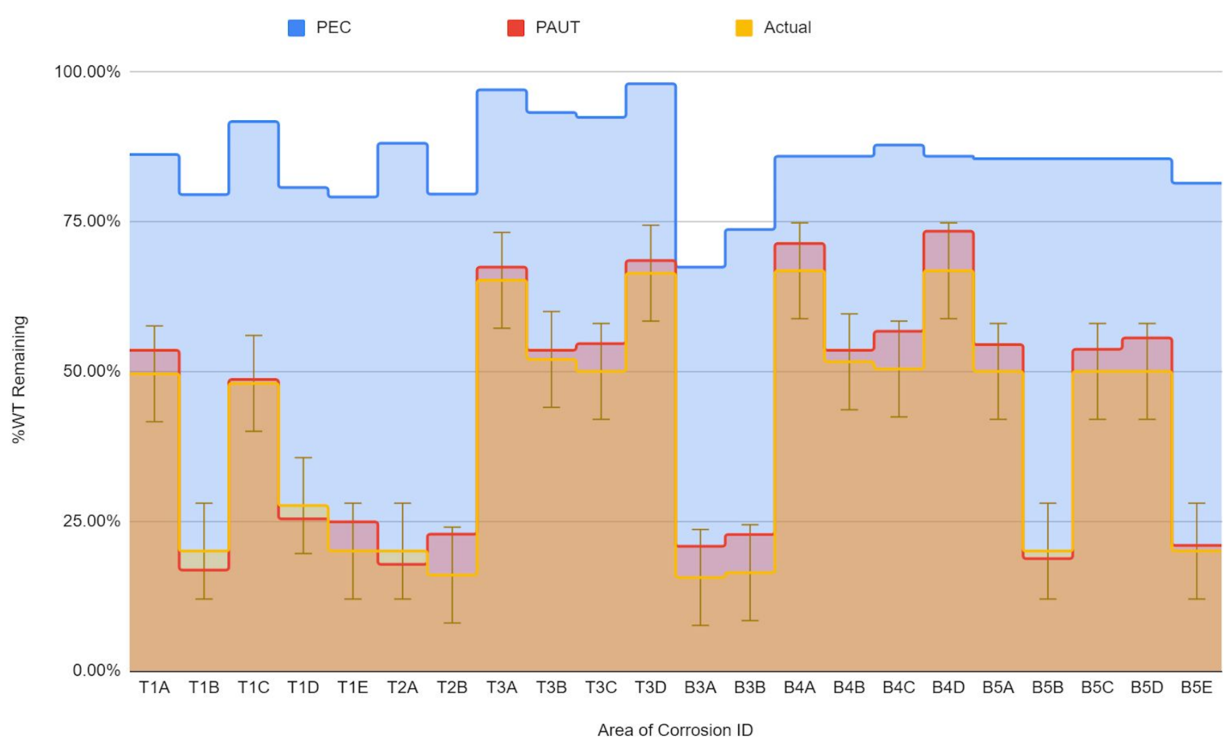


Figure 1 - Qualification Defects Summary (Allowable Measurement Range Shown as Vertical "Error" Bars)

1. Introduction

1.1. Purpose

This document details the acceptance tests that were completed on non-destructive test (NDT) payloads for use on an in-service floor inspection robot. Results of acceptance tests are provided in Section 3 of this report. Section 4 provides Square Robot's conclusions, as NDT results are analyzed.

The results of the validation tests were used to determine whether a payload meets the basic functional requirements, as defined by API 653[1], to perform a tank floor inspection for Square Robot.

1.2. Background

Square Robot (SR) designs, manufactures, tests, and certifies in-service tank floor inspection robots. Veritank, a wholly owned subsidiary of Square Robot, provides the go-to-market inspection services utilizing these robots. These robots are capable of performing inspections with various payloads. The data collected during an inspection is used to evaluate the integrity of the tank floor, most often by measuring the remaining thickness of the steel plates that make up the tank floor.

API 653 does not require a specific technology for bottom plate thickness measurements. The most commonly used measurement tools are Magnetic Flux Leakage (MFL) and Ultrasonic (UT) systems. The Silverwing MFL system[2] (shown in Figure 2) is able to detect defects as small as 2 mm (0.08 in) diameter flat bottom hole (FBH) 50% deep, measure material loss of 20% or greater, and identify whether the loss of thickness is located on the top or bottom surface of the plate. This industry-standard MFL system can be used to provide an ideal dataset to compare alternative NDT systems against.

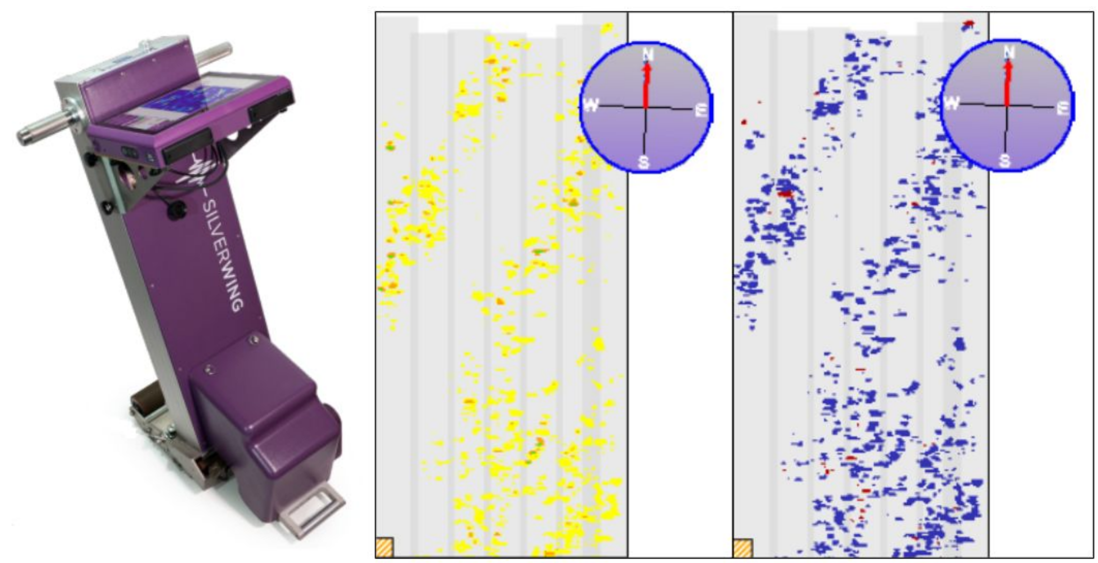


Figure 2 - Silvering MFL System and Data Examples (middle: %WT Loss Heat Map, right: Top/Bottom Defect Identification)

[1] API STD 653 5TH ED (A1)
[2] Silverwing MFL Floormap Specifications Sheet

The three primary technologies available for integration on the robot are electromagnetic, ultrasonic, and visual. Visual inspection provides qualitative data of the product-side of the plate, replacing the physical presence of the inspector inside of the tank. It does not satisfy the API 653 requirements for determining and predicting plate thickness loss. Pulsed Eddy Current (PEC)[3] and Phased Array Ultrasonic Testing (PAUT) sensors are capable of measuring plate thickness and have been integrated on the SR robot. These sensor technologies were evaluated in an environment simulating the robot's.

The qualification tests and acceptance standards used in this report are derived from API 653 Annex G - Qualification of Tank Bottom Examination Procedures and Personnel. The qualification test plate is fabricated with new steel and contains the designed flaws defined in API 653 Section G.5.1. The drawing for the plate (20C-216-1) is included in the Appendix of this report.

2. Methods

2.1. Test Plate

Test plates, particularly for NDT payload validation, are made up of low carbon steel. Square Robot and Veritank possess several test plates of various sizes that present with a variety of defects, impurities, and finishes. This variance is essential to properly evaluate a payload's detection capabilities in both ideal and realistic settings. A new test plate should be approved by the test operator to ensure that no changes to the procedure are necessary. All test plates must be inspected by an industry-accepted NDT sensor or be manufactured to a specification, for a baseline definition of the plate. It is this plate definition that results will be compared to.

The test plate used for NDT payload validation testing is a fabricated plate with known defects defined by API-653 Section G.5.1 Qualification Test Plates and summarized below in Table 1.

Table 1 - API-653 Qualification Test Plate Requirements

Remaining Bottom Thickness (t)	**Minimum Number of Pits (Hemispherical, Underside)**	**Minimum Number of Pits (Hemispherical, Product-Side)**
t < 0.050"	2	0
0.050" < t < 1/2T	5	2
1/2T < t < 2/3T	4	2

Square Robot's API-653 Qualification Test plate (SRPN 02926) contains the API-653 flaws as well as additional pitting and a 2"x4" patch plate for additional payload testing. The API-653 designed flaws for qualification are defined in Table 2. The full list of defects on the test plate are provided in Tables 3 through 6. Defects with a flat-bottomed cross-section and defects located within 6" of a plate edge are not included in the API-653 qualification. These additional defects were added to the plate to provide more opportunities to evaluate a payload's capabilities. The results related to the additional defects are included in the Appendix of this report.

Table 2 - Square Robot API-653 Qualification Test Plate Specifications

Remaining	**Number of**	**Number of**	**Number of**	**Number of**	**Patch Plate**

[3] Eddyfi Underwater Pulsed Eddy Current (PEC) Probes

Bottom Thickness (t) (in)	**Pits (Hemispherical, Underside)**	**Pits (Hemispherical, Product-Side)**	**Pits (Hemispherical, Product-Side, Within 6" from Plate Edge)**	**Pits (Flat-bottomed, Product-Side)**	2"x4"x¼" low carbon steel, welded to API-653 plate on plate edge
t < 0.050	2	2	2	2	
0.050 < t < 1/2T	5	5	2	2	**1"x1" Cluster of Random Defects**
1/2T < t < 2/3T	4	4	2	2	

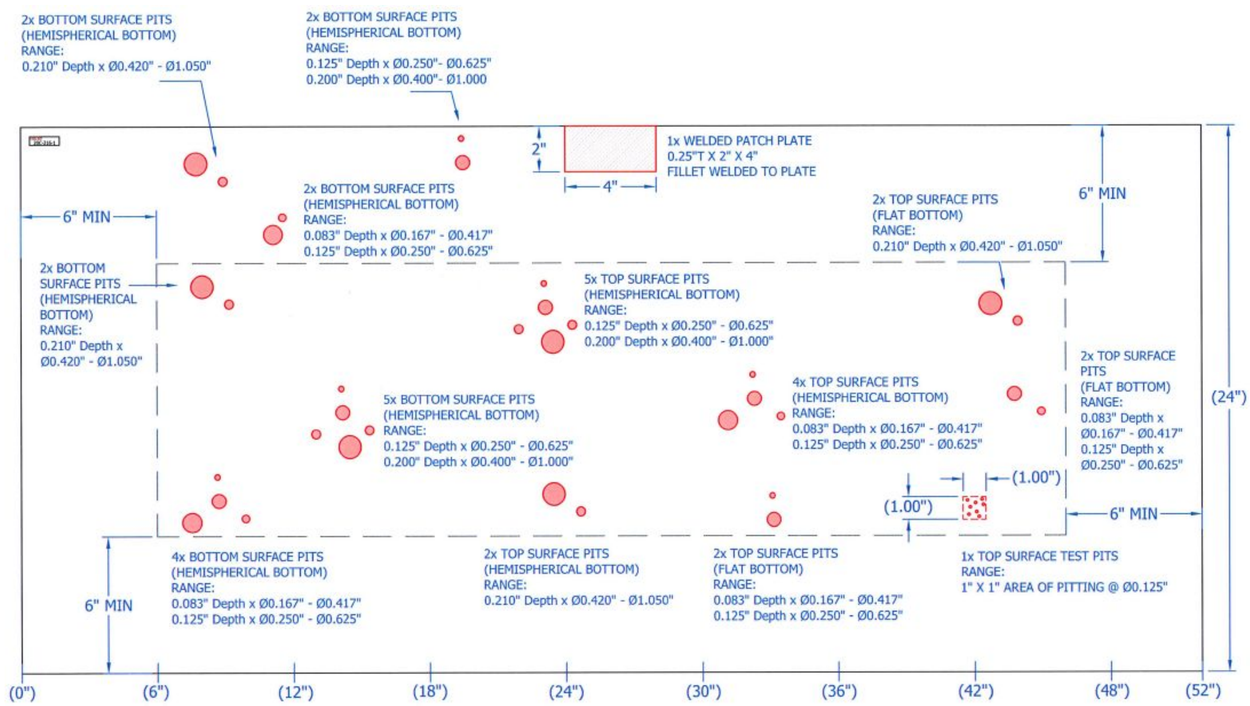


Figure 3 - API-653 Test Plate Drawing (SRPN 02926)

A complete mechanical drawing and inspection of the plate is included in the Appendix of this report (see Figures 57-59). Figure 3 provides the high-level defect specifications for the plate. Figures 4 and 5 show the physical plate's top and bottom sides. Note that when viewing the plate from the bottom-side, defect patterns will appear mirrored when comparing the photographs to the mechanical drawings, as the mechanical drawings present the defects from the top-side.

Figure 4 - API-653 Test Plate (SRPN 02926), Top (Product-Side) View

Figure 5 - API-653 Test Plate (SRPN 02926), Bottom View

3. Results

3.1. API-653 Plate

3.1.1. Plate Definition

SRPN 02926 is a low-carbon steel plate manufactured according to API-653 Section G to be used for NDT qualification testing. It measures 24 inches wide, 52 inches long, and 0.25 inches thick (610 mm x 1321 mm x 6.35 mm). The plate is uncoated. See Appendix A3 for a complete mechanical drawing and inspection report of the plate. A description of the plate and its defects are provided in the subsequent paragraphs. Figure 6 highlights the locations of the qualification defect clusters as they will appear in the NDT data, depending on the side being surveyed.

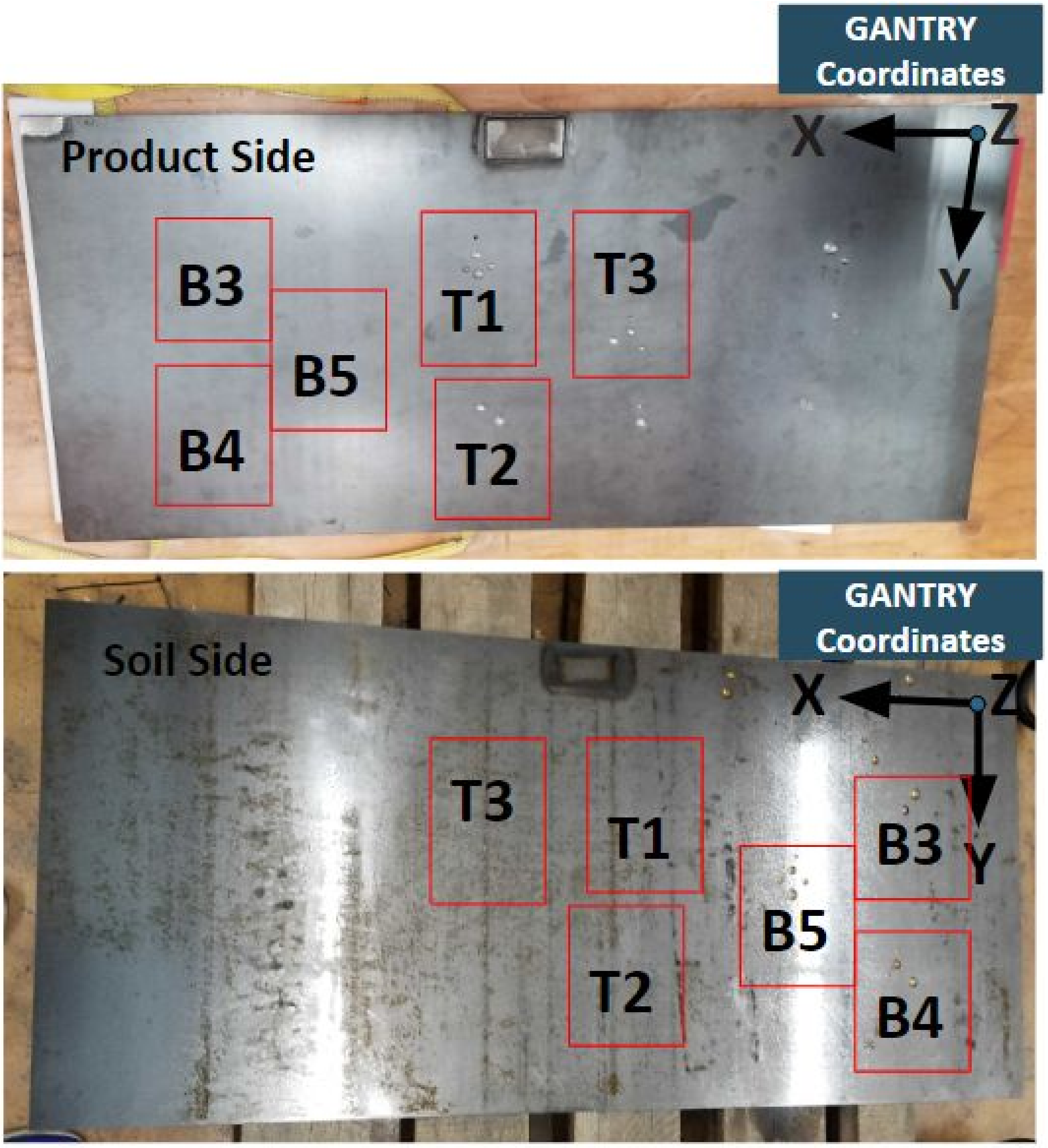


Figure 6 - SRPN 02926 Qualification Plate with API-653 Defects Highlighted

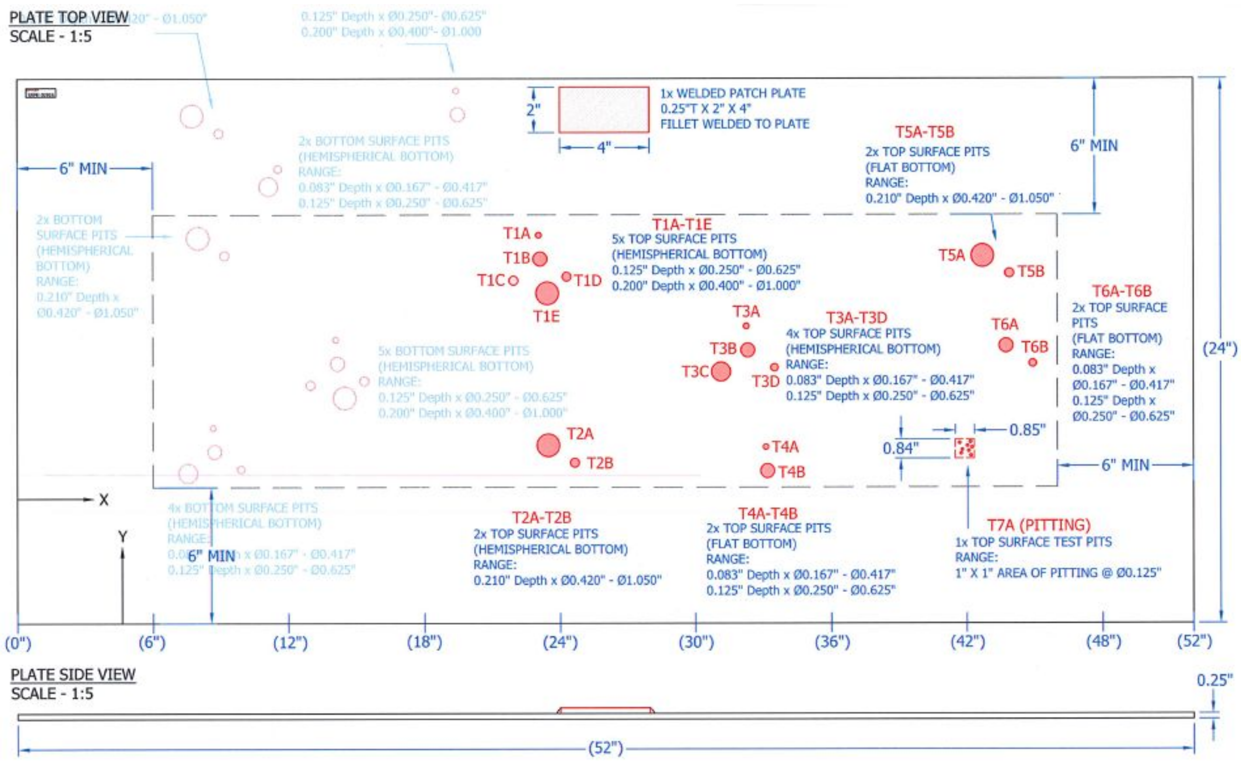


Figure 7 - SRPN 02926 Product Side Defects

The product side of SRPN 02926 has seven distinct groups of defects: T1, T2, T3, T4, T5, T6, and T7. Groups T1, T2, T3, and T7 contain defects with hemispherical bottoms, and are located at least 6 inches from the edge of the plate. Groups T4, T5, and T6 contain defects with flat bottoms, and are also located at least 6 inches from the edge of the plate. API-653 Section G recommends avoiding flat bottom holes for the purposes of evaluation, as they can be hard to detect and are considered unrealistic.

Therefore, only the hemispherical defects, Groups T1, T2, T3, and T7, are considered API-653 qualification criteria. Groups T4, T5, and T6 are considered to be non-qualification defects. The figures and tables below define the size, type, and position of the product side qualification and non-qualification defects.

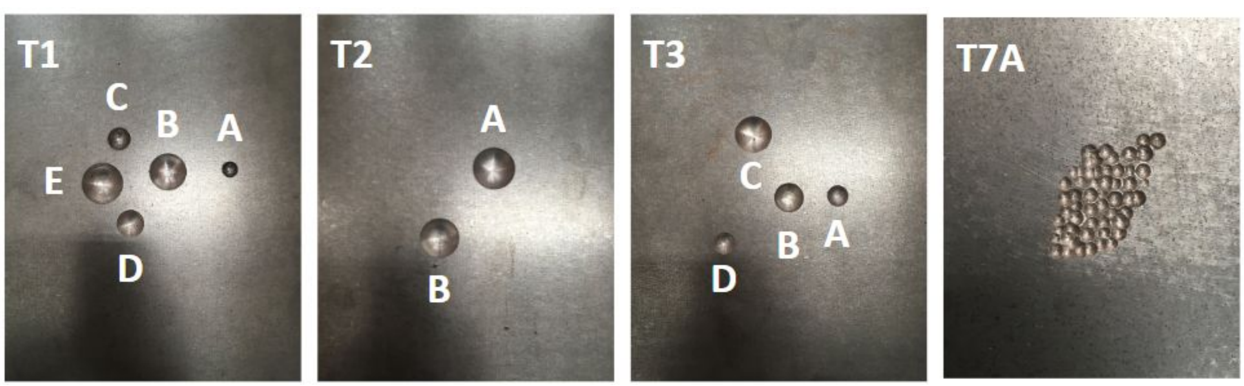


Figure 8 - SRPN 02926 Product Side Qualification Defects

Table 3 - SRPN 02926 Product Side Qualification Defect Size and Location

Defect Size and Position: Product Side Qualification Defects												
ID	T1A	T1B	T1C	T1D	T1E	T2A	T2B	T3A	T3B	T3C	T3D	T7A
Diameter (in)	0.251	0.584	0.348	0.424	0.644	0.630	0.583	0.303	0.414	0.514	0.301	0.043-0.128
Diameter (mm)	6.38	14.83	8.84	10.77	16.36	16.00	14.81	7.70	10.52	13.06	7.65	1.09 - 3.08
Depth (in)	0.126	0.200	0.130	0.181	0.200	0.200	0.210	0.087	0.120	0.125	0.084	0.010-0.060
Depth (mm)	3.20	5.08	3.30	4.60	5.08	5.08	5.33	2.21	3.05	3.18	2.13	0.10 - 1.5
Thickness Remaining (in)	0.12	0.05	0.12	0.07	0.05	0.05	0.04	0.16	0.13	0.13	0.17	0.24 - 0.19
Thickness Remaining (mm)	3.15	1.27	3.05	1.75	1.27	1.27	1.02	4.14	3.30	3.18	4.22	6.1-4.8
Position (X) (in)	23.45	23.45	22.90	24.23	23.60	23.72	24.80	32.03	32.03	31.06	32.76	41.59
Position (X) (m)	0.60	0.60	0.58	0.62	0.60	0.60	0.63	0.81	0.81	0.79	0.83	1.06
Position (Y) (in)	17.43	16.46	15.71	15.83	15.43	7.60	6.77	12.68	11.95	11.44	10.98	7.11
Position (Y) (m)	0.44	0.42	0.40	0.40	0.39	0.19	0.17	0.32	0.30	0.29	0.28	0.18

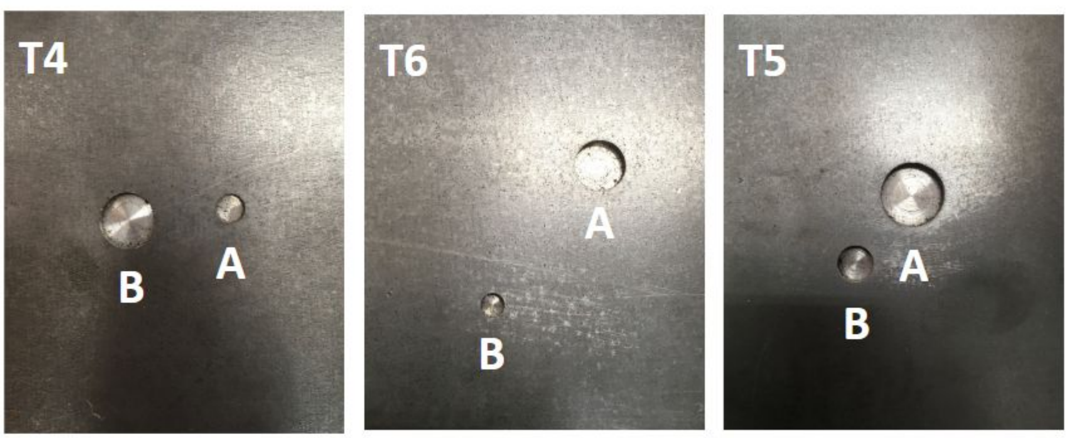


Figure 9 - SRPN 02926 Product Side Non-Qualification Defects

Table 4 - SRPN 02926 Product Side Non-Qualification Defect Size and Location

Defect Size and Position: Product Side Non-Qualification Defects						
ID	T4A	T4B	T5A	T5B	T6A	T6B
Diameter (in)	0.269	0.516	0.784	0.442	0.445	0.197
Diameter (mm)	6.83	13.11	19.91	11.23	11.30	5.00
Depth (in)	0.085	0.121	0.202	0.210	0.123	0.084
Depth (mm)	2.16	3.07	5.13	5.33	3.12	2.13
Thickness Remaining (in)	0.17	0.13	0.05	0.04	0.13	0.17
Thickness Remaining (mm)	4.19	3.28	1.22	1.02	3.23	4.22

Position (X) (in)	32.76	32.83	42.72	43.28	44.49	41.59
Position (X) (m)	0.83	0.83	1.09	1.10	1.13	1.06
Position (Y) (in)	7.48	6.54	16.50	15.79	12.64	11.69
Position (Y) (m)	0.19	0.17	0.42	0.40	0.32	0.30

Figure 10 - SRPN 02926 Soil Side VIew

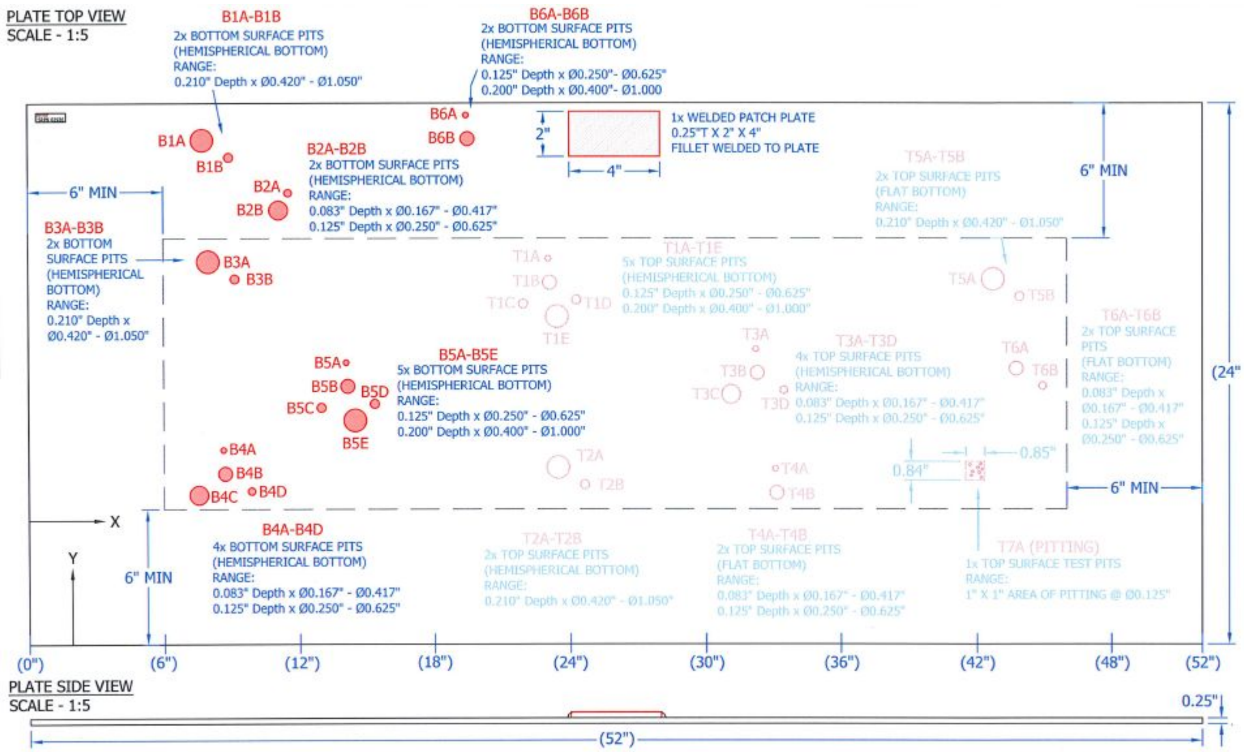


Figure 11 - SRPN 02926 Soil Side Defects

The soil side of SRPN 02926 has 6 distinct groups of defects: B1, B2, B3, B4, B5, and B6. Groups B3, B4, and B5 have hemispherical bottoms and are located at least 6 inches away from the edge of the plate, and therefore, are considered to be the soil side qualification defects. Groups B1, B2, and B6 also have hemispherical bottoms, but are located within 6inches of the plate edge. Figures 12-13 and Tables 5-6 provide complete definitions of the qualification and non-qualification defects.

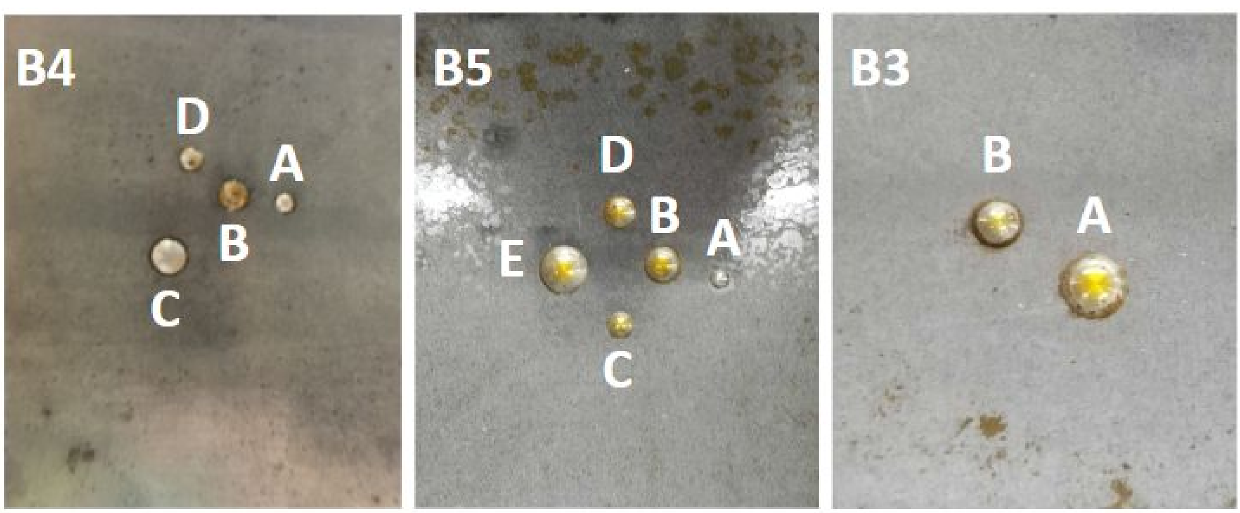
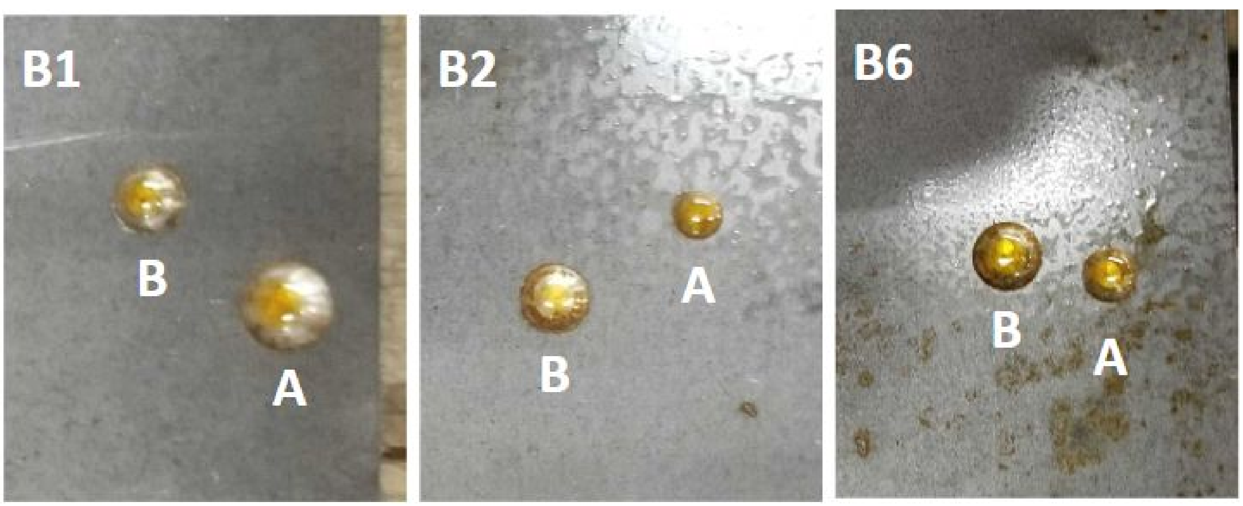


Figure 12 - SRPN 02926 Soil Side Qualification Defects

Figure 12 shows the soil side qualification defects. Note that when viewed through NDT data from the product-side of the plate, the defects will appear as mirror images when compared to Figure 12. Figure 13 shows the soil side non-qualification defects.

Table 5 - Soil Side Qualification Defect Definition

Defect Size and Position: Soil Side Qualification Defects											
ID	B3A	B3B	B4A	B4B	B4C	B4D	B5A	B5B	B5C	B5D	B5E
Diameter (in)	0.636	0.488	0.298	0.488	0.537	0.373	0.245	0.471	0.338	0.396	0.622
Diameter (mm)	16.15	12.40	7.57	12.40	13.64	9.47	6.22	11.96	8.59	10.06	15.80
Depth (in)	0.21	0.21	0.08	0.12	0.12	0.08	0.13	0.20	0.13	0.13	0.20
Depth (mm)	5.36	5.31	2.11	3.07	3.15	2.11	3.18	5.08	3.18	3.18	5.08
Thickness Remaining (in)	0.04	0.04	0.17	0.13	0.13	0.17	0.13	0.05	0.13	0.13	0.05
Thickness Remaining (mm)	0.99	1.04	4.24	3.28	3.20	4.24	3.18	1.27	3.18	3.18	1.27
Position (X) (in)	6.79	7.44	8.01	8.07	7.11	8.62	14.17	14.37	13.62	15.12	14.37
Position (X) (m)	0.17	0.19	0.20	0.21	0.18	0.22	0.36	0.36	0.35	0.38	0.36
Position (Y) (in)	16.97	16.02	8.29	7.52	6.56	6.85	13.29	12.54	11.93	12.01	11.20
Position (Y) (m)	0.43	0.41	0.21	0.19	0.17	0.17	0.34	0.32	0.30	0.31	0.28



Figures 13 - SRPN 02926 Soil Side Non-Qualification Defects

Table 6 - Soil Side Non-Qualification Defect Definition

Defect Size and Position: Soil Side Non-Qualification Defects						
ID	B1A	B1B	B2A	B2B	B6B	B6A
Diameter (in)	0.64	0.489	0.363	0.496	0.492	0.638
Diameter (mm)	16.26	12.42	9.22	12.60	12.50	16.21
Depth (in)	0.21	0.21	0.09	0.13	0.13	0.20
Depth (mm)	5.41	5.38	2.21	3.18	3.18	5.08
Thickness Remaining (in)	0.04	0.04	0.16	0.13	0.13	0.05
Thickness Remaining (mm)	0.94	0.97	4.14	3.18	3.18	1.27
Position (X) (in)	7.05	7.84	9.93	9.33	17.91	18.15
Position (X) (m)	0.18	0.20	0.25	0.24	0.45	0.46
Position (Y) (in)	23.34	22.36	19.88	18.76	22.85	21.93
Position (Y) (m)	0.59	0.57	0.50	0.48	0.58	0.56

3.1.2. Tests Completed

The following NDT inspections were completed on SRPN 02926 for this report, listed in the order that they were performed:

i. PEC - automated gantry acquisition using vehicle-simulated setup (see Section 2.2.5)
   a. Product-side up
      i. PEC Resolution ½” x 1”, No trackline overlap
      ii. PEC Resolution ½” x 1”, ~50% trackline overlap
      iii. PEC Resolution 1” x 1”, No trackline overlap
      iv. PEC Resolution 1” x 1”, ~50% trackline overlap
      v. PEC Resolution ¼” x 1”, No trackline overlap
   b. Soil-side up
      i. PEC Resolution ½” x 1”, No trackline overlap
      ii. PEC Resolution ½” x 1”, ~50% trackline overlap
      iii. PEC Resolution 1” x 1”, No trackline overlap
      iv. PEC Resolution 1” x 1”, ~50% trackline overlap
      v. PEC Resolution ¼” x 1”, No trackline overlap

ii. PAUT - automated gantry acquisition using vehicle-simulated setup (see Section 2.2.4)
   a. Product-side up
      i. Speed 5 cm/s (2 in/s), No trackline overlap
      ii. Speed 5 cm/s (2 in/s), ~90% trackline overlap
      iii. Speed 10 cm/s (4 in/s), No trackline overlap
      iv. Speed 10 cm/s (4 in/s), ~90% trackline overlap
      v. Speed 15 cm/s (6 in/s), No trackline overlap
      vi. Speed 15 cm/s (6 in/s), ~90% trackline overlap
      vii. Speed 20 cm/s (8 in/s), No trackline overlap
      viii. Speed 20 cm/s (8 in/s), ~90% trackline overlap
   b. Soil-side up
      i. Speed 5 cm/s (2 in/s), No trackline overlap
      ii. Speed 5 cm/s (2 in/s), ~90% trackline overlap
      iii. Speed 10 cm/s (4 in/s), No trackline overlap

iv. Speed 10 cm/s (4 in/s), ~90% trackline overlap
v. Speed 15 cm/s (6 in/s), No trackline overlap
vi. Speed 15 cm/s (6 in/s), ~90% trackline overlap
vii. Speed 20 cm/s (8 in/s), No trackline overlap
viii. Speed 20 cm/s (8 in/s), ~90% trackline overlap

3.1.3. PEC Results

SRPN 02926 was autonomously inspected on April 22-24, 2020 using a Pulsed Eddy Current (PEC) NDT system mounted on the gantry system. This autonomous PEC data acquisition was performed under conditions designed to emulate the vehicle's operating environment. The 7-channel PEC array (referred to as transducer) was mounted to the gantry at a fixed standoff from the plate of 0.5 inches. Missions were run at 4in/s (10cm/s), 2in/s (5cm/s), and 1in/s (3 cm/s), speeds decreasing as the sensor's resolution was increased. Data was gathered at 1"x1", 1x½", and 1x¼" resolutions. A separate PEC calibration was performed for each of the resolutions. To ensure consistency across data samples, the same location was used for all calibrations and the quality criteria of accepted calibrations were maintained at less than or equal to 1.1% variance for 2 averaging points. The PEC results are shown in Figures 14 through 40 and summarized in Tables 7 and 8. The colormaps shown in Figures 14-40 are expressed in %WT loss. All data is shown in the Gantry coordinate frame.

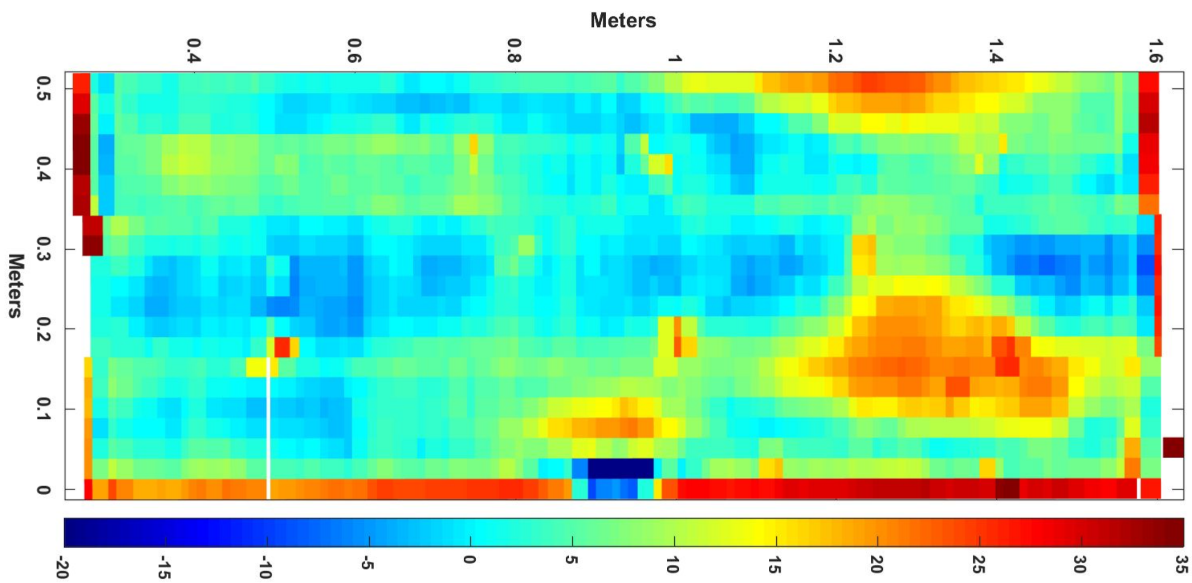


Figure 14 - SRPN 02926 PEC Results, Product Side Scan 1"x1" Resolution, 0% Overlap

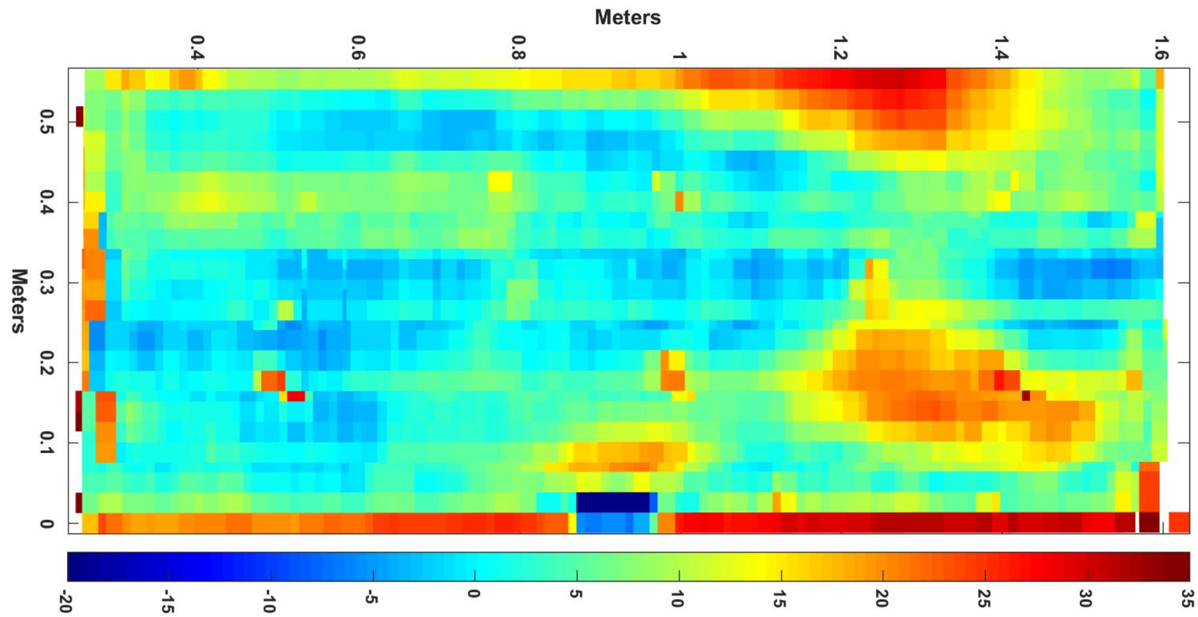


Figure 15 - SRPN 02926 PEC Results, Product Side Scan 1"x1" Resolution, 50% Overlap

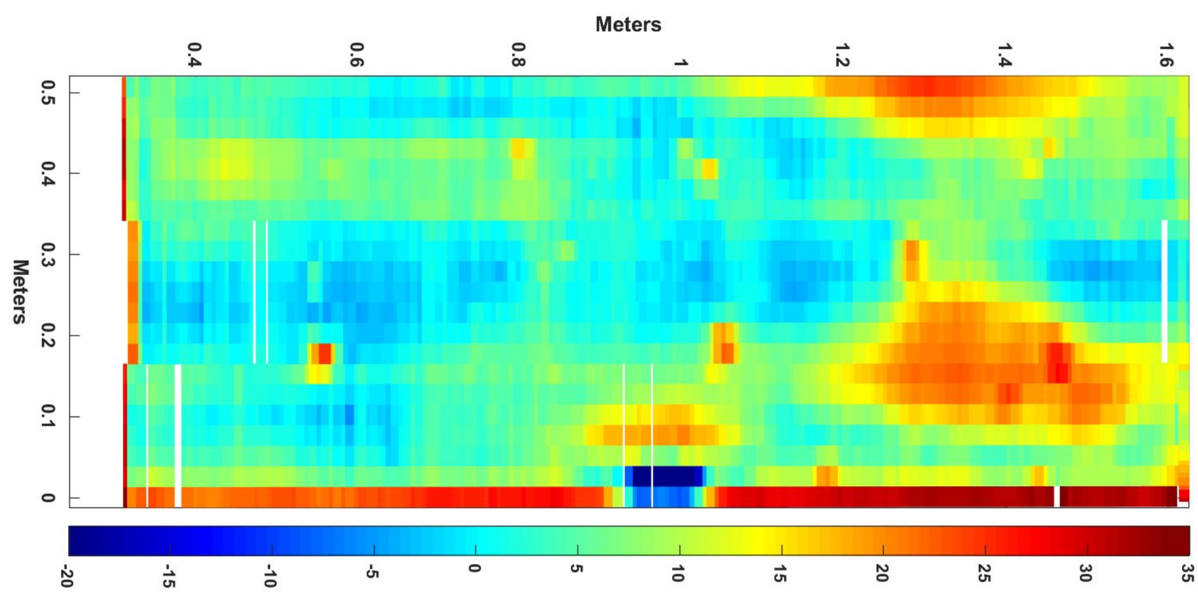


Figure 16 - SRPN 02926 PEC Results, Product Side Scan, ½"x1" Resolution, 0% Overlap

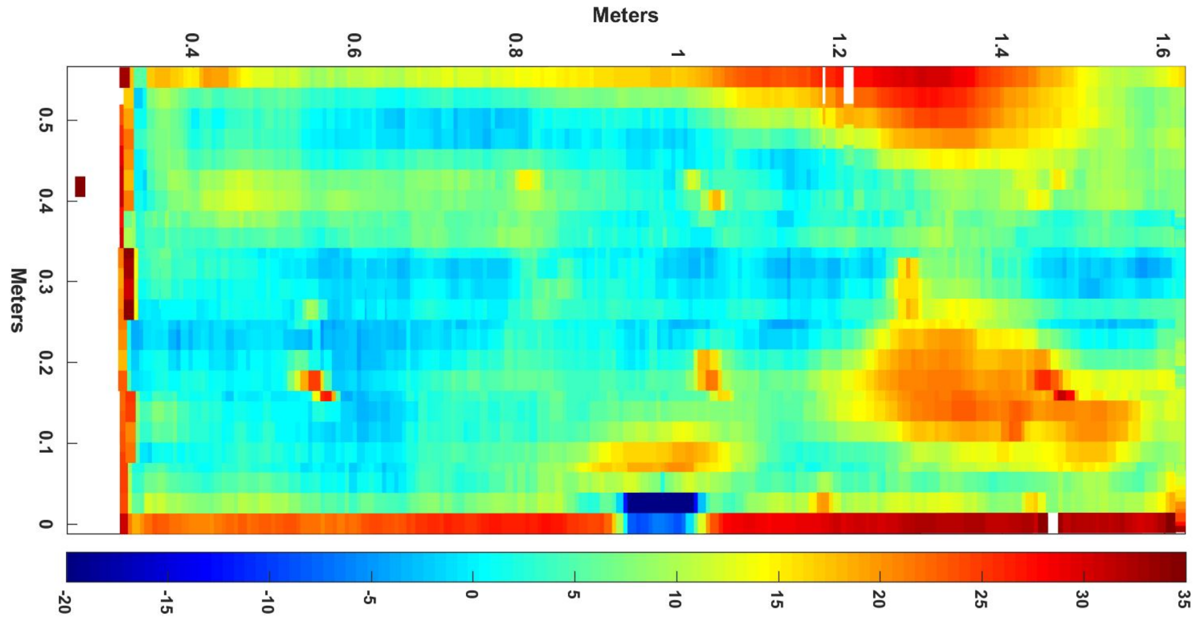


Figure 17 - SRPN 02926 PEC Results, Product Side Scan, ½"x1" Resolution, 50% Overlap

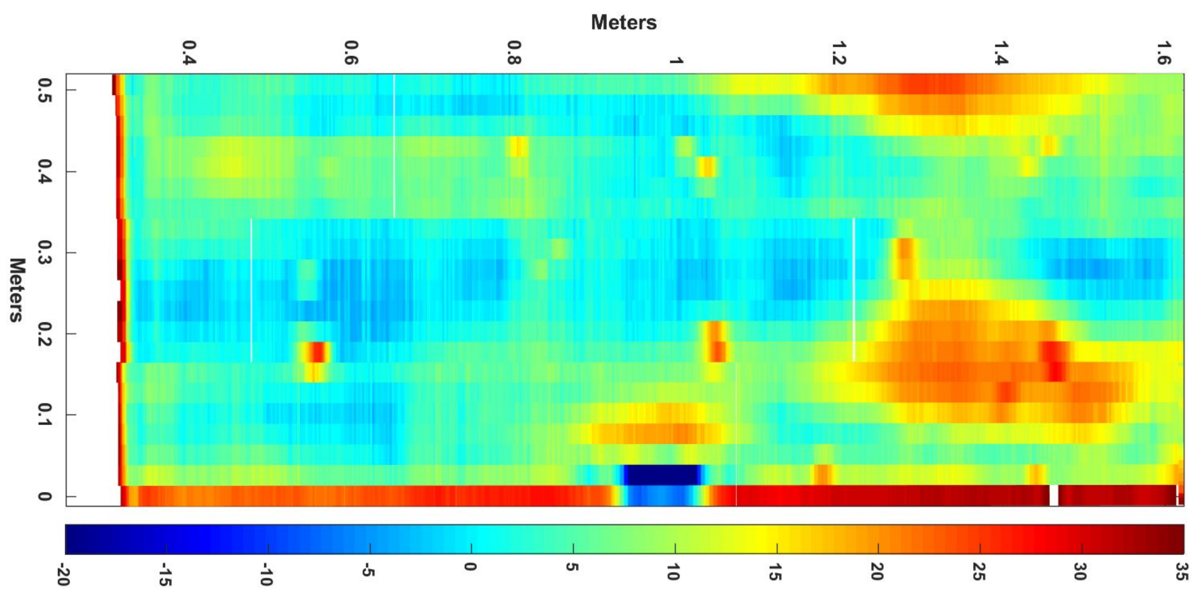


Figure 18 - SRPN 02926 PEC Results, Product Side Scan, ¼"x1" Resolution, 0% Overlap

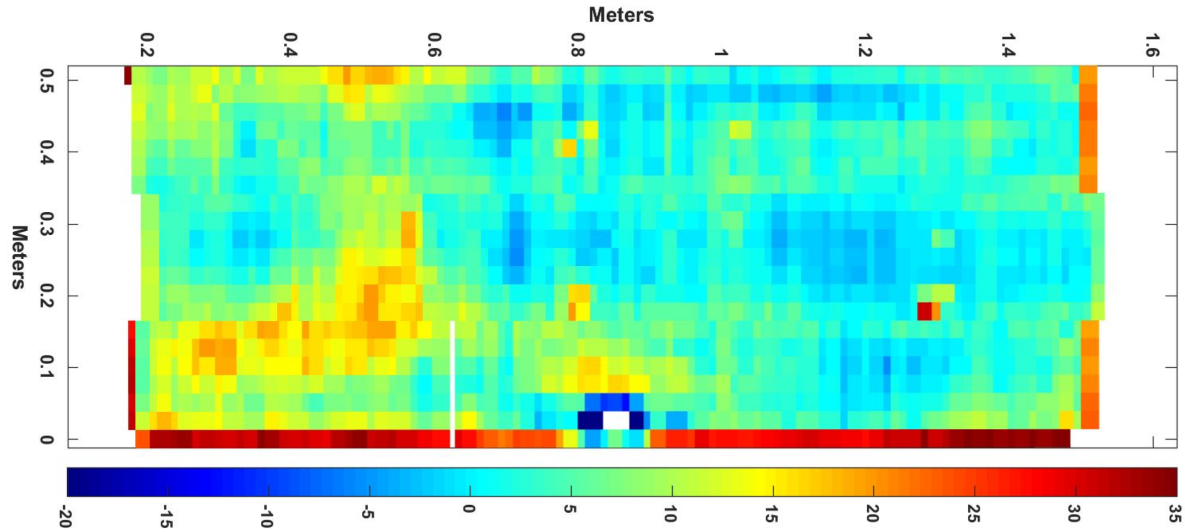


Figure 19 - SRPN 02926 PEC Results, Soil Side Scan, 1"x1" Resolution, 0% Overlap

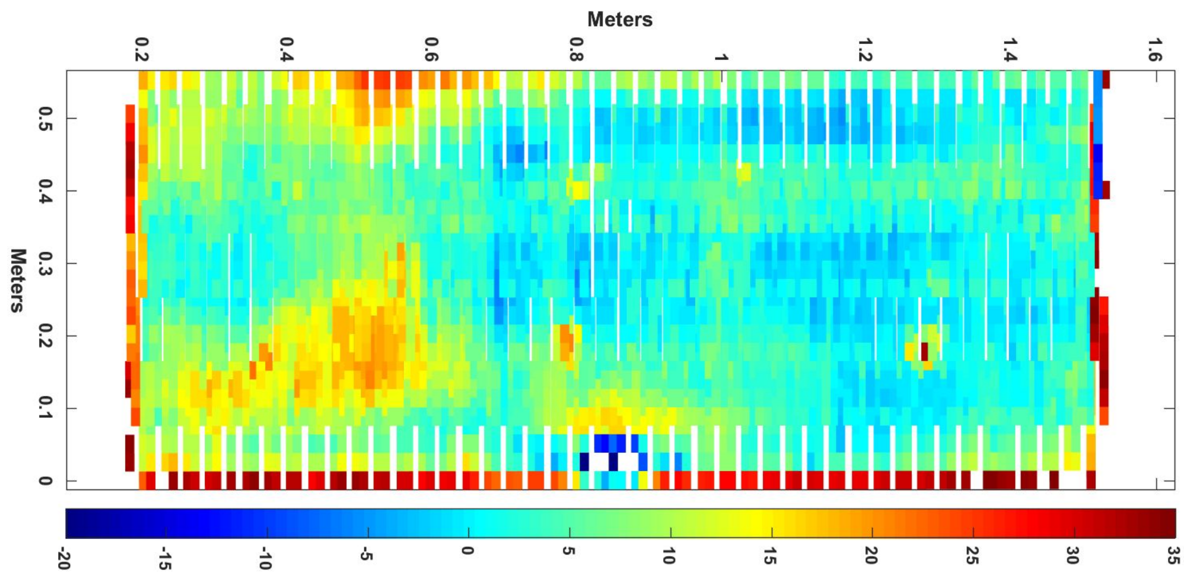


Figure 20 - SRPN 02926 PEC Results, Soil Side Scan, 1"x1" Resolution, 50% Overlap

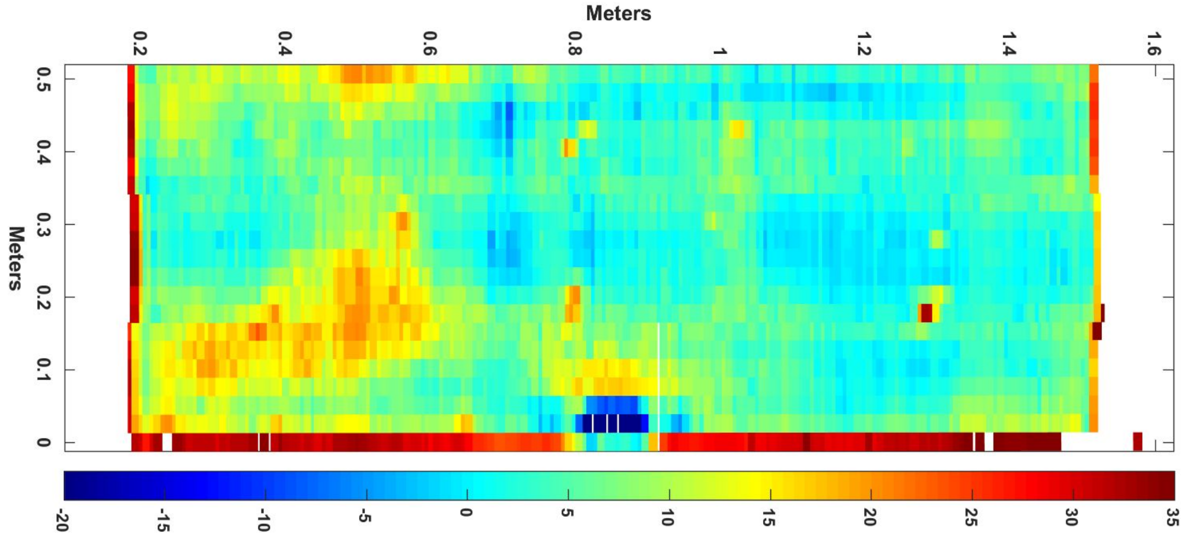


Figure 21 - SRPN 02926 PEC Results, Soil Side Scan, ½"x1" Resolution, 0% Overlap

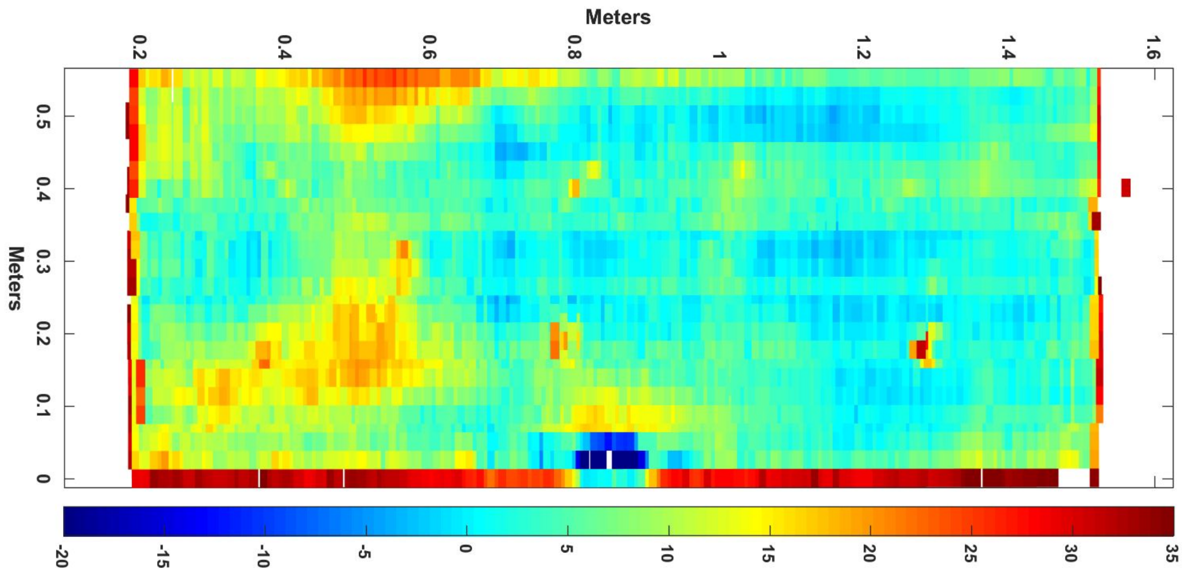


Figure 22 - SRPN 02926 PEC Results, Soil Side Scan, ½"x1" Resolution, 50% Overlap

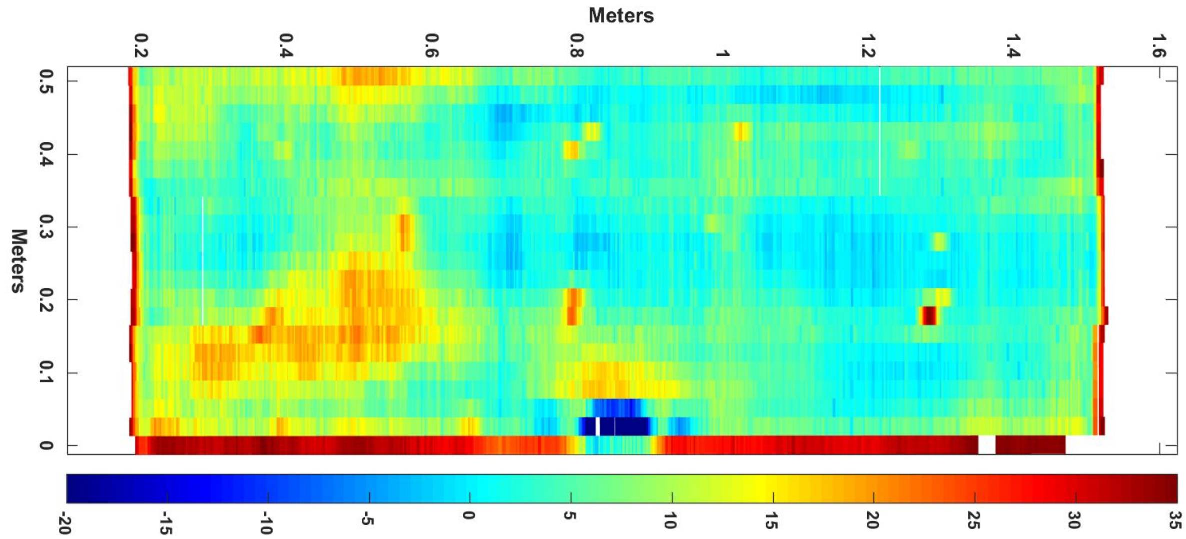


Figure 23 - SRPN 02926 PEC Results, Soil Side Scan, ¼"x1" Resolution, 0% Overlap

SRPN 02926 PEC missions surveyed the entirety of the plate approached from both the product side and soil side of the plate. Note that Figures 19 through 23 show the plate as surveyed from the soil side of the plate and therefore the results are mirror images of the results from product side inspections. The PEC system consistently detected the presence of the welded lap joint on the plate's edge (See Figure 24), and sized it to be 4" x 2" (0.10 m x 0.05 m). This reflects the actual dimensions of the weldment.

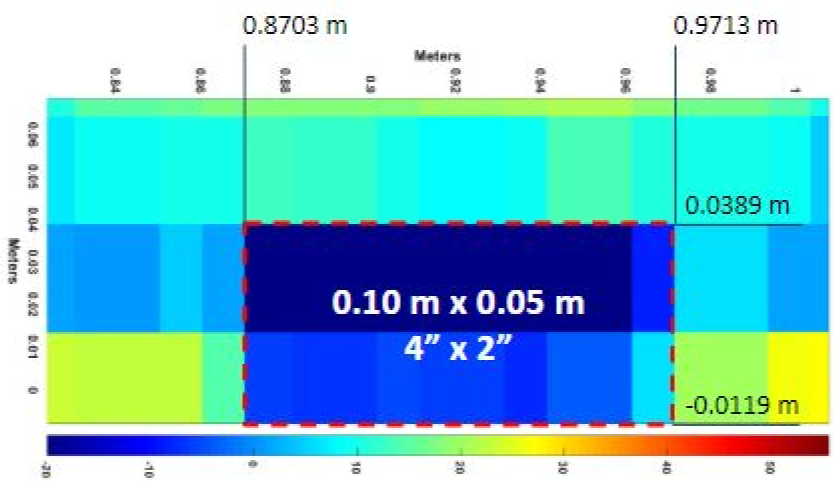


Figure 24 - SRPN 02926 PEC Results, Product Side Scan, 1"x1" Resolution, 50% Overlap, Weldment Sizing

The machined defects can be seen as smaller areas with greater wall thickness loss than their immediate surroundings. Figure 25 highlights the API-653 qualification defects as they would be located on the plate. The defects were measured to be within a %WT loss of 6% to 35%.

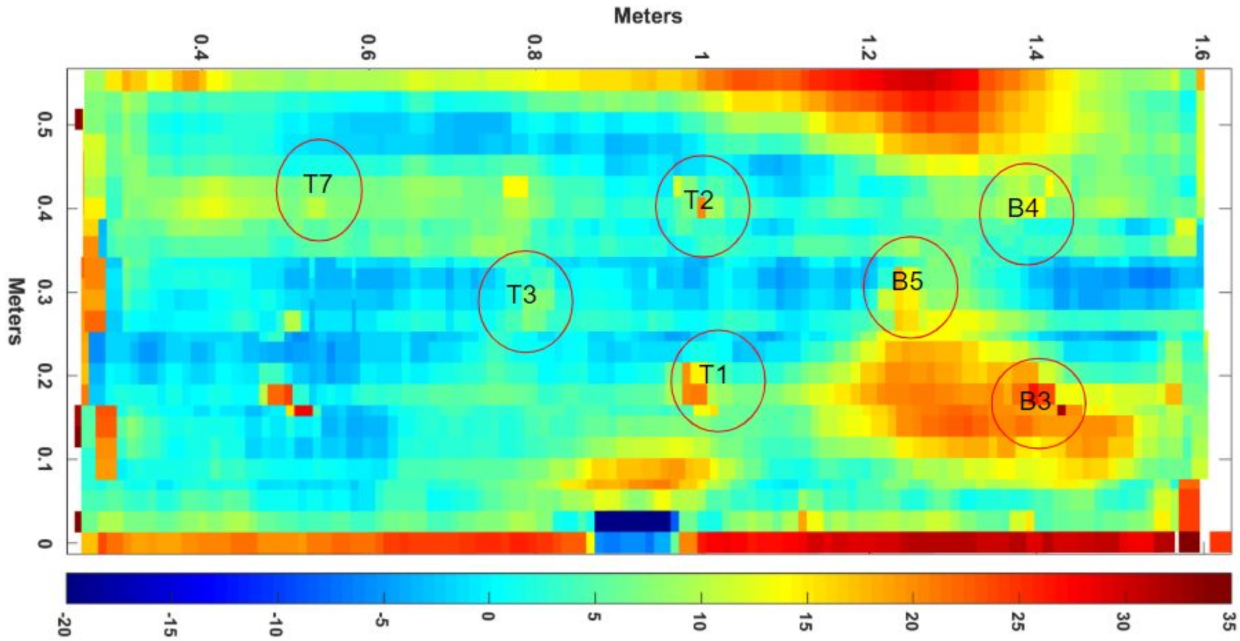


Figure 25 - SRPN 02926 PEC Results, Product Side Scan - Qualification Defects Circled

Large areas of measured %WT loss greater than 0% are consistently detected in all of the PEC results, as highlighted in Figure 26. These areas could be caused by any of the following:

- Corrosion (real detection),
- Presence of a plate edge,
- Change in plate material properties.

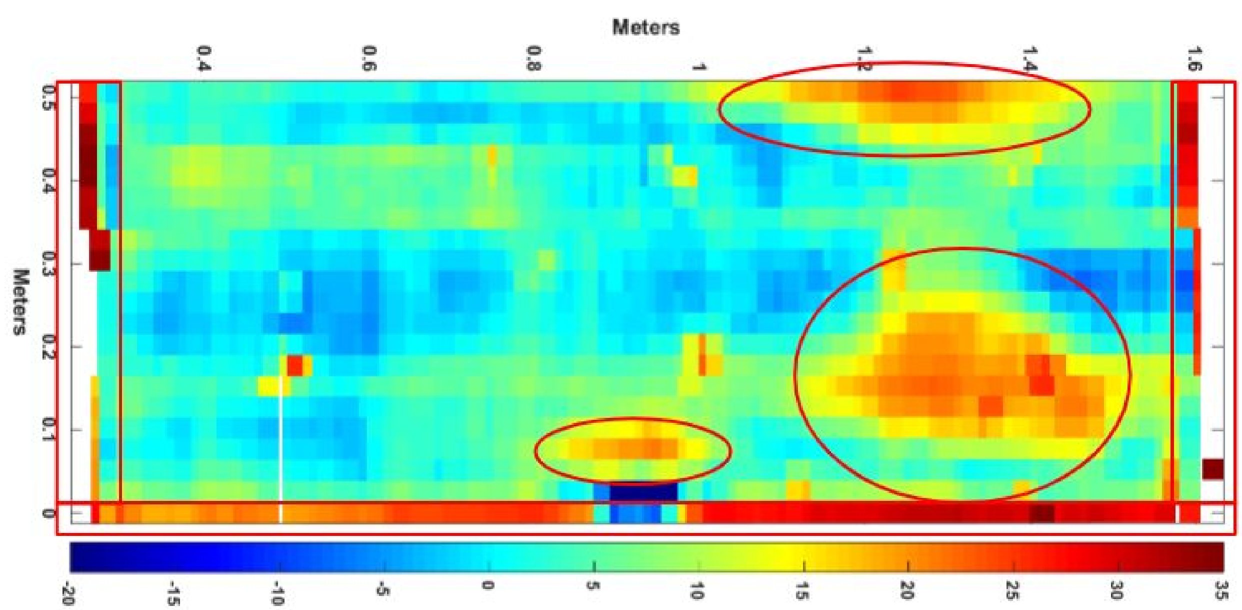
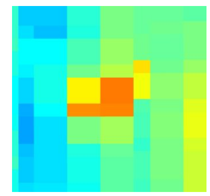
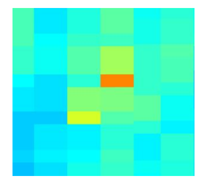
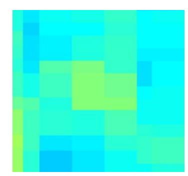
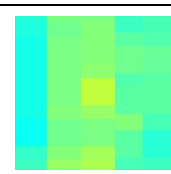
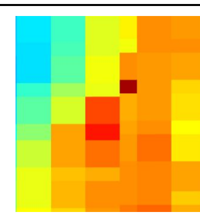
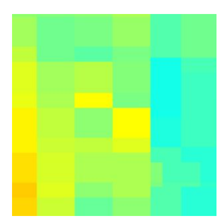


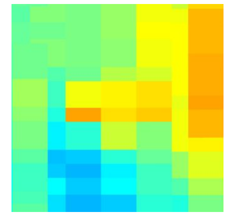
Figure 26 - SRPN 02926 PEC Results, Product Side Scan - False Detections Circled

The detailed results of the identified qualification defects, detected in the 1”x1” resolution, 50% overlap, product side inspection are summarized below in Table 7 and shown in Figures 27 through

33. The soil side detailed inspection results are summarized in Table 8 and shown in Figures 34 through 40.

Table 7 - SRPN 02926 PEC Results, Product Side Scan, API-653 Qualification Defects

Area of Corrosion ID	Actual %WT Remaining	Actual Wall Loss %	Max PEC Measured %WT Loss for Group	Difference	% Error	Defect Image
T1A	50%	50.4%	20.9%	29.5%	59%	
T1B	20%	80.0%	20.9%	59.1%	74%	
T1C	48%	52.0%	20.9%	31.1%	60%	
T1D	28%	72.4%	20.9%	51.5%	71%	
T1E	20%	80.0%	20.9%	59.1%	74%	
T2A	20%	80.0%	20.4%	59.6%	75%	
T2B	16%	84.0%	20.4%	63.6%	76%	
T3A	65%	34.8%	7.6%	27.2%	78%	
T3B	52%	48.0%	7.6%	40.4%	84%	
T3C	50%	50.0%	7.6%	42.4%	85%	
T3D	66%	33.6%	7.6%	26.0%	77%	
T7A	96% - 76%	4% - 24%	10.7%	-7% - +13%	+55%- -168%	
B3A	15.60%	84.4%	32.6%	51.8%	61%	
B3B	16.40%	83.6%	32.6%	51.0%	61%	
B4A	66.80%	33.2%	14.1%	19.1%	58%	
B4B	51.60%	48.4%	14.1%	34.3%	71%	
B4C	50.40%	49.6%	14.1%	35.5%	72%	
B4D	66.80%	33.2%	14.1%	19.1%	58%	

B5A	50.00%	50.0%	18.6%	31.4%	63%	
B5B	20.00%	80.0%	18.6%	61.4%	77%	
B5C	50.00%	50.0%	18.6%	31.4%	63%	
B5D	50.00%	50.0%	18.6%	31.4%	63%	
B5E	20.00%	80.0%	18.6%	61.4%	77%	

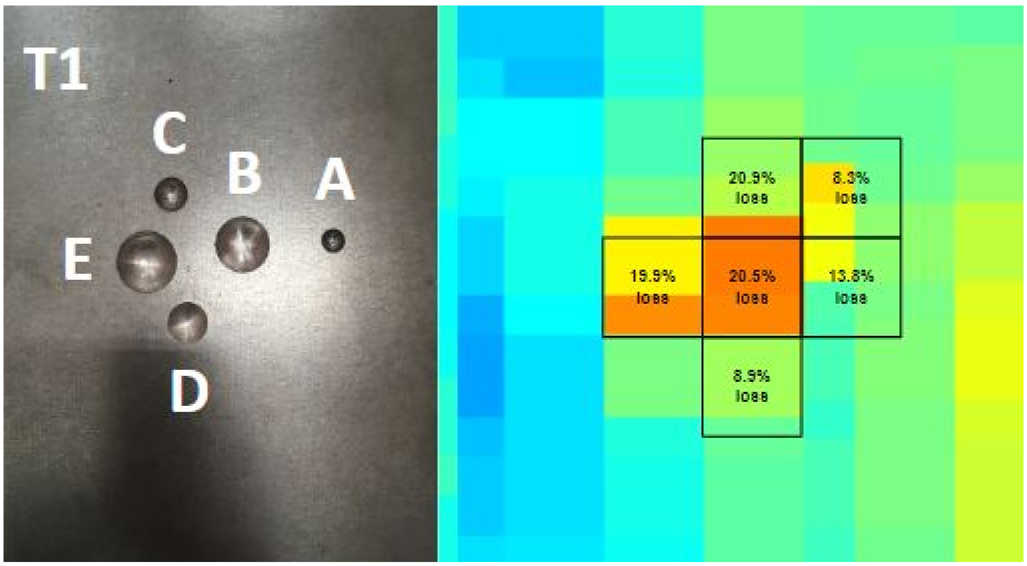


Figure 27 - PEC Results, Product Side Scan, Defect Group T1

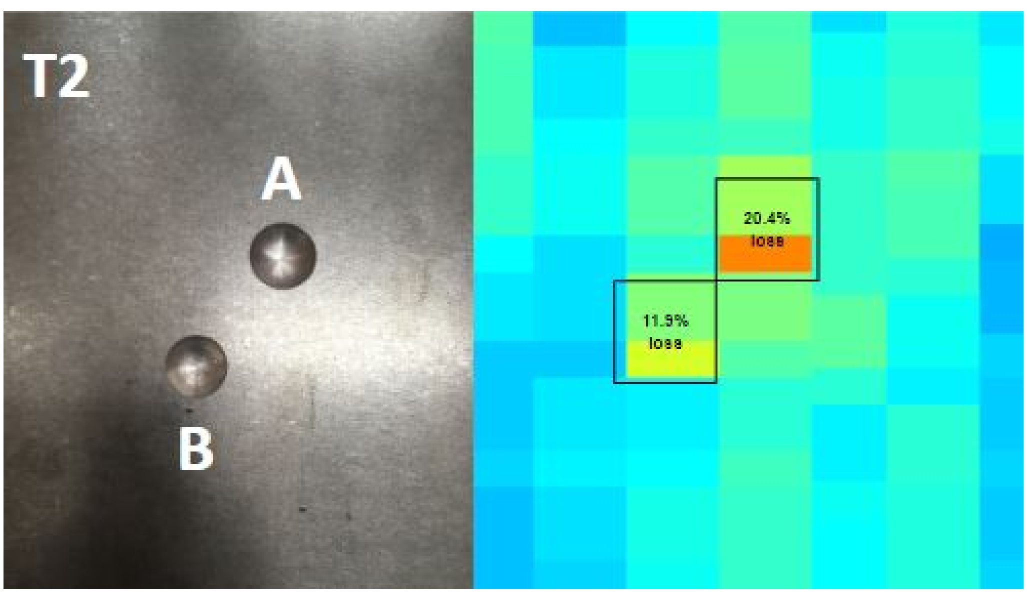


Figure 28 - PEC Results, Product Side Scan, Defect Group T2

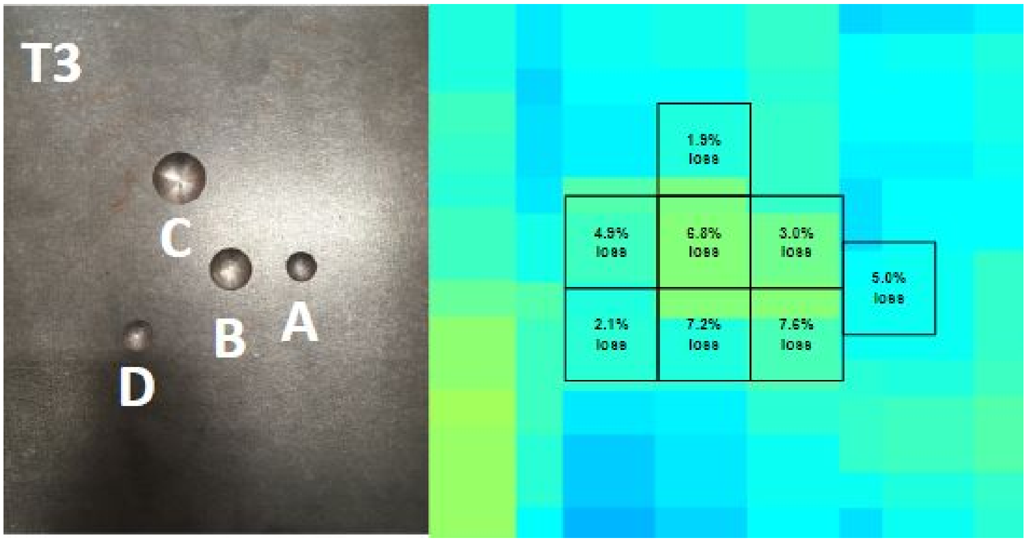


Figure 29 - PEC Results, Product Side Scan, Defect Group T3

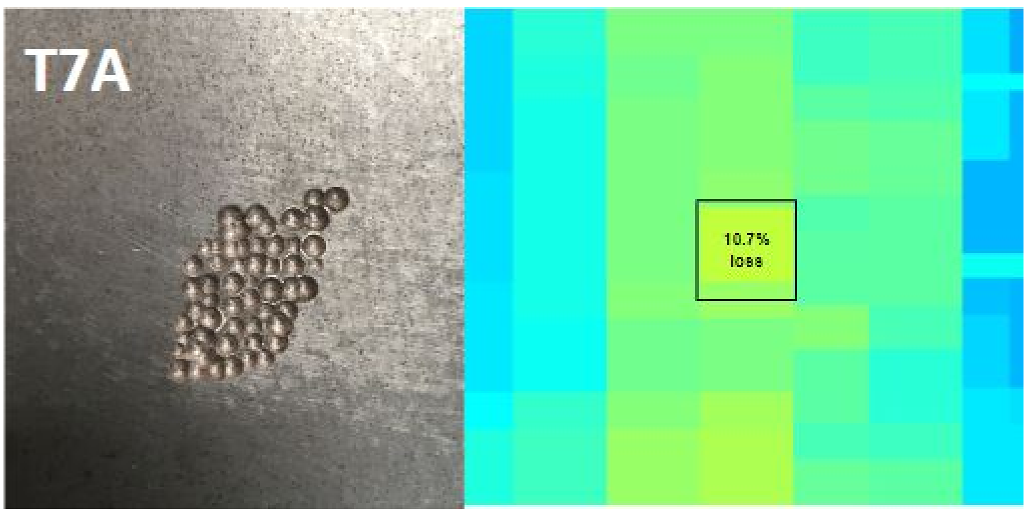


Figure 30 - PEC Results, Product Side Scan, Defect Group T7

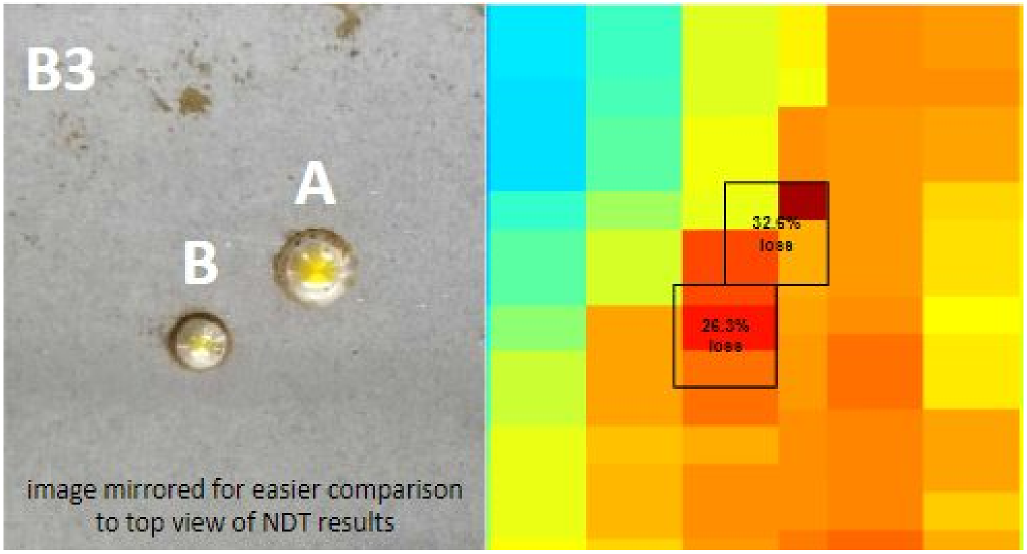


Figure 31 - PEC Results, Product Side Scan, Defect Group B3

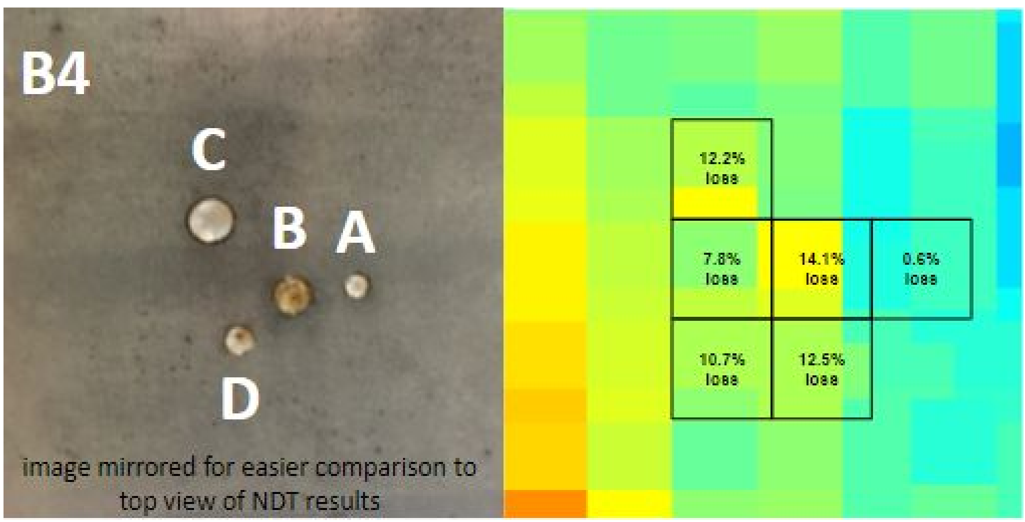


Figure 32 - PEC Results, Product Side Scan, Defect Group B4

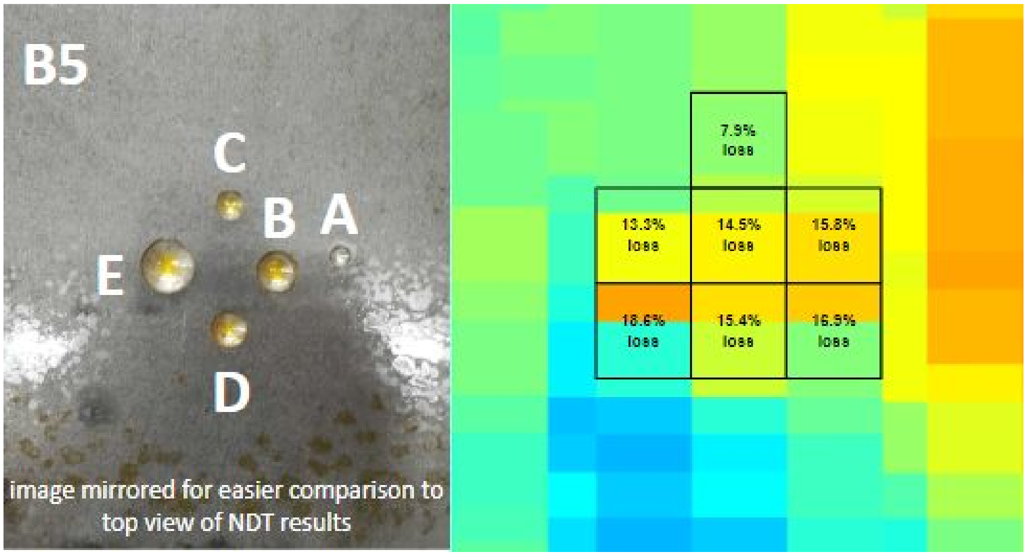
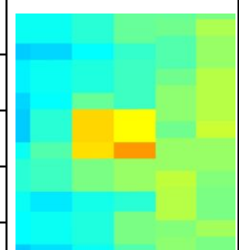
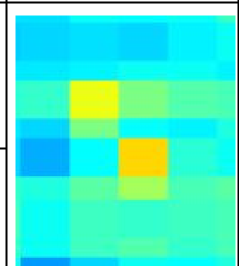
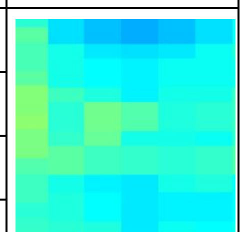
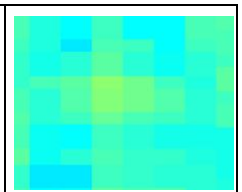
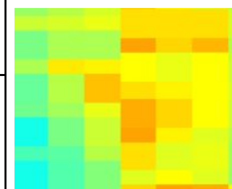
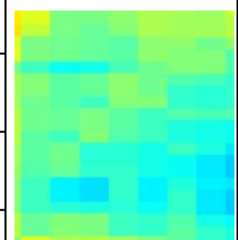
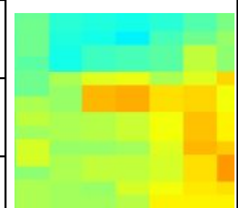


Figure 33 - PEC Results, Product Side Scan, Defect Group B5

Table 8 - SRPN 02926 PEC Results, Soil Side Scan, API-653 Qualification Defects

Area of Corrosion ID	Actual %WT Remaining	Actual Wall Loss %	PEC Measured %WT Loss	Difference	% Error	Defect Image
T1A	50%	50.4%	16.80%	34%	67%	
T1B	20%	80.0%	16.8%	63%	79%	
T1C	48%	52.0%	16.8%	35%	68%	
T1D	28%	72.4%	16.8%	56%	77%	
T1E	20%	80.0%	16.8%	63%	79%	
T2A	20%	80.0%	13%	67%	84%	
T2B	16%	84.0%	16.7%	67%	80%	
T3A	65%	34.8%	6.50%	28%	81%	
T3B	52%	48.0%	6.5%	42%	86%	
T3C	50%	50.0%	6.5%	44%	87%	
T3D	66%	33.6%	6.5%	27%	81%	

T7A	96% - 76%	4% - 24%	7.80%	-3% - 16.2%	-95% - 67.5%	
B3A	15.60%	84.4%	17.8%	66.60%	79%	
B3B	16.40%	83.6%	19.40%	64.20%	77%	
B4A	66.80%	33.2%	7.8%	25.40%	77%	
B4B	51.60%	48.4%	7.8%	40.60%	84%	
B4C	50.40%	49.6%	7.8%	41.80%	84%	
B4D	66.80%	33.2%	7.8%	25.40%	77%	
B5A	50.00%	50.0%	18.8%	31.20%	62%	
B5B	20.00%	80.0%	18.8%	61.20%	77%	
B5C	50.00%	50.0%	18.8%	31.20%	62%	
B5D	50.00%	50.0%	18.8%	31.20%	62%	
B5E	20.00%	80.0%	18.8%	61.20%	77%	

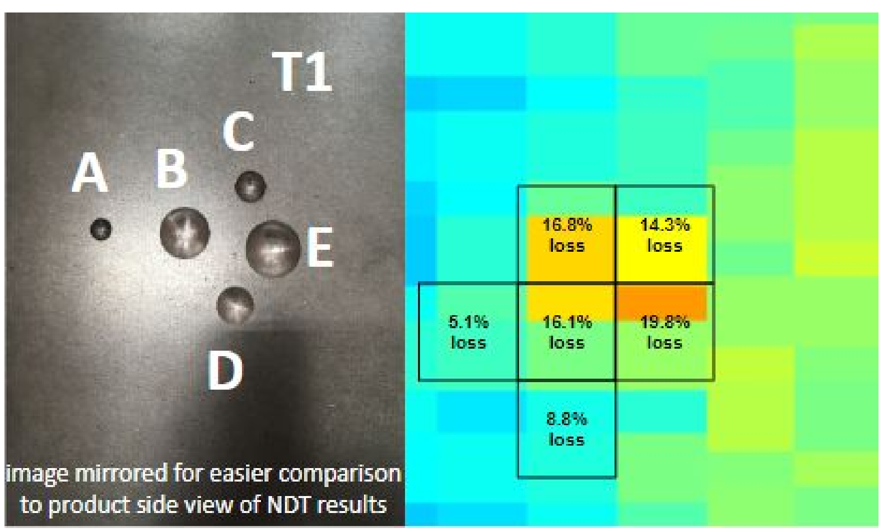


Figure 34 - PEC Results, Soil Side Scan, Defect Group T1

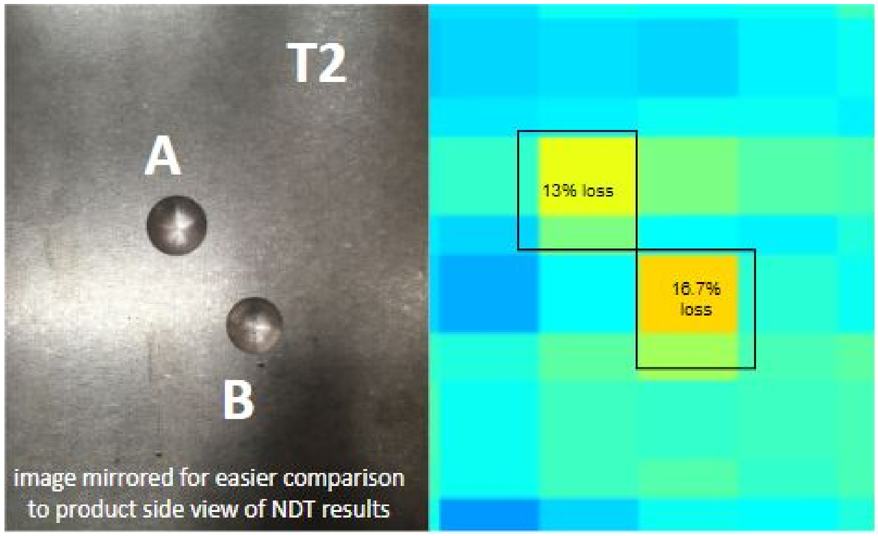


Figure 35 - PEC Results, Soil Side Scan, Defect Group T2

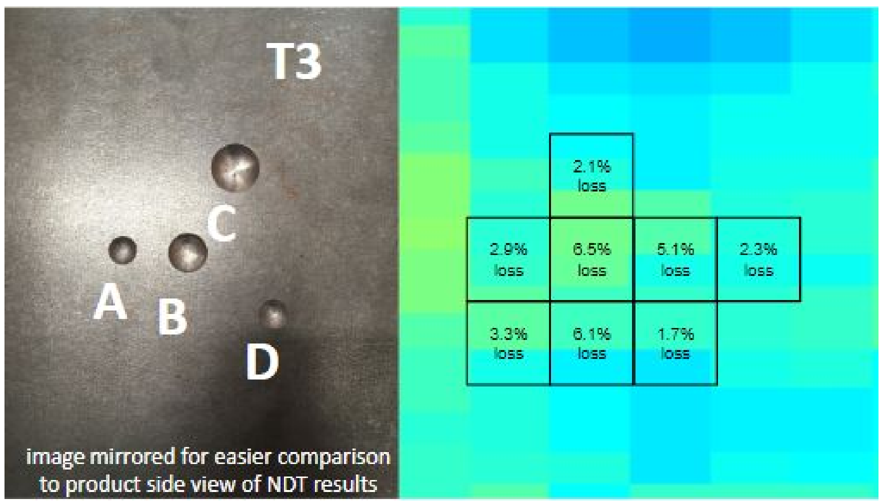


Figure 36 - PEC Results, Soil Side Scan, Defect Group T3

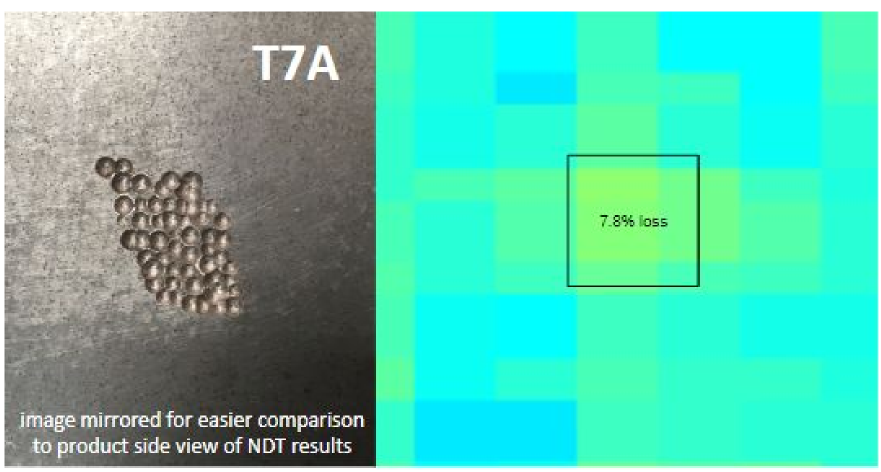


Figure 37 - PEC Results, Soil Side Scan, Defect Group T7

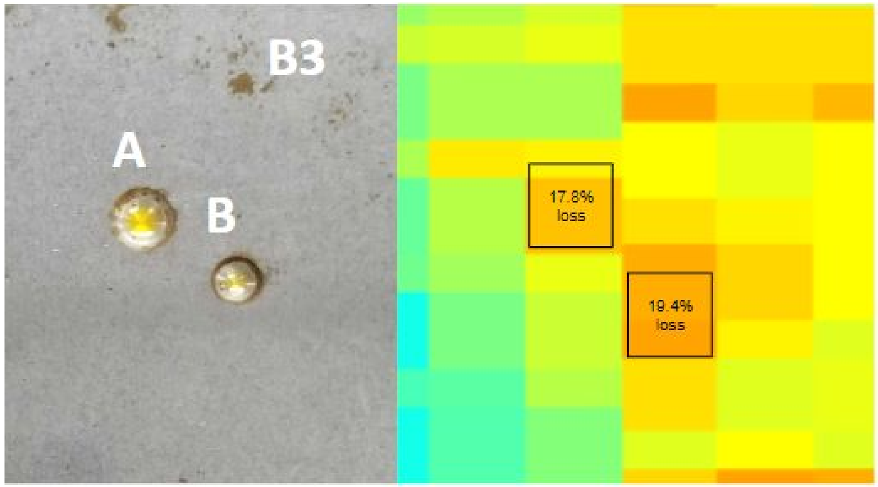


Figure 38 - PEC Results, Soil Side Scan, Defect Group B3

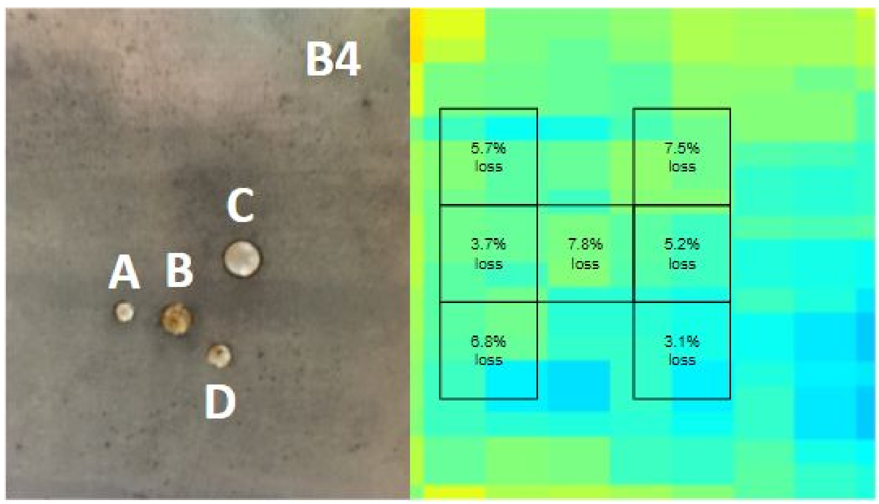


Figure 39 - PEC Results, Soil Side Scan, Defect Group B4

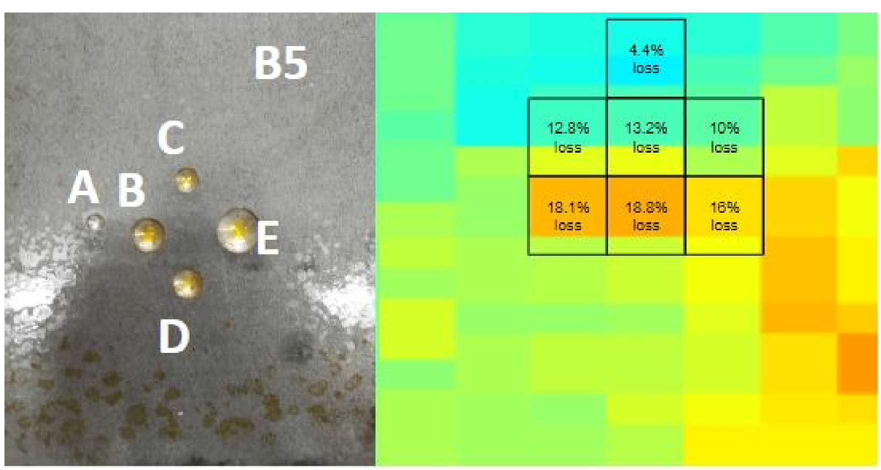


Figure 40 - PEC Results, Soil Side Scan, Defect Group B5

3.1.4. PAUT Results

SRPN 02926 was autonomously inspected on April 22-24, 2020 using a Phased Array Ultrasonic Testing (PAUT) NDT system mounted on the gantry system. This autonomous PAUT data acquisition was performed under conditions designed to emulate the vehicle's operating environment. The 256-element PAUT array (referred to as transducer) was mounted to the gantry at a fixed standoff from the plate of 2" (50 mm). Missions were run at 2 in/s (5 cm/s), 4 in/s (10 cm/s), 6 in/s (15 cm/s), and 8 in/s (20 cm/s). Tracklines primarily covered the 12" wide area on the plate that contained the qualification defects. The length of the transducer inside of the gantry system physically limited the survey to this area of the plate. The PAUT results are shown in Figures 43 through 47 and summarized in Table 9. The colormaps shown in Figures 43-47 are in %WT loss as defined by Figure 41. The majority of the plate was determined to be healthy, with no thickness loss, shown as gray. Defects were detected using the gate settings shown in Figure 42. To further investigate each detected defect and accurately determine defect size, gate settings were modified for each pit found.

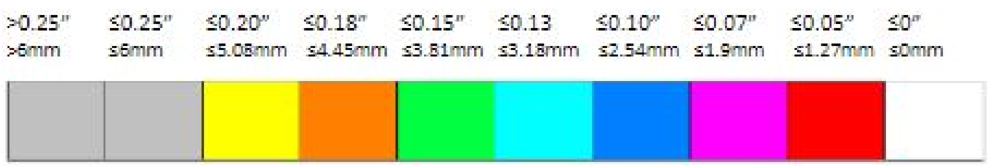


Figure 41 - PAUT Colormap Thickness Scale

Gate Name	Start [mm]	Width [mm]	Threshold	Evaluation Type	Gate Mode	Dependent Gate
Gate I	0.01	80	50.00	Maximum	Absolute	None
Steel	1	10	30.00	Maximum	Absolute	Gate I

Figure 42 - PAUT Gate Settings for Defect Detection

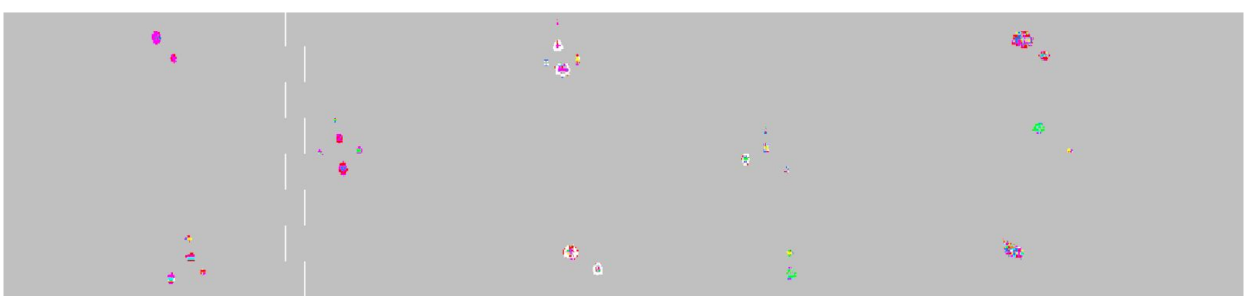


Figure 43 - SRPN 02926 PAUT Results, Product Side Scan, 2 in/s (5cm/s), 0% Overlap

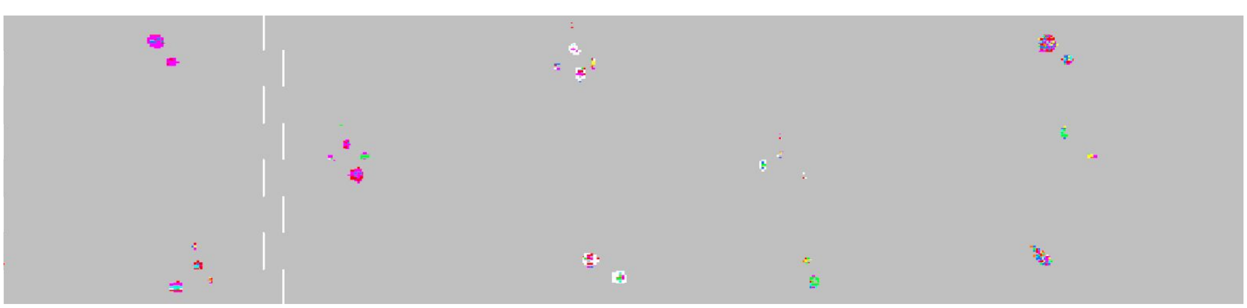


Figure 44 - SRPN 02926 PAUT Results, Product Side Scan, 4 in/s (10cm/s), 0% Overlap

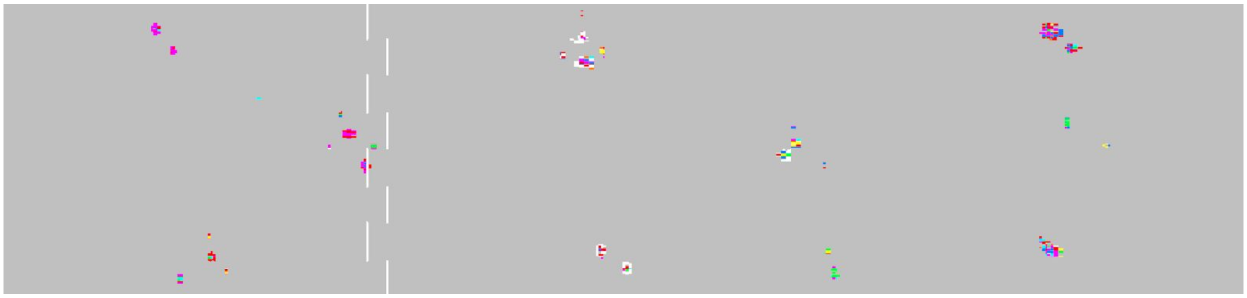


Figure 45 - SRPN 02926 PAUT Results, Product Side Scan, 6 in/s (15cm/s), 0% Overlap

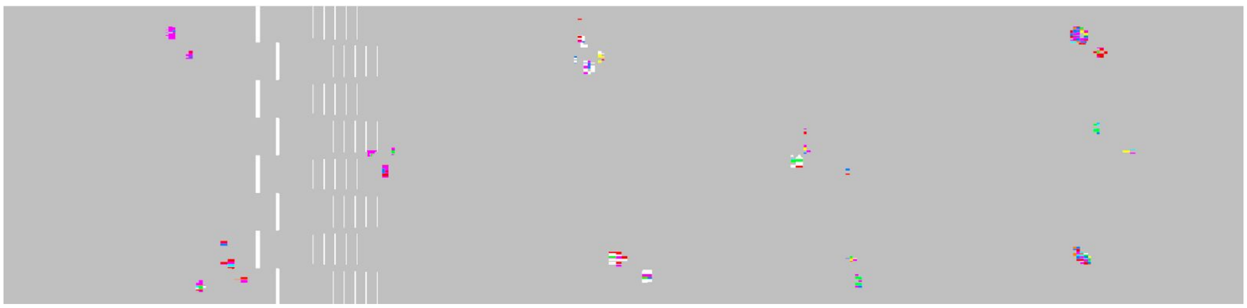
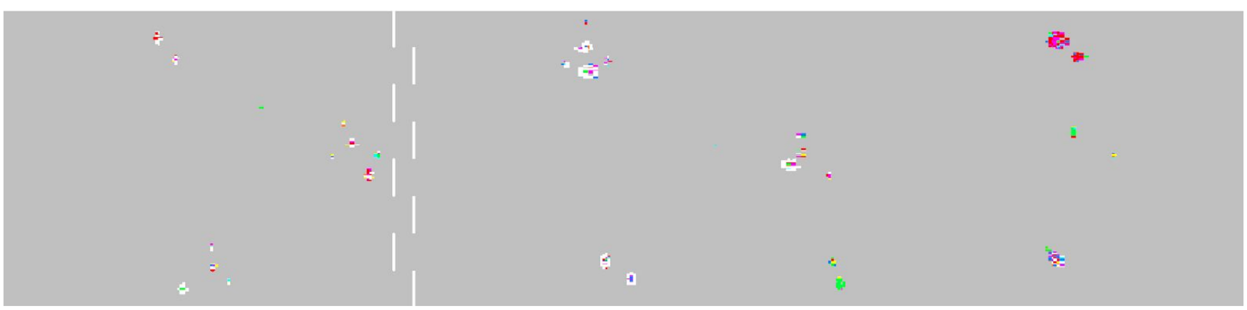


Figure 46 - SRPN 02926 PAUT Results, Product Side Scan, 8 in/s (20cm/s), 0% Overlap

	Gate Name	Start [mm]	Width [mm]	Threshold	Evaluation Type	Gate Mode	Dependent Gate	Gate Color
1	Gate I	0.01	81	35.00	Maximum	Absolute	None	
2	Coating	1	7	35.00	Maximum	Absolute	Gate I	
3	Steel	1	7	25.00	Maximum	Absolute	Coating	



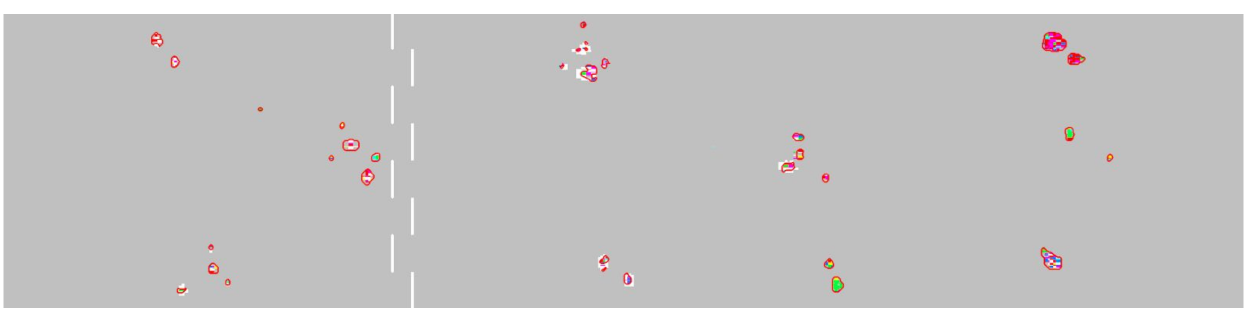
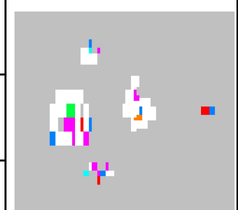
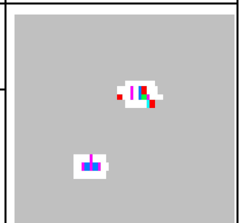
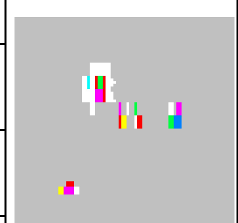
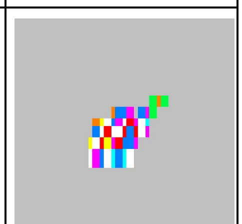
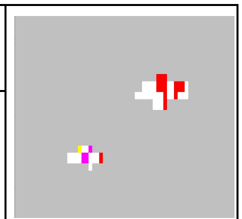
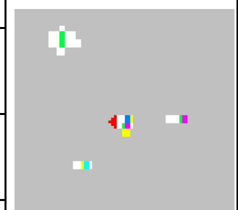
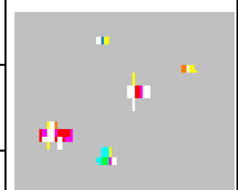


Figure 47 - SRPN 02926 PAUT Results, Mission 3 (6 in/s [15cm/s]), Gate Settings (Top), Raw Results (Middle), Defects Highlighted (Bottom)

Figure 47 shows results from the 6 in/s (15 cm/s) PAUT data collection with three gates, attempting to better estimate the sizing of the defects. The red highlighted areas are detailed in an extended, automated PAUT report, included in the documentation package of this report. However, a single gate setting is not appropriate to accurately determine sizing for each defect. As such, a detailed analysis, conducted by an ASNT NDT Level III Examiner, of each detected defect is presented in Table 9. This analysis acts as a defect sizing or prove-up examination, and is discussed in Section 4.1 to qualify the sensor against the API 653 qualification requirements.

Table 9 - SRPN 02926 PAUT Results, Product Side Scan, API-653 Qualification Defects

Area of Corrosion ID	Actual Wall Loss %	Actual Flaw Depth inches [mm]	PAUT Measured Flaw Depth inches [mm]	Difference inches [mm]	% Error	Defect Image
T1A	50.4%	0.13 [3.200]	0.12 [2.95]	0.010 [0.25]	7.8	
T1B	80.0%	0.20 [5.080]	0.21 [5.28]	-0.008 [-0.20]	-3.9	
T1C	52.0%	0.13 [3.302]	0.13 [3.26]	0.002 [0.04]	1.3	
T1D	72.4%	0.18 [4.597]	0.19 [4.74]	-0.006 [-0.14]	-3.1	
T1E	80.0%	0.20 [5.080]	0.19 [4.77]	0.012 [0.31]	6.1	
T2A	80.0%	0.20 [5.080]	0.21 [5.22]	-0.006 [-0.14]	-2.8	
T2B	84.0%	0.21 [5.334]	0.19 [4.90]	0.017 [0.43]	8.1	
T3A	34.8%	0.09 [2.210]	0.08 [2.07]	0.006 [0.14]	6.3	
T3B	48.0%	0.12 [3.048]	0.12 [2.95]	0.004 [0.10]	3.2	
T3C	50.0%	0.13 [3.175]	0.11 [2.88]	0.012 [0.30]	9.3	
T3D	33.6%	0.08 [2.134]	0.08 [2.00]	0.005 [0.13]	6.3	
T7A	4-24%	0.06 [1.524]	N/A	N/A	N/A	

B3A	84.4%	0.21 [5.359]	0.20 [5.03]	0.013 [0.33]	6.2	
B3B	83.6%	0.21 [5.309]	0.19 [4.90]	0.016 [0.41]	7.6	
B4A	33.2%	0.08 [2.108]	0.07 [1.82]	0.011 [0.29]	13.7	
B4B	48.4%	0.12 [3.073]	0.12 [2.95]	0.005 [0.12]	4.0	
B4C	49.6%	0.12 [3.150]	0.11 [2.75]	0.016 [0.40]	12.7	
B4D	33.2%	0.08 [2.108]	0.07 [1.69]	0.016 [0.42]	19.8	
B5A	50.0%	0.13 [3.175]	0.11 [2.89]	0.011 [0.29]	9.0	
B5B	80.0%	0.20 [5.080]	0.20 [5.16]	-0.003 [-0.08]	-1.6	
B5C	50.0%	0.13 [3.175]	0.12 [2.94]	0.009 [0.24]	7.4	
B5D	50.0%	0.13 [3.175]	0.11 [2.82]	0.014 [0.36]	11.2	
B5E	80.0%	0.20 [5.080]	0.20 [5.02]	0.002 [0.06]	1.2	

Detailed A-Scans of each defect can be found in the Appendix

4. Conclusions

4.1. Discussion of Results

4.1.1. Significance of Results

The results from testing provide a baseline for the data quality generated by a PEC or PAUT sensor on a Square Robot system. Evaluating the sensors under conditions emulating the robot's environment against an industry-accepted qualification plate serves to validate a payload for in-service aboveground storage tank inspection. The procedure developed herein can be used to gather data for future acceptance testing.

4.1.2. Discussion of Results

The results from testing show a consensus amongst the sensor systems on the locations of designed flaws on SRPN 02926. The API-653 defined defects can be seen in each of the sensor thickness maps (see Figure 48). These results show an overall ability of each sensor type, PEC and PAUT, to detect thickness loss on a low-carbon steel plate. Figure 48 shows plate thickness as a percent of wall thickness loss. The colormap transitions from blue to red, based on the measured %WT loss. A plate with 0.25" (6.35 mm) thickness remaining has 0% WT loss and is shown as blue. Green represents 5-10% WT loss on the PEC data, and 30% WT loss on the PAUT sensor data. Red represents 30% WT loss on the PEC data, and 50% WT loss on the PAUT sensor data.

The results show that PEC reports thicknesses generally greater than MFL or PAUT, the exception being areas of false detections. A detailed analysis of the A-scans and patterns suggested that the large areas of false detection are material property variations in the plate. The physics of the PEC system are such that isolated pits or defect clusters are averaged with their immediate surroundings, an area approximately 1” in diameter (0.79 in^2). This averaging effectively reduces the resolution of the measured data and generates results that underestimate a defect's wall loss; or equivalently overestimates a defect's remaining wall thickness. Results show that PEC is capable of detecting defects as small as the user-configured, along-track resolution (1”, 0.5” or 0.25”), as well as areas of greater thickness (weldments). The thickness measurements reported by PEC should be taken as an indication of overall health of the 1” diameter area around each data point. If a more accurate (<±20%) thickness measurement of a small area (~0.79 in^2) is needed, a different sensor must be used.

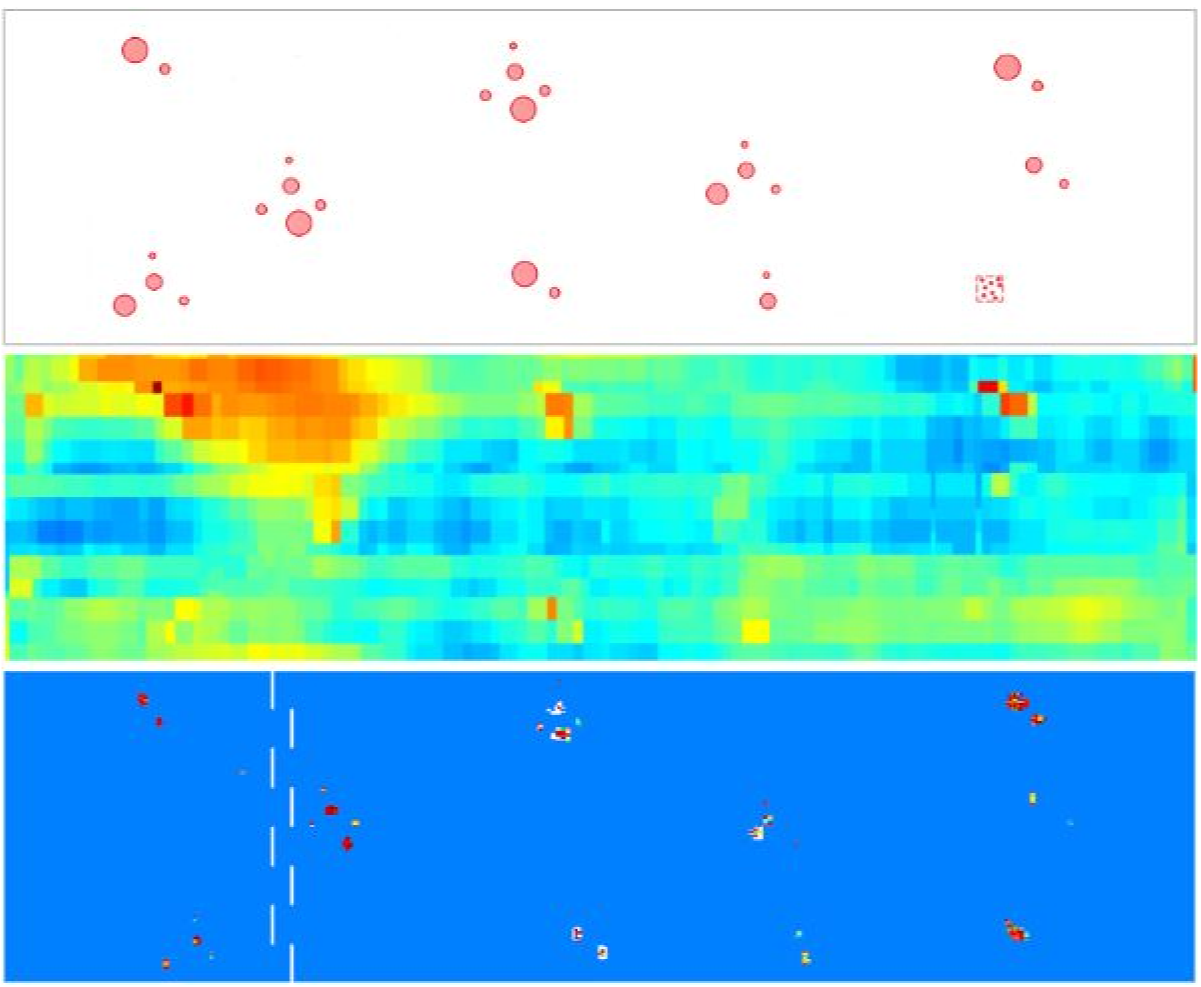


Figure 48 - Thickness Results: Drawing of Details (top), PEC (mid), PAUT (bottom)

Multiple datasets were acquired with the PAUT and PEC sensors to test system repeatability. Both sensors showed consistency across datasets. Figures 49 and 50 show side-by-side results of four independent runs on each side of SRPN 02926 using the PAUT system. The repeatability of the

PAUT results add confidence that the sensor data gathered by the system reflects real detections, and not false positives. Additionally, the results show the system's ability to perform regardless of survey speed. Data was acquired at the lower (2, 4 in/s [5 ,10 mm/s]), nominal (6 in/s [15 cm/s]), and upper (8 in/s [20 cm/s]) speed range of the vehicle. At 8 in/s [20 cm/s] three of the defects, B5A, B5B, and T3A were not consistently detected. This is likely caused by data loss (presenting as white lines along the trackline) and the higher survey speed. Multiple data collections were conducted at each speed. For all runs except the 8 in/s runs, all defects were detected. For robot operations, based on the PAUT results, it is recommended that the survey be run at 6 in/s (15 cm/s) with 0-50% overlap. This will ensure all defects are detected. The 50% overlap will act as an assurance that the plate is completely inspected while reducing the occurrence of false detections.

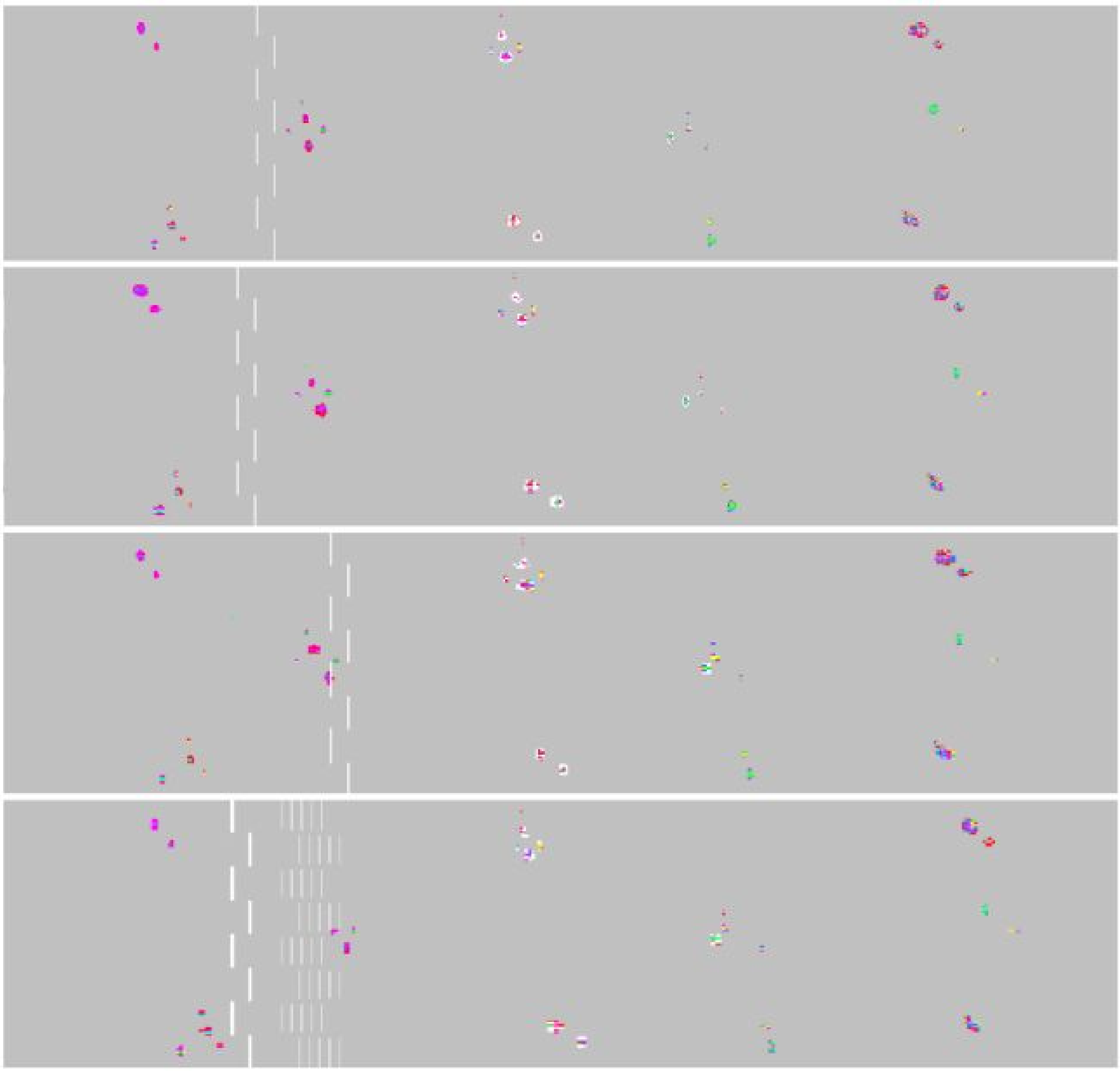


Figure 49 - PAUT Results Repeatability, Product Side (from top to bottom: 2in/s [5cm/s], 4 in/s [10cm/s], 6 in/s [15cm/s], 8 in/s [20cm/s])

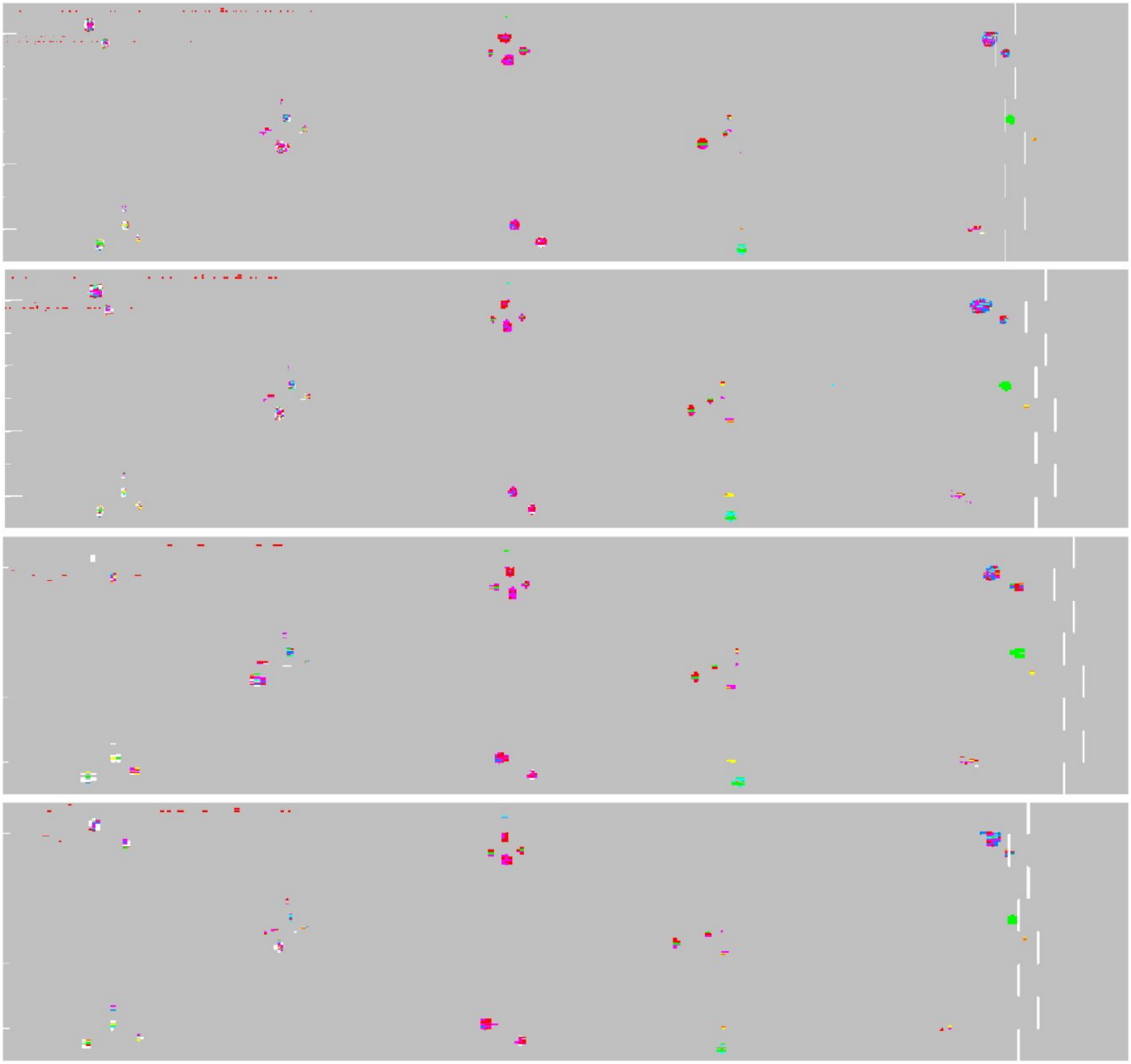


Figure 50 - PAUT Results Repeatability, Soil Side (from top to bottom: 2in/s [5cm/s], 4 in/s [10cm/s], 6 in/s [15cm/s], 8 in/s [20cm/s])

The PEC system proved to generate repeatable results on SRPN 02926, as shown in Figures 51 and 52. The PEC results with higher resolution improved the quality of the image, but did not significantly affect defect detection. The higher resolution also required slower speeds, between 3-5 cm/s. The desired survey speed for the robot is 4-6 in/s (10-15 cm/s), in order to reduce the time to inspect and optimize vehicle operating times. As such, and given the similar results regardless of resolution, it is recommended that PEC surveys be completed at a resolution of 1”x1” at 4 in/s.

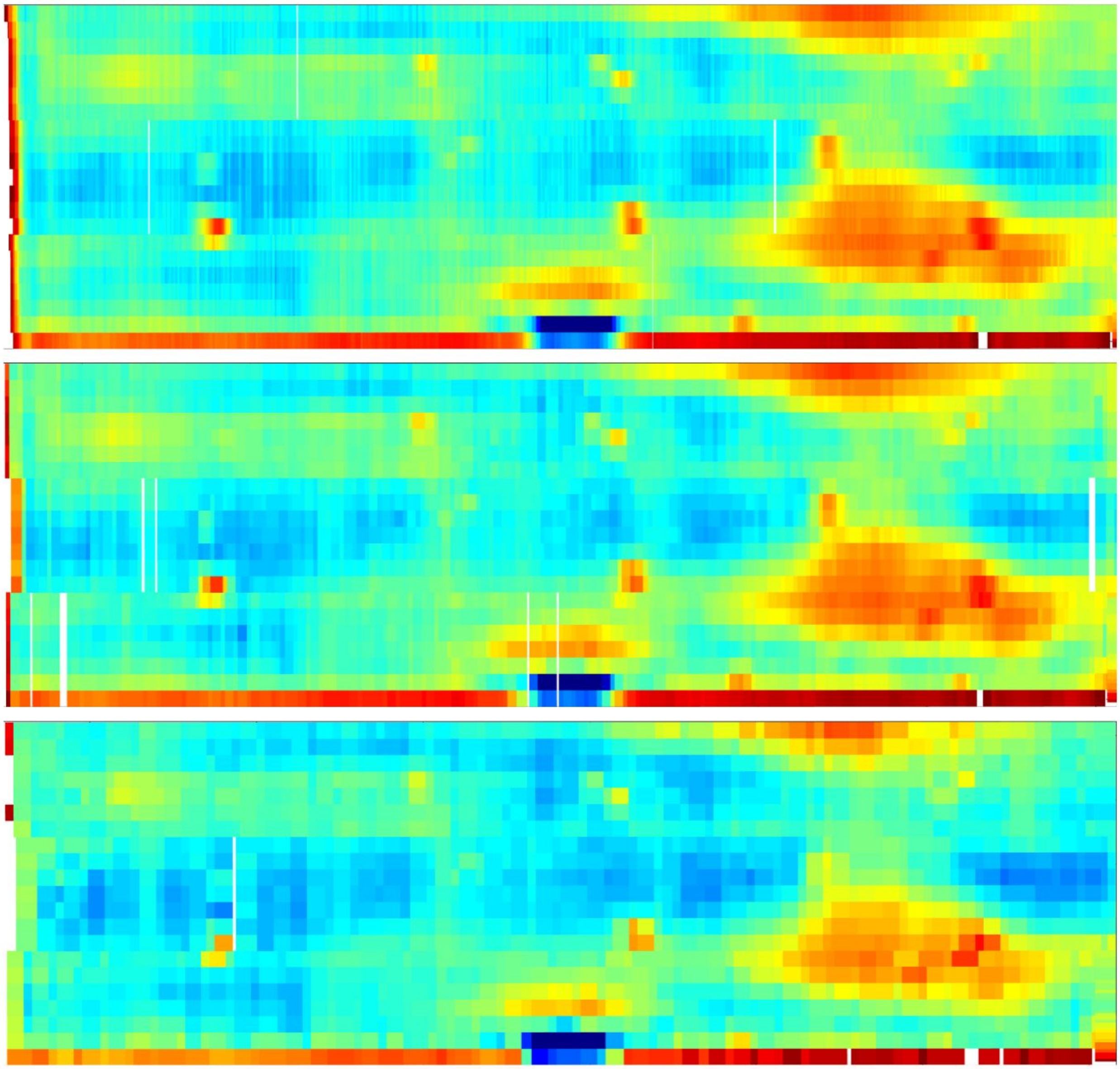


Figure 51 - PEC Results Repeatability, Product Side (from top to bottom: 1 in/s [3cm/s], 2 in/s [5cm/s], 4 in/s [10cm/s])

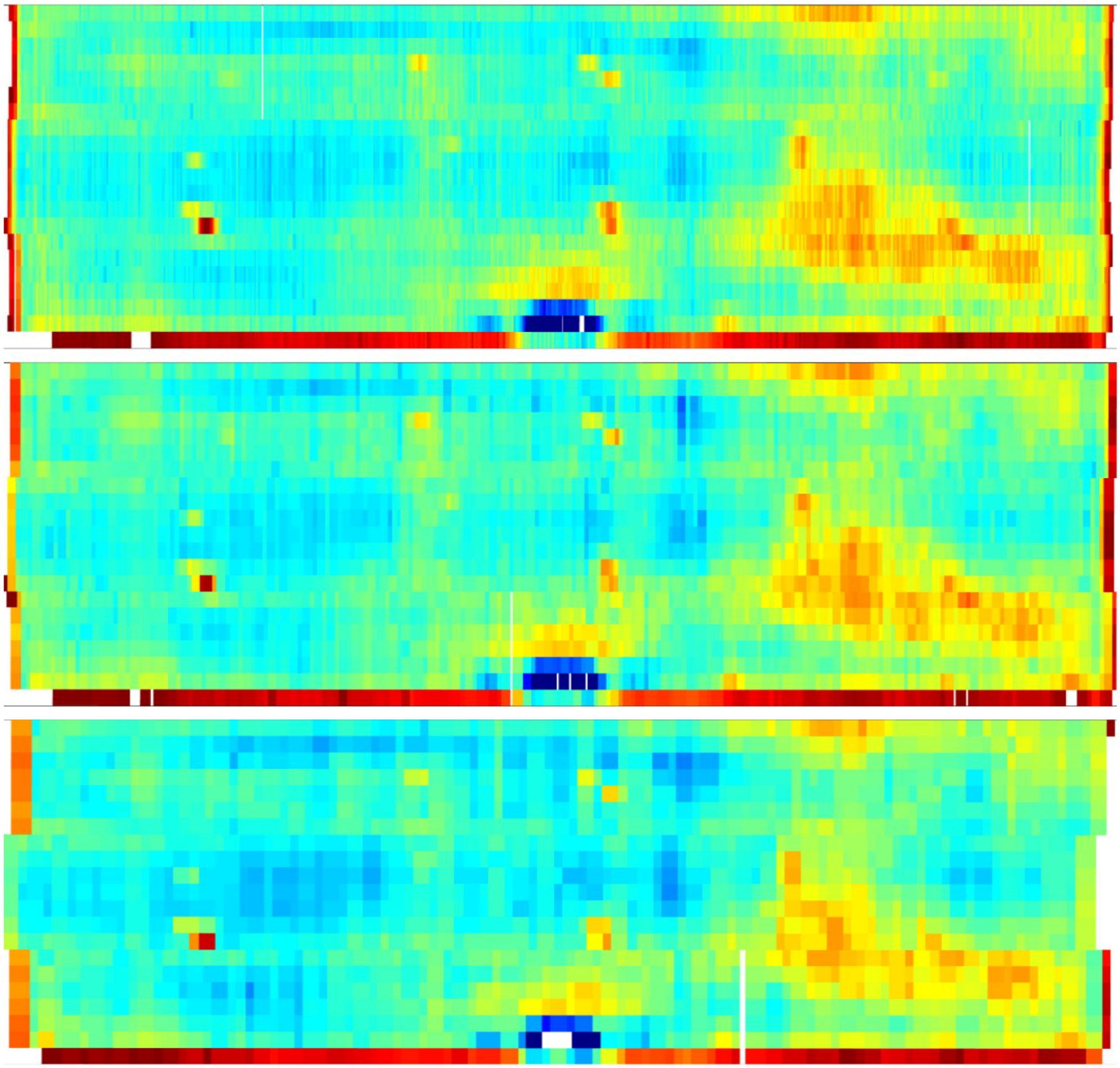


Figure 52 - PEC Results Repeatability, Soil Side (from top to bottom: 1 in/s [3cm/s], 2 in/s [5cm/s], 4 in/s [10cm/s])

Additional figures showing data overlays between each of the sensors and the plate's drawing are provided in Figure 53-55. One can further observe the similarities in the shape of defect clusters on the API-653 SRPN 02926 plate across the data sets. The exact location of defects do appear to shift from dataset to dataset. Due to the human errors inherent in the plate placement in the gantry, the accuracy of the location of defects is expected to vary as much as ±2 inches (51 mm). Once installed on the robot, the accuracy of the measurement's location is determined by the navigational accuracy of the robot, eliminating human error/uncertainty.

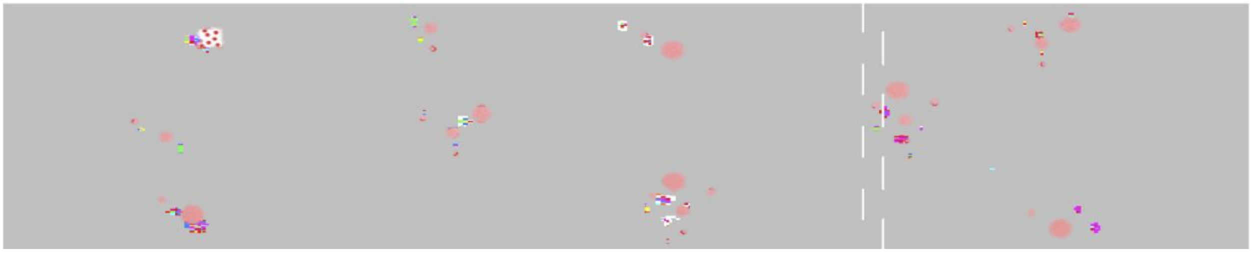


Figure 53 - Overlay of PAUT and SRPN 02926 Drawing

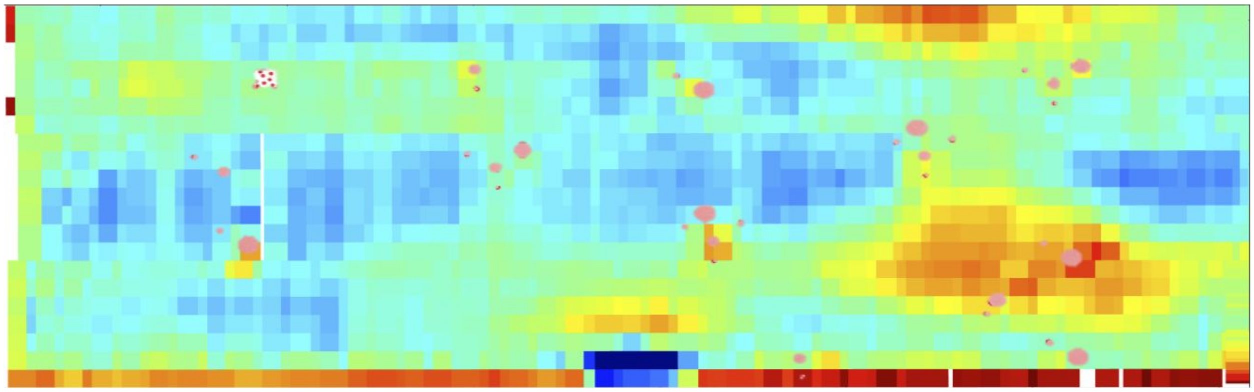


Figure 54 - Overlay of PEC and SRPN 02926 Drawing

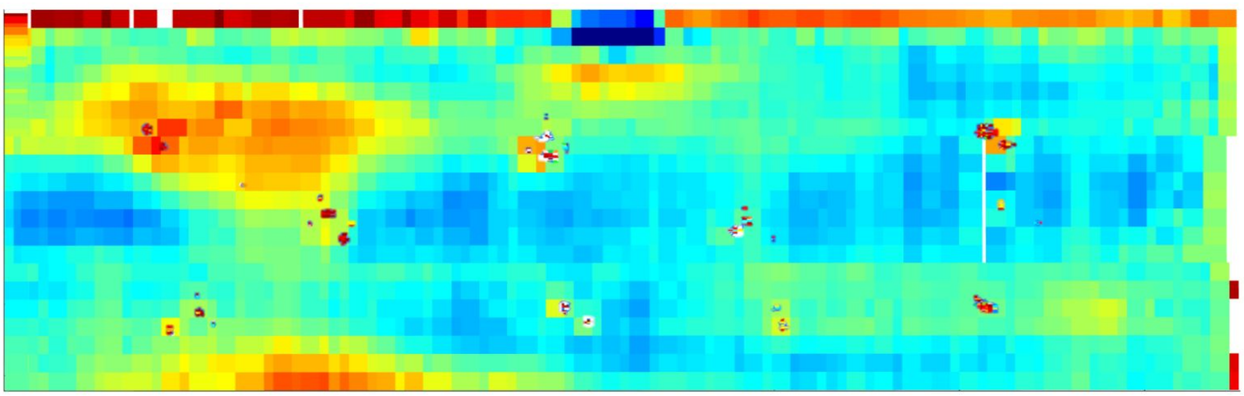


Figure 55 - Overlay of PEC and PAUT Results

API-653 provides the qualification specifications defined in Table 10.

Table 10 - API-653 Qualification Test Acceptance Standards

Scanning Procedure/Operator/Equipment Standards	**Remaining Wall Thickness (in)**	**Flaws That Must be Found**
	t < 0.050 in	90% - 100%
	0.050 in < t < 1/2T	70% - 90%
	1/2T < t < 2/3T	40% - 60%
	Area of general corrosion	100%

Prove-up Procedure/Operator/Equipment Standards	Type of Tank Bottom	Prove-up (Flaw Depth)
	Not coated	±0.020 in
	Thin coating < 0.030 in	±0.030 in
	Thick coating > 0.030 in	Per agreement with owner/operator

Figure 56 and Table 11 provide summaries of the results for each qualification defect, as a function of % Wall Thickness remaining.

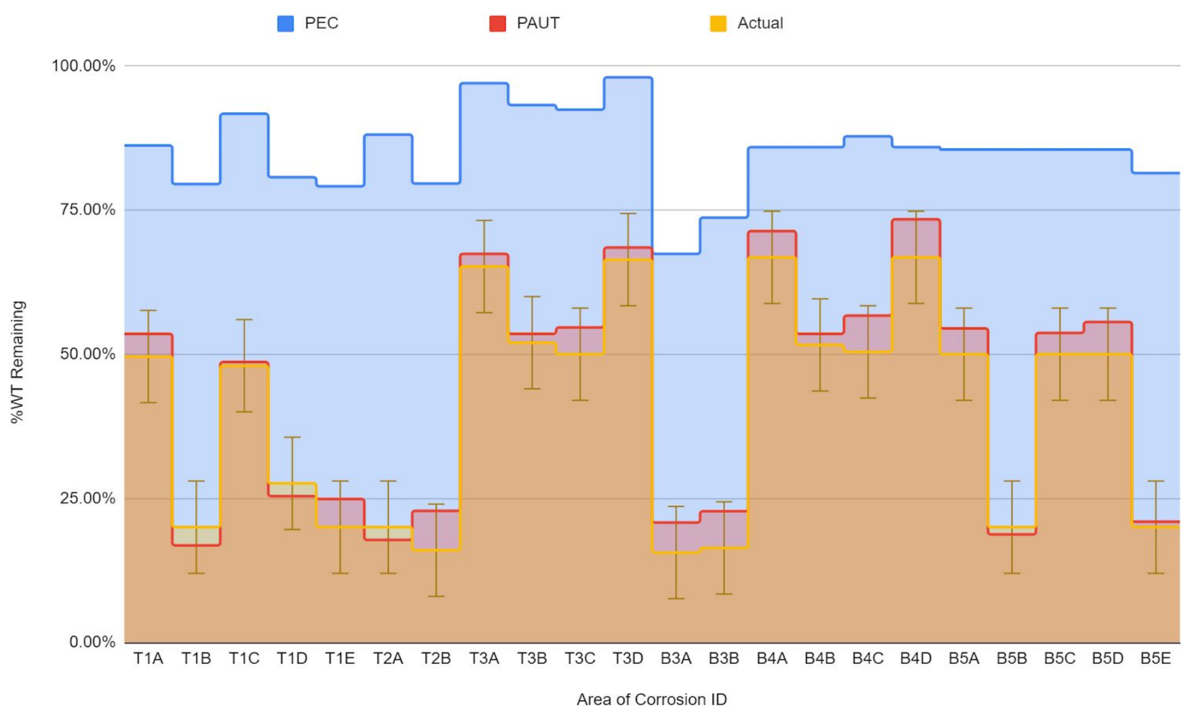


Figure 56 - Qualification Defects Summary of %WT Remaining (Allowable Measurement Range Shown as Vertical "Error" Bars)

PEC results consistently measure significantly greater %WT remaining when compared to PAUT data and the known thickness of the defects. PEC results averaged a 41% WT Remaining Difference (70% Error) from the known defect depth. The PEC data %WT Remaining Difference increased as the size of the defect decreased, an expected performance behavior given the averaging area of the PEC data samples. PEC does not meet API-653 Annex G Qualification Test Acceptance Standards for defect sizing/prove-up.

PAUT results meet API-653 Annex G Qualification Test Acceptance Standards for defect sizing/prove-up. All defect sizing results were within the allowable ±0.020 inches. The sizing analysis was completed on the 6 in/s (15 cm/s) dataset with no overlap. During a tank inspection, the robot will survey the tank with PAUT at 6 in/s, with 0-50% overlap to maximize the percentage of the floor covered in the survey.

Table 11 - Qualification Defects - Summary of %WT Remaining Results

Area of Corrosion ID	**Location *(X,Y)* *Gantry Coordinates [m]***	**Actual %WT Remaining**	**PEC %WT Remaining**	**PAUT %WT Remaining (+/- 5%)**
T1A	$(X,Y)_{gantry}$ = (0.39,0.66)	49.60%	86.20%	53.54%
T1B	$(X,Y)_{gantry}$ = (0.36,0.66)	20.00%	79.50%	16.85%
T1C	$(X,Y)_{gantry}$ = (0.35,0.64)	48.00%	91.70%	48.66%
T1D	$(X,Y)_{gantry}$ = (0.35,0.69)	27.60%	80.70%	25.35%
T1E	$(X,Y)_{gantry}$ = (0.34,0.67)	20.00%	79.10%	24.88%
T2A	$(X,Y)_{gantry}$ = (0.15,0.68)	20.00%	88.10%	17.80%
T2B	$(X,Y)_{gantry}$ = (0.13,0.71)	16.00%	79.60%	22.83%
T3A	$(X,Y)_{gantry}$ = (0.27,0.88)	65.20%	97.00%	67.40%
T3B	$(X,Y)_{gantry}$ = (0.25,0.88)	52.00%	93.20%	53.54%
T3C	$(X,Y)_{gantry}$ = (0.24,0.87)	50.00%	92.40%	54.65%
T3D	$(X,Y)_{gantry}$ = (0.23,0.91)	66.40%	98.00%	68.50%
B3A	$(X,Y)_{gantry}$ = (0.37,0.23)	15.60%	67.40%	20.80%
B3B	$(X,Y)_{gantry}$ = (0.35,0.25)	16.40%	73.70%	22.79%
B4A	$(X,Y)_{gantry}$ = (0.16,0.29)	66.80%	85.90%	71.34%
B4B	$(X,Y)_{gantry}$ = (0.14,0.29)	51.60%	85.90%	53.54%
B4C	$(X,Y)_{gantry}$ = (0.12,0.25)	50.40%	87.80%	56.69%
B4D	$(X,Y)_{gantry}$ =	66.80%	85.90%	73.39%

	(0.13,0.30)			
B5A	$(X,Y)_{gantry}$ = (0.28,0.42)	50.00%	85.50%	54.49%
B5B	$(X,Y)_{gantry}$ = (0.26,0.42)	20.00%	85.50%	18.74%
B5C	$(X,Y)_{gantry}$ = (0.25,0.41)	50.00%	85.50%	53.70%
B5D	$(X,Y)_{gantry}$ = (0.25,0.45)	50.00%	85.50%	55.59%
B5E	$(X,Y)_{gantry}$ = (0.23,0.44)	20.00%	81.40%	20.94%

API-653 splits the inspection process into two parts - the bottom scan and the sizing or prove-up. A bottom scan focuses on the detection of corrosion on a tank bottom. The API-653 acceptance criteria used to qualify an inspection process or operator for bottom scan are as follows:

- 90%-100% probability of detecting flaws of %WT loss > 80%
- 70%-90% probability of detecting flaws of 50% < %WT loss < 80%
- 40%-60% probability of detecting flaws of 33% < %WT loss < 50%
- 100% probability of detecting areas of general corrosion

The PEC and PAUT systems evaluated in this report demonstrate the ability to meet:

- 90%-100% probability of detecting flaws of %WT loss > 80%
- 70%-90% probability of detecting flaws of 50% < %WT loss < 80%
- 40%-60% probability of detecting flaws of 33% < %WT loss < 50%
- 100% probability of detecting areas of general corrosion

SRPN 02926, being a manufactured plate with API-653 designed defects, lacked the general corrosion of a tank plate. However, a prior study completed with the sensor system on a decommissioned test plate (referred to as plate A4) confirmed both sensors' abilities to detect general corrosion. For more information on this study, see SRPN 02887. It is important to note that while the PEC sensor did meet API requirements to detect the presence of corrosion in the locations of the qualification defects, the sensor lacked the resolution to resolve single defects within a cluster. The PAUT sensor was able to detect each individual defect within a cluster, and every qualification defect present on the plate, for all runs at the robot's operational speed.

The API-653 acceptance criteria for a process or operator that sizes or proves-up indications are:

- Not coated - measure flaw depth to accuracy within ± 0.020 in
- Thin coating < 0.030 in - measure flaw depth to accuracy within ± 0.030 in
- Thick coating > 0.030 in - determined by owner and inspector

The PAUT system evaluated in this report demonstrated the ability to determine the remaining thickness of detected defects to within 0.020 inches of the actual remaining thickness. The detailed results of which are provided in Table 9. These results for the 15 cm/s run with no overlap determined a measured defect size as close as 0.002" from the actual size, and at most 0.017" from the actual defect size. The average difference between the PAUT measured defect depth and the actual defect depth is 0.01". Table 12 provides the average difference between the actual and measured PAUT results for each API-653 qualification defect type. The defects with depths > 0.21" (remaining thickness < 0.050") resulted in the least accurate measurements on average 0.013" (0.33 mm) different from the actual defect depth. The results exceed API-653 Annex G requirements.

Table 12 - Qualification Defects - PAUT Results Overview

Plate Side	**Defect Sizing** (t ≡ remaining thickness, T ≡ 0.25")	**Quantity of Defects**	**Quantity Detected by PAUT**	**Average Depth Error** (Actual - Measured) [inches]
Product	t < 0.050"	2	2	0.007"
Product	0.050" < t < 1/2T	5	5	0.011"
Product	1/2T < t < 2/3T	4	4	0.007"
Soil	t < 0.050"	2	2	0.014"
Soil	0.050" < t < 1/2T	5	5	0.012"
Soil	1/2T < t < 2/3T	4	4	0.008"

4.2. Conclusions

From these results Square Robot has determined that the PEC system can be used to survey (bottom scan) large tank floors and detect areas of general corrosion. Areas within 8" (20 cm) of a plate edge or weldment have a high likelihood of being a false detection and should be viewed as such by an inspector. PEC should not be used to prove-up or characterize the remaining thickness of a tank floor, as its results show a "best case" view of the plate and will not accurately measure the thickness of localized pitting.

The PAUT system meets API-653 Annex G Qualification Test Acceptance Standards for defect sizing/prove-up. The system detected and sized more than the minimum API-653 defects. All defect sizing results were within the allowable ±0.020 inches. The PAUT system can be used to measure and characterize the remaining thickness of a low-carbon steel tank floor and can be expected to meet API-653 standards using the robot's standard procedure for surveying. PAUT results are expected to agree with those of an out-of-service MFL inspection.

4.3. Future Work

Continued examinations of sensor performance in a vehicle-simulated environment are planned to further prove the Square Robot's approach to in-service tank inspection.

Appendix

A1. Acronyms

MFL	Magnetic-Flux Leakage
PAUT	Phased Array Ultrasonic Testing
PEC	Pulsed Eddy Current
QTY	Quantity
SRPN	Square Robot Part Number
WT	Wall Thickness

A2. Definitions

Bottom scan	API-653 states: The use of equipment over large portions of the tank bottom to detect corrosion in a tank bottom. One common type of bottom-scanning equipment is the Magnetic Flux Leakage (MFL) scanner.
Sizing *or* Prove-up	API-653 states: The activity that is used to accurately determine the remaining bottom thickness in areas where indications are found by the bottom scanning equipment. This is often accomplished using the UT method.
Swath	Length of inspected coverage across-track by a sensor array as it sweeps (along-track) a surface. A sensor's swath is directly related to the length of the NDT array and the distance of the array from the surface to be inspected.

A3. API 653 Plate Drawing 20C-216-1 (SRPN 02926)

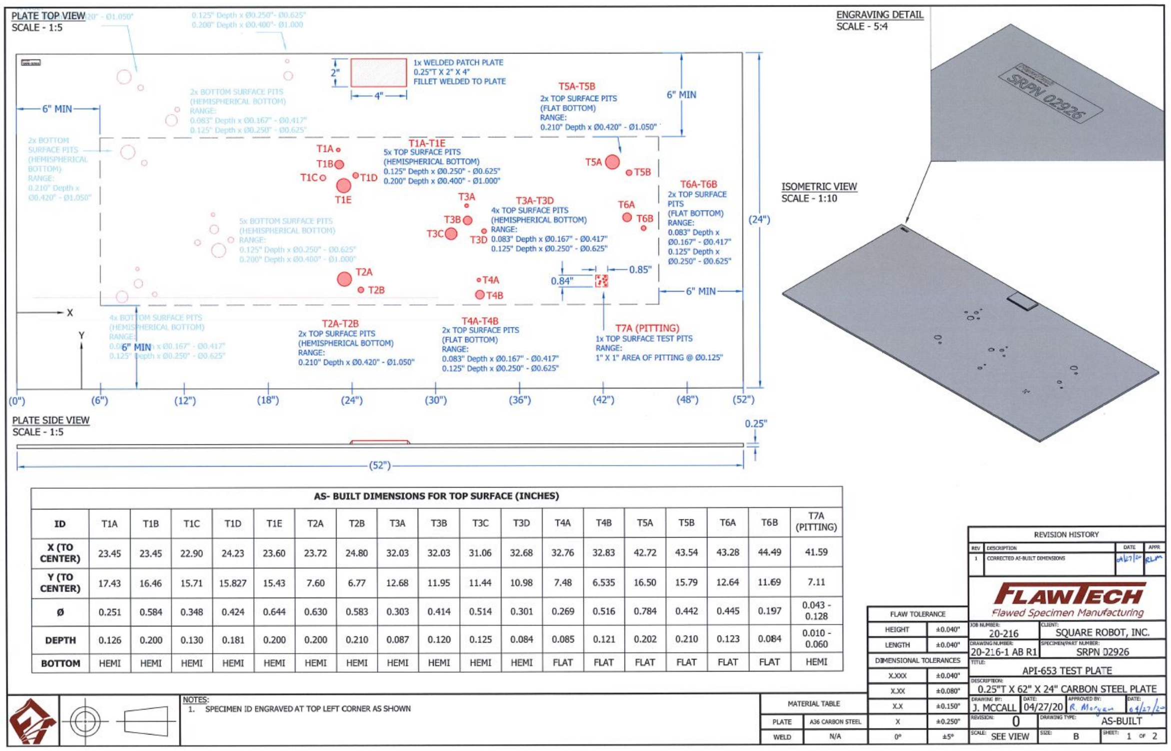


Figure 57 - 20-216-1 AB R1, API 653 Plate Drawing for SRPN 02926

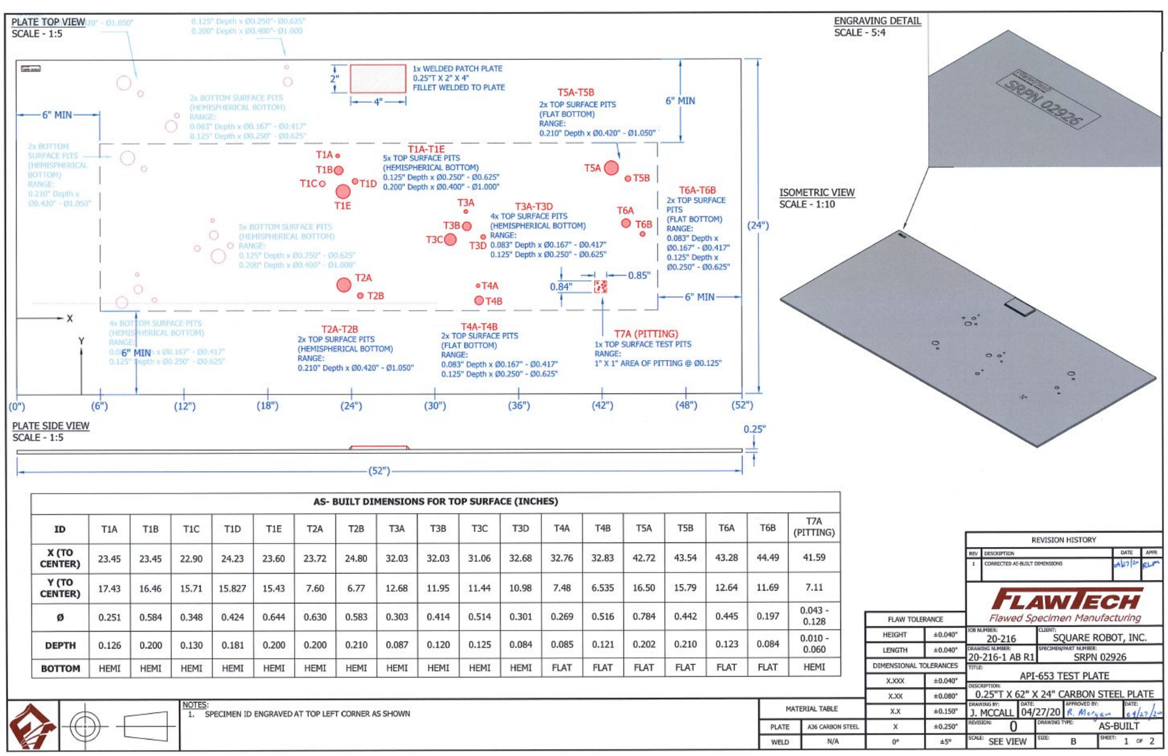
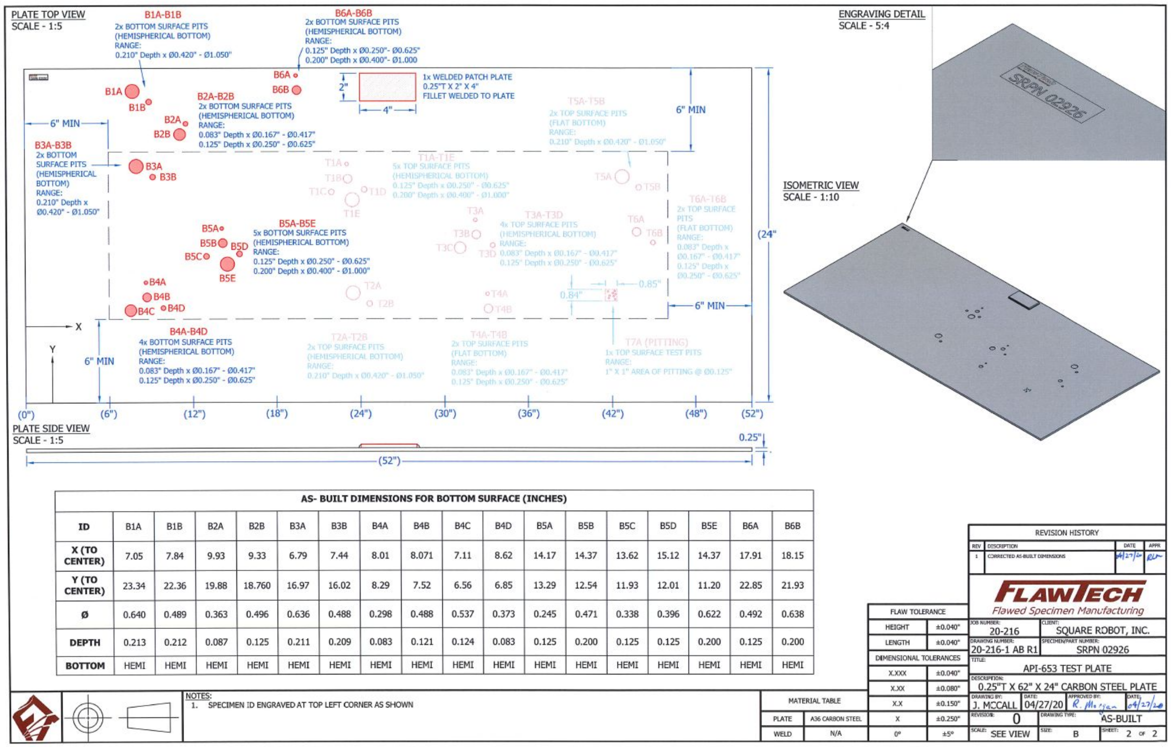


Figure 58 - 20-216-1 AB R1, API 653 Plate SRPN 02926 Inspected Defect Sizing, Product Side



AS- BUILT DIMENSIONS FOR BOTTOM SURFACE (INCHES)																	
ID	B1A	B1B	B2A	B2B	B3A	B3B	B4A	B4B	B4C	B4D	B5A	B5B	B5C	B5D	B5E	B6A	B6B
X (TO CENTER)	7.05	7.84	9.93	9.33	6.79	7.44	8.01	8.071	7.11	8.62	14.17	14.37	13.62	15.12	14.37	17.91	18.15
Y (TO CENTER)	23.34	22.36	19.88	18.760	16.97	16.02	8.29	7.52	6.56	6.85	13.29	12.54	11.93	12.01	11.20	22.85	21.93
Ø	0.640	0.489	0.363	0.496	0.636	0.488	0.298	0.488	0.537	0.373	0.245	0.471	0.338	0.396	0.622	0.492	0.638
DEPTH	0.213	0.212	0.087	0.125	0.211	0.209	0.083	0.121	0.124	0.083	0.125	0.200	0.125	0.125	0.200	0.125	0.200
BOTTOM	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI	HEMI

Figure 59 - 20-216-1 AB R1, API 653 Plate SRPN 02926 Inspected Defect Sizing, Soil Side

