FINAL REPORT

Comparative Testing of Radiographic Testing, Ultrasonic Testing and Phased Array Advanced Ultrasonic Testing Non Destructive Testing Techniques in Accordance with the AWS D1.5 Bridge Welding Code

BDK84-977-26

Submitted to

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DISCLAIMER PAGE

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

METRIC CONVERSION TABLE

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

TECHNICAL REPORT DOCUMENTATION PAGE

Technical Report Documentation Page

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16. Abstract

A comprehensive body of non-destructive testing data was collected from steel bridge welds under real-world conditions in a fabricator's shop. Three different non-destructive testing (NDT) techniques were used on each weld inspection, these being Radiographic Testing (RT), conventional Ultrasonic Testing (UT), and Phased Array Ultrasonic Testing (PAUT). These data were then compared to determine whether PAUT might in future be adopted under the American Welding Society (AWS) D1.5 code as a suitable substitute for the currently required RT. Rejection rates using PAUT were similar to those of RT and UT, thereby allaying concerns that the potentially more sensitive PAUT might result in unnecessary rejections. Although all three NDT techniques generally agreed, there were some rare exceptions. These occurred when edge flaws were present, resulting in a PAUT acceptance despite a RT rejection. Additional testing was performed on three custom-designed test plates with built-in edge flaws. These plates were inspected using a procedure that also included supplemental manual and raster scanning. Using this testing procedure the PAUT came into total agreement with RT and UT regarding all plate defects. It was concluded that PAUT would make a suitable substitute for RT (and UT) in bridge weld inspection, provided an appropriate procedure is followed. Considerable cost savings could be realized by making such a change.

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EXECUTIVE SUMMARY

A comprehensive body of non-destructive testing data was collected from steel bridge welds under real-world conditions in a fabricator's shop. Three different non-destructive testing (NDT) techniques were used on each weld inspection, these being Radiographic Testing (RT), conventional Ultrasonic Testing (UT), and Phased Array Ultrasonic Testing (PAUT). These data were then compared to determine whether PAUT might in future be adopted under the American Welding Society (AWS) D1.5 code as a suitable substitute for the currently required RT. Rejection rates using PAUT were similar to those of RT and UT, thereby allaying concerns that the potentially more sensitive PAUT might result in unnecessary rejections. Although all three NDT techniques generally agreed, there were some rare exceptions. These occurred when edge flaws were present, resulting in a PAUT acceptance despite a RT rejection. Additional testing was performed on three custom-designed test plates with built-in edge flaws. These plates were inspected using a procedure that also included supplemental manual and raster scanning. Using this testing procedure the PAUT came into total agreement with RT and UT regarding all plate defects. It was concluded that PAUT would make a suitable substitute for RT (and UT) in bridge weld inspection, provided an appropriate procedure is followed. Considerable cost savings could be realized by making such a change.

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CHAPTER 1 – INTRODUCTION

1.1 BACKGROUND

The welds used in the construction of steel bridges must be properly inspected according to the American Welding Society (AWS) D1.5 *Bridge Welding Code* [1]. The code requires the use of non-destructive testing (NDT) techniques to detect flaws/defects without damaging or compromising the weld itself. The current code accommodates two volumetric NDT techniques, these being *Radiographic Testing* (RT) and conventional *Ultrasonic Testing* (UT). However, both of these methods have shortcomings.

In the case of RT, the weld to be inspected is placed between a source of radiation and the detecting device, usually photographic film, and the radiation is allowed to penetrate the part for an appropriate length of time. The resulting radiograph is a two-dimensional projection of the weld onto the film, producing a latent image of varying densities according to the amount of radiation reaching each area of the photographic film.

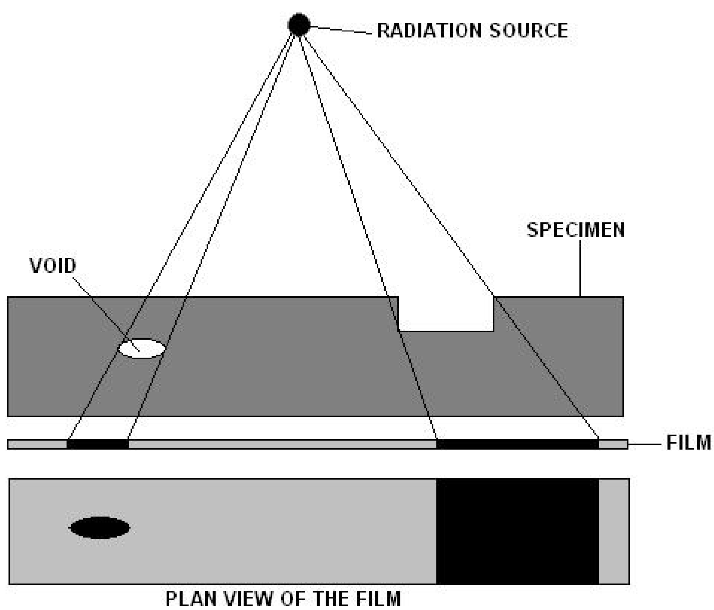

Figure 1-1 The Radiographic Testing (RT) Technique

Because of the need for strong radiation sources, RT can present serious safety issues and must be performed by specialized operators. The costs for such services can be significant, while additional expense results from disruption of work schedules while personnel are restricted from entering the hazardous zone created around the testing site.

It is anticipated that FDOT would be able to save $2 - $4 million a year in RT expenses passed onto them by fabricators, if a safer and more convenient alternative NDT technique could be used instead. The following is a list of radiographic expenses associated with several recent FDOT projects:

Financial Project No.210255-1-52-01, Bridge of Lions:	$ 100,000.00
Financial Project No.249035-1-62-60, Palmetto Expressway:	$1,500,000.00
D-4 I-595 PPP:	$1,500,000.00
Financial Project No.255854-1-62-04, Tampa Airport:	$ 100,000.00

In addition to safety and cost issues, defects such as delaminations and planar cracks are difficult to detect using radiography, which is why ultrasonic testing is the preferred method for detecting this type of discontinuity.

The conventional UT covered by the AWS D1.5 *Bridge Welding Code* uses a single-element acoustical probe – known technically as a *monolithic* probe – to emit an ultrasonic beam in a fixed direction. Fundamentally, UT uses an echo-location approach to determine the presence and position of flaws. To test or interrogate a large volume of material, a conventional probe must generally be physically turned or moved to sweep the beam through the area of interest. Conventional UT has a number of advantages over RT in that it is more portable, can easily penetrate to larger depths, is nonhazardous, requires accessibility to only one surface, and is more capable of determining the depth location of flaws. However, UT requires considerable operator skill to manipulate the probe and interpret the received signals. Importantly, most UT systems provide no recorded medium, such that results can only be interpreted in real-time on the spot, with no opportunity for further review at a later time or date.

Recent developments in NDT have resulted in *Phased Array Ultrasonic Testing* (PAUT*)*, but this has not yet been approved for use under the AWS D1.5 *Bridge Welding Code*.

In contrast to conventional UT, the beam from a phased array probe can be moved electronically, without moving the probe, and can be swept through a wide volume of material at high speed.

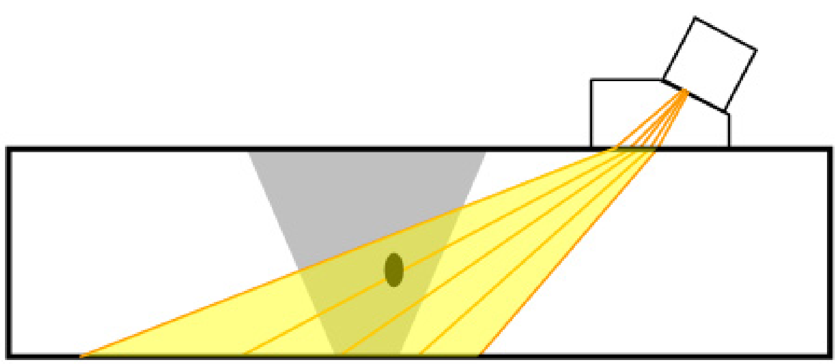

Figure 1-2 The Phased Array Ultrasonic Testing (PAUT) Technique

The beam is controllable because a phased array probe is made up of multiple small elements, each of which can be pulsed individually at a computer-calculated timing. Phased Array Ultrasonic Testing (PAUT) can potentially provide superior results to conventional UT while retaining the benefits over RT. Furthermore, modern PAUT equipment can create and store a complete electronic record of the inspection process and results, including geometric location information.

If it can be unequivocally demonstrated that Phased Array Ultrasonic Testing (PAUT) can be successfully adopted as a substitute for RT in the inspection of bridge welds, this would benefit FDOT and fabricators through increased speed, lower cost, better defect detection, scan reproducibility, less subjectivity, auditable results, no environmental hazards, and minimal disruption of work schedules.

1.2 STATEMENT OF HYPOTHESIS

It is hypothesized that Phased Array Ultrasonic Testing (PAUT) can be successfully and safely adopted into the AWS D1.5 code as a substitute for RT in the inspection of bridge welds under real-world conditions.

1.3 OBJECTIVES

The present research set out to gather a definitive body of comparative data using the three aforementioned NDT techniques, with the goal of providing the justification needed for the eventual official adoption of PAUT as a substitute for RT on steel bridge welds.

Phased Array Ultrasonic Testing (PAUT) is not an entirely new technique and its capabilities have been previously demonstrated in other disciplines and fields. Its general applicability to steel welds has also been shown in a laboratory setting using calibration blocks and/or sample welds containing known defects.

What sets this present research apart is the collection of actual “real world” steel bridge data – that being comparative RT, UT, and PAUT data all gathered in parallel as a normal part of the required NDT performed in a fabricator’s shop during the construction of steel bridges. The frequency and type of defects involved, the welding techniques and procedures utilized, the NDT protocols, and the personnel performing the work are all representative of current steel bridge fabrication practices and testing statewide.

To facilitate this technology transfer, a collaborative partnership was established between the University of South Florida (USF), the FDOT State Materials Office (SMO), and Tampa Tank, Inc. - Florida Structural Steel (TTI-FSS) – a steel fabricator company and vendor. Additional collaboration was secured with KTA-Tator, Inc. – a steel fabrication inspection services company.

1.4 RESEARCH APPROACH

The research effort was broken down into a sequence of six basic tasks, as follows:

Task 1 – Procure the necessary Phased Array NDT equipment along with all required accessories and consumables.

Task 2 – Coordinate through the FDOT SMO the use of the Phased Array NDT unit by a participating fabricator (TTI-FSS).

Task 3 – Receive, log, and collate the Radiographic Testing (RT), Ultrasonic Testing (UT), and Phased Array Ultrasonic Testing (PAUT) data generated, including UT reports, RT reports, and PAUT record storage.

Task 4 – Coordinate and call meetings to address equipment concerns, data collection issues, and to assess progress.

Task 5 – Review the final body of data. Perform analysis and statistical evaluation.

Task 6 – Provide a final report prepared in accordance with the FDOT Guidelines for Preparing Draft and Final Reports.

CHAPTER 2 – EQUIPMENT

2.1 PHASED ARRAY INSTRUMENT & ACCESSORIES

Figure 2-1 Sonatest *Veo*™ Phased Array Instrument

The following equipment and necessary accessories were procured from SONATEST, INC.

PHASED ARRAY INSTRUMENT (SONAAP VEO 16/128 BNC)
BNC connector, USB memory stick, user guide manual and CD, 2 lithium ion batteries, protective screen, mains cable power cord, AC adaptor, Veo™ strap, certificate of conformance and calibration certificate.

QUICK TRACE ENCODER FOR PHASED ARRAY SYSTEM (SONAAP ASM-0203-OD200)

TRANSDUCER (SONAAP T1-PE-2.25M20E1.2P)
Type 1 DAAH, linear pulse-echo array, 2.25 MHz, 20 elements, 1.2 mm pitch.

INSTRUMENT TO TRANSDUCER CONNECTIONS (SONAAP ASM-9038-IX200)
Type 1 DAAH cable & adapter, single socket, I-PEX connector.

35-DEGREE TRANSDUCER MOUNTING WEDGE (T1-35WOD-REXO)
Type 1, External Mounted Wedge, 35 Degrees (SW), Rexolite Material, No Contour.

FLAT TRANSDUCER MOUNTING WEDGE (T1-25.4TOD-REXO)
Type 1 External Mounted Wedge, 0 Degree (Flat), Rexolite Material, No Contour, 25.4 mm Thickness

SOFTWARE FOR PHASED ARRAY SYSTEM (SONAAP SOFTWARE TOFD)

2.2 CONVENTIONAL UT INSTRUMENT

The Olympus EPOCH XT Ultrasonic Flaw Detector is designed for inspection flexibility and for use in extreme environments. It combines a multitude of enhanced flaw detection and measurement features, including Dynamic DAC/TVG (Distance Amplitude Correction/ Time Varied Gain), On-board DGS/AVG and AWS D1.1 & D1.5 criteria.

Figure 2-2 Olympus Panametrics EPOCH XT™

2.3 RADIOGRAPHIC TESTING

The Radiographic testing was performed by a Level 2 radiographer in conformance with the requirements of AASHTO/AWS D1.5M/D1.5-10 Bridge Welding Code using the fabricator's standard radiographic procedure (TTFS RT2).

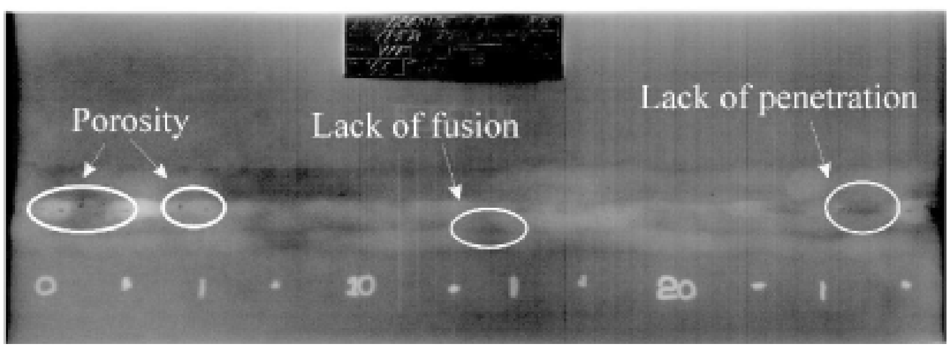

Figure 2-3 Typical RT Film for a Weld with Flaws, Veiga *et al*. [2]

CHAPTER 3 – ANALYSIS OF RESULTS

3.1 PROCEDURE & BODY OF DATA

The PAUT testing procedure used to collect and interpret the main body of data was written by an *American Society of Non-Destructive Testing* (ASNT) level 3 consultant. The complete reference is given as Mauzeroll [3]. A general revision of this PAUT procedure was issued on November 28th, 2013, as version 2, so as to be in accordance with the AWS D1.5 Annex X draft, released on July 8th, 2013. This revision is referenced as Mauzeroll [4].

When the initial body of data was collected, a decision was made to consider the relative merits of the three NDT techniques (RT, UT & PAUT) separately, without any attempt to combine data from more than one method in any single report. This effectively meant that only the primary scan portion of the PAUT procedure in reference [3] were applied. This was restricted to scanning only in a straight line with no manipulation, at a fixed distance from the centerline of the weld, without any of the recommended supplemental scanning provided for in the full PAUT procedure. No attempt was made to incorporate any manual wedge manipulation or raster scanning, as this is traditionally considered the domain of conventional UT.

The main body of data is included in Tables 3-1, 3-2 and 3-3 on the following pages. These accept/reject outcomes were compiled from the TTI-FSS official RT, UT and PAUT reports, these having been prepared by ASNT level 2 certified technicians by interpreting the raw NDT data. Interpretation of the RT and UT data was performed in accordance with all applicable codes and criteria in force at the time.

3.2 STATISTICAL ANALYSIS

From the body of data the following statistics have been determined:

Number of Bridge Welding Projects: 2 (I-595 and the Selmon Expressway)

Number of Jobs: 5

Number of Pieces: 35

Number of Bottom Flange (BF), Top Flange (TF) & Web (WB) IDs: 58

Number of Phased Array Ultrasonic Tests (PAUT) Performed: 92

Number of conventional Ultrasonic Tests (UT) Performed: 54

Number of Radiographic Tests (RT) Performed: 108

Number of Phased Array Ultrasonic Test (PAUT) Rejects: 8 (out of 92 = 8.7%)

Number of conventional Ultrasonic Test (UT) Rejects: 4 (out of 54 = 7.4%)

Number of Radiographic Test (RT) Rejects: 10 (out of 108 = 9.3%)

3.3 REJECTION RATES & UNNECESSARY REJECTIONS

It had been an open question as to whether the adoption of PAUT would result in a significantly increased rate of rejections, due to its perceived superior detection capabilities. The above statistical analysis of the results shows that the rejection rates for all three NDT techniques (PAUT 8.7%, UT 7.4%, and RT 9.3%) are very similar. In the entire body of data, there were no recorded part IDs rejected by PAUT that passed UT and were also accepted by RT. Although it is generally believed that PAUT is indeed capable of detecting previously overlooked minor flaws, these need not result in unnecessary rejections if the PAUT testing is done in accordance with an appropriate procedure with specific rejection criteria.

Table 3-1 Body of Data 1

JOB#	PIECE #	ID#	PAUT		UT		RT	
			Sonatest Veo		Olympus Epoch XT			
5424G	5G1B	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	6G2B	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
5424H	10H8A	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF2-TF3	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF3-TF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		WB1-WB2	A	Accept	A		A-B	Accept
			B	Accept			B-C	Accept
	11H9A	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF2-TF3	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF3-TF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		WB1-WB2					A-B	Accept
							B-C	Accept
	12H10A	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF2-TF3	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF3-TF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		WB1-WB2					A-B	Accept
							B-C	Accept
	13H11A	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF2-TF3	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF3-TF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	14H12A	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
		TF2-TF3					A-B	Accept
							B-C	Accept
		TF3-TF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	29H3C	BF3-BF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	30H4C	BF3-BF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept

Table 3-2 Body of Data 2

JOB#	PIECE #	ID#	PAUT		UT		RT	
			Sonatest Veo		Olympus Epoch XT			
5424H	31H5C	BF3-BF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	32H6C	BF3-BF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	33H7C	BF3-BF4	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	9H7A	TF2-TF3	A	Accept	A	Accept		
		TF3-TF4	A	Accept	A	Accept		
		WB1-WB2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
5424M	13M1C	BF1-BF2	A	**Reject**	A	**Reject**	A-B	**Reject**
							B-C	**Reject**
		TF1-TF2	A	**Reject**	A	**Reject**	A-B	Accept
			B	Accept			B-C	Accept
		WB1-WB2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	14M2C	TF1-TF2	A	Accept	A	Accept	A-B	Accept
							B-C	Accept
	15M3C	TF1-TF2			A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	16M4C	TF1-TF2	A	**Reject**	A	Accept	A-B	**Reject**
			B	**Reject**			B-C	Accept
	17M5C	TF1-TF2	A	**Reject**	A	**Reject**	A-B	**Reject**
							B-C	Accept
5424Q	17Q1E	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	18Q2E	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	19Q3E	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	20Q4E	BF1-BF2	A	Accept	A	Accept	A-B	Accept
			B	Accept			B-C	Accept
	23Q1G	BF1-BF2	A	Accept	A	Accept	A-B	Accept
							B-C	Accept
	23Q1G-2	BF1-BF2	A	Accept	A	Accept	A-B	Accept
							B-C	Accept
	24Q2G	BF1-BF2	A	Accept	A	Accept	A-B	Accept
							B-C	Accept
	24Q2G-2	BF1-BF2	A	Accept	A	Accept	A-B	Accept
							B-C	Accept
	25Q3G	BF1-BF2	A	Accept	A	Accept		

Table 3-3 Body of Data 3

JOB#	PIECE #	ID#	PAUT		UT		RT		
			Sonatest Veo		Olympus Epoch XT				
5424Q	26Q4G	BF1-BF2	A	Accept	A	Accept			
	3Q1A	BF1-BF2	A	Accept	A	Accept	A-B	Accept	
			B	Accept			B-C	Accept	
	4Q2A	BF1-BF2	A	Accept	A	Accept	A-B	Accept	
			B	Accept			B-C	Accept	
	6Q4A	BF1-BF2	A	Accept	A	Accept	A-B	Accept	
			B	Accept			B-C	Accept	
5716	1A6A	BF1-BF2	A	Corrupt	A	Corrupt	A-B	Reject	
							B-C	Accept	
		BF2-BF3	A	Corrupt	A	Corrupt	A-B	Accept	
							B-C	Reject	
		TF1-TF2	A	Accept	A	Accept	A-B	Accept	
							B-C	Accept	
		TF2-TF3	A	Reject	A	Accept	A-B	Reject	
							B-C	Accept	
		WB1-WB2	A	Accept	A	Accept	A-B	Accept	
							B-C	Accept	
		WB2-WB3	A	Accept	A	Accept	A-B	Reject	TYPE I
							B-C	Accept	
	2A7A	BF1-BF2	A	Reject	A	Accept	A-B	Reject	
			B	Reject			B-C	Accept	
		BF2-BF3	A	Accept	missing rpt.	Reject	A-B	Accept	
			B	Accept	reject from PA conclusion		B-C	Reject	TYPE II
	3B1A	BF1-BF2	A	Accept	A	Accept	A-B	Accept	
			B	Accept			B-C	Accept	
	4B2A	BF1-BF2	A	Accept	A	Accept	A-B	Accept	
			B	Accept			B-C	Accept	

3.4 PAUT AS A REPLACEMENT FOR RT

The current code (AWS D1.5) that covers the NDT of bridge welds mandates a testing protocol that requires acceptance using both RT and conventional UT flaw detection techniques for fracture-critical welding. The goal of the present study is to evaluate whether PAUT could be adopted as a substitute for RT, resulting in a new protocol that involves PAUT and UT acceptance only (no RT).

Since the body of data returned *Accept* (A) or *Reject* (R) results for all three NDT methods for each part ID inspected, it is possible to compare the outcomes under both the old protocol (RT & UT) and the proposed new protocol (PAUT & UT). It should be noted that this new protocol is more conservative than would be the case if PAUT was to replace both RT and UT. Conventional UT generally provides more coverage than the supplementary UT included in the full PAUT procedure.

Table 3-4 Effect of Protocol for all possible PAUT, UT, RT comparison combinations – assuming each NDT method can result in an ACCEPT (A) or REJECT (R)

ACCEPT or REJECT	NEW PROTOCOL PA	NEW PROTOCOL UT	EXPERIMENTAL COMPARISON PA	EXPERIMENTAL COMPARISON UT	EXPERIMENTAL COMPARISON RT		OLD PROTOCOL UT	OLD PROTOCOL RT	ACCEPT or REJECT
A	A	A	A	A	A		A	A	A
A	A	A	A	A	R	TYPE I	A	R	R
R	A	R	A	R	A		R	A	R
R	A	R	A	R	R	TYPE II	R	R	R
R	R	A	R	A	A	TYPE III	A	A	A
R	R	A	R	A	R		A	R	R
R	R	R	R	R	A		R	A	R
R	R	R	R	R	R		R	R	R

NOTE: For brevity PAUT is labeled as just PA in the above Table 3-4

The preceding Table 3-4 lists all the combinations theoretically possible when comparing the three NDT methods, and shows the corresponding outcomes when applying the two protocols. In the majority of cases both protocols agree, such that either both accept or both reject. In these cases there would be no concern in replacing RT with PAUT. However, there are three possible result combinations (labeled: TYPE I, TYPE II & TYPE III) that would be of special interest if they were to appear in the actual body of data collected.

- TYPE I – In this case the new protocol (PAUT & UT) would *Accept*, while there would have been a *Reject* under the old protocol (UT & RT). This is because the PAUT and RT are in complete disagreement. This is of concern because with a TYPE I situation the PAUT fails to detect a flaw that is seen by RT and which would have caused a rejection under the old protocol.

- TYPE II – On the face of it this type of situation may seem innocuous since both protocols agree to *Reject*. However, it should be noted that the final outcome is as a direct result of a UT *Reject* in each protocol, with the PAUT and RT being in complete disagreement. Without conventional UT, a TYPE II would essentially become a TYPE I.

- TYPE III – Although in this situation the PAUT and RT are in complete disagreement, the outcome is opposite to that of a TYPE I. Here, the new protocol would *Reject* while the old protocol would *Accept*. Although conservative, it is not necessarily a good thing since the outcome could be construed as an “Unnecessary Reject”. The grinding out and repair of acceptable weld is not good structurally or financially.

3.5 PRESENCE OF TYPE I OR TYPE II OUTCOMES IN THE BODY OF DATA

TYPE I & II outcomes are simply statistical possibilities, and it was not previously known if they would be observed during real-world testing. By analyzing the body of data collected and presented in the previous tables it can be seen that single examples of TYPE I & II outcomes were indeed present – and are labeled. As mentioned previously in section 3.3, no TYPE III outcomes were observed.

The presence of TYPE I & II outcomes in the main body of data (although rare) did merit the need for some further investigation prior to deciding upon whether or not to recommend a code change where PAUT replaces RT. When studying the specific type of weld defect involved in the observed TYPE I & II outcomes, it was found that edge flaws were responsible in each case, as shown by the reports included in APPENDIX A.

CHAPTER 4 – SUPPLEMENTARY TEST PLATE DATA

4.1 PRIMARY SCAN PORTION VERSUS FULL PAUT TESTING PROCEDURES

The full PAUT procedure includes a provision (Refs [3] & [4], Section 11.2) that specifically addresses transversely or semi transversely oriented flaws and those located near ends or edges. In addition to the primary scan portion of the PAUT procedure, the full procedure calls for supplemental manual PAUT at edges and raster scanning down the middle of the weld to eliminate missing any transverse indications.

It was hypothesized that by applying the full PAUT testing procedure of reference [4], including the supplementary manual PAUT, the edge flaws responsible for the TYPE I and TYPE II outcomes would become observable with PAUT, and result in a similar *Reject* outcome as indicated by RT.

4.2 CUSTOM TEST PLATES

Defects of all types are relatively uncommon in bridge welds, and their occurrence during real-world inspections at a fabricator's shop is unpredictable. Therefore to further investigate the effect of PAUT procedures it was necessary to commission some "Test Plates" containing simulated flaws of various types, including edge flaws.

Three custom test plates were designed and built. These test plates were constructed of steel and included various features (holes of different depths and diameters, porosity, tungsten inclusions, grinder gouges, centerpunch indentations, hole with slug, hole with broken drill, air-arc below flush, etc.) designed to simulate the presence of defects, including edge flaws.

Design drawings of the three test plates are included in APPENDIX B.

4.3 EFFECT OF PROCEDURE ON OUTCOMES IN THE TEST PLATE DATA

The RT, UT and PAUT data obtained from inspections of all three test plates were initially interpreted using only the primary scan portion of the PAUT procedure as adopted previously for the main body of data. Unfortunately, Test Plates 1 and 3 were unable to provide further insight since all three NDT methods rejected these plates based on the same indications.

APPENDIX C includes the RT and UT reports for Test Plate 2. In this case a single TYPE II outcome was detected in the data for Test Plate 2 when applying only the primary scan portion of the PAUT procedure (no supplementary manual PAUT or raster scanning). In this case the PAUT was hardly able to detect indication #1 due to its relative angle, and therefore accepted (did not reject) based on this particular indication. UT did however reject based on indication #1.

Significantly, Test Plate 2 was then reinterpreted according to the full PAUT procedure of reference [4], including raster scanning, resulting this time in a rejection. The PAUT reports for Test Plate 2 reinterpreted using the full procedure are shown in Tables 4-1 & 4-2.

Table 4-1 – Reinterpreted PAUT Report Conclusions for Test Plate 2

Phased Array Report			
Job#	Test Plate	Part #	2
Page:		1 of 2	

General Information:

Client: FDOT	**PO#**
Contact:	**Job #**
Project/Equipment: AWS D1.5 RT Comparison Study	**Location:**
Brief Description of NDT Performed: PAUT of groove welds for AWS D1.5 RT comparison study.	

Technical Information:

Standard:	**Material:** Carbon Steel
Criteria: AWS D1.5 Sec 6, 2008. Aws D1.1, Clause 6 Part G 2010, ASTM E 2700-09, ASTM E 2491-06	**Weld Details:** Groove Weld, Double Bevel
Procedure: #PR-PAE-Structural Welds, AWS D1.5	**Surface Conditions:** Flat without reinforcement

Equipment:

Prepared Setup:		
Technique:	Sectorial PE	**Couplant:** Sonotech Ultragel II
Instrument:	**Manufacturer:** Sonatest **Model:** Veo 16/64	**Software Version:** 3.2.1 R1 **Serial Number:** I006495
Transducer:	**Manufacturer:** Sonatest **Model:** PE-2.25M20E1 **Probe Serial #:** SN-0215 **Cable Serial #:** SN-0307	**Frequency:** 2.25mHZ **# Elements:** 20 **Pitch:** 0.047 **Gap:** **Elevation:**
Wedge:	**Model:** Sonatest TI-35WOD **Material:** Rexolite	**Cut Angle:** 10 Degrees **Wedge Back Height:**
Focal Laws:	**Scan Type:** Sectorial PE **# Active Elements: 16** **Elements Used: 5-20**	**Angle(s):** 35-75 Degrees **S-Scan Angle Res: .5 degree** **Focalisation Type:** Constant Path **Focal Distance: 10in**
Calibration Blocks(s):	**Distance Cal.:** IIW Type 1 SN-10-2484	**Sensitivity Cal.:** IIW Type 1 SN-10-2484

Report Conclusions: (Refer to report content to see all results)

Indication 1 can hardly be seen due to the orientation of the indication when doing an encoded scan However when you raster scan (per the procedure) you can see it clearly.
Indication 11 is part of indication 2.

	2/12/2014		Level 2	
Technician Name	**Date**	**Technician Signature**	**Certification**	**Verified By**

Table 4-2 – PAUT Report for Test Plate 2 with Raster Scan Needed for Indication #1

Phased Array Report	
Job # Test Plt	Part # 2
Page: 2	

Weld ID	Thickness	Contact Surface	Weld Config	Accept/Reject	Indication No.	DAC/TCG dB Ref	Evaluation						Positioning		Remarks
							OR		Type of Indication	Length	Height	Depth	X Axis Position	Y Axis Position	
							Amp From DAC/TCG (%)	Amp from Dac/TCG (dB)							
WELD 1	1	A	G	R	1	35.5	140	N/A	SI	1.2	N/A	0.92	0.25	3	Raster Scan
WELD 1	1	A	G	R	2	35.5	200	N/A	SI	1.42	N/A	0.85	0.17	6.25	Encoded Scan
WELD 1	1	A	G	R	3	35.5	200	N/A	SI	1.4	N/A	0.79	0	11	Encoded Scan
WELD 1	1	A	G	R	4	35.5	20	N/A	POR	1	N/A	0.94	1.25	10	Encoded Scan
WELD 1	1	A	G	R	5	35.5	27	N/A	POR	0.25	N/A	0.85	-1.2	14	Encoded Scan
WELD 1	1	A	G	R	6	35.5	27	N/A	POR	0.25	N/A	0.68	-0.9	14	Encoded Scan
WELD 1	1	A	G	R	7	35.5	72	N/A	POR	0.35	N/A	0.6	-0.5	14	Encoded Scan
WELD 1	1	A	G	R	8	35.5	164	N/A	POR	0.35	N/A	0.55	-0.18	14	Encoded Scan
WELD 1	1	A	G	R	9	35.5	26	N/A	POR	0.25	N/A	0.32	0.4	14	Encoded Scan
WELD 1	1	A	G	R	10	35.5	27	N/A	POR	0.25	N/A	0.11	1.2	14	Encoded Scan
															All measurements
															in inches

Legend for Types of Indications:					
LOF	Lack or Fusion	UC	Undercut	AL	Misalignment
LOP	Lack of Penetration	POR	Porosity	BT	Burn Through
CK	Crack	NR	Non Relevant Indication	SURF	Surface Indication
SI	Slag Inclusion	CV	Concavity	LAM	Lamination

	2/12/2014		Level 2	
Technician Name	Date	Technician Signature	Certification	Verified By

CHAPTER 5 – DISCUSSION & CONCLUSIONS

5.1 DISUSSION OF RESULTS

The main body of data contained very few rejects, and therefore demonstrated the excellent quality of workmanship in the fabricator's shop. When a weld was rejected, the flaw was detected equally well under the old (RT & UT) and new (PAUT & UT) protocols in the majority of cases. Only one single TYPE I outcome was seen, along with just one TYPE II outcome.

As regards the supplementary test plate data, there was a single TYPE II outcome present, but only when inspected according to just the primary scan portion of the PAUT procedure. Once the data was reinterpreted using the full PAUT procedure (including raster scanning) the TYPE II outcome was replaced by rejection agreement by all three NDT methods.

This provides compelling (although not definitive) evidence that adherence to the full PAUT procedure will ensure effective flaw detection (including edge and transverse/semi transverse defects) when using PAUT as the only NDT method, and will potentially eliminate TYPE II outcomes.

No TYPE I outcomes were present in the test plate data, this being the rare case where RT rejects a weld despite it having passed inspections by both PAUT and UT. It seems unlikely that the full PAUT procedure would eliminate this type of outcome when conventional UT has already failed to detect a rejectable defect. It may be that given the inherent complexities of weld inspection there will always be the remote possibility of a TYPE I outcome. This does not mean that expensive and hazardous RT should continue to be mandated for every weld inspection just to address this atypical case. It is neither practical nor cost-effective to detect 100% of flaws, the expectation being only that the NDT method(s) chosen should be capable of detecting the vast majority of reportable flaws. In this vein the present study seems to suggest that PAUT can be just as effective as RT, yet achieve this at much lower cost.

With similar rejection rates seen for the three NDT techniques, and given the absence of TYPE III outcomes in the data, it would appear that PAUT does not necessarily lead to unnecessary rejections.

5.2 CONCLUSIONS

Based on the data collected as part of this research, PAUT would make a suitable replacement for RT (and conventional UT as well) in the AWS D1.5 Bridge Welding Code, provided that an effective and full PAUT testing procedure is followed. This procedure should include supplemental manual and raster scanning to ensure detection of end/edge flaws and transverse/semi transverse indications.
Rejection rates were found to be very similar among the three NDT techniques compared in the main body of data collected. This suggests that any future adoption of PAUT does not appear to carry with it an increased risk of unnecessary rejections and the associated negatives of grinding out sound welds.

REFERENCES

[1] AASHTO/AWS D1.5M/D1.5:2010 Bridge Welding Code, American Welding Society, Miami, Florida, ISBN: 978-0-87171-781-8, 6th Edition, August 18th, 2010, 456 pages.

[2] Veiga, J. L. B. C., de Carvalho, A. A., da Silva, I. C., Rebello, J. M. A., "The Use of Artificial Neural Network in the Classification of Pulse-echo and TOFD Ultra-Sonic Signals", *J. Braz. Soc. Mech. Sci. & Eng*., vol.27, no.4, Rio de Janeiro, October/December, 2005, pp. 394-398.

[3] Mauzeroll, L.,"Structural Welds Inspection Using Encoded Phased-Array Ultrasonic Testing on Butt Welds from 0.5" to 2.5" thick", Tampa Tank Inc., Florida Structural Steel. Inspection Procedure # PR-PAE - Structural Welds, AWS D1.5, **Version 1**, March 25th, 2012, 45 pages.

[4] Mauzeroll, L.,"Structural Welds Inspection Using Encoded Phased-Array Ultrasonic Testing on Butt Welds from 0.5" to 2.5" thick", Tampa Tank Inc., Florida Structural Steel. Inspection Procedure # PR-PAE - Structural Welds, AWS D1.5, **Version 2**, November 28th, 2013, 44 pages.

APPENDIX A –

Report Conclusions Indicating the Presence of TYPE I & II Disagreements between NDT Methods

Table A-1 – TYPE I Outcome

Phased Array Report			
Job#	5716	Part #	1A6A
Page:		1 of 2	

General Information:

Client:	**PO#**
Contact:	**Job # 5716**
Project/Equipment: AWS D1.5 RT Comparison Study	**Location:** Tampa Tank
Brief Description of NDT Performed: PAUT of groove welds for AWS D1.5 RT comparison study.	

Technical Information:

Standard:	**Material:** Carbon Steel
Criteria: AWS D1.5 Sec 6, 2008. Aws D1.1, Clause 6 Part G 2010, ASTM E 2700-09, ASTM E 2491-06	**Weld Details:** Groove Weld, Single Bevel
Procedure: #PR-PAE-Structural Welds, AWS D1.5	**Surface Conditions:** Flat without reinforcement

Equipment:

Prepared Setup:			
Technique:	Sectorial PE	**Couplant:**	Sonotech Ultragel II
Instrument:	**Manufacturer:** Sonatest **Model:** Veo 16/64	**Software Version:** 3.2.1 R1 **Serial Number:** I006495	
Transducer:	**Manufacturer:** Sonatest **Model:** PE-2.25M20E1 **Probe Serial #:** SN-0215 **Cable Serial #:** SN-0307	**Frequency:** 2.25mHZ **# Elements:** 20 **Pitch:** 0.047 **Gap:** **Elevation:**	
Wedge:	**Model:** Sonatest TI-35WOD **Material:** Rexolite	**Cut Angle:** 35 Degrees **Wedge Back Height:**	
Focal Laws:	**Scan Type:** Sectorial PE **# Active Elements: 16** **Elements Used: 5-20**	**Angle(s):** 35-75 Degrees **S-Scan Angle Res: 1 degree** **Focalisation Type:** Constant Path **Focal Distance: 3in**	
Calibration Blocks(s):	**Distance Cal.:** IIW Type 1 SN-10-2484	**Sensitivity Cal.:** IIW Type 1 SN-10-2484	

Report Conclusions: (Refer to report content to see all results)

An A edge indication found on RT which was rejected. The same indication passed UT. Nothing was seen on PAUT.

	5/16/2012		Level 2	
Technician Name	**Date**	**Technician Signature**	**Certification**	**Verified By**

Table A-2 – TYPE II Outcome

Phased Array Report			
Job#	5716	Part #	2A7A BF2-3
Page:		1 of 2	

General Information:

Client:	**PO#**
Contact:	**Job # 5716**
Project/Equipment: AWS D1.5 RT Comparison Study	**Location:**
Brief Description of NDT Performed: PAUT of groove welds for AWS D1.5 RT comparison study.	

Technical Information:

Standard:	**Material:** Carbon Steel
Criteria: AWS D1.5 Sec 6, 2008. Aws D1.1, Clause 6 Part G 2010, ASTM E 2700-09, ASTM E 2491-06	**Weld Details:** Groove Weld, Single Bevel
Procedure: #PR-PAE-Structural Welds, AWS D1.5	**Surface Conditions:** Flat without reinforcement

Equipment:

Prepared Setup:		
Technique:	Sectorial PE	**Couplant:** Sonotech Ultragel II
Instrument:	**Manufacturer:** Sonatest **Model:** Veo 16/64	**Software Version:** 3.2.1 R1 **Serial Number:** I006495
Transducer:	**Manufacturer:** Sonatest **Model:** PE-2.25M20E1 **Probe Serial #:** SN-0215 **Cable Serial #:** SN-0307	**Frequency:** 2.25mHZ **# Elements:** 20 **Pitch:** 0.047 **Gap:** **Elevation:**
Wedge:	**Model:** Sonatest TI-35WOD **Material:** Rexolite	**Cut Angle:** 35 Degrees **Wedge Back Height:**
Focal Laws:	**Scan Type:** Sectorial PE **# Active Elements: 16** **Elements Used: 5-20**	**Angle(s):** 35-75 Degrees **S-Scan Angle Res: 1 degree** **Focalisation Type:** Constant Path **Focal Distance: 3in**
Calibration Blocks(s):	**Distance Cal.:** IIW Type 1 SN-10-2484	**Sensitivity Cal.:** IIW Type 1 SN-10-2484

Report Conclusions: (Refer to report content to see all results)

Xray revealed an indication near the A edge. UT confirmed an indication about 1/8 long. However, PAUT did not show anything at the 80% FSH threshold for investigation @+9dB. A small notch was noticed on the underside of the flange. It is possible that this is what was seen with Xray and UT although I believe it was a small piece of slag embedded in the edge that the welder claimed he saw and removed directly on the edge of the flange, about 1" from surface.

	5/7/2012		Level 2	
Technician Name	**Date**	**Technician Signature**	**Certification**	**Verified By**

APPENDIX B –

Design Drawings of the Three Test Plates Containing Simulated Flaws

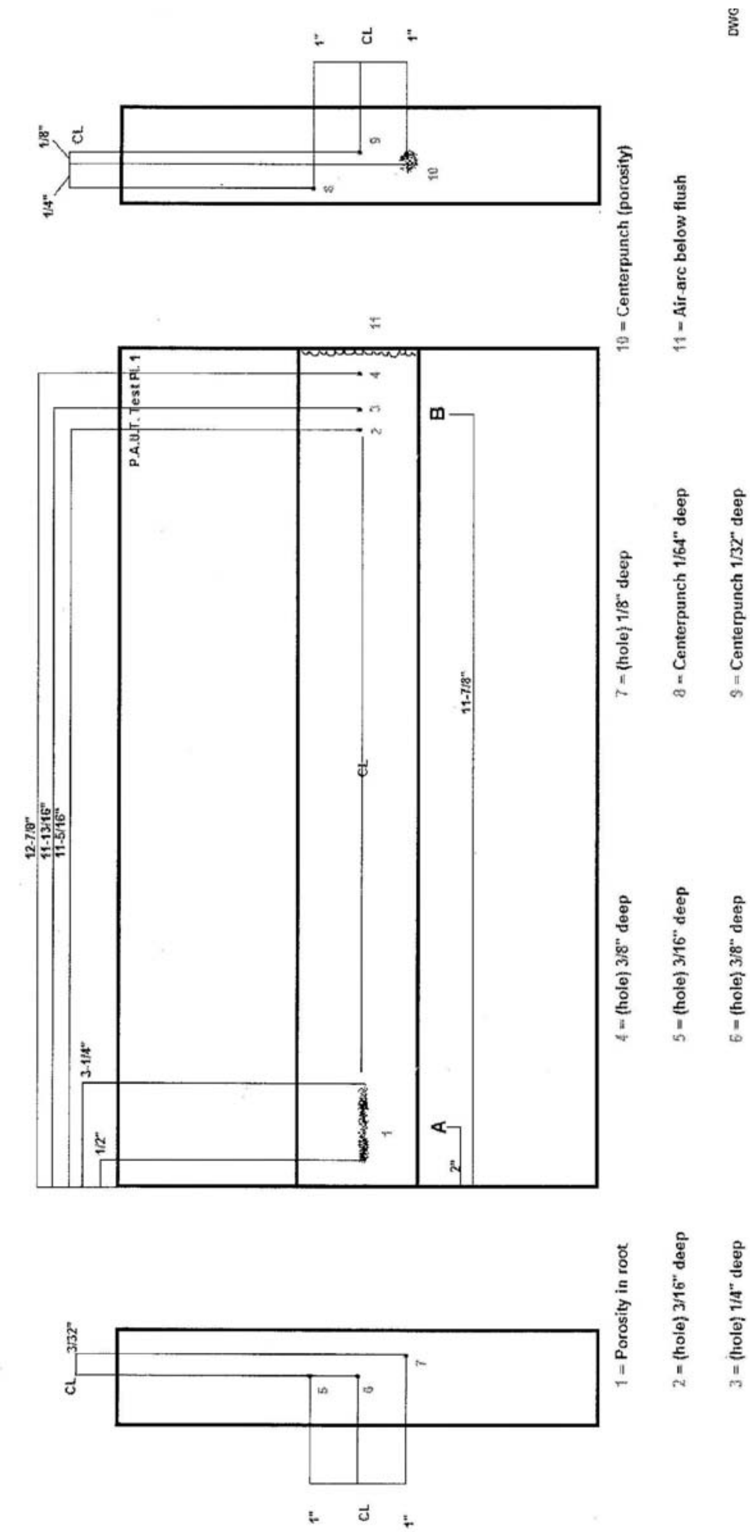

Figure B-1 – Design Drawing of Test Plate 1

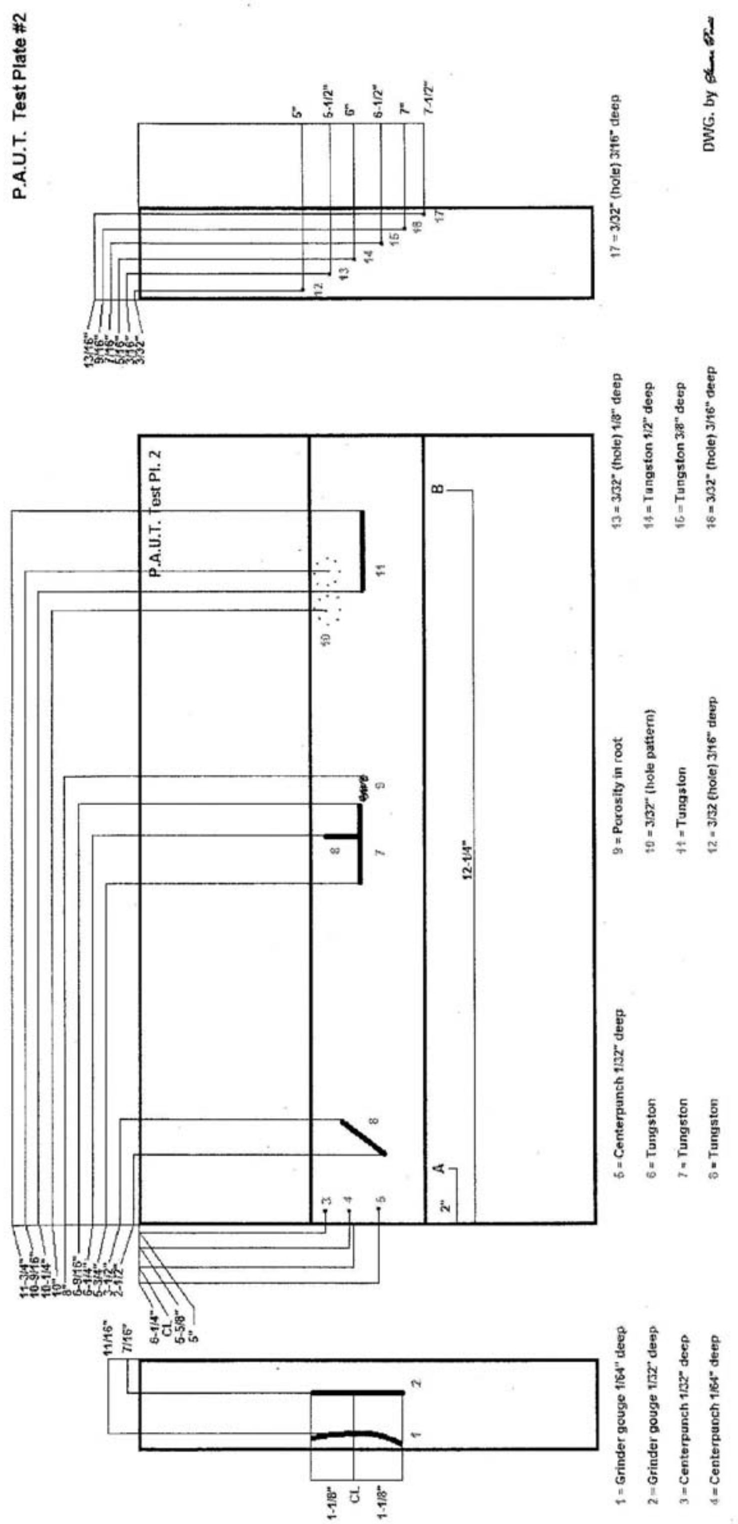

Figure B-2 – Design Drawing of Test Plate 2

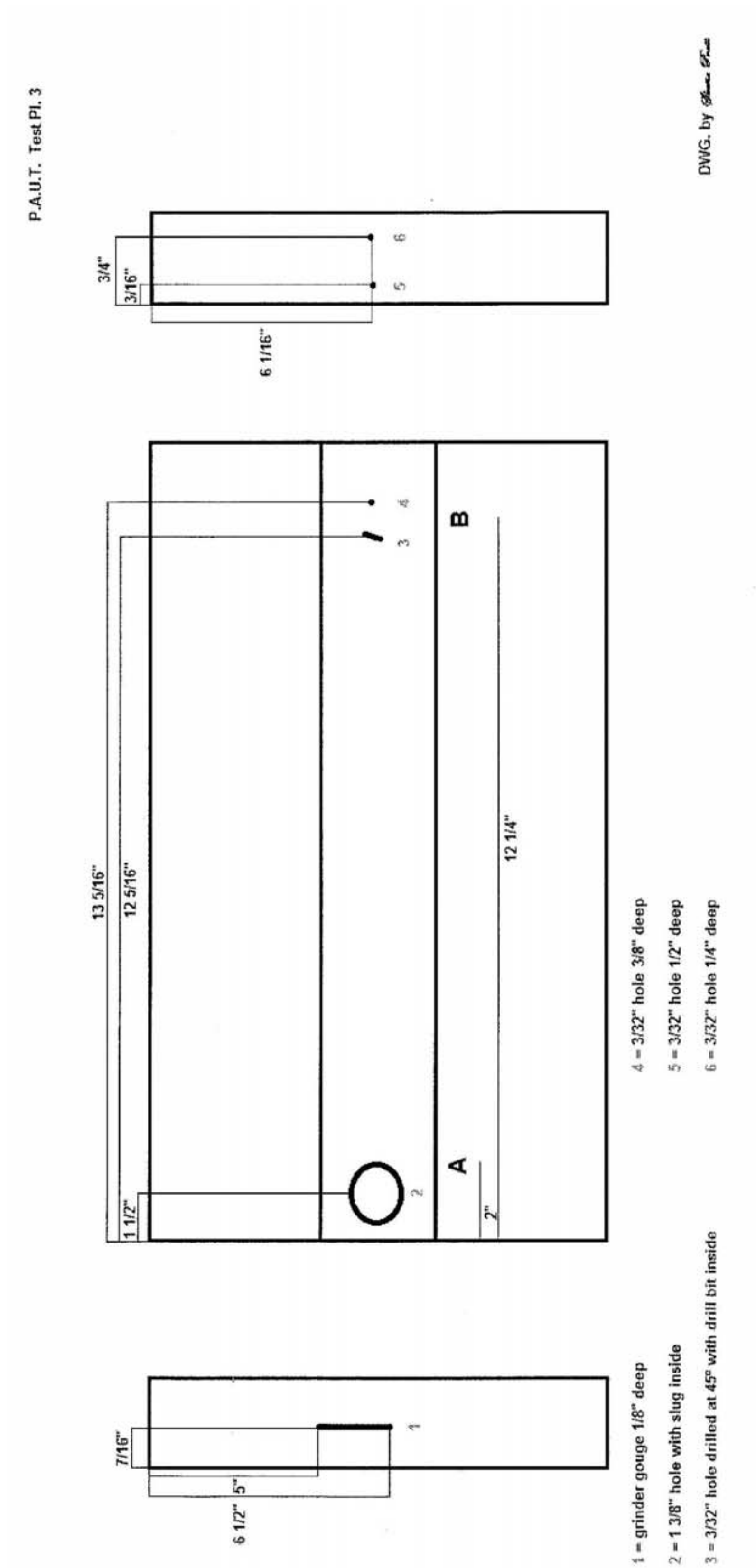

Figure B-3 – Design Drawing of Test Plate 3

APPENDIX C –

RT & UT Reports for Test Plate 2

Table C-1 – RT Report for the Test Plates

Job# P.A.U.T. Test Plates		**Applicable Code/ Acceptance Standards per AWS D1.05** **Radiographic Procedure TTFS RT2**	
FPID # :			
Project :			
Thickness of joint: 1'		Kv & Ma used:300kv 3 ma	Exposure Time: 1 min.
Thickness of joint:		Kv & Ma used:	Exposure Time:
Thickness of joint:		Kv & Ma used:	Exposure Time:
Thickness of joint:		Kv & Ma used:	Exposure Time:
Thickness of joint:		Kv & Ma used:	Exposure Time:
Thickness of joint:		Kv & Ma used:	Exposure Time:
Film to source: 26"	Film to source:		
Film Type: D7	Film Type:		
Screens: .005/.010	Screens:		

Piece #	I.D. #	Film view	Accept	Reject	Remarks
TP-1		A-B		X	Porosity @ A edge, 1 1/4" slag line above A,
					porosity cluster. Three porosity indications above B.
TP-2		A-B		X	Tungsten inclusion above A 1"" towards B.
					Tungsten inclusion above A 4" towards B.
					Lack of fusion 1 1/2" long above B.
					Six indications on B edge.
TP-3		A-B		X	Porosity @ A edge, 1 1/4" inclusion above A.
					Slag and porosity above B.

We the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in conformance with the requirements of ASSHTO/AWS D1.5M/D1.5-08 Bridge Welding Code

Radioagrapher(s)	Authoirized By:
Interpreter:	Date:
Test Date:12-18-13	

Table C-2 – Conventional UT Report for Test Plate 2

CONTRACT: TEST PLATE 2

MODEL OF UNIT: Olympus Epoch XT

SERIAL# OF UNIT: 101343606

Legend
T.F. = Top Flange N.S. = Near Side
B.F.-Bottom Flange F.S. = Far Side
L.E.= Left End R.E.=Right End

REPORT#: 1

WELDING PROCESS: SAW

JOINT DESIGN: CJP

PIECE MARK	Splice location	FACE	TRANSDUCER ANGLE	INDIC. NO.	INDICATION LEVEL	REFERENCE LEVEL	ATTENUATION FACTOR	INDICATION RATING	SOUND PATH	DEPTH FROM FACE A	LENGTH OF INDICATION	X DISTANCE	Y DISTANCE	THICKNESS	ACCEPTED	REJECTED	LENGTH AND QUANTITY OF WELDS TESTED AND COMMENTS
					A	B	C	D									
Test Plate 2 / Y Starts at Edge A																	
TP2	WELD A	A	70	1	45.9	52	4.196	-10	3.098"	.940"	1.25"	-.5" - .75"	3"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	2	49.8	52	3.338	-6	2.669"	.913"	1.75"	.125"	6"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	3	53.9	52	2.602	-1	2.301"	.787"	1.5"	-.125"	11"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	4	59.4	52	4.004	3	3.002"	.973"	1.125"	1.375"	10.25"	1"		x	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	5	55.9	52	2.838	1	2.419"	.854"	.25"	-1.375"	1'-2"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	6	57.5	52	2.16	3	2.08"	.711"	.25"	-1"	1'-2"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	7	54.1	52	1.754	0	1.877"	.642"	.375"	-.625"	1'-2"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	8	54.1	52	.542	2	1.271"	.435"	.375"	-.125"	1'-2"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	9	52.9	52	0	1	.840"	.287"	.25"	.5"	1'-2"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	10	52.9	52	0	1	.2"	.072"	.25"	1"	1'-2"	1"		X	(Class A) Tested 100% to D1.5 tension code
TP2	WELD A	A	70	11	55.7	52	3.524	0	2.762"	.945"	.75"	0 - .75"	6.25"	1"		X	(Class A) Tested 100% to D1.5 tension code

REPORT BY: (TECHNICIAN ________ DATE 1/22/2014

QA / WITNESS : ________ DATE ________

All testing was done in accordance with Procedure # AWS-UT-2
All testing conforms with AWS D1.5