COMPARISON OF NONDESTRUCTIVE TESTING TECHNOLOGIES USED FOR INSPECTION OF WELDED JOINTS

A Thesis Presented to the Faculty of Graduate School at the University of Missouri-Columbia

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Master of Science

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by

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The undersigned, appointed by the Dean of Graduate School, have examined the thesis entitled

COMPARISON OF NONDESTRUCTIVE TESTING TECHNOLOGIES USED FOR INSPECTION OF WELDED JOINTS

Presented by **Habiburahman Hotaki**

A candidate for the degree of **Master of Science,**

And hereby certify, in their opinion, it is worthy of acceptance.

Professor Glenn Washer, PE

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Professor Gregory Triplett

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ABSTRACT

The purpose of this research is to report on the comparison between different nondestructive test (NDT) methods applied for the detection of defects in welds. NDT methods such as Ultrasonic Testing (UT), Magnetic Particle Testing (MT) and Radiographic Testing (RT) may be applied for the detection of surface and subsurface defects in steel bridge members. However, each of these technologies may have a different response to the same defect, based on the physics of the technology. As a result, test results may vary between each of the techniques. Critical defects such as cracks may be detected by one technology, but not by another, leading to inconsistent results and undermining confidence in the test results. Inconsistencies between MT, UT and RT were identified in the study. In this research, MT, RT, and UT results from the inspection of the Sherman Minton Bridge were compared with physical test results obtained from cores taken at 21 different locations across the bridge. Comparisons for surface breaking cracks and subsurface defects (including cracks) were provided. This research also evaluated the limitations of MT, RT, and UT methods regarding defect types and disposition in welds and their locations on the tension tie chord of the bridge. It was presented through the study that RT missed many planar flaws compared with UT and laboratory results. The number of flaws detected by UT at the core locations was higher than any other method. Finally, ROC (Receiver Operating Characteristic) and POD (Probability of Detection) analysis were also conducted based on the results from 21 cores and results from field inspection of the Sherman Minton Bridge.

1 INTRODUCTION

The overall purpose of this research was to report on the comparison between different nondestructive test (NDT) methods applied for the detection of defects in welds. NDT methods such as Ultrasonic Testing (UT), Magnetic Particle Testing (MT) and Radiographic Testing (RT) may be applied for the detection of surface and subsurface defects in steel bridge members. However, each of these technologies may have a different response to the same defect, based on the physics of the technology. Critical defects such as cracks may be detected by one technology, but not by another, leading to inconsistent results and undermining confidence in the test results.

The objective of the research is to evaluate the consistency of test results from each of these technologies. In the study, MT, RT, and UT results from the inspection of the Sherman Minton Bridge were compared. The Sherman Minton Bridge is a two span tied arch bridge spanning the Ohio River. Vertical butt welds in the tie girder were inspected between the months of June and December, 2011 using VI, MT, UT and RT NDT methods. During the course of the inspections, 21 cores were removed from the bridge for laboratory assessment of their metallurgy and to characterize flaws at those locations. The result of these laboratory studies were compared with the results from the NDT field test results. In addition, the NDT field test results obtained from testing all of the vertical butt welds in the bridge were compared to assess the consistency of the field test results. Additional information regarding the SMB can be found in section 2.3 of this thesis. Comparisons for surface breaking cracks and subsurface defects (including cracks) were provided. Inconsistencies between MT, UT and RT were identified in the study.

This research also evaluated the limitations of MT, RT, and UT methods considering defect types in welds and their locations on the tension tie chord of the bridge. For example, access to the surface being tested is required for certain methods. If access to the surface is unavailable due to interfaces such as plates attached to the surface, the method cannot be effective.

ROC (Receiver Operating Characteristic) analysis was conducted based on the lab results from 21 cores of the Sherman Minton Bridge. ROC analysis is a method for assessing the reliability of NDT technologies in terms of accuracy of the disposition in the test results. The analysis method was used to compare the results of flaw detection between UT and RT.

A POD (Probability of Detection) comparison was conducted, based on the field inspection data from 352 butt weld locations along the bridge. POD analysis is a method of assessing NDT reliability as a function of flaw size (i.e. length or height). Overall, 802 indications were reported from 352 locations. These indications were organized in a binary (hit/miss) data format. Then, POD assessments were conducted for both UT and RT inspections.

2 BACKGROUND

2.1 Types of Flaws in Welded Components

The overall purpose of NDT for weld assessment is to ensure the quality of the weld by detecting flaws such that the flaws may be assessed and repaired if necessary. Typical weld flaws can be characterized as either surface breaking flaws or subsurface flaws. Certain NDT technologies can only detect flaws that are surface-breaking, while other NDT technologies can detect both surface-breaking and subsurface flaws. Subsurface flaws can be characterized as either volumetric or planar flaws. A "volumetric" flaw is a flaw that has a height to width ratio of close to one (*1*). In contrast, a "Planar" flaw has a height to width (or thickness) ratio much larger than one; i.e., its width (or thickness) is very small compared to its height (*1*). Cracks are planar flaws, because the height and length of a crack is typically much greater than the thickness of the crack itself. Cracks may be subsurface flaws, contained entirely between the surfaces of the metal, or may extend to the surface, i.e. be surface-breaking flaws.

Flaws may result from different sources, such as fabrication, construction or in-service performance of welds. Typical weld fabrication flaws include cracks, lack of fusion, incomplete penetration, and volumetric inclusions (e.g. slag and porosity) (*2*). Fabrication flaws are of concern because they may cause the in-service failure of welds (*3*). For example, welded components containing fabrication flaws may be degraded when subjected to thermal or mechanical fatigue (*4*). For highway bridges, fatigue loading caused by truck traffic can cause cracks to initiate and grow from weld defects. Volumetric flaws are generally less critical than planar flaws, because planar flaws (i.e.

cracks) can propagate readily under fatigue loading and lead to member fracture (*5*). Typically, planar flaws are structurally unacceptable with their criticality depending on flaw size, shape and location (*2; 5*). Volumetric flaws are considered less significant, but may still be problematic depending on the length and volume of the flaw (*5*). For instance, the fatigue endurance of a volumetric slag inclusion decreases rapidly with increasing slag length when the length of the flaw is less than 10-12 mm; for slag lengths of 12 mm and greater, the fatigue endurance remains constant (*6*). A diagram of common flaws in welded components that are of major concern were gathered from many sources (i.e. nuclear industry reports and guidelines, NDT handbooks, various online articles, and etc…) and have been organized and illustrated in Appendix-A (*7; 8*).

2.2 NDT Technologies for Detecting Different Flaws in Welds

Visual inspection (VI), MT, UT, and RT techniques are widely used to inspect flaws in welds described in section 2.1. Surface flaws are detectable with MT and VI. VI is also commonly used to determine the size of a weld and to check a weld for undercut, under-fill, overlap, arc length, excessive convexity and arc strike (*9-11*). Subsurface flaws are detectable with UT and RT (*12*).

There are many approaches to consider in order to compare NDT techniques and to determine how well they detect different flaw types. These approaches include capability tests, reliability tests, and comparative assessments (*13*). Capability tests are usually considered as a means to demonstrate the capability of an NDT technique for its flaw detection of different sizes and shapes (*13*). Reliability tests may be performed to show that the reliability of an NDT technique is equal to or greater than another, or to establish a required level of reliability (*13*). Comparative assessments are used to compare one technology with another for a specific task (*13*). In this study, a POD curve comparison was conducted on the field data of the SMB (Chapter 6 of this thesis) (*13*).

2.3 Overview of Sherman Minton Bridge (SMB)

The SMB is located along Interstate–64 carrying Eastbound (EB) and Westbound (WB) traffic over Ohio River between New Albany, IN and Louisville, KY. Two tied arch truss spans, 800-ft each, support two levels of roadway located on upper and lower deck portal frames (Figure 2-1). The tie girder of the SMB was identified as a fracture critical member (FCM) on the bridge. FCM in a bridge is a steel member in tension whose failure would result in collapse or partial collapse of the whole bridge (*14*; *15*). The welded portion of the floor beam connections to the tie girder were also identified as FCMs. The tie girders of SMB were constructed of T-1 (A514) steel. A high-strength steel (F_y = 100 ksi) that can have reduced fracture toughness relative to modern-day steel. These girders were subject to in-depth inspection and periodic NDT inspection. In-depth inspections of portions of the SMB were completed in 1981, 1992, 2004, 2006, 2007, and 2011. Cracks were found in different weld types on the tie girders during these periodic in-depth inspections. These cracks were located in complete joint penetration (CJP) butt welds in the tie girder web, as well as in the top and bottom plates of the tie girder box. The fillet welds connecting the corners of the box girder were also identified as areas where cracking had occurred. Similarly, cracks were found on longitudinal connection plates (part of the lower lateral shelf plate connection) welded to the web of the tie girder (*11*; *16*). Because the tie girder is an FCM, these cracks could have resulted in collapse of the bridge if they propagated. To mitigate the risk of collapse of the structure, a comprehensive inspection, including NDT, was undertaken in 2011. The MT, UT, RT and VI and the inspection procedures were focused on the welded components in the tie girders (e.g. bottom plate, top plate, upstream web, downstream web, and shelf plate).

2.3.1 Closure of Sherman Minton Bridge

The SMB was closed to traffic on September 9th, 2011 and remained closed until February 17th, 2012 (*17*). Several NDT technologies were used in the tie girder inspection of SMB, as described in section 2.2. Indiana Department of Transportation (INDOT) conducted a new round of inspections on the SMB (April 2011) (*17*). During this inspection period, in late summer 2011, a 2.5 in crack was found in one of the butt welds on the FCM tie girder (Figure 2-2a) (*17*). Based on the Fitness for Service (FFS) analysis by Purdue University, it was concluded that a crack with the same characteristics could cause the tie girder to fracture at a service temperature of 30º F (-1ºC).

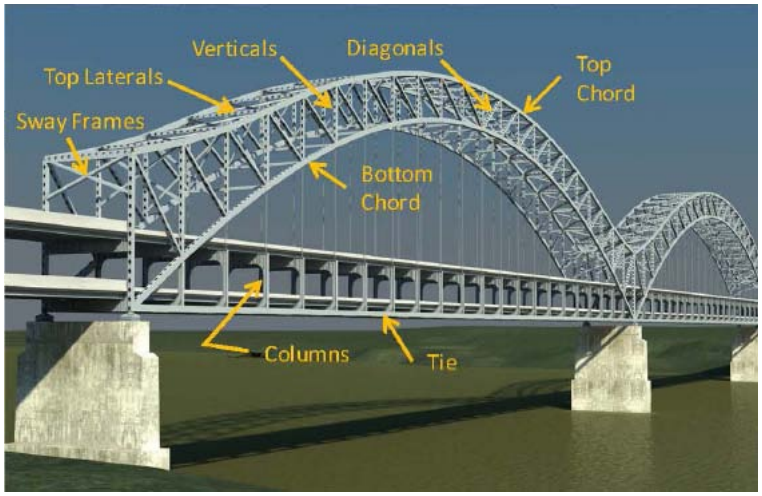
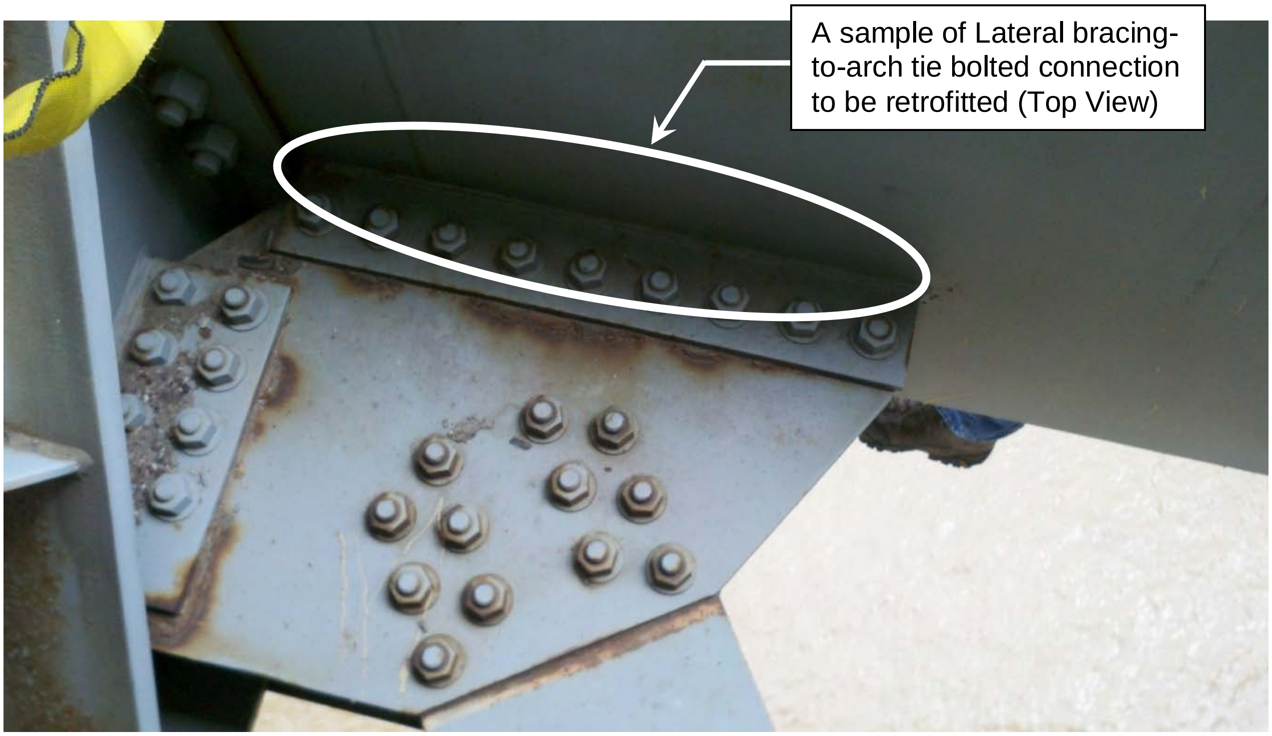


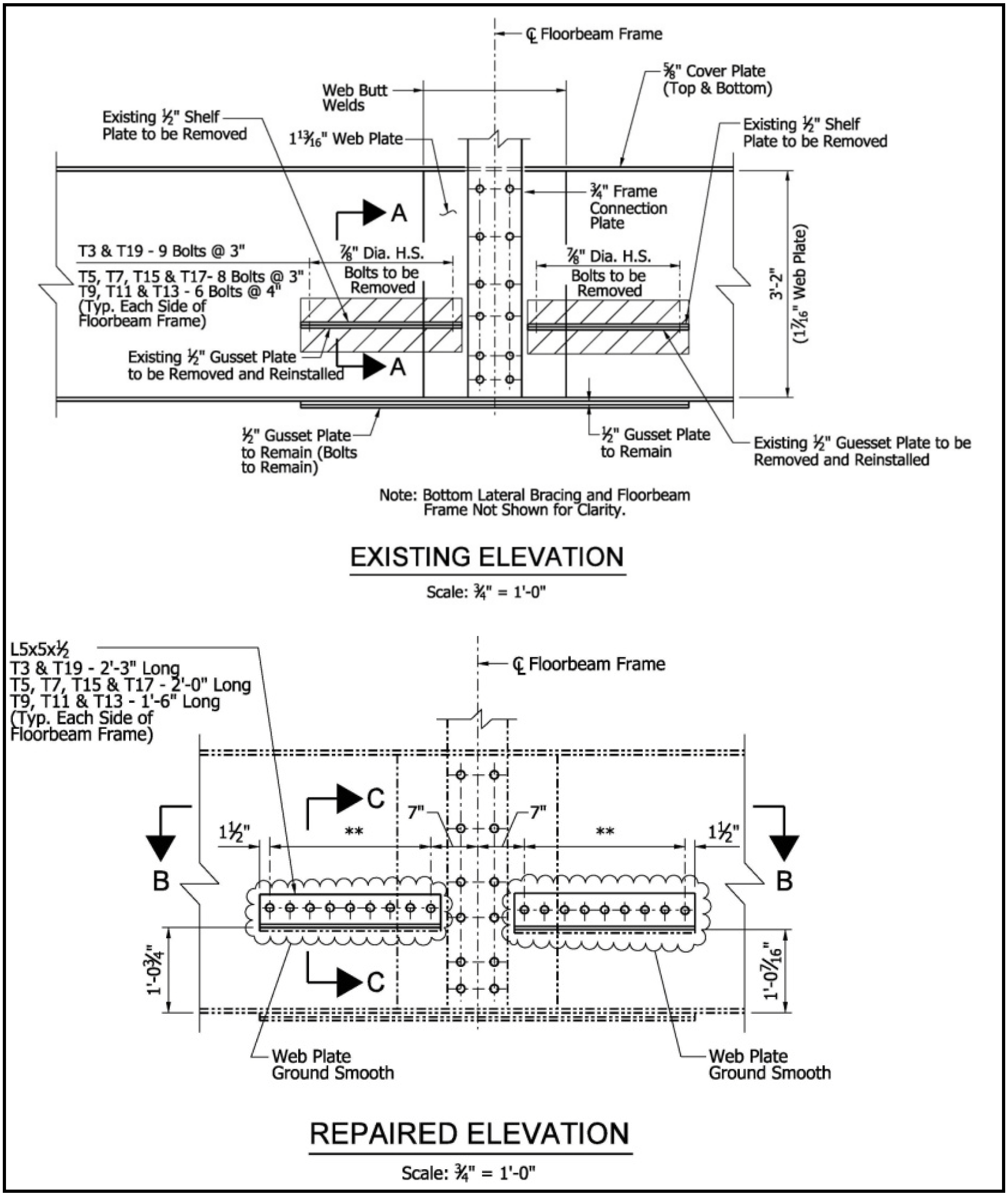
Figure 2-1. Illustration of major components of SMB (*18*)

To facilitate the inspection process, the inspector firm hired by INDOT named and categorized each butt weld on the FCM tie girder (352 butt welds). The nomenclature and acronyms used for the SMB will be discussed in the later chapters. The particular crack of concern and primary reason for closing the bridge was located on (US tie/T3KY/DS face of DS vertical plate) which means the upstream tie girder, the third panel point on Kentucky side, and downstream face of the downstream vertical plate. However, according to Gorrill, in addition to this particular butt weld crack, there were many other factors that led the bridge to the full closure (*18*). The finding of this crack was the concrete evidence proving that the bridge was potentially unsafe. This crack was found during the process of retrofitting the shelf plate (lateral bracing-to-arch tie connections) (Figure 2-2b). The process of retrofitting required that the 88 lateral bracing-to-arch tie connection plates to be removed and the welded connections to the tie to be replaced with a bolted detail (Figure 2-2c).

(a)


A sample of Lateral bracing-to-arch tie bolted connection to be retrofitted (Top View)

(b)



(c)

Figure 2-2. (a) MT showing the crack after removal of the connection plate (b) Top view of lateral bracing-to-arch tie connection (c) Bolted detail of the connection (*18*).

2.4 Welding Inspection Techniques

This section describes three NDT techniques used for inspection of the tie girder butt welds of the SMB. RT, UT, and MT techniques were used to detect surface and subsurface flaws of the welds. This section also describes briefly the reliability of each technique.

2.4.1 Radiographic Testing (RT)

The radiographic testing (RT) technique is an effective and well-established method of NDT that has been practiced for more than a century (*2; 19*). In 1895, some mystifying rays were discovered by Wilhelm Konrad Roentgen. These rays have been named after the inventor and called Roentgen rays or X-rays (*19*). A radiographic image is produced by radiating the welded element (or any specimen) using an X-ray or a gamma-ray source (*12*). X-rays and gamma rays have very short wavelengths, compared to other waves in nature, that permit them to penetrate through materials (*20*). In addition to X and gamma sources, there are several other radiation sources with different energy levels used for inspection of specimens with different thicknesses (*2; 20*).

In the RT method, photons (X or gamma rays) are scattered and/or absorbed through interactions with the material. The intensity of the rays emanating from the surface of the material is dependent on the density of the material. Embedded discontinuities or flaws affect the intensity of the rays emanating from the material. The intensity of the rays is recorded by exposing a film; variations in the intensity appear on the film as an indication of a flaw.

Access to both sides of the specimen is one of the requirements of a conventional RT; in other words, the RT setup needs the radiation source on one side and the detector on the other side of the specimen (Figure 2-3) (*2*). Indications on the produced image will be fixed and related to the location of the detector and source (Figure 2-3) (*2*). To produce a good quality image, RT technicians are required to calculate the exposure time and to determine correct exposure conditions (*21*). Penetrameters or image quality indicator (IQI) devices are used to verify the quality and sensitivity of a radiographic image (*2; 21*). According to Ewert, significant parameters for an image quality and good detection of a flaw are image unsharpness and contrast-to-noise ratio (CNR). Volumetric discontinuities can be detected easily by radiographic techniques because RT method is very sensitive to the density changes associated with slag and porosity in a welded component (*22*).

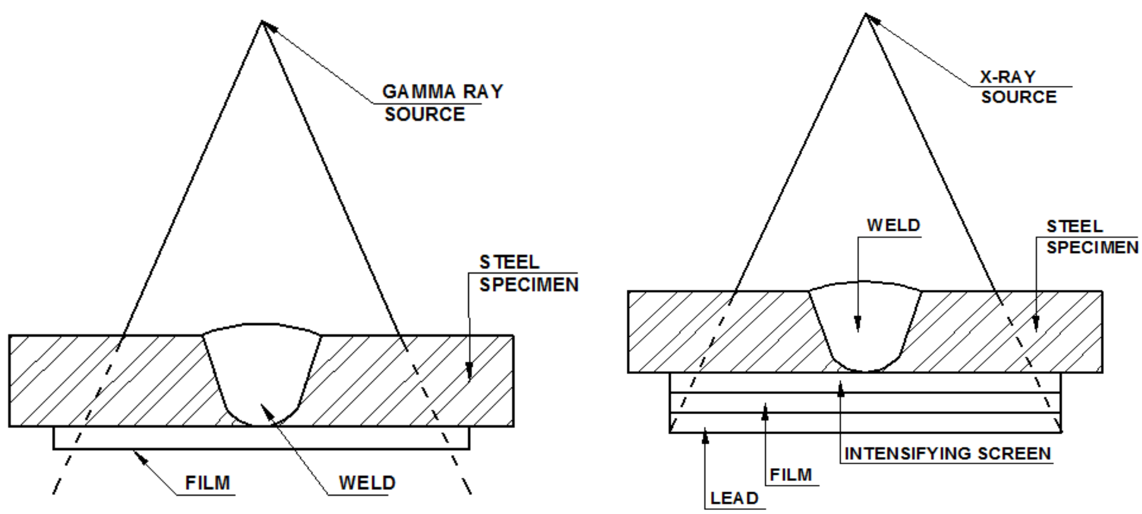


Figure 2-3. Apparatus set-up for a typical radiographic inspection with X and gamma ray sources

2.4.1.1 Transition from Film-Based to Digital Radiography

Conventional or film-based radiography, discussed previously, is being updated with modern digital technology (*23*). Filmless, or Digital Radiographic Testing (DRT), has been proven more advantageous than the film-based or traditional technique for many reasons. Digital radiography makes it possible to have a high quality image with a high performance level when compared to the classic film-based RT. For instance, amorphous silicon has enabled the x-ray flat detectors for medical purposes with a real time digital imaging and significantly high performance level (*24*). Furthermore, DRT is known for its rapid data transferring and low radiation dose characteristics. Fluoroscopy is an example of one of the DRTs that has a high frame rate and low radiation dose, unlike the conventional RT imaging (*24*). Generally, the low cost of DRT techniques is also one of the reasons for preference of DRT over film-based RT (*24*). In contrast, narrow dynamic range and silver (Ag) shortage in nature are main concerns for film-based RT technique (*19*). DRT covers several filmless digital detector technologies (Figure 2-4). These technologies, discussed below, can be used with either X-ray or gamma ray sources (*2*).

2.4.1.2 Digital Technologies

One of the digital technologies is called "Computed Radiography, (CR)", also known as storage phosphor plate radiography (Figure 2-4). This type of the DRT was used in the inspection of the SMB to produce results analyzed in this research. CR uses photo-stimulated X-ray storage phosphor plates (*25*). Moran described the procedure of CR in detail as follows:

…exposure of a phosphor plate to radiation results in charges being stored in the crystal lattice of the phosphor material. The amount of charge stored depends on the radiation dose received; the resulting stored charges constitute a latent radiographic image. Subsequent illumination of the detector with visible laser radiation releases the stored charges which emit luminescence at wavelengths that depend on the chemical composition of the phosphor (*2*).

Direct digital detector array (DDA – flat panels) is another type of digital detector technology. In digital radiography (DR), an RT image is created and displayed on a computer monitor on a real-time basis. Detector technologies for DR include amorphous silicon sensors (a-Si), amorphous selenium (a-Se), and CMOS (Complementary Metal-Oxide Silicon) (*25*; *26*). These detectors convert the x-ray or gamma ray photons directly to a digital image, i.e. a digital radiograph.

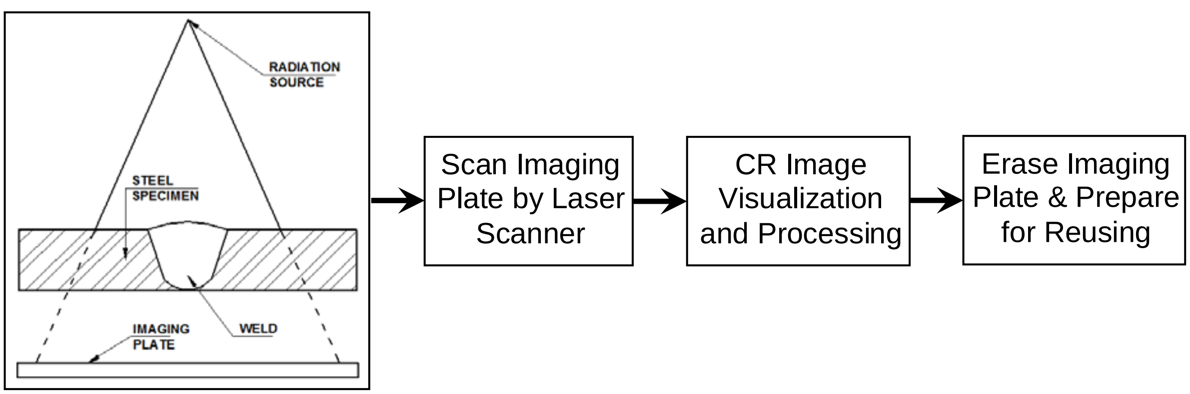


Figure 2-4. **Computed Radiography (CR) concept.**

2.4.1.3 Reliability of Digital Radiographic Testing (DRT)

The reliability of a radiographic inspection is directly related to both the quality of an RT image and the quality of the interpretation of that image (*23*). According to Silva and Deprins, high quality of radiographic images depends on various factors such as the following (*26*; *27*):

- Focus-to-film distance,
- Focus size,
- Film-to-object distance,
- Using of screens (e.g. slower phosphor screens, and higher scan resolution),
- Filter geometry,
- Longer exposure time,
- Film type, and
- Chemical film processing

Moreover, the image quality also depends on the size of these defects and their location and orientation relative to the size and thickness of the inspected components (*28*). Meyer illustrated in a comprehensive chart that the RT image quality and quality of the image interpretation are directly related to the quality of equipment, procedures, and personnel.

There are other publications describing the reliability assessment of RT. For instance, Nacereddine conducted a study focused on weld defect detection based on DRT image processing (*28*). The paper described some drawbacks and reliability issues of the RT technique. Similarly, Jaenisch conducted a POD modeling study on DRT and investigated the reliability of DRT in 2007 (*29*). The study concluded that when developing a POD evaluation for RT, multiple factors should be considered because the POD model does not include the human factors while interpreting an RT image. A POD assessment of radiography, based on field data from SMB, will be discussed in detail later in this thesis.

2.4.2 Ultrasonic Testing (UT)

UT has been used widely and effectively since it was introduced to the NDT industry in 1960's (30). UT is known as a standard NDT technique for locating and sizing of surface, near-to-surface, and subsurface flaws in different types of metals (31). UT is an NDT technique in which the transmitted acoustic waves are reflected by planar and volumetric flaws. Some of the volumetric and planar flaws for which UT has proven to be a viable technique for detection include: cracks, lack of fusion, porosity, and other imperfections in welds (30; 31). Conclusions from many studies conducted on the reliability of UT inspection have shown that UT is the preferred method compared to RT for several reasons (2). Difficulty of RT method in detecting planar flaws is one of the reasons typically provided in the research. RT is outstanding for detecting volumetric flaws (i.e. slag, porosity, etc), although most of the volumetric flaws are not as significant as the planar flaws. In contrast, UT is a reliable method for detecting both planar and volumetric flaws.

The physics behind UT is that the acoustic waves (ultrasonic waves) with high frequency and short wavelength are transmitted into the test object to obtain information about the object. The transmitted waves are reflected when they interact with interfaces such as surface boundaries, cracks and other discontinuities. After reflection, two parameters are measured: the duration of the wave travel in the object, or round trip time, and amplitude of the received signal. Based on the data obtained from these parameters, the location and size of flaws, discontinuities, and boundaries can be determined (*2; 32*).

The thickness of a material can be determined based on the velocity and flight time of waves that travel through the specimen:

$$T = \frac{C\,t}{2} \qquad \textbf{Equation 2-1}$$

Where T is the material thickness (m), C is material sound velocity (m/sec), and t is time of flight (sec). The relative change in amplitude is measured in decibels (dB) which can be calculated using the following equation:

$$dB = 20 \log \frac{A_1}{A_2} \qquad \textbf{Equation 2-2}$$

Where A_1 denotes signal being evaluated and A_2 denotes a reference signal. The acceptance or rejection criteria of flaws are assessed based on the AWS code (AWS-D1.5 for bridge welds) (*33*). There are four classes of indications (i.e. A, B, C and D) based on the recorded signal amplitude, according to the AWS code (*33*). Indications classified as class-A, known as large flaws, are always unacceptable regardless of the length of the indication. Categories B and C, known as medium and small flaws respectively, are only rejectable if the length of an indication exceeds certain limits. Flaws in class-D, known as minor flaws, are always acceptable (*11; 34*).

Human factors should be considered during UT inspection because the inspector's performance is an important factor in interpretation, especially in rejection or acceptance of a flaw. A very small change by the inspector in reading of a signal can have a significant impact on the flaw class type selection.

In addition to the human factors, there are several other factors affecting the reading and interpreting of a signal. For instance, according to Thompson, the signal weakness and strength of the acoustic energy depends on the flaw size, roughness, location, orientation, and shape. Other affecting factors include properties of the transducer, and characteristics of the material itself.

2.4.2.1 Reliability of Ultrasonic Testing (UT)

For all NDT techniques, especially for UT, two significant parameters are considered for the reliability assessments – detection and characterization of an indication (*35*). Detection refers to one of the NDT methods detects ("Hit") or does not detect ("Miss") a particular flaw. Probability of Detection (POD) curve can provide a good deal of information on flaw detection percentage of a technique as a function of flaw size (*35*; *36*). Characterization is concerned with specifying the properties of a defect such as length, height, width, location, and type.

Determining the reliability of an NDT technique depends on many factors, and a joint European-American workshop developed an empirical formula that describes the reliability of an NDT technology (*37*):

$$R = f_{(IC)} - g_{(AP)} - h_{(HF)} \qquad \textbf{(Equation 2-3)}$$

Where R represents the reliability of an NDT technology, IC represents the intrinsic capability of an NDT technology, AP shows the effect of application parameters, and HF shows the effect of human factors on the technology. This equation looks simple, but the characterization of the parameters is difficult, especially, when considering the human factor changing from one inspector to another.

As it is stated previously, during ultrasonic inspection, reading and recording of the amplitude response is quite significant for reliability of the method and the assessment of an indication. A small change in reading the signal amplitude can change the status of an indication from rejected to accepted or vice versa. According to Green, material defects, ultrasonic testing equipment with different bandwidths, and characteristics of a defect can cause significant changes in echo amplitudes. These changes directly affect the reliability of ultrasonic inspection technique and decrease the confidence level of flaw detection (*38*). Many studies were conducted to ensure the reliability of UT technique in detection and characterization of flaws in welded components and are discussed in the following paragraphs.

Anderson conducted a study on low-frequency Phased Array UT on different types of specimens including centrifugally and statically cast stainless steel (CCSS and SCSS), columnar, and equiaxed grain structures. Based on Anderson's study, low frequency UT showed many difficulties in detection of thermal fatigue cracks, even though these cracks were near to the surface of the specimens, approximately 20% to 30% of the wall thickness deep. However, mechanical fatigue cracks were generally detected very well by UT, even if the cracks were relatively small. Anderson's conclusions highlighted that the best cumulative flaw (i.e. mechanical and thermal fatigue) detection was conducted with a 500 kHz frequency array and the overall detection of flaws was 71%. Phased array UT technique using 750 kHz detected 57% of flaws, which dropped significantly compared to 500 kHz array; finally, using 1.0 MHz frequency the detection rate was 52%.

Carvalho conducted a study with a Round Robin Test (RRT) and this experiment had similar results as Anderson's. In the experiment, two types of defects were considered (i.e. lack of penetration and lack of fusion, Table-1) (*39*). According to Carvalho, the manual ultrasonic inspection technique is less reliable than the automated ultrasonic technique. The probability of detection of manual UT was a significant concern highlighted in this study. Furthermore, the performance-based reliability of the UT method and errors due to confusion between lack of penetration (LP) and weld root signals were the major concerns of the study. Therefore, automatic UT inspection was recommended since the errors due to human involvements are less than the manual UT. However, according to Hands, automated NDT technologies for larger areas require substantially high economic investment.

In 2003, Heasler and Doctor evaluated the reliability of ultrasonic inspection by conducting three Round-Robin tests (RRT) (*40*). The focus of the study was on length sizing, depth sizing, and flaw detection capabilities of the ultrasonic technique. The conclusions of the three RRTs highlighted many discrepancies in the length sizing capability of UT. One of the inspector teams reported extremely under-sized flaw lengths for larger flaws. It was assumed that the discrepancies among various inspection teams were due to the small sizes of the specimens used for this research. However, overall results showed a 70% POD for detection of a 5 mm flaw and a 90% POD for detection of a 10 mm deep flaw.

Based on many studies conducted on reliability of UT, factors that can affect the reliability of UT include the material and grain structure, performance of inspectors, and human factors (*36*; *39*). Most of the studies conducted on reliability of UT considered planar flaws that are usually found during in-service inspection rather than volumetric flaws that are usually found during fabrication (2).

2.4.3 Magnetic Particle Testing (MT)

MT is an NDE technique for detecting surface-breaking cracks in steel. In 1918, William Hoke, while working in a mechanic shop, accidentally realized that defects embedded near the surface and/or at the surface of a specimen could be detected using magnetic particles (colored metal shavings) and basic principles of the magnetism. Hoke discovered that a surface and/or subsurface flaw in a magnetized specimen caused the magnetic field to deviate from its original organized patterns within the steel and a flux leakage field would be created around the flaw. He found that the metallic grindings/particles from hard steel parts created patterns around the surface cracks on the face of the steel parts. After sprinkling fine ferromagnetic powder on the steel parts, a visible indication of the flaw was created on the surface by particles collecting around the flaw. Later, deForest developed the discovery of Hoke into the first magnetic NDT inspection technique, called magnetic particle method or MT(41; 42).

In magnetic particle inspection, discontinuities oriented in a transverse direction to the direction of the magnetic field cause a leakage field at and above the surface of the ferromagnetic specimen, as illustrated in Figure 2-5. In the figure, surface-breaking cracks, creating small air gaps (usually 0 to 4 mm), cause the magnetic flux to leak out of the specimen and the produced field is called flux leakage field. Congestion of particles held magnetically by the leakage field specifies the geometry of the flaw such as its location, size, shape, and extent (Figure 2-5). Magnetic particles are applied over a surface either as dry particles or as wet particles (*43*).

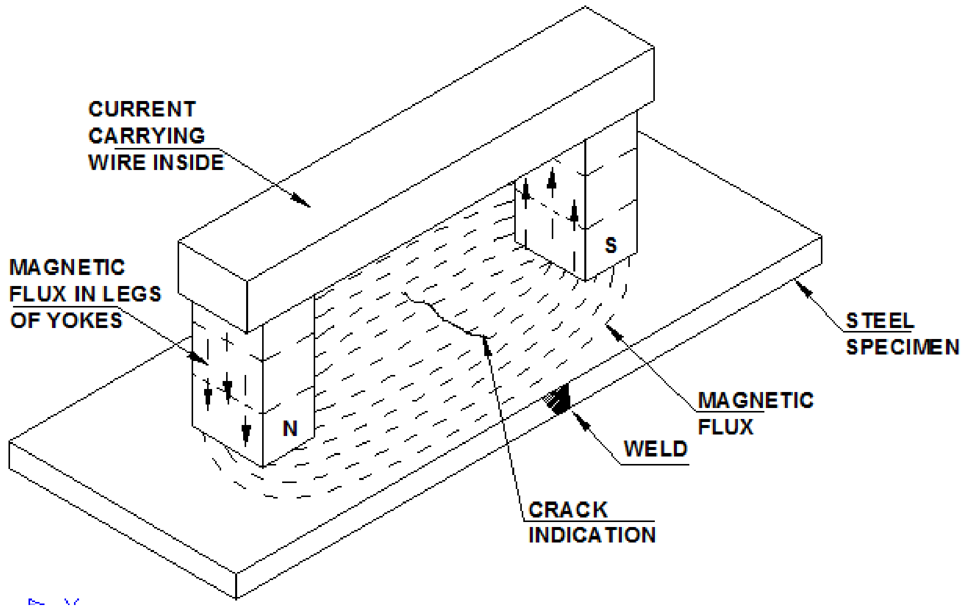


Figure 2-5. Schematic concept of magnetic particle inspection and flux leakage field

When magnetic particle inspection technique is chosen for inspecting a specimen or a structure, it is necessary for the inspector to have prior knowledge of the orientation of surface cracks for more reliable MT application. Knowing the crack orientation helps the inspector to apply the magnetic field at a normal angle with the anticipated flaw. Generally, MT method is sensitive to linear surface cracks rather than round-shaped flaws, and a lower false calls rate for linear cracks was observed in the past studies (*44*).

There are advantages and disadvantages for using MT method. Some of the advantages of MT include its rapidness, economic application, visually positive output, and rapid training of inspectors. Generally, MT is rapidly applicable on any structure with a reasonable output, regardless of the size of a structure. On the other hand, disadvantages of MT method include its limitation to only ferromagnetic materials and surface-breaking cracks and the need for complete magnetization coverage of materials in at least two directions. Furthermore, in certain cases, MT method requires a demagnetization process after its application (*45*).

2.4.3.1 Reliability of Magnetic Particle Testing (MT)

Schoefs studied the reliability of MT technique and other NDT methods. In the study, receiver operating characteristic (ROC) curves were used for reliability assessments. ROC curve is produced by plotting the POD versus probability of false calls (PFC) for an NDT technique. Using ROC, Shoefs confirmed that in some cases, the performance of an NDT technique is related to the location of the joint to be inspected on the structure. In the study, MT was considered for the inspection of two types of steel joints (Y-shaped and T-shaped). The results of the experiment confirmed that the POD of a given crack at the Y-shaped joint is lower than the same crack at the T-shaped joint (*46*).

2.5 A Comparison of RT and UT (Literature Survey)

To achieve the purpose of this research, a great deal of information was obtained by conducting a literature survey of publications discussing the nature, reliability, performance, and capability of detection of both RT and UT. Publications focused on the preference of a method and comparison of RT and UT were also considered in the literature survey. Some of the publications herein are focused on the direct comparison of RT and UT using Round Robin Tests (RRT), inter-laboratory tests performed independently several times.

Pacific Northwest National Laboratory (PNNL) reported to the U.S. Nuclear Regulatory Commission on the assessment of technical gaps of these two NDT methods and PNNL's preference of UT over RT (report: PNNL-19086) (*2*). To compare RT with UT and to assess technical gaps of these NDT methods, the research team chose a time interval between 1980 and 2009 for a publication survey. The team reviewed over 600 journal papers, conference papers, and technical reports, and over 100 documents related to the comparison of RT and UT.

2.5.1 Role of POD Curve in Comparing Two NDT Methods

Since a bridge's structural integrity is a major concern, the assessment choice for a reliable NDE technology to inspect the structure is crucial. The preference of one technique over another directly depends on the POD curve. Based on many studies and experiments that were conducted to evaluate and compare capabilities of two NDT techniques, the probability of detection (POD) curve for each method is a primary factor. Comparing directly POD curves from two different experiments is not recommended due to the many factors that directly affect the POD curve (*2*). For instance, the experiment procedures and set-ups vary from one experiment to another with factors such as different geometries, specimen materials, defect characteristics, etc (*2*). A list of possible factors was developed that divided into different categories that can affect the results of POD curve as shown in Table 2-1 (*35*). The table describes factors affecting the test object such as material characteristics, thickness and surface conditions. The table also lists factors that affect defects such as shape and orientation of the defect. For example, UT depends on the reflection of acoustic waves from the defect in the material; the orientation and shape of the defect will affect how likely it is a given defect will be detected; consequently, the POD curve will be affected.

A practical description of the POD derivation and application procedure is provided by Health and Safety Executive (HSE) in London, 2006 (*47*). This research considered the limitations of POD curves. Also, this study showed that practical applications of POD, first developed in 1960s and 1970s for aerospace industry, have also been adopted by other industries such as the following:

- Aircraft structures: Using X-Ray RT to detect inclusions in Titanium castings
- NORDTEST trials: Comparing MUT with X-Ray RT applied on steel butt welds
- The PISC Trials: Application of UT on thick nuclear pressure vessels
- Offshore Tubular Joints: Using underwater MT method to detect fatigue cracks
- Dutch Welding Institute (NIL): Using mechanized UT for flaws in thin steels
- LPG Storage Vessels: Developing POD practical guidelines by Georgiou

Table 2-1. Possible factors affecting POD curve.

Categories	Factors
Testing Object	Material(s)
	Material inhomogeneities and anisotropies
	Stresses
	Geometry and geometrical details: Cut-outs, holes, edges, narrow angles
	Thicknesses
	Surface Condition and cleaning
	Special processes used: Welding etc
	Coating and Insulation
Defects	Type(s)
	Sizes: Length, height, opening/width
	Locations
	Geometrical shape
	Orientation
	Roughness
NDE Technique	Type and operation principles
	Equipment including transducers
	Equipment characteristics and settings: Frequency, gain, etc.
	Sensitivity adjustment
	Calibration and functional checks
	Preparatory work: Cleaning, etc.
	Supplementary techniques and aids
	Reporting format
Testing Conditions	Access
	Operator positions
	Environment type
	Temperature
	Humidity
	Radiation and other hazards
	Process and other liquids including fresh or sea water
	Light levels
	Influence of coatings and insulation
	Personnel working hours
NDE Personnel	Education
	Experience
	Certification: Type, level, etc.
	Special training and experience
	Motivation
	Working hours

2.5.2 Replacement of RT with UT

Replacing one NDT technique with another is a complicated process that requires a series of studies and experiments prior to choosing one technique over another in order to prove the capability and reliability of the replacement technique (13). Studies conducted on the comparison of UT over RT typically consider two main parameters: flaw detection and flaw sizing capabilities. Studies comparing the sizing capabilities of UT and RT are very limited (2).

Radiographic inspection is an orientation limited technique; that is, it is difficult for RT to detect flaws which are located along through-thickness direction (2). Since RT produces a 2D image from a 3D object, only the flaw length will be shown in an RT image (2). Therefore, the worst case assumption is used for the depth of a flaw in the RT technique. When considering planar flaws such as cracks or lack of fusion, the depth location of flaws becomes very important. This highlights the fact that RT has a disadvantage in the determining the depth of flaws, as opposed to UT, and this is one of the reasons that supports replacement of RT with UT (2).

Babcock reported in 2004 for HSE that if a crack orientation is more than approximately 8º, the RT technique will not be able to detect the crack (48). RT has this particular problem with detection of planar defects because naturally growing cracks may lie at different orientations. Munns and Schneider studied the capability of radiography in detection of large planar manufacturing defects in thick-section welds. In the study, the through-wall extent dimension of the defects was larger than 15 mm and the defects were located in butt-welded steel specimens with thicknesses ranging between 50 mm to 114 mm. For the experimental purposes, seven butt-welded steel specimens were considered, containing a total of 19 planar defects, ranging in through-wall size from 14 mm to 52 mm. Experimental results supported the simple theoretical arguments about the RT detectability, as Munns described these theories: The RT flaw detectability decreases as the thickness of steel specimen increases and as the angle of orientation between flaw and radiographic beam is increased. In contrast, RT detectablility increases as the flaw gape increases; that is, higher misorientation angles can be tolerated for more gaped "opened" flaws (*49*). These results are illustrated in Figure 2-6.

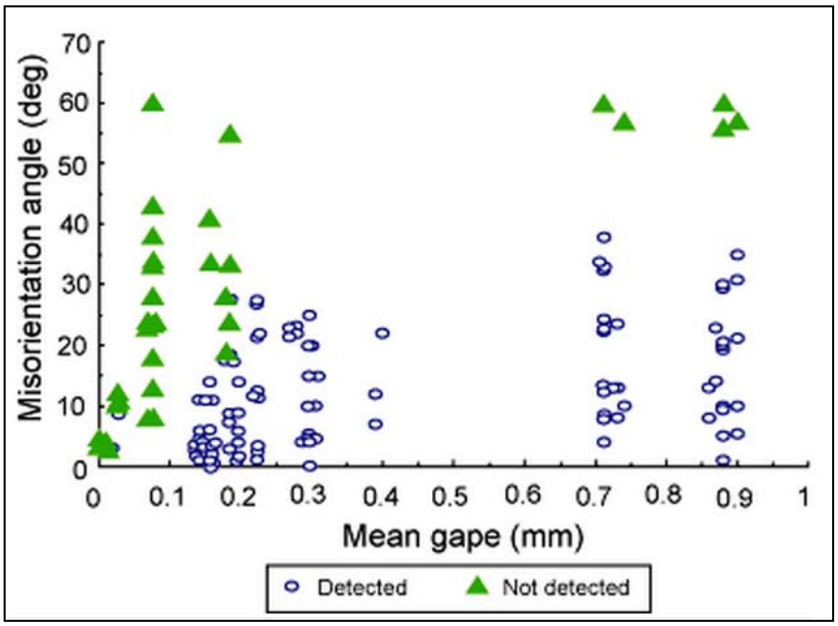


Figure 2-6. RT detectability variation with flaw misorientation angle and gape (*49*)

Babcock also notes a major health disadvantage of the RT method due to X and gamma rays. These rays cannot be detected by senses, but are very hazardous. Set up time, space allocation, and operating cost are additional factors that contribute to disadvantages of the RT technique.

On the other hand, ultrasonic testing has been proven to be reliable in detecting planar flaws. Manual ultrasonic inspection is widely used because of flexibility and cost effectiveness in lieu of automated UT. However, as a major disadvantage, manual UT requires a high degree of experience and skill from inspectors so that they are familiar with method of scanning, identification of the indications, and interpretation of the results (*48*).

2.5.2.1 Flaw Length Measurement of RT Compared with UT

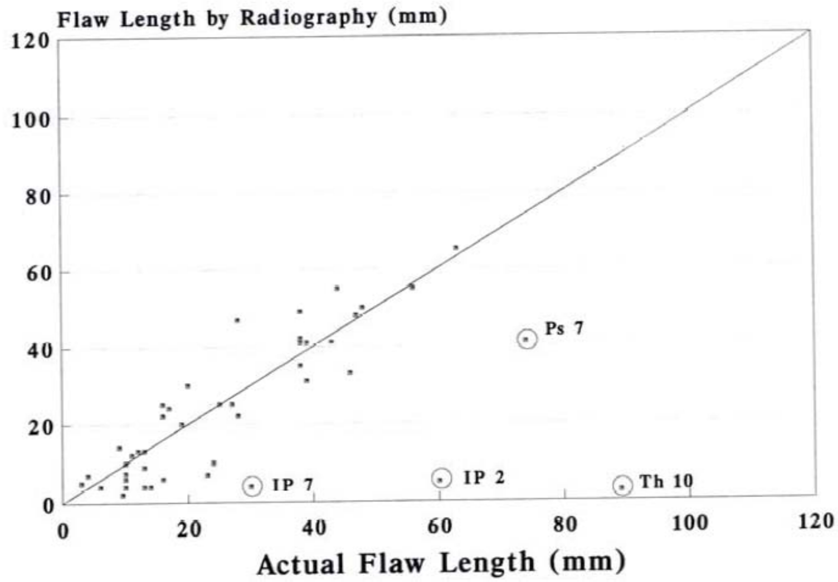
Similar to one of the objectives of this research (i.e. comparison of RT with UT), Babcock described an experiment that included 55 flaws. The objective of the experiment was to compare ultrasonics and radiography with the sectioning/lab results.

In the experiment, 45/55 flaws were considered for RT and 51/55 flaws were considered for UT and the results were compared with the sectioning/physical inspection results. The remaining flaws for RT and UT, not considered in the analysis, were due to either lack of field or lab data (Refer to Appendix-G). The flaws had different characteristics such as, lengths, heights, and shape. The experiment concluded the following table (Table 2-2) comparing RT and UT considering flaw length measurement:

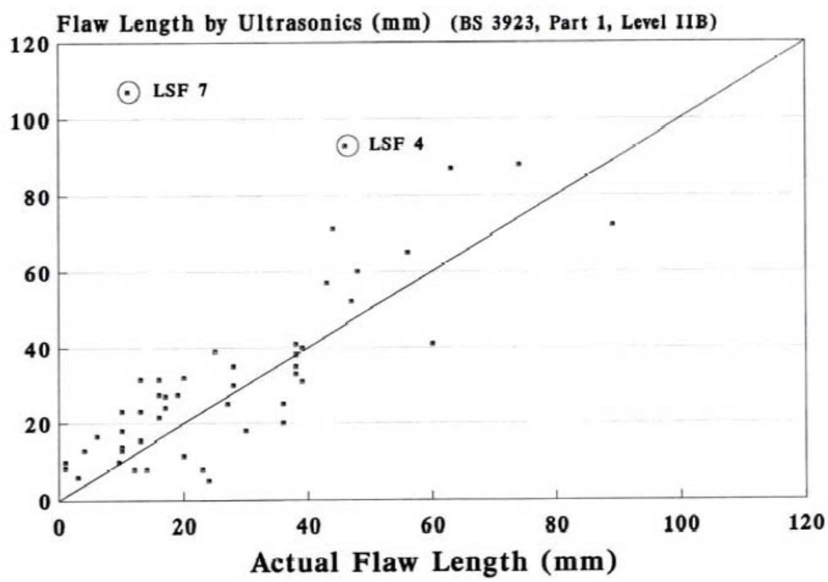
Table 2-2. RT and UT results compared with sectioning results.

Comparison Parameters	RT vs. Sectioning		UT vs. Sectioning	
	RT	Sectioning	UT	Sectioning
Mean Flaw Length (mm)	22.7	27.7	32.7	26.5
Standard Deviation	17.7	19.6	24.3	19.6
Number of Flaws	45	45	51	51

Furthermore, qualitative measurements of scattered results from the ideal line are also illustrated for both RT and UT in Figure 2-7. Once again, UT was proven the preferred technique considering flaw length measurement and flaw detectability.



(a)



(b)

Figure 2-7. RT and UT measurements vs. actual flaw lengths (48)

In Figure 2-7, PS is planar surface flaw, IP is isolated porosity, TH is threadlike flaw, and LSF is lack of sidewall fusion. As it can be observed, RT failed to correctly measure the flaws circled on the Figure 2-7a, unlike UT. However, UT had a couple indications off the actual measurements (*48*).

2.5.2.2 Probability of Detection (POD) of RT Compared with UT

A guideline was developed by Forli in 1995 in order to compare reference and replacement techniques. The guideline included direct comparison, absolute comparison, relative comparison, and POD curve comparison. Furthermore, this guideline was implemented practically on POD of both RT and UT techniques. In POD assessment of both techniques, RT was chosen as a reference technique and UT as a replacement technique. Since the POD curve is usually plotted as a function of defect size (i.e. flaw height or length), a total of 141 defects were distributed into categories of different heights and one median value representing the height of the whole group. These defects were categorized into 4 categories based on the height. The range of defect heights for 4 categories was from 0.7 to 5.0 mm (i.e. 0.7 mm, 1.6 mm, 3.0 mm, and 5.0 mm). Table 2-3 represents the data from 4 categories.

Based on the tabulated data in Table 2-3, an appropriate conclusion cannot be drawn on the suitability of replacing radiography with ultrasonics. Therefore, a series of calculations should be done and other approaches should be considered to provide a proper conclusion (i.e. POD assessment of both techniques). According to Figure 2-8 and Table 2-3, for defects above 1.0 mm, UT meets the basic detection criteria for the rest of defects. This supports the idea of replacement of RT with UT. Forli described the basic detection criteria as two main parameters. One of these parameters was the lower 95% confidence level of the POD value for the replacement NDE technique that should be equal to or higher than the average POD value for the reference technique minus 0.1 (dashed line in Figure 2-8) (*13*). Another parameter was the difference between the average value and the lower 95% confidence level of the POD value for the reference technique that should be equal to or less than 0.1 (*13*). Consequently, Figure 2-8 indicates that both the average POD curve and the 95% lower confidence curve for UT are above the dashed-line threshold curve, assigned as a basic criterion by Forli.

Table 2-3. POD curve parameters for 4 groups based on defect size (height).

POD Parameters	Group 1	Group 2	Group 3	Group 4	All
Defect height (mm)	**0.7**	**1.6**	**3.0**	**5.0**	**2.0**
No. of defects in a group (N)	40	38	30	33	141
No. of defects detected by RT (nr)	12	16	17	24	69
No. of defects detected by UT (nu)	9	18	18	25	70
Average POD values for RT (Pr)	0.30	0.42	0.57	0.73	0.49
Lower 95% POD confidence for RT (Pr95)	0.18	0.28	0.40	0.57	0.42
Assessment threshold to test confidence in RT POD (Pro=Pr-0.1)	0.20	0.32	0.47	0.63	0.39
Average POD values for UT (Pu)	0.23	0.47	0.60	0.75	0.50
Lower 95% POD confidence for UT (Pu95)	0.12	0.33	0.43	0.60	0.42
Pr95 ≥ Pro?	No	No	No	No	Yes
Pu95 ≥ Pro?	No	Yes	No	No	Yes

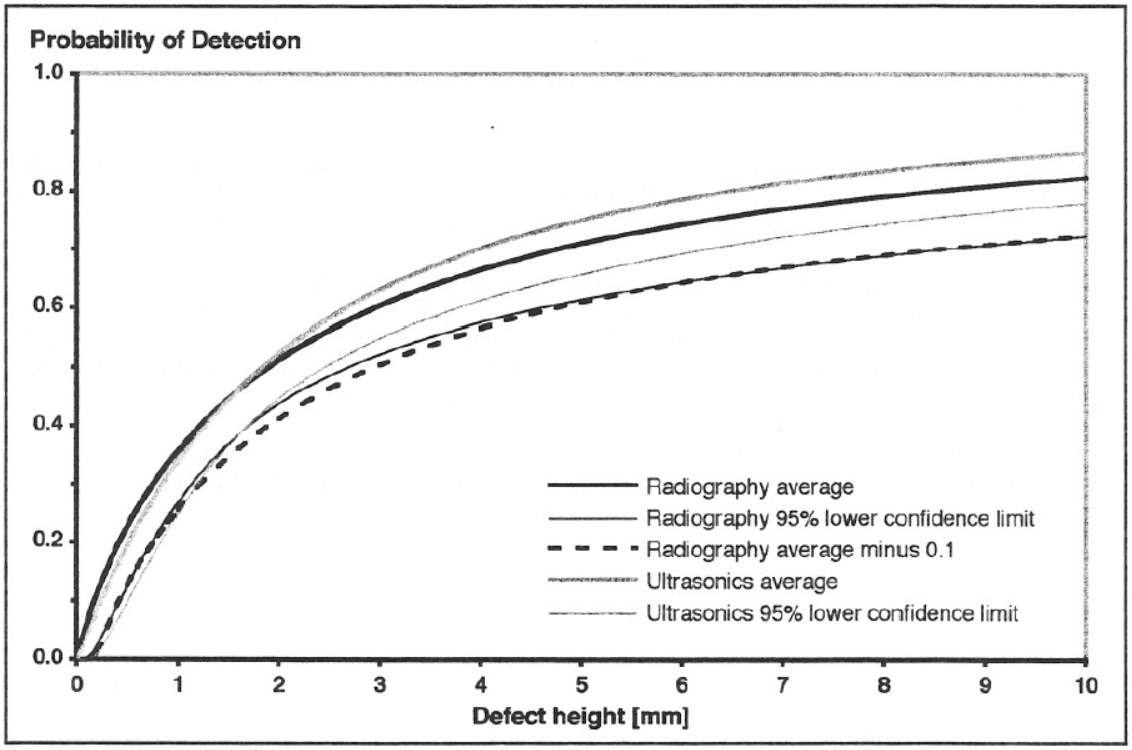


Figure 2-8. POD curve comparison of RT and UT including 95% lower confidence limits based on Table 2-3 (*13*)

2.5.2.3 ASME Code Acceptance of Replacement of RT with UT

Replacement of RT with UT has been suggested by published code cases from the ASME Boiler and Pressure Vessel and ASME Pressure Piping. To date, three code cases from ASME Boiler and Pressure Vessel and two code cases from ASME Pressure Piping have been published (*2*). In these five code cases, CC-168 and CC-179 focus on pressurized piping welds used in electric power generating stations. CC-N-659 and CC-N-713 focus on nuclear welded components. CC-2235 concentrates on power boilers and pressure vessels; this is discussed in detail in the following paragraph.

There are few articles presenting the technical basis of these code cases, but there is some literature for CC-2235 and CC-N-659. CC-2235 focuses on construction of power boilers, pressure vessels, and transportation tanks under ASME BPV Sections I, VIII (Division 1 and 2), and XII. CC-2235 was first approved in 1996 which enabled the use of UT instead of RT (*50*). In this code case, a tremendous performance of UT was demonstrated using an 18-in heavy section test block containing embedded flaws and a 10-in test block with subsurface flaws. Rana concluded that there are powerful incentives for use of effective UT and the development of acceptance standards for the fitness for service (FFS) approach. The reason for the incentives is that by using the effective UT procedure, such as code case 2235, the round-shaped flaws can certainly be detected. Also, the fracture mechanic based flaw acceptance criteria can eliminate irrelevant and costly repairs of unimportant imperfections found in the vessel fabrication (*50*).

RT and UT are complementary inspection techniques. RT is an ASME-approved volumetric method for fabrication/construction inspection of welds and has been commonly used for the detection of fabrication imperfections. UT has been the recommended volumetric method for pre-service and in-service inspection because of its high detectability of planar flaws. Replacing RT with UT for fabrication inspection has an advantage in that the same method, with potentially the same acceptance criteria, is used for inspection throughout the lifetime of the component (*2; 50*).

2.5.2.4 FHWA Recommendation on Replacement of RT with UT

Most of the published literature focusing on comparing RT with UT is from nuclear power plants, boiler and pressure vessels, and other mechanical related industry. Few studies with this same purpose have been done for steel highway bridges; therefore, the literature is rather limited. The Federal Highway Administration (FHWA) conducted a study and reported on comparison of automated UT, manual UT, and RT. The study also evaluated the effectiveness of automated UT as a replacement for RT for fabrication inspection of welds in steel bridges. Results from the field, a fabrication shop, and lab inspections were compared with each other throughout this study.

FHWA launched a thorough literature and code survey focusing on comparison of AUT, UT, and RT in industries other than bridge fabrication. A market survey of available sources for AUT systems was also conducted. Laboratory research was done comparing AUT and RT inspection of butt welds containing common defects. Finally, field testing studies were conducted to evaluate the feasibility, accuracy, reliability, and defect sensitivity of AUT relative to RT in a bridge fabrication shop during the fabrication process (*51*).

FHWA concluded that AUT is a viable technique for fabrication inspection of butt welded steel plates. Based on the results, AUT images provided more complete information than manual UT and RT about the characteristics of defects in the weld. RT and AUT results were consistent. The slight lack of agreement between AUT and RT was due to the difference between physics of these techniques. The inconsistencies between results of RT and UT in regards to their physics are discussed later in this thesis. Finally, FHWA recommended a future research on defect sensitivity of AUT in comparison to RT to provide more information on the differences that exist in the acceptance-rejection criteria between AUT/UT and RT (*51*).

3 BRIDGE INSPECTION

3.1 Field Inspection

As discussed in chapter 2 of this thesis, the Sherman Minton Bridge was subject to a periodic hands-on inspection since 1981. After discovery of some major cracks in the vertical butt welds of its tie girders in 2011, the bridge was closed for almost six months to be retrofitted and to evaluate the fitness for service (FFS) criteria for the bridge. During this time, numerous investigations were conducted on this bridge by various firms. Investigations included many parts of the bridge, including arch tie inspection, concrete deck evaluation, tie girder inspection, and cable assessment. This research focuses only on the NDE data from welded joints of tie girders of the bridge.

The SM Bridge has two 800-foot spans with each span containing two tie girders and each tie girder containing 22 welded joints. A total of 88 (22 times 4) welded joints were subject to inspection. Each vertical welded joint of the box girder has 4 individual vertical butt welds. The location of each of the four vertical butt welds can be described as follows: the location may be on the Kentucky side, i.e. side of joint closest to the state of Kentucky, or on the Indiana side (i.e. closest to Indiana). On either side the location can be described as upstream or downstream, as defined by the flow direction of the Ohio River. Figure 3-1 illustrates the location description for the Indiana side of a joint, indicating the upstream and downstream vertical butt welds. Therefore, a total of 352 (88 times 4) locations were subject to inspection using four different NDT techniques (i.e. MT, UT, RT, and VI). Table 3-1 shows the field work summary and percentage of overall joints inspected by four NDT methods. Less than ten percent of total joints were subject to re-inspection in order to compare the results of different field inspections. 21 cores were taken out of the tie girders with different locations and were re-inspected metallurgically in the ATS lab using sectioning and destructive testing. The lab inspection, which included thorough investigation of 21 cores and investigation of flaws, is described in section 3.2.

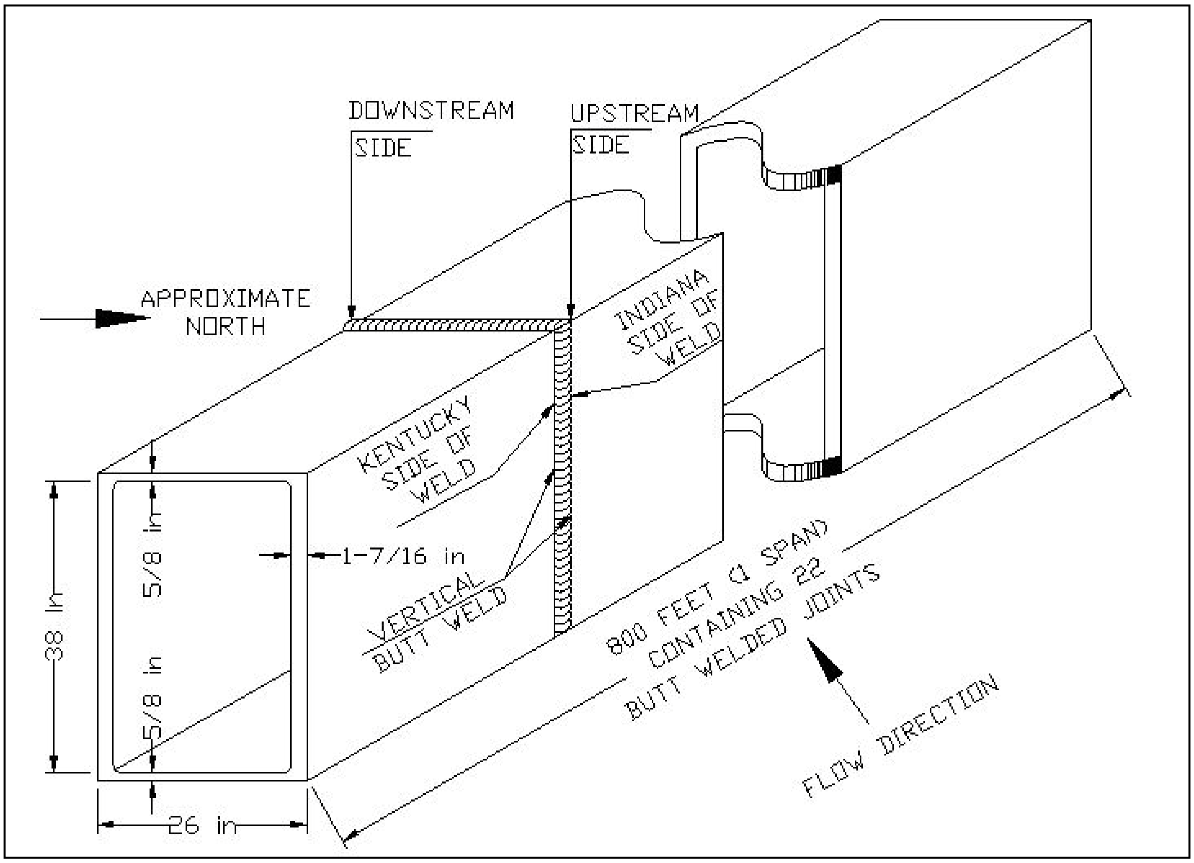


Figure 3-1. Illustration of a butt welded joint on a tie girder box

Table 3-1. SMB completed field work summary table as of October 2nd, 2011.

Field Work Description	Total Butts	Remaining Butts	Percentage
Paint Removed vertical butts =	352	0	100%
Paint Removed horizontal butts =	211	141	60%
UT/MT Tested vertical butts =	347	5	99%
UT/MT Tested horizontal butts =	63	289	18%
RT Tested vertical butts =	264	88	75%
RT Tested horizontal butts =	0	352	0%
X-ray Tested vertical butts =	107	245	30%
X-ray Tested horizontal butts =	0	352	0%
RT/X-ray Tested vertical butts =	371	-19	100%
RT/X-ray Tested horizontal butts =	0	352	0%

3.2 Laboratory Analysis of Cores

For comparison purposes, 21 cores inspected by both lab and field inspectors were considered. Throughout this data analysis, it was assumed that the lab results are actual (true) results. Core analysis was completed by ATS, a material testing company located in Louisville, Kentucky. The objective of ATS investigations on 21 cores was to report on the causes and characteristics of the flaws embedded in the core samples (*52*). The following procedures were conducted on each core:

- Visual inspection and optical microscopic examination
- Chemical analysis
- Scanning electron microscopic (SEM) examination
- Microanalysis
- Metallurgy and hardness
- Laboratory UT, MT and RT analyses

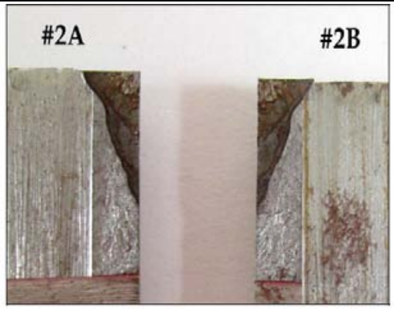
Purdue University provided the ATS lab with three cores which had been removed from the tie girders before closure of the bridge (*52*). The remaining 18 cores were removed after the bridge closure. The lab report described indications embedded in the cores which may have been detected by MT, UT, and/or RT. A thorough RT inspection was conducted on the cores in the lab. According to ATS, 12 of 21 cores contained major crack-like planar indications. Table 3-2 describes the geometry and locations of 21 core samples. Butt welds connecting web plates of different thicknesses are listed in Table 3-2 for each core. The abbreviations used for locations of the cores are defined in Appendix-B. The approximate distances of the cores from top of the web plate are also included in the table except cores #2 and #3 due to lack of information about the locations of these cores. According to Table 3-2, core diameters ranged from 0.7 in to 3.72 in. Most of the cores were removed around the shelf plate locations because the shelf plate regions contained more flaws than any other regions on the butt welded web plates. The thicknesses of the welds in each core are also listed in the table. Typical photographs of each core are shown in Table 3-3.

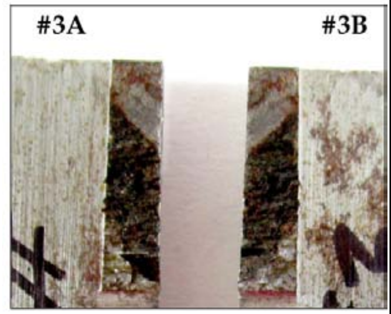
Table 3-2. Description and measurements of 21 Cores.

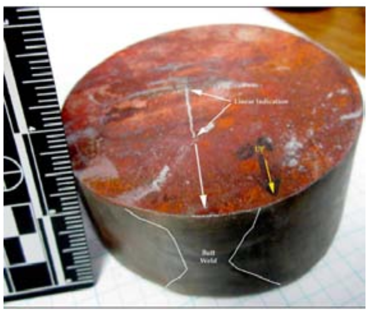
Core No.	Core Location Along the Tie Girder	Core Diameter (in)	Transition Plate Thickness (in)		Weld Thickness (in)	Core Distance from Top Flange App. (in)
			Thick Web	Thin Web		
1	US, S-1, T17, DV, KY	3.70	1.81	1.44	1.52	22
2	Unknown Location	0.70	-	-	1.62	-
3	Unknown Location	0.70	-	-	1.50	-
4	US, S-1, T3, DV, KY	3.70	1.82	1.41	1.47	26
5*	DS, S-2, T9, UV, KY*	2.62	1.75	1.39	1.53	4
6	DS, S-2, T14, DV, KY	2.62	1.74	1.46	1.77	21
7	US, S-1, T8, UV, IN	3.72	1.95	1.45	1.55	26
8	DS, S-1, T5, UV, IN	2.62	1.82	1.66	1.80	26
9	US, S-1, T21, DV, KY	2.62	1.67	1.36	1.39	26
10	DS, S-2, T19, UV, IN	3.72	1.78	1.44	1.52	27
11	US, S-1, T1, DV, KY	2.62	1.45	1.26	1.33	27
12	US, S-1, T12, UV, KY	1.68	1.62	1.22	1.49	27
13	DS, S-2, T9, UV, IN	2.62	1.47	1.38	1.33	27
14	US, S-1, T13, DV, IN	2.75	1.52	1.39	1.41	27
15	US, S-2, T8, DV, IN	2.17	1.83	1.45	1.60	15
16	US, S-1, T11, UV, IN	2.16	1.73	1.44	1.67	3
17	DS, S-2, T3, DV, KY	2.16	1.71	1.45	1.53	18
18	US, S-1, T9, DV, IN	2.17	1.72	1.45	1.60	12
19	DS, S-1, T20, UV, IN	2.16	1.56	1.46	1.69	27
20	DS, S-2, T4, DV, KY	2.16	1.87	1.46	1.70	7
21	US, S-2, T9, DV, KY	1.59	1.78	1.52	1.55	5

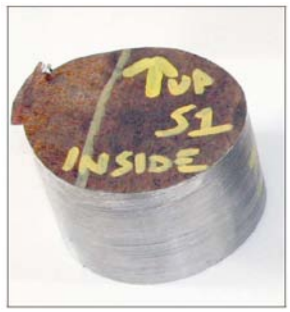
(*) This core was located on upstream vertical plate (UV) on Kentucky side as shown in here, but UT reported the indications of this core on downstream vertical plate (DV) in all final reports. This error was found and corrected during this research and personal contact with the Fish & Associates, Inc.

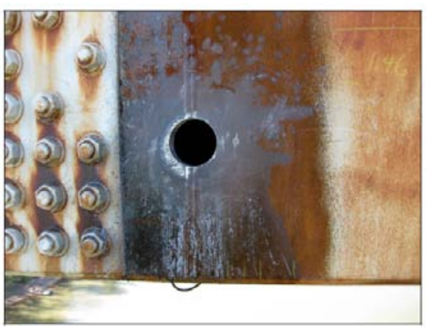
Table 3-3. Pictures of 21 cores organized in rows left to right based on core number.

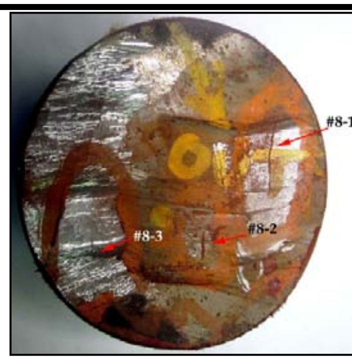


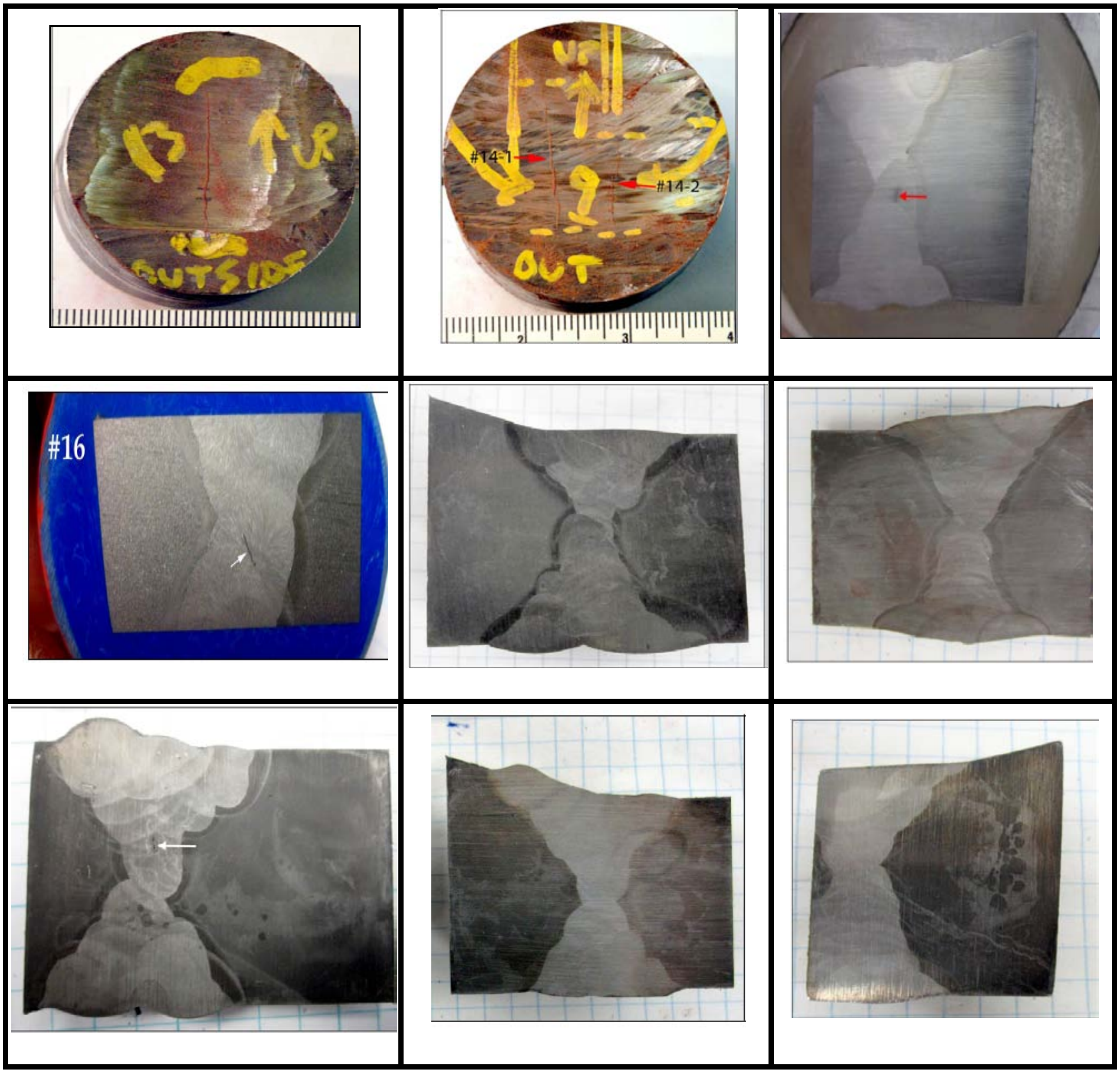








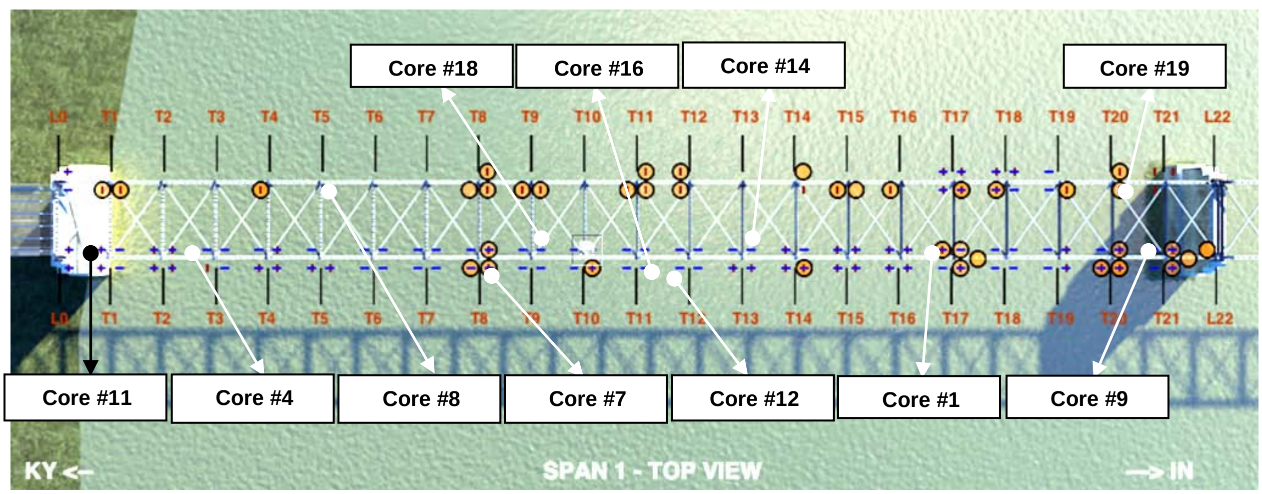




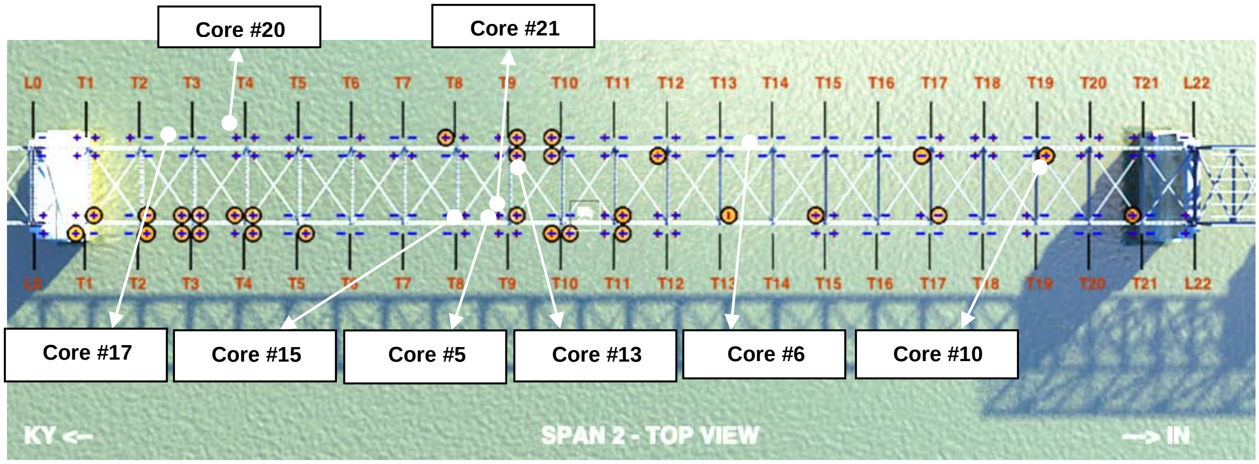
Core photographs were provided by Michael Baker Jr. Inc. at the time of core removal in the field; however, some of these pictures are from the ATS lab taken after grinding, macro-etch, and/or micro-etch. The locations of these cores on the tie girders of the bridge are illustrated on a photo of the bridge spans, taken from the top, as shown in the next section.

3.3 Identifying Core Locations on the Bridge by FIM

A Forensic Information Model (FIM) was created by Thornton Tomasetti from field inspection reports, including the previous inspection periods, to visualize the locations of the indications in butt welds along the tie girders of the bridge (*17*). Therefore, the locations of 21 cores were identified on FIM in Figure 3-2. This identification of core locations on the top view of the bridge spans also simplifies the understanding of location nomenclature and abbreviations used in Table 3-2. According to Davey, the purpose of producing an FIM was to identify any locations on which inspection had not been conducted. In addition, FIM was used to assure any possible trends at certain butt welds that had been identified as having many indications in previous inspection periods.



(a)



(b)

Figure 3-2. Spans 1 and 2 field inspection results by Thornton Tomasetti

One of the purposes of the FIM was to deliver an updated online inspection report to the client. The field inspection reports were attached to an Excel database following the inspection. The worksheets were linked to a website to facilitate the reporting process. The following two links were generated from the last update made in online database in 2011. From these links, final field reports for all 352 butt weld locations along the bridge can be accessed:

http://www.kdelta.com/Span2/index.html#top

http://www.kdelta.com/Span1/index.html#top

4 RESULTS AND DATA ANALYSIS

For comparison purposes, two techniques were considered in detail (UT and RT) because capabilities of these two techniques are very close to each other and the preference of one over another is arguable. Therefore, technical gaps, advantages, and disadvantages of both UT and RT were thoroughly analyzed, identified, and compared through this research. MT inspection results were also considered for surface breaking flaws in 21 cores.

All MT, RT, and UT results from field and lab inspections were gathered in two main summary tables. Timelines of field inspections, dates of the 21 cores taken out of the tie girders, and the accept/reject indications of each core were presented in Table 4-1. Defect length, height, and quantity are listed for each core in Table 4-2. Table 4-2 also shows an approximate overlap of flaw lengths between lab and field. To determine an approximate overlap between indications of the lab and field, core pictures, core locations, field reports, and lab reports were considered.

Table 4-1 summarizes the results of the laboratory study. Two cores (#2 and #3) did not have known locations or field inspection data. Healthy cores (without cracks) were reported for five out of 21 cores, showed in the Table 4-2. Surface-breaking flaws, or planar indications which initiated from the surface of tie girder web plates were found in nine cores out of 21 cores. Of these nine cores, only Core #1 was identified with a flaw initiated from the interior surface of the web plate. The remaining 8 cores had flaws initiated from the exterior surface of the web plate. Subsurface flaws were found in 5 cores out of 21 cores (Figure 4-1). Among these cores, Core #5 had one major subsurface hydrogen-induced flaw (at/after fabrication time). The other 4 cores had minor volumetric flaws such as slag and porosity.

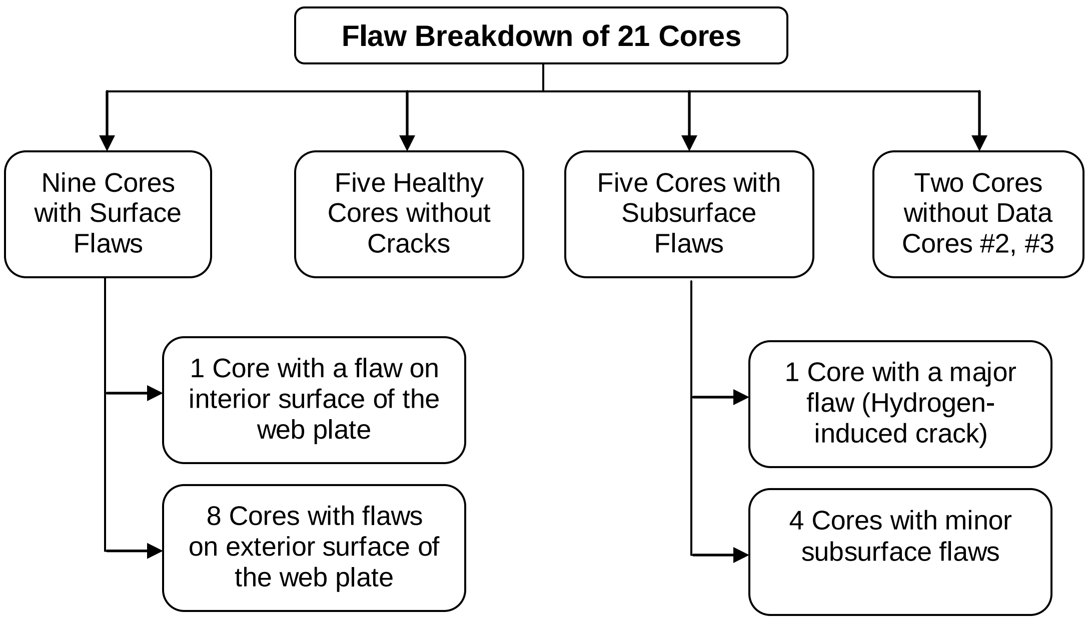


Figure 4-1. Summary of laboratory results for the 21 core samples

4.1 MT Detectability of Surface Flaws

Magnetic particle testing technique is widely used to detect surface-breaking flaws in the welded components, discussed in detail in section 2.4.3. Analysis of MT field inspections showed that out of 9 cores containing surface flaws only 3 cores were identified as having surface flaws by MT (Table 4-1). The remaining 6 cores were accepted by MT; however, these 6 cores were located either close to or behind the shelf plates (Appendix-F for core photographs). Therefore, it is possible that MT may not have had access to detect surface-breaking flaws at these core locations. MT and UT were conducted by the same inspector and within the same timeframe, and some of the shelf plates were attached to the girder at the time of inspection. In spite of the shelf plates being located close to or at the Cores #1, #8, and #11 locations, MT detected the surface flaws of these cores. As it can be observed in Table 4-1, MT could not detect subsurface flaws, so all cores with such flaws were reported as accepted by MT.

Table 4-1. Field inspections timeline, coring dates & accept/reject indications of 21 cores.

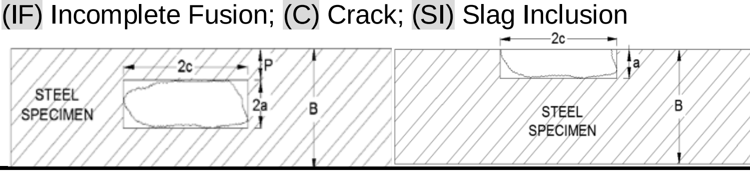
Core No.	Flaw Disposition	Magnetic Particle				Ultrasonic				Radiography				Core Removal			
		May	Jun.	Jul.	Sep.	May	Jun.	Jul.	Sep.	May	Jun.	Jul.	Sep.	May	Jun.	Sep.	Oct.
1	Int. Surface	***23***				***23***							***29***			***B29th***	
2	Unknown															***B9th***	
3	Unknown															***B9th***	
4	Ext. Surface		16				***17***						***15***			***20***	
5	Subsurface				15				***15***				***20***			***A9th***	
6	NIF		28				28						17			***A9th***	
7	NIF		14				***14***						16			***A9th***	
8	Ext. Surface				***28***				27				26				***5***
9	Ext. Surface				22				22				***27***				***3***
10	Ext. Surface				17				17				***19***				***1***
11	Ext. Surface				***13***				***13***				24				***5***
12	Ext. Surface		12				13						30				***7***
13	Ext. Surface			7				7					20				***7***
14	Ext. Surface		12				***12***						***27&30***				***7***
15	Subsurface				27				***27***				22			***A9th***	
16	Subsurface				29				***29***				***30***			***A9th***	
17	NIF		8				***8***						***24***			***A9th***	
18	NIF		14				14						17			***A9th***	
19	Subsurface		10			***21***										***A9th***	
20	NIF				15				***15***				***23***			***A9th***	
21	Subsurface				28				***28***				22			***A9th***	

Note: Shaded cells with **Bold** and *Italic* format indicate that the core was rejected. Regular cells indicate that the core was accepted by the related technique. The number inside each cell shows the exact date of inspection. ***A9th***, ***B29th*** and ***B9th***, respectively, mean after 9th September, before 29th September, and before 9th of September, 2011 which was the bridge closure date. NIF (No Indication Found. Int. (Interior). Ext. (Exterior).

Table 4-2. Summary of both field (UT & RT) and lab inspections for 21 cores.

Flaw Indications (ATS Lab)				UT Indications at Core Locations (in)			RT Indications at Core Locations (in)			Method Indicated Correctly
Core No.	Depth a/2a[1] (in)	Length 2c[2] (in)	From Surface P[3] (in)	Depth	Length	Overlap	Length	Overlap	Type	
1	0.62	1.61	NA	1.49	11.2	1.61	1.2	0	P, IF	UT
2	0.62	0.19	NA	No Data			No Data			NA
3	0.47	0.25	NA	No Data			No Data			NA
4	0.31	1.125	NA	0.82	2.5	0	0.5	0.5	IF	RT
5	0.97	1.2	0.23 -I 0.36 -E	0.90	2.5	1.2	1	1	C	UT & RT
6	NIF	NIF	NA	NIF			1.4	0	IF	UT
7	NIF	NIF	NA	0.8	1.625	0	NIF			RT
8	0.11	0.68	NA	Missed by UT (At Shelf Plate Location)			Missed by RT			NONE
	0.1	0.26	NA							
	0.14	0.49	NA							
9	0.16	0.63	NA	Missed by UT (At Shelf Plate Location)			1	0.63	C	RT
10	0.26	0.94	NA	0.61	1	0	Accepted Cracks b/w holes			RT
11	0.38	1.44	NA	0.75	3.62	1.44	0.6	0	SI	UT
12	0.22	1.44	NA	Missed by UT (At Shelf Plate Location)			Missed by RT			NONE
13	0.35	1.5	NA	Missed by UT (At Shelf Plate Location)			Missed by RT			NONE
14	0.27	1.5	NA	0.65	8.5	0.8	1.17	1.17	C	UT and RT
	0.24	1					4 cracks(1.17, 0.22, 0.23, 0.3)			
15	0.008	0.086	0.78-I 0.78-E	0.71	1.1	0.086	0.35	0.086	IF	UT
16	0.007	0.1	0.90 -I 0.68-E	Missed by UT			0.2	0.1	IF	RT
17	NIF	NIF	NA	NIF			0.2	0	P	UT
18	NIF	NIF	NA	NIF			0.8	0	SI	UT
19	0.011	0.08	0.89 -I 0.71-E	0.6	1.25	0.08	Missed by RT			UT
20	NIF	NIF	NA	NIF			1.1	0	P, IF	UT
21	0.002	0.01	0.28-I 1.28-E	1.34	1	0.01	Missed by RT			UT

([1]) “a” Depth through the thickness direction (from the surface), “2a” maximum subsurface depth; ([2]) “2c” Length vertically (parallel to weld); ([3]) P is the flaw depth below the surface (I - from interior & E - exterior surfaces of the web plate); (NA) Not applicable only for surface flaws; (NIF) No indications found; (P) Porosity; (IF) Incomplete Fusion; (C) Crack; (SI) Slag Inclusion



4.2 Table 4-2 Observations and Discussions

Core #1 contained a 1.61 in crack as determined by the ATS lab analysis. The UT report showed an 11.2 in indication across a length that included the location of the core. As such, the overlap was determined to be the length of the crack, 1.61 in. Figure 4-2 shows the location of this core near to the shelf plate. RT inspected this core location after its removal (Table 4-1). For RT, an indication measuring 1.2 inches was located nearby the core, but not within the core because the core was removed. Consequently, an overlap of 0 was determined. Small diameter holes inside the Core #1 indicate previous core removals.

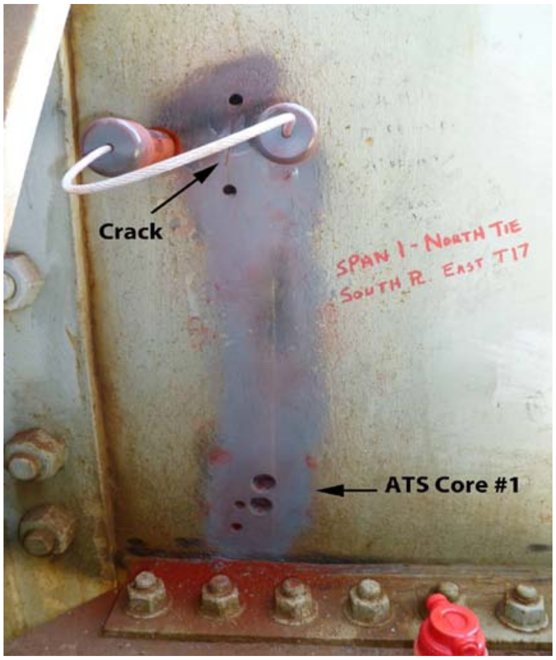


Figure 4-2. Location of Core #1 on the exterior face of the web (Supplied by Baker Inc.)

Cores #2 and #3 had 0.19 in and 0.25 in cracks, respectively. The locations of these cores were unknown.

According to lab analysis, core #4 had a 1.125 in long planar indication. The UT report showed a 2.5 in long indication near the location of the core, but not within the core. Since this core was also located near the shelf plate, it is possible that UT may not have had access to detect this indication (Figure 4-3). The RT report showed a 0.5 in long incomplete fusion at the core location (26 in from top of the web plate). Figure 4-3 shows a surface longitudinal crack at the center of the core along the weld. Based on the core picture, approximately half of the crack was above the origin and half was below the origin (origin at 26 in from top). RT reported a 0.5 in incomplete fusion from 26 in to 26.5 in measured from top of the web. Therefore, it was assumed that RT had an overlap of 0.5 in with the half of the crack located below the origin.

Figure 4-3. Left: Core #4 location. Right: Core #4 after removal (Supplied by Baker Inc.)

Core #5 contained a 1.2 in long subsurface crack. The UT report was mislabeled at this location; this error was determined through review of the field test results (*11*) and has been corrected to provide the results shown here. UT reported an indication 2.5 in long within the area of the core, resulting in an overlap of the length of the crack

(1.2 in). RT reported a crack indication 1.0 in long within the area of the core, resulting in an overlap of 1.0 in (Appendix-F).

Core #6 did not contain any indications, based on ATS lab report. The UT report was consistent with the lab report, but RT reported a 1.4 in incomplete fusion at this core location. The indication by RT was considered as a false call. Consequently, UT was determined as the correct method inspecting this core location.

Core #7 was also one of the healthy cores because it did not have any indications. For this core, the RT report was consistent with the lab and RT accepted this location. However, UT had a rejectable false indication at this core location. Therefore, RT was determined as the correct inspection method.

Cores #8, #9, #12, and #13 were located behind the shelf plates. It was assumed that UT did not have access to inspect these locations; therefore, in this research, UT was not assessed for missed indications at these core locations. RT also missed defects at these locations, with the exception of core #9 with RT reporting a 1 in crack. Lab results showed a 0.63 in long brittle cleavage crack at this core location. Therefore, RT indication had 0.63 in overlap with the lab report at core #9 location.

Core #10 contained a 0.94 in long surface-breaking inter-granular crack. UT report showed a 1 in long class-D indication, resulting in an overlap of the length of the crack (0.94 in). RT showed acceptable cracks between holes that were previously drilled and were included in the core #10. UT missed the flaw of this core location. Since RT indicated the cracks which were overlapped with the core location, RT was determined as the correct inspection method

Core #11 contained a 1.44 in long indication. Lab results characterized this indication as a crack. UT reported a 3.62 in long class-D indication at this core location, resulting in a 1.44 in overlap with the crack. RT reported a 0.6 in long slag inclusion near this location (30 in to 30.6 in from top), but not within the core location. Therefore, UT was determined as the correct inspection method

Core #14 contained two indications (1.5 in and 1 in long). Lab reported these indications as brittle fractures. UT reported an 8.5 in long indication from 19 in to 27.5 in from top of the web plate. The core origin/center was located approximately 27 in from top. Therefore, an approximate 0.8 in overlap of UT indication with 1.5 in actual lab measurement was noted (Figure 4-4). RT reported four cracks (1.17 in, 0.22 in, 0.23 in, and 0.30 in) at 28 in distance from top of the web. An approximate overlap of 1.17 in was considered between RT and lab measurements.

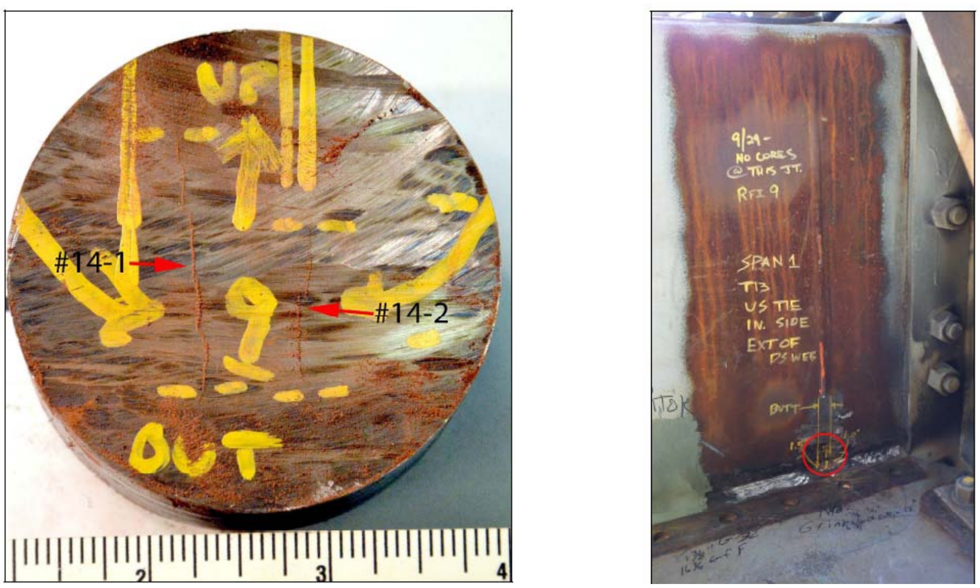


Figure 4-4. Left: Core #14 at the lab. Right: Core #14 location (Supplied by Baker Inc.)

Core #15 contained a 0.086 in long subsurface defect. The lab characterized this defect as a crack/slag inclusion. UT reported a 1.1 in long class-A indication at this location, resulting with a 0.086 in overlap with the lab measurement. RT reported a 0.35 in long incomplete fusion. Consequently, due to a high severity indication of UT (class-A) and incorrect flaw characterization of RT, UT was determined as the correct inspection method.

Core #16 contained a 0.1 in long subsurface defect. This defect was also characterized as a crack/slag inclusion. UT missed this crack. RT reported a 0.2 in long incomplete fusion at this core location, resulting in 0.1 in overlap with the actual crack length. Therefore, RT was determined as the correct inspection method.

Cores #17, #18, and #20 were healthy because they did not contain any flaws, based on the ATS lab final report. UT results were consistent with the actual/lab results, but RT had false alarms at these core locations. RT reported a 0.2 in long porosity for core #17, a 0.8 in long slag inclusion for core #18, and a 1.1 in long porosity/incomplete fusion for core #20. Therefore, UT was determined as the correct inspection method.

Core #19 contained a 0.08 in long subsurface crack. UT reported a 1.25 in long class-A indication at this region, resulting in an overlap of 0.08 in with the actual crack length. RT missed this crack and it was assumed that this false negative result of RT was due to small size of the crack. Therefore, UT was determined as the correct inspection method.

Core #21 had the smallest subsurface crack of 0.01 inch in length. Although the crack was very small in size, UT detected and reported a 1.0 in indication at the region. RT missed this crack due to its small size. The detection of this crack by RT in the lab was also difficult. ATS lab used multi-directional radiography for this particular core to detect this tiny crack.

According to the data in Table 4-2, UT was more successful than RT. UT had 11 correct inspection results among 15 cores (4 cores behind shelf plates and 2 cores without data are excluded), while RT had 7 correct results among 16 cores (Figure 4-5).

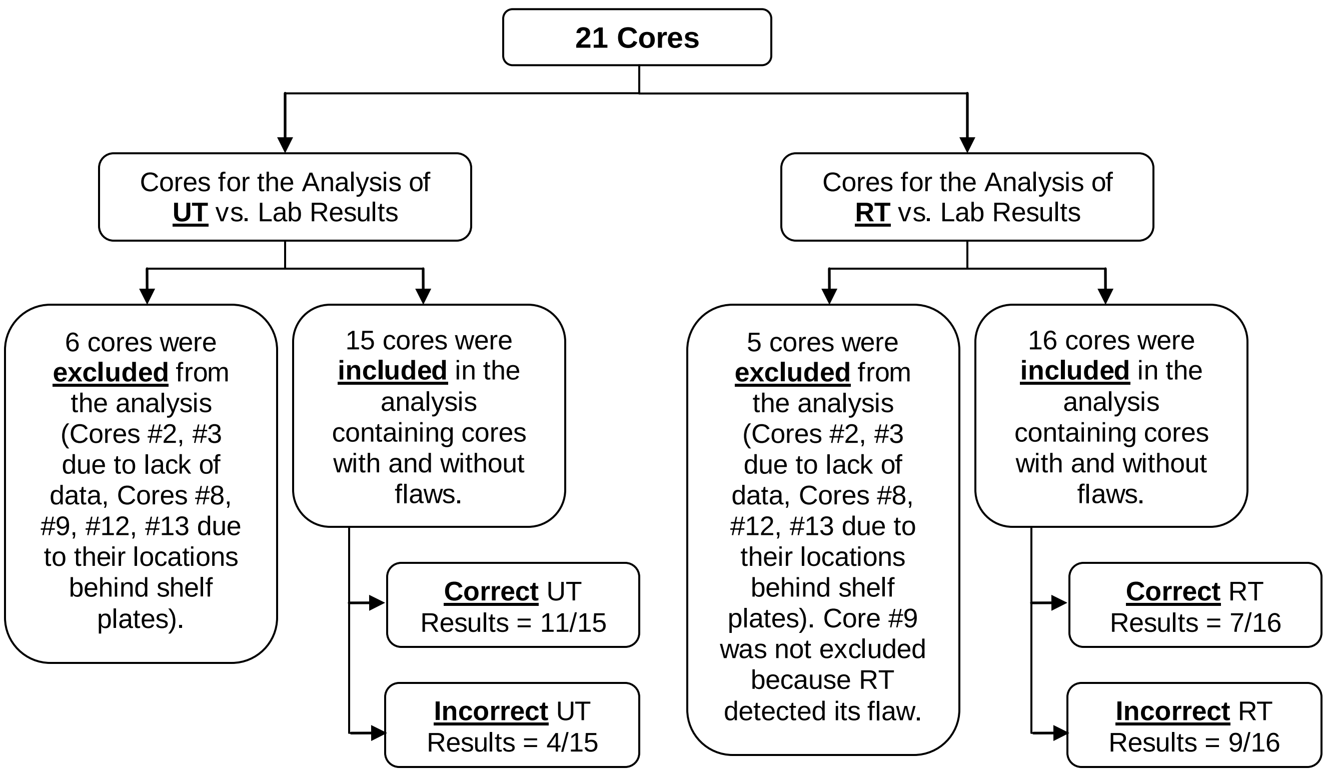


Figure 4-5. Summary of the comparative analysis of UT and RT vs. lab results based on Table 4-2

4.3 Flaw Characterization of UT and RT vs. Lab Sectioning

Crack or planar flaw detectability of RT was proven less effective than the UT based on the results and comparisons of Table 4-3. 14 cores had flaws (cores #2 and #3 were not included). Out of 14 cores, 10 cores were considered for UT - cores #8, #9, #12, and #13 were excluded due to their locations behind shelf plates. Out of 14 cores, 11 cores were considered for RT - excluded cores were the same as shown for UT except core #9 because RT detected the flaw of this core location.

Based on Table 4-3, RT missed cracks of 6/11 cores (cores #1, #11, #15, #16, #19, and #21). However, UT missed cracks of 3/10 cores (cores #4, #10, and #16).

According to Table 4-3 and Figure 4-1, five cores were reported healthy after sectioning (i.e. Cores #6, #7, #17, #18, and #20). The lab reports for these five cores showed NIF (no indication found), but field RT reports indicated some volumetric discontinuities in these cores. For instance, field RT inspection for Core #6 indicated a 1.4" long incomplete fusion (IF), but after sectioning, it was assumed that this indication on RT image was probably due to the surface profile produced between two weld passes. To prove this assumption, the lab conducted an RT inspection with multiple orientations for these cores. Similarly, the crack in Core #21, missed by RT, was small (0.01" long as in Table 4-2) and oriented parallel with the X-Ray beam, which was very difficult for RT to characterize.

Table 4-3. Flaw characterization of UT and RT vs. sectioning.

Core No.	ATS Lab Flaw Characterization	UT Flaw Characterization	RT Flaw Characterization
1	C	Class A	P, IF
2	IC, HI	No Data	No Data
3	IC, DDR	No Data	No Data
4	PI, CO	Missed	IF
5	C	Class A	C
6	NIF	NIF	IF
7	NIF	Class A	NIF
8	IC	Missed	Missed
9	BCC	Missed	C
10	IC, QC	Missed	Accepted C
11	C, SI	Class B	SI
12	CO, DF	Missed	Missed
13	CO, IC	Missed	Missed
14	CO, BF	Class C	4 C
15	C, SI	Class A	IF
16	C, SI	Missed	IF
17	NIF	NIF	P
18	NIF	NIF	SI
19	C	Class A	Missed
20	NIF	NIF	P, IF
21	C	Class A	Missed

(IC) Inter-Granular Crack	(NIF) No Indication Found
(HI) Hydrogen-Induced Damage	(PI) Planar Indication
(DDR) Ductile Dimple Rupture	(CO) Corrosion
(C) Crack	(BCC) Brittle Cleavage Crack
(P) Porosity	(QC) Quasi-Cleavage
(IF) Incomplete Fusion	(DF) Ductile Fracture
(SI) Slag Inclusion	(BF) Brittle Fracture

4.4 Flaw Detectability of UT and RT vs. Lab Sectioning

For this section, the same assumptions described in section 4.3 were considered. Based on Table 4-3, it was determined that RT missed 2/11 flaws (from cores #19 and #21) while UT missed 3/10 flaws (from cores #4, #10, and #16). Although the quantity of missed flaws by RT is less than the UT, RT detected some minor volumetric flaws in lieu of planar flaws, which can be considered as missed flaws. Therefore, according to the data, it can be concluded that the flaw detectability of UT is also better than the RT method.

Based on the results presented in the final field inspection report, it appeared that UT had missed a major crack in Core #5. However, through this research it was found that UT did detect this flaw, but there was a problem with the labeling of the UT inspector firm, as indicated in Table 3-2.

Figure 4-6 compares UT, RT, and lab by illustrating missed flaws, detected flaws, false calls, over-measured flaws, and under-measured flaws. ATS lab results were considered as the reference data compared with UT and RT.

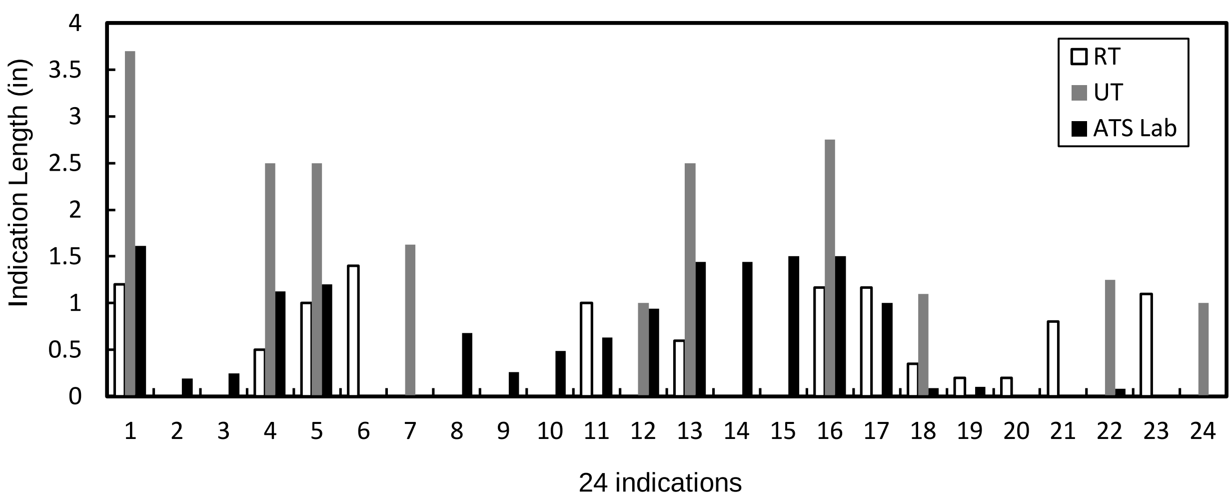


Figure 4-6. Comparison of RT, UT, and lab for 24 indications in 21 cores

4.5 Flaw Length Measurement of UT and RT vs. Lab Sectioning

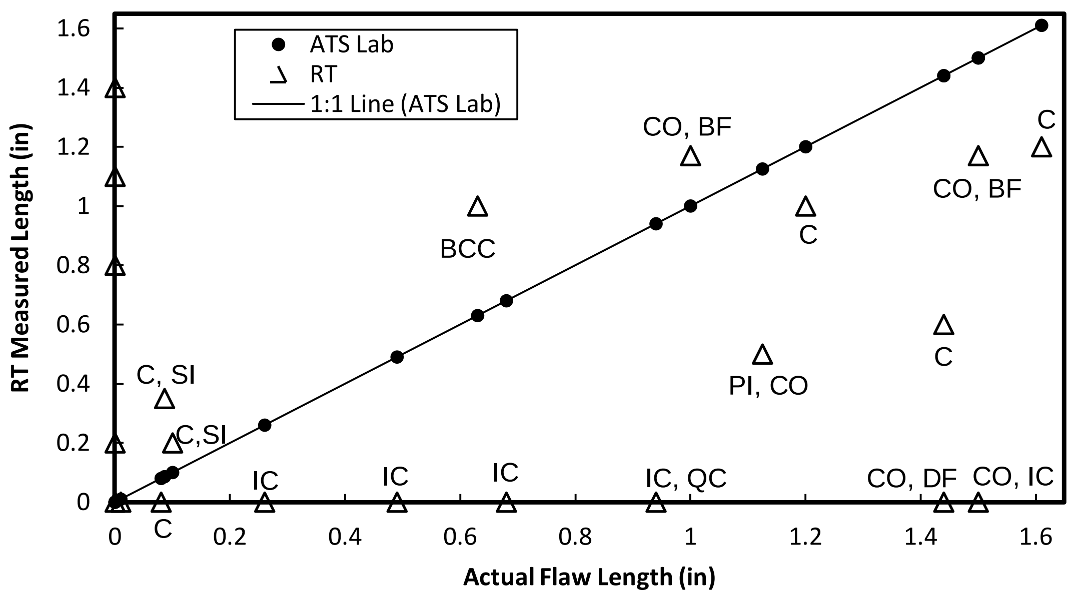
As discussed in section 2.5.3, Babcock presented an experiment comparing UT and RT to consider the flaw length measurement characteristic. Similarly, according to the results from 21 SMB cores, 22 flaws were detected by sectioning (excluding cores

#2 and #3). The following Table 4-4 indicates the mean flaw length, standard deviation, and number of flaws for RT, UT, and lab sectioning. UT results for Cores #14 and #1 indicated flaws with lengths of 8.5” and 11.2” respectively. These flaw lengths were greater than the core diameters (Table 3-2). Since these two flaw lengths had significant effect on the standard deviation and mean values, the maximum flaw lengths (i.e. core diameters) were considered for both of these cores.

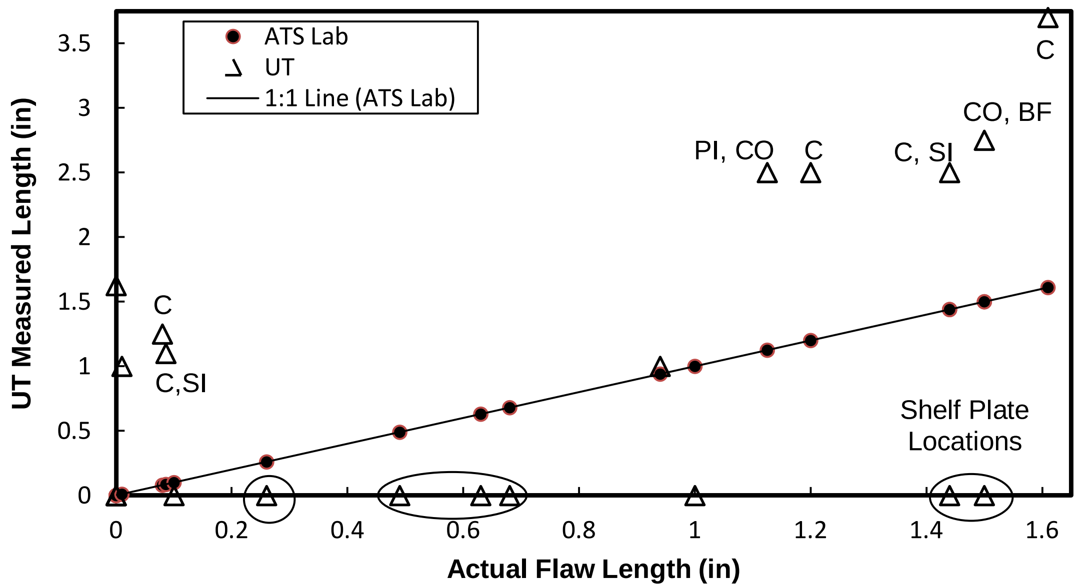
Table 4-4. RT and UT results vs. lab indications for 21 cores.

Comparison Parameters	RT and UT vs. Lab		
	RT	UT	Lab
Mean Flaw Length (in)	0.486	0.906	0.640
Standard Deviation	0.517	1.183	0.617
Number of Flaws	22	22	22

In Figure 4-7, only 22 data points (flaw quantity except cores #2, #3) were considered. Quantitative comparison of length measurements indicated that UT had slightly more scattered results than RT. Also, Table 4-4 shows UT having a greater standard deviation than the RT when compared to the lab results; this means wider range of normal distribution curve. These results are reasonable because length measurement of UT is different from RT. Using RT technique, the length of a flaw is directly measured from an RT image. However, in UT method, the edges of an indication are identified where the measured amplitude changes -6 dB or drops 50% below the appropriate amplitude level for the given indication class (*34*; *48*). In addition to the greater standard deviation of UT, data points on the horizontal axis in Figure 4-6b show missed flaws by UT. However, as circled on the figure, these missed flaws were included in the cores behind the shelf plates and UT did not have access to detect in the field. On the other hand, RT had many false calls in addition to missed flaws. All data points located on the vertical axis of Figure 4-7a suggest that RT had false calls; this supports the data presented in Table 4-3 and the discussion in section 4.2. Comparison of RT and lab sectioning showed that RT missed a 0.01” long crack related to core #21. This particular crack, hard to see in Figure 4-7a, was both very small and parallel to the radiation beam path and it was difficult for RT to detect. Based on Figure 4-7a, RT missed many planar flaws such as inter-granular cracks. RT also missed a ductile fracture, a quasi-cleavage, and some corrosion indications. The nomenclature and abbreviations indicated on Figure 4-7 was defined in Table 4-3.



(a)



(b)

Figure 4-7. RT & UT length measurements vs. actual flaw length

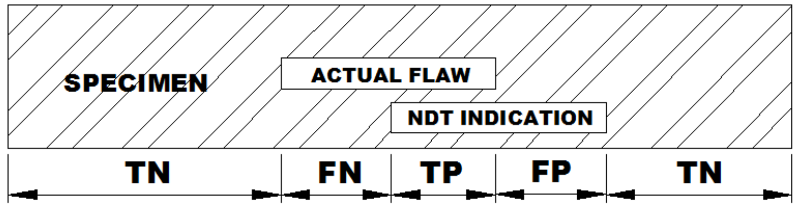
5 ROC ANALYSIS FOR 21 CORES

Receiver operating characteristics (ROC) analysis can be used to assess the reliability of NDT systems. An ROC curve can be used to evaluate the reliability of an inspection technique by assessment of true positive versus false positive detection rates (*53*). In ROC analysis, the NDT method classification of each indication is compared to its true classification based on an appropriate threshold. Sensitivity and specificity are two important parameters for ROC analysis. Sensitivity is the proportion of correctly classified indications among all those that are truly positive; specificity is the proportion of correctly classified indications among all those that are truly negative (*54*).

5.1 Basic ROC Calculation Method

In 2005, Fücsök applied the ROC analysis on radiographic inspection techniques via multiple round robin tests. In order to determine the reliability of the radiographic testing and the human factors involved in RT, an international round robin test was conducted. Croatian, Hungarian, and Polish laboratories participated in this experiment and inspected 38 films, containing 206 defects of different types and sizes (*53*).

Based on Fücsök's calculations, POD, or probability of true positive indications (vertical axis of ROC) and probability of false positive indications (horizontal axis of ROC), were calculated for the data from 19 cores of SMB. The first step of this method was to produce Table 5-1. There are four possible situations in an NDT diagnosis; that is, true positive, true negative, false positive, and false negative (Figure 5-1).



Notes:

True Positive (TP): The flaw was detected where it was present.

True Negative (TN): The flaw was not detected where it was not present.

$$POD = P(TP) = TP / (TP+FN)$$

False Positive (FP): The flaw was detected where it was not present.

False Negative (FN): The flaw was not detected where it was present.

$$PFA = P(FP) = FP / (FP+TN)$$

Figure 5-1. 4 possible cases of an NDT result and probabilities of true positive and false positive

Based on Figure 5-1 and Tables 4-2 and 4-3, the four possible situations (TP, TN, FP, and FN) can be determined for both RT and UT.

Table 5-1. Four cases for field UT and RT of 19 SMB cores.

Four cases	Actual Results (ATS Lab)	Field NDT Results	
		RT	UT
TP	14	6	7
TN	5	1	4
FP	Not Applicable	4	1
FN	Not Applicable	8	7

Table 5-1 shows that 14 cores had flaws and 5 cores did not have flaws, based on the lab results. RT detected 6/14 cores with flaws (TP) and the remaining 8/14 were false negative indications as reported by RT. Also, RT reported 1/5 cores as healthy (TN) and the remaining 4/5 were reported as false positive indications by RT. UT detected 7/14 cores with flaws, and the remaining 7/14 cores were reported as false negatives by UT. Similarly, UT reported 4/5 cores as healthy and 1/5 was a false positive case for UT. Consequently, both FP and FN of UT were less than FP and FN of RT.

Probabilities of TP and FP indications were calculated for both UT and RT. As a result, two points were produced and plotted, Figure 5-2. The reliability increases by going to the upper left corner. The upper left corner in the Figure 5-2 indicates the lab results because the lab results were considered as the actual/perfect results. When comparing UT with RT, UT was more reliable than RT, based on the SMB core data.

<u>Ultrasonics ROC Point:</u>

POD = P(TP) = TP / (TP+FN) = 7 / (7+7) = 0.50

PFA = P(FP) = FP / (FP+TN) = 1 / (1+4) = 0.2

<u>Radiography ROC Point:</u>

POD = P(TP) = TP / (TP+FN) = 6 / (6+8) = 0.43

PFA = P(FP) = FP / (FP+TN) = 4 / (4+1) = 0.8

<u>ROC Plot for UT and RT:</u>

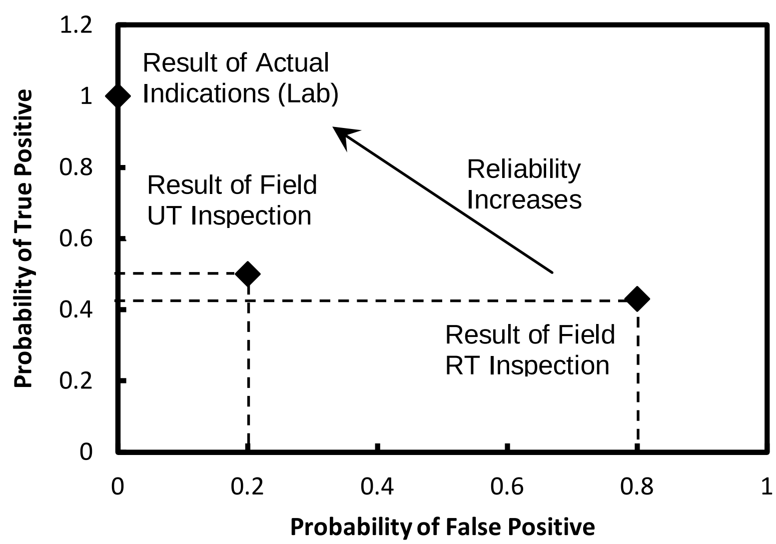


Figure 5-2. ROC points for UT and RT based on 19 cores data

5.2 Basic ROC Calculation (Excluding Cores Next to Shelf Plates)

5.2.1 Assumptions for Exclusion of Particular Cores

Overall, there were 9 cores located either very close to or right behind the shelf plate locations (pictures in Appendix-F). In the ROC calculation of section 5.1, all of these cores were included. Some of the flaws of these cores were missed by either UT or RT or both (Table 4-2). In this section, among these 9 cores, some of them were excluded from ROC analysis, based on the assumptions discussed in the following paragraphs. The summary is given in Table 5-2.

Core #1 was excluded from the ROC analysis of RT, but it was included for UT due to timeline of the inspections. According to Table 4-1, RT inspected the core #1 location after removal of the core; therefore, RT did not report the flaws at the core location. However, UT inspected the core location prior to removal of the core. According to Figure-F5-B, this core was located above the shelf plate, so UT had access to inspect this core. Therefore, it was included in the analysis for UT.

Core #4 was included in the ROC analysis for both RT and UT. According to Table 4-1, both RT and UT inspected the core location prior to removal of the core. Also, Figure-F11-B indicates that the core #4 was located above the shelf plate; therefore, it is possible that UT may not have had access to inspect this core location. Since the shelf plate was located under the core and it did not cross this core location, it was included in the ROC analysis.

Core #8 was excluded from the ROC analysis due to its location. Figure-F31-A shows that this core was located behind the shelf plate. The figure indicates the core location after removal of the core and shelf plate. In the figure, the ground area indicates the shelf plate location after its removal. According to Table 4-1, UT and RT were performed before core removal at this location on 27th and 26th September 2011, respectively. Also, the core was taken out of the base metal of the girder that did not include the vertical butt welded joint. Therefore, due to the location, the flaws at the core #8 were missed by both UT and RT.

Core #9 was considered for ROC analysis of RT, but not for UT, due to its location. RT showed a clear image of both the flaw and the shelf plate. RT indicated a 1.0 in long crack for core #9 which had 100% overlap with the lab results (illustrated in Figure 5-3). However, UT missed the flaw at this core location because the shelf plate crossed the core location and limited the access for UT inspection.

Core #10 was included in ROC analysis of RT, but not UT, due to its location. According to the inspection timeline (Table 4-1), RT and UT inspected this core location prior its removal on 19th and 17th September 2011, respectively. Figure-F41-A shows two holes, previously drilled, at the core #10 location. RT reported some accepted cracks between the two holes. However, UT reported a 1.0 in long indication underneath the core location, not at the core location. Therefore, it was assumed that UT may have encountered inaccessibility issue at the core location.

Core #11 was included in the ROC analysis for both RT and UT. UT reported an indication at the core location and commented that the reported indication could have been longer, but the gusset plate (shelf plate) limited the UT access at the core location. In other words, UT detected the flaw at the core. However, RT reported some indications around the core, but not at the core location.

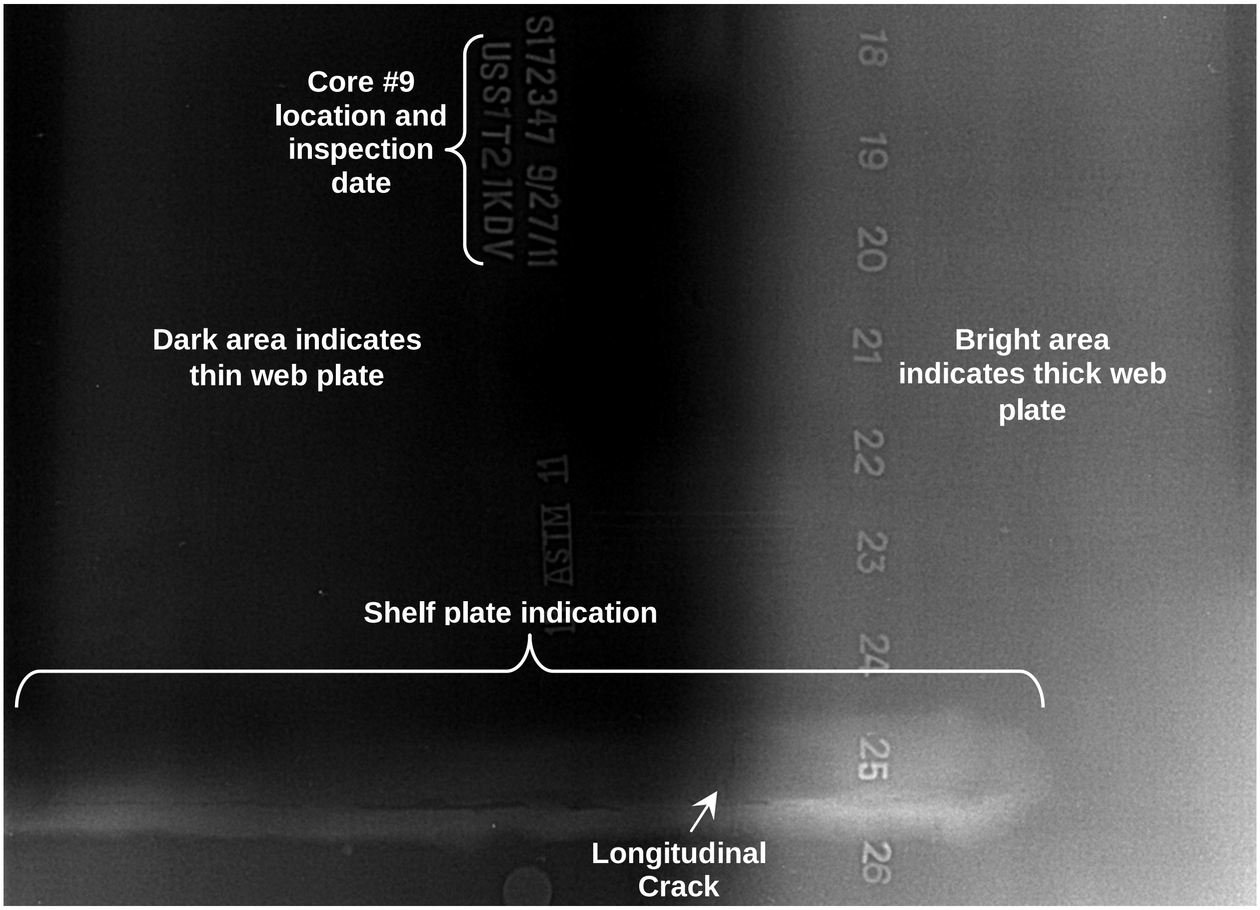


Figure 5-3. RT image for core #9 showing the shelf plate and a longitudinal crack along the weld from 25” to 26”

Cores #12 and #13 were excluded from ROC analysis because they were located behind the gusset plate; also, RT and UT could not detect the flaws of these core locations.

Core #14 was considered in the ROC analysis, although it was located at the shelf plate. RT and UT detected the flaw of this core location. RT was performed two times on this location; one was before core removal (Sep. 27th 2011) and another was after core removal (Sep. 30th 2011), according to Table 4-1.

Table 5-2. ROC Assumptions for the cores located nearby the shelf plates.

Core No.	Cores Located Nearby the Shelf Plates	For ROC (RT)		For ROC (UT)		Brief Reasons for Considering and Not Considering of the Cores in the ROC analysis
		Inc.	Exc.	Inc.	Exc.	
1	US, S-1, T17, DV, KY		✓	✓		Timeline of Inspection: RT inspected after removal.
4	US, S-1, T3, DV, KY	✓		✓		RT & UT inspected the core prior its removal. Core was located above the shelf plate.
8	DS, S-1, T5, UV, IN		✓		✓	It was located behind the shelf plate and removed from the base metal, not from the vertical butt weld.
9	US, S-1, T21, DV, KY	✓			✓	RT had a clear image of the shelf plate and flaw. Shelf plate existence limited the UT access.
10	DS, S-2, T19, UV, IN	✓			✓	RT inspected the core prior its removal and showed cracks. Shelf plate limited the UT access.
11	US, S-1, T1, DV, KY	✓		✓		UT and RT indicated flaws around the core. UT reported the presence of a possible flaw behind the shelf plate.
12	US, S-1, T12, UV, KY		✓		✓	RT and UT both missed the flaw. The core was located behind the shelf plate.
13	DS, S-2, T9, UV, IN		✓		✓	RT and UT both missed the flaw. The core was located behind the shelf plate.
14	US, S-1, T13, DV, IN	✓		✓		RT and UT detected the flaws of the core. RT was performed twice (before and after core removal).

5.2.2 Calculation of ROC Points for UT and RT

Based on Table 5-2, section 5.2.1, and lack of data for cores #2 and #3, 6 cores were excluded from the ROC analysis for RT and 7 cores were excluded from ROC analysis for UT. Consequently, Table 5-3 can be considered for the basic ROC calculations.

Table 5-3. Four cases for field UT and RT of SMB cores.

Four cases	Cores Considered for RT (Lab)	Field RT Results	Cores Considered for UT (Lab)	Field UT Results
TP	10	6	9	7
TN	5	1	5	4
FP	Not Applicable	4	Not Applicable	1
FN	Not Applicable	4	Not Applicable	2

Exclusion of some particular cores, located nearby the shelf plates, increased the probability of true positive (PTP) on the ROC plot. PTP for UT increased from 50% to 78% and PTP for RT increased from 43% to 60%.

Similar to previous calculations, ROC points were calculated. Since the false calls did not change, the horizontal axis of the ROC plot remained the same for both RT and UT. However, there was an increase in the true positive (TP) fraction or POD axis of the ROC plot for both RT and UT (Figure 5-4).

<u>Ultrasonics ROC Point:</u>

POD = P(TP) = TP / (TP+FN) = 7 / (7+2) = 0.78

PFA = P(FP) = FP / (FP+TN) = 1 / (1+4) = 0.2

<u>Radiography ROC Point:</u>

POD = P(TP) = TP / (TP+FN) = 6 / (6+4) = 0.6

PFA = P(FP) = FP / (FP+TN) = 4 / (4+1) = 0.8

<u>ROC Plot for UT and RT:</u>

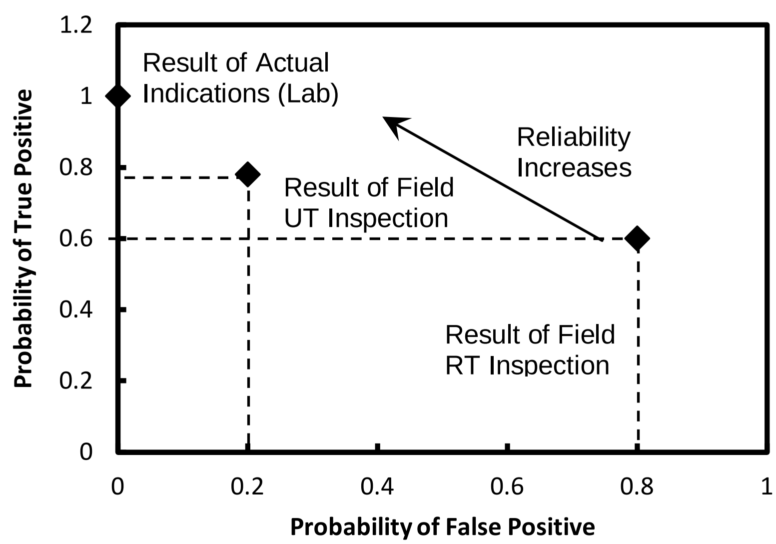


Figure 5-4. ROC points for UT and RT based on core data

5.3 Alternative Method for ROC Analysis

Eng recommended two formats for data to be organized for ROC analysis (54). These formats are based on the inspector's confidence rating. In the first format (Format-A), there is one of six possible ratings that can be applied to an indication. These ratings are defined from one to six as follows:

1 = Definitely Negative	4 = Possibly Positive
2 = Probably Negative	5 = Probably Positive
3 = Possibly Negative	6 = Definitely Positive

In the second format (Format-B), the dataset is divided into two parts (truly positive and truly negative observations). Then, the inspector rates each positive and negative indication on a confidence scale from 1 to 3 (i.e. low, moderate, and high). The latter format is most commonly used, and therefore was used for producing ROC curves from NDT data.

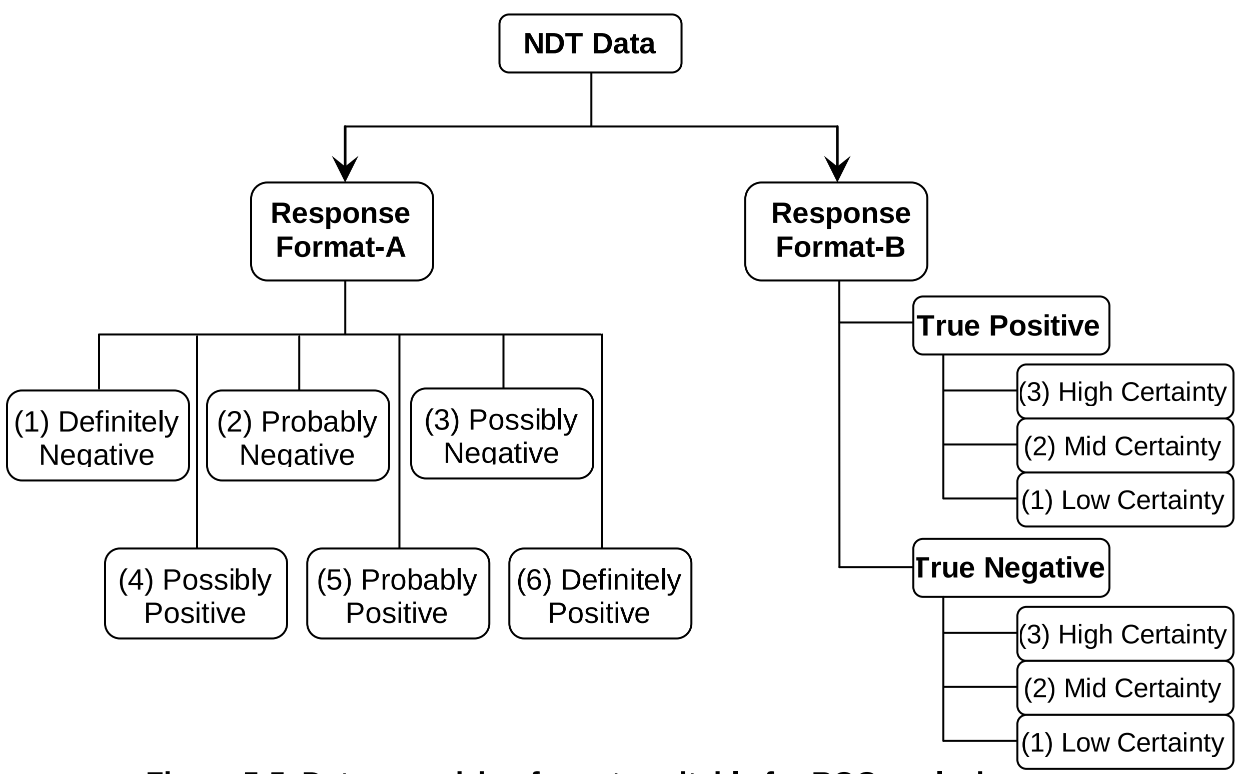


Figure 5-5. Data organizing formats suitable for ROC analysis

5.3.1 Assumptions for the Alternative ROC Method

For UT, class-A and class-B indications were considered in the highest confidence rating of 3. Class-C indications were considered in the moderate confidence rating of 2, and class-D indications in the lowest confidence rating of 1. Considering the field limitations during the UT inspection, missed indications by UT were considered in the lowest confidence rating of 1.

For the RT dataset, missed indications were categorized as the lowest confidence rating of 1, due to human factors and physics of the technique. In the same way, false alarms (i.e. false positives) were categorized in the moderate confidence rating of 2. These assumptions are reflected in Table 5-1, which contains data from the laboratory core report, the UT, and the RT methods. For each method, the digit 1 indicates an indication was detected, and the digit 0 indicates no indication was detected. Confidence levels for each core result are also shown. These data were used as input data for an ROC analysis software tool, as described below.

Table 5-4. Binary core data with confidence ratings for ROC.

Core ID Number	ATS Lab		Ultrasonics			Radiography		
	True +/- (1/0)	Location	UT +/- (1/0)	Location	Confidence Rating	RT +/- (1/0)	Location	Confidence Rating
1	1	core	1	core	3	1	core	3
4	1	core	0	none	1	1	core	3
5	1	core	1	core	3	1	core	3
6	0	none	0	none	3	1	core	2
7	0	none	1	core	3	0	none	3
8	1	core	0	none	1	0	none	1
9	1	core	0	none	1	1	core	3
10	1	core	1	core	1	1	core	2
11	1	core	1	core	3	1	core	3
12	1	core	0	none	1	0	none	1
13	1	core	0	none	1	0	none	1
14	1	core	1	core	2	1	core	3
15	1	core	1	core	3	1	core	2
16	1	core	0	none	1	1	core	2
17	0	none	0	none	3	1	core	2
18	0	none	0	none	3	1	core	2
19	1	core	1	core	3	0	none	1
20	0	none	0	none	3	1	core	2
21	1	core	1	core	3	0	none	1

5.3.2 Producing ROC Curves for RT and UT

A web-based ROC calculator was developed by Department of Radiology and Radiological Science of Johns Hopkins University, School of Medicine (55). This online calculator was originally designed for radiologists and medical doctors. In the present research, this Java application was used for NDT reliability purposes. After entering the data in the format presented in Table 5-1, the application calculated sensitivities and specificities to produce an empirical ROC curve. The area under curve (AUC) was also calculated.

To produce an ROC curve, the first step of the application was to recognize the number of true positive and true negative indications based on the lab results. For the cores, there were 14 true positive indications and 5 true negative indications. The second step was to distribute these true positive and negative indications into 6 categories, based on the confidence ratings listed in Table 5-1 for each NDT method. Number 6 represented the strongest evidence of defect presence. The following table was produced by the application for each NDT method.

Table 5-5. ROC curve output data points for UT and RT.

Response	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6
UT Response:						
Truly Negative Indications	4	0	0	0	0	1
Truly Positive Indications	0	0	6	1	1	6
UT Observed Operating Points:						
False Positive Fraction	0.00	0.20	0.20	0.20	0.20	1.00
True Positive Fraction	0.00	0.43	0.50	0.57	1.00	1.00
RT Response:						
Truly Negative Indications	1	0	0	0	4	0
Truly Positive Indications	0	2	3	0	3	6
RT Observed Operating Points:						
False Positive Fraction	0.00	0.00	0.80	0.80	0.80	1.00
True Positive Fraction	0.00	0.43	0.64	0.86	1.00	1.00

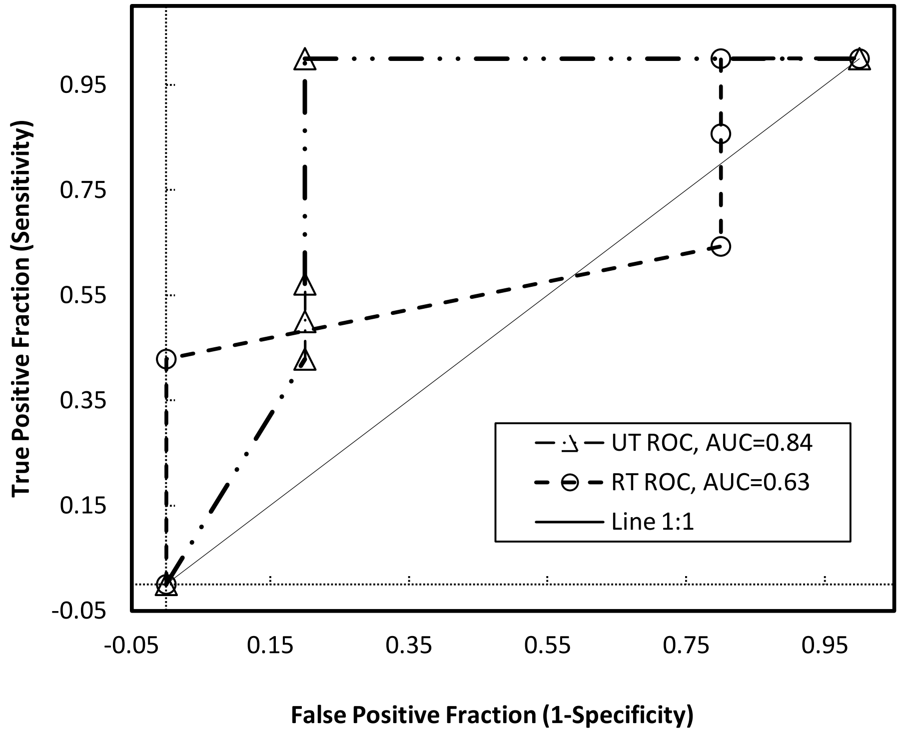


Figure 5-6. Empirical ROC curve for UT and RT based on 19 cores data

The following hand calculations are included to support a clear understanding of data points on the empiric ROC curves for UT and RT. The procedure in the hand calculation is similar to Eng's method. The points are not exactly in the order as they are in the output of the online application, but the resulting curves are the same.

UT Response		**1**		**2**		**3**		**4**		**5**		**6**	
Truly Positive		0		0		6		1		1		6	
Truly Negative	↑	4	↑	0	↑	0	↑	0	↑	0	↑	1	↑
Threshold Ratings b/w + & -	Below 1		Between 1 & 2		Between 2 & 3		Between 3 & 4		Between 4 & 5		Between 5 & 6		Over 6
TPF = TP/(TP+FN)	14/(14+0) = 1		14/(14+0) = 1		14/(14+0) = 1		8/(8+6) = 0.57		7/(7+7) = 0.5		6/(6+8) = 0.43		0/(0+14) = 0
FPF = FP/(FP+TN)	1-[0/(0+5)] = 1		1-[4/(4+1)] = 0.2		1-[4/(4+1)] = 0.2		1-[4/(4+1)] = 0.2		1-[4/(4+1)] = 0.2		1-[4/(4+1)] = 0.2		1-[0/(0+5)] = 1

RT Response	**1**	**2**	**3**	**4**	**5**	**6**
Truly Positive	0	2	3	0	3	6
Truly Negative	1	0	0	0	4	0

Threshold Ratings b/w + & -	Below 1	Between 1 & 2	Between 2 & 3	Between 3 & 4	Between 4 & 5	Between 5 & 6	Over 6
TPF = TP/(TP+FN)	14/(14+0) = 1	14/(14+0) = 1	12/(12+2) = 0.86	9/(9+5) = 0.64	9/(9+5) = 0.64	6/(6+8) = 0.43	0/(0+14) = 0
FPF = FP/(FP+TN)	1-[0/(0+5)] = 1	1-[1/(1+4)] = 0.8	1-[1/(1+4)] = 0.8	1-[1/(1+4)] = 0.8	1-[1/(1+4)] = 0.8	1-[5/(5+0)] = 0	1-[5/(5+0)] = 0

5.4 Alternative ROC Method (Excluding Cores Next to Shelf Plates)

The same assumptions for the cores located nearby the shelf plates, discussed in section 5.2.1, can be considered for the alternative method, developed by Eng.

Considering core exclusions, Table 5-6 can be considered as the software input.

Table 5-6. Binary core data with confidence ratings for ROC (excluded cores).

Core No.	**Ultrasonics**					**Radiography**				
	ATS Lab		**Field Results**			**ATS Lab**		**Field Results**		
	True +/- (1/0)	**True Location**	**UT +/- (1/0)**	**UT Location**	**UT Confidence**	**True +/-**	**True Loc.**	**RT +/- (1/0)**	**RT Location**	**RT Confidence**
1	1	core	1	core	3	Excluded from ROC Analysis				
4	1	core	0	none	1	1	core	1	core	3
5	1	core	1	core	3	1	core	1	core	3
6	0	none	0	none	3	0	none	1	core	2
7	0	none	1	core	3	0	none	0	none	3
8	Excluded from ROC Analysis					Excluded from ROC Analysis				
9						1	core	1	core	3
10						1	core	1	core	2
11	1	core	1	core	3	1	core	1	core	3
12	Excluded from ROC Analysis					Excluded from ROC Analysis				
13										
14	1	core	1	core	2	1	core	1	core	3
15	1	core	1	core	3	1	core	1	core	2
16	1	core	0	none	1	1	core	1	core	2
17	0	none	0	none	3	0	none	1	core	2
18	0	none	0	none	3	0	none	1	core	2
19	1	core	1	core	3	1	core	0	none	1
20	0	none	0	none	3	0	none	1	core	2
21	1	core	1	core	3	1	core	0	none	1

Table 5-7. ROC curve output data points for UT and RT (excluded cores).

Response	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6
UT Response:						
Truly Negative Indications	4	0	0	0	0	1
Truly Positive Indications	0	0	2	0	1	6
UT Observed Operating Points:						
False Positive Fraction	0.00	0.20	0.20	0.20	1.00	
True Positive Fraction	0.00	0.67	0.78	1.00	1.00	
RT Response:						
Truly Negative Indications	1	0	0	0	4	0
Truly Positive Indications	0	0	2	0	3	5
RT Observed Operating Points:						
False Positive Fraction	0.00	0.00	0.80	0.80	1.00	
True Positive Fraction	0.00	0.50	0.80	1.00	1.00	

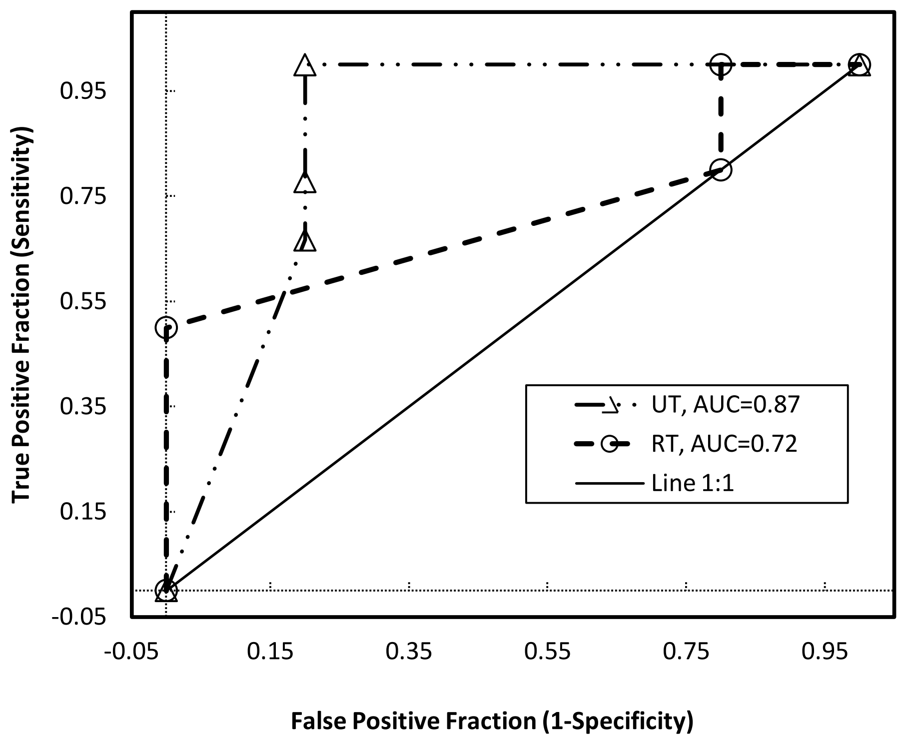


Figure 5-7. Empirical ROC curve for UT and RT (some cores excluded)

<u>Note:</u> Area under curve (AUC) for UT increased from 84% to 87% and AUC for RT increased from 63% to 72%.

6 POD COMPARISON OF RT AND UT USING MH-1823 SOFTWARE

The Department of Defense developed a guide book (MIL-HDBK-1823A) for reliability assessment of nondestructive evaluation systems. The main focus of this guide book was to assess reliability of NDE systems by POD analysis as a function of flaw size. POD curves are not used to assess the smallest crack an NDT method can detect, but rather to assess the largest crack a method may miss. According to Volker, it has been determined that an NDE technique does not have a specific POD because POD curve does not depend only on physics of the technique, but also other factors as discussed in Table 2-2, developed by Forli (*56*).

Two statistical approaches for constructing a POD curve were considered in the guide book. One approach was based on signal response and another was based on binary (hit/miss) data. This book specifically discussed the application of these POD approaches on UT, eddy current (ET), MT, and fluorescent penetrant (PT) tests.

The MH-1823 algorithm calculates the POD using four link functions to plot sizes within ($-\infty < x < \infty$) and POD within ($0 < y < 1$). These functions are the *logit* (logistic or log-odds function), *probit* (inverse normal function), the *complementary log-log* function (often called Weibull by engineers), and *loglog* function. These link functions are used to connect the values at 0 (missed flaws) to the values at 1 (hit data) and to estimate a POD for the system. These functions are as below (MIL-HDBK-1823A):

logit $f(X) = g(y) = \log\left(p/(1-p)\right)$

probit $f(X) = g(y) = \Phi^{-1}(p)$

cloglog $f(X) = g(y) = \log\left(-\log(1-p)\right)$

loglog $f(X) = g(y) = -\log(-\log(p))$

Where f(x) is an appropriate algebraic function (often, but not always, this is polynomial), and Φ is standard normal cumulative density function (CDF). In this research only the first function, *logit*, was used (for PODs generated by other functions, refer to Appendix-E). The POD links used in MH-1823 software are as below:

$$probit\ link\text{:}\ \ POD(a, \ldots) = 1 - \Phi\left(f_{(x)}\right)$$

$$logit\ link\text{:}\ \ POD(a, \ldots) = \frac{\exp\left(f_{(x)}\right)}{1 + \exp\left(f_{(x)}\right)}$$

$$cloglog\ link\text{:}\ \ POD(a, \ldots) = 1 - \exp\left(-exp\left(f_{(x)}\right)\right)$$

$$loglog\ link\text{:}\ \ POD(a, \ldots) = -\exp\left(-exp\left(-f_{(x)}\right)\right)$$

Note that in illustrated POD curves (Figure 6-1, and Figure 6-2), the definition of parameters is as follows:

a_{50} = estimate of flaw length for 50% POD

a_{90} = estimate of flaw length for 90% POD

$a_{90/95}$ = lower bound for 90% POD with 95% confidence (scalar quantity)

μ = It is a model parameter that locates the curve horizontally and it is the log of the size having 50% probability of detection (for log(x) model)

б = A model parameter and the inverse of the POD curve’s “slope”

n_{hits} = number of detected flaws

n_{total} = number of total flaws

6.1 SMB Input Data for MH-1823 Algorithm

In this research, UT and RT results from field inspection of SMB compared with each other using the MH-1823 software. To provide adequate data for comparison of these two methods, more data than only the 21 cores were required to construct a proper POD curve. In the 352 vertical butt weld locations on the Sherman Minton Bridge, 802 indications were detected by inspection firms. These indications were detected by either UT or RT, or both. The indications were listed in an Excel worksheet in a format suggested by MH-1823 POD algorithm. The complete list of indications with their locations along the tie girders is given in Appendix-D. Using the binary (hit/miss) approach described in MIL-HDBK-1823, POD curves were produced for UT and RT.

Appendix-D includes four tables for four ties of the bridge (Upstream Span-1, Upstream Span-2, Downstream Span-1, and Downstream Span-2). For each of the locations (802 indications) listed in Appendix-D, an inspection firm indicated that at least one flaw was detected by either RT or UT, or both.

6.2 Assumptions Used for the SMB Field Datasets

The following assumptions were made while analyzing the field data:

6.2.1 Sufficient Data Points

To produce a proper POD curve based on binary or hit/miss data, at least 120 data points are required. This requirement of MIL-HDBK-1823A was met by considering 802 indications gathered from field inspections for the SMB. These indications were either detected by RT or UT, or both. Two datasets for these indications were considered – RT and UT datasets. In Chapter-4, results of 21 cores inspected by both lab and field inspectors were considered. The results were accurate, having the confirmation of the lab, but not sufficient in number to meet the requirements of the algorithm. Therefore, additional field test data was included in the POD analysis.

6.2.2 Determination of Hit/Miss Data and Sizing Accuracy

Inspection firms indicated the existence and the length of each indication (Appendix-D). Therefore, it was assumed that the field data for 352 locations, listed in Appendix-D, were all true. In other words, it was assumed that there were no false positive (FP) indications, because there was no other data available to determine the FP indications. As such, the presence of an indication, recorded by the inspector, was considered as “Hit” or (1). Similarly, the absence of an indication was considered as “Miss” or (0).

6.2.3 Output

Since the 802 indications were gathered from the field and there was no involvement of a lab to confirm the results, other than the inspection records of the inspector firm, the output POD was considered as an approximate analysis of the data, based on the assumptions previously described.

6.3 MH-1823 Software

The MH-1823 POD software is based on R console, a powerful statistical and graphic language (http://www.r-project.org/). R is a GNU (a free operating system) project and is open-source. In addition to receiving support by some of the most well known applied statisticians in the world, R is continually updated. In this research, R version 3.0.3 (2014.03.06) is used. Within R language the MH-1823 POD software (version 4.0.1), written by Annis, was used for producing the POD curve for SMB data. It can also be downloaded from the website (http://StatisticalEngineering.com/mh1823/).

6.4 How to Recognize an Invalid POD Produced by MH-1823

According to recommendations of the software writer, Annis, and the MIL-HDBK-1823A statistical methods, the minimum POD value on the graph must be 0 and maximum value must be 1 (*57*). These conditions are easily met by most, but not all, POD datasets. If the min(POD)>0, due to background noise for example, or the max(POD)<1, caused perhaps by difficulties in accessing the inspection site, then the POD vs. size model will not agree with your POD data. This can be determined by looking at the POD vs. size plot. If there are missed data points at large sizes where the POD is near 1, or hits at small sizes where the POD is near 0, then the model does NOT agree with the data. Whenever any model disagrees with the data being modeled, the result will be invalid.

6.5 Limitations of MH-1823 and SMB Inspection Data

Table 6.1 describes the limitations suggested by MH-1823 software and the correspondence of the SMB field data. While using this software, it should be considered what type of data is being input and analyzed because the response is going to be directly related to the input data. In this research, field data were used. Although the inspection firm confirmed the data through various reports, the POD response was considered as an approximate result. Radiography was proven as a less effective inspection technique based on MH-1823 analyses. The field data showed too many missed flaws by RT and the binomial based software could not draw a POD.

Table 6-1. Limitations of MH-1823 and SMB field data correspondence.

Limitations of MH-1823	Correspondence with SMB Field Data
The NDE technique must have results showing either signal response or hit/miss information. For images, some pre-processing identifications might be required to convert them to signal response or hit/miss input.	Both UT and RT provided hit/miss information. Confirmation of inspection firm was also considered for each one of 802 indications. False calls and locations without any flaw were excluded from the analysis.
Indications supposed to be the input data must have measurable characteristics such as length, height, or chemical composition.	Field UT showed indications with their length, height, and location in the weld. RT showed indications with length and location on welds.
The MH-1823 POD software assumes that the input data are correct. That is, if the size is X, then it is the true size. Also, if the response is Y, then it is the true response. If the input data are approximate, then the response would be approximate, as well.	Since for construction of a proper POD curve a lot of data points are required, herein field inspection data (802 indications) were used. If only 21 core results were considered the response would be accurate, but the data would not be sufficient. Thus an approximate POD curve was generated based on field data.
The MH-1823 POD simulation assumes that the minimum value for POD is 0 and the maximum value is 1. If the output POD shows the min(POD)>0 and max(POD)<1 due to inaccuracy of the input data or signal contamination by excessive background noise, the result will be wrong. Refer to Section 5.2.	The POD curve produced by MH-1823 based on field inspection data of SMB for UT seems to be correspondent with the software suggestions. However, RT hit/miss data could not agree with the software requirements due to excessive missed data compared to hit.

6.6 POD as a Function of Flaw Length for UT Based on SMB Data

802 indications in vertical butt welded locations on 4 tie girders of the SMB were considered in the POD analysis (Appendix-D). 634 out of 802 flaws were detected by the UT method. The remaining 168 (~21%) flaws were missed by UT because these flaws were either located where shelf plates were attached to the girder or they were of volumetric type. Flaw length at 50% of POD was 0.505 inches, at 90% of POD was 1.653 inches, and at 90% of POD with 95% confidence, the flaw length was 1.97 inches (Figure 6-1).

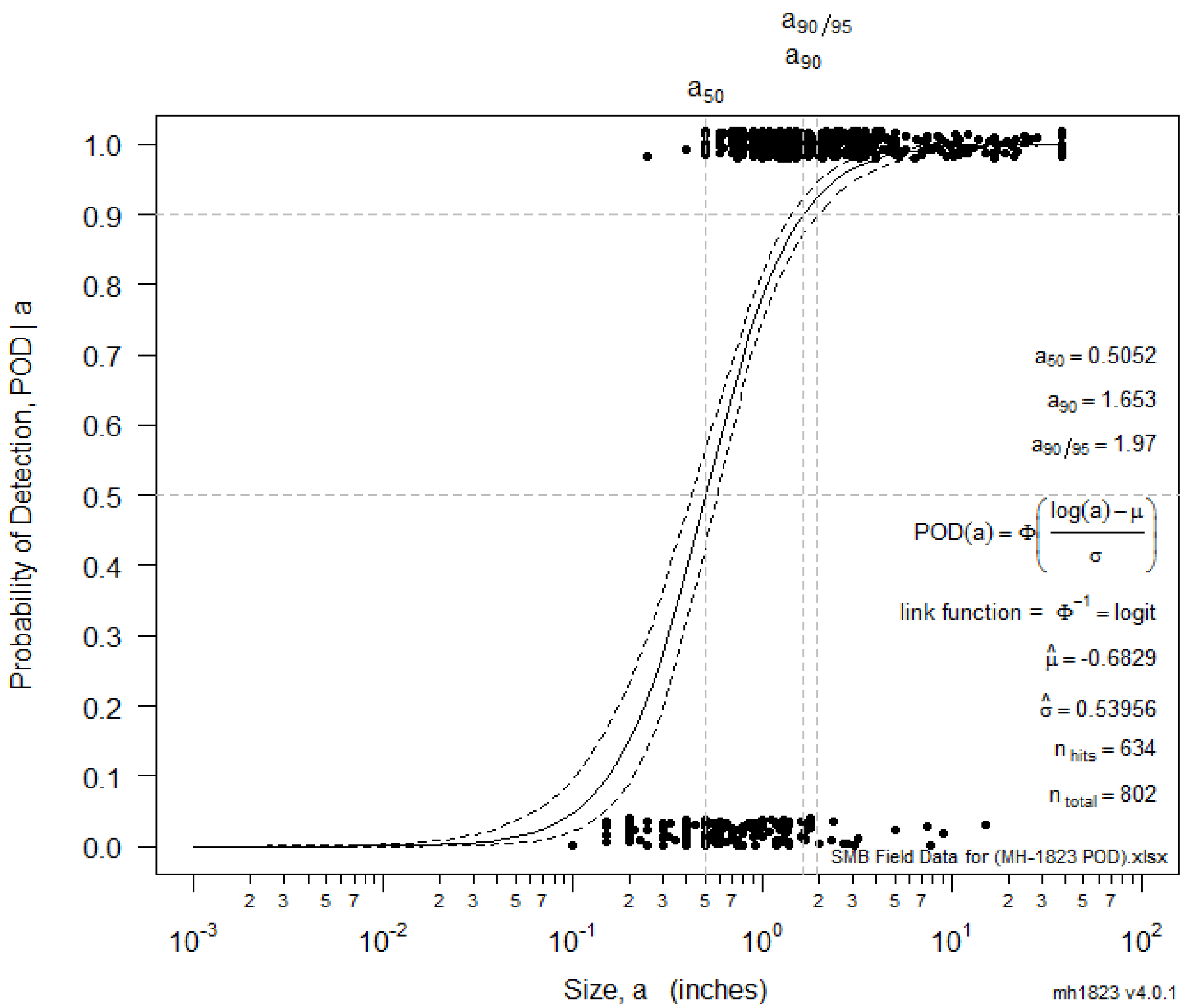


Figure 6-1. UT POD as a function of flaw length (logarithmic horizontal axis)

Complying with the requirements of section 6.2, the POD curve was also generated with linear horizontal axis. Section 6.2 suggested that if a POD plot contains missed data at larger size values where the curve approaches to 1, then the data do not agree with the model. This can be more clearly observed when the horizontal axis is in linear mode (Figure 6-2).

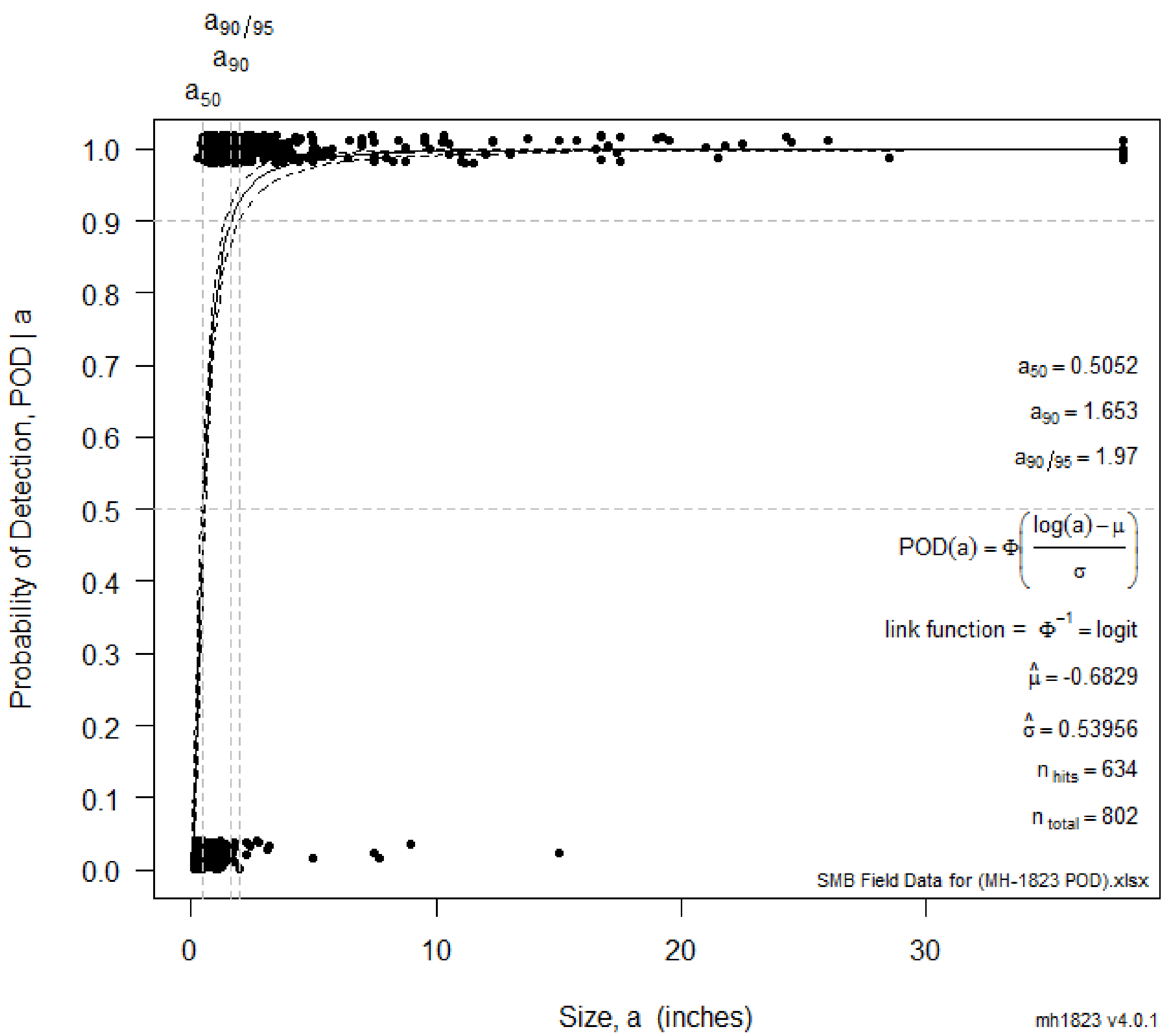


Figure 6-2. UT POD as a function of flaw length (linear horizontal axis)

6.7 Problems with RT Inspection Dataset

As it was discussed before, 802 indications were recorded in vertical butt welds by either RT or UT. Based on the field inspection data and the assumptions indicated in section 6.2, RT missed 537 flaws (67%). Therefore, MH-1823 POD software using two-parameter model could not draw an appropriate POD curve for the RT dataset. The conventional methods in MIL-HDBK-1823A did not apply on this dataset. This situation is consistent with the dataset as described by Knopp in 2012 (*58*). POD analysis of a difficult dataset was analyzed by Generazio in 2011, and this analysis also revealed that in such cases, conventional methods for determining POD do not work. New POD parameters presenting upper and lower asymptotes are needed to be added to the POD model. This approach (adding lower and upper asymptotes) or the one use by Generazio (Design of Experiment for POD or DOEPOD) was non-parametric assumptions, unlike the MH-1823 algorithm. DOEPOD methodology for binary datasets is designed to determine if the dataset provides a binomial-based 95% lower confidence limit (LCL). 95% LCL is at least 0.9 at the flaw size, which is called $a_{90/95}$. It is also designed to identify if the POD is monotonically increasing with the flaw size greater than $a_{90/95}$ (*59*).

Obviously, considering direct comparison of RT and UT, RT missed more flaws having larger sizes than UT. Hit/miss data points for RT are shown in Figure 6-3. Based on the excessive number of missed flaws with larger lengths, MH-1823 algorithm displayed an error message saying “Too many misses with model POD > 0.9”.

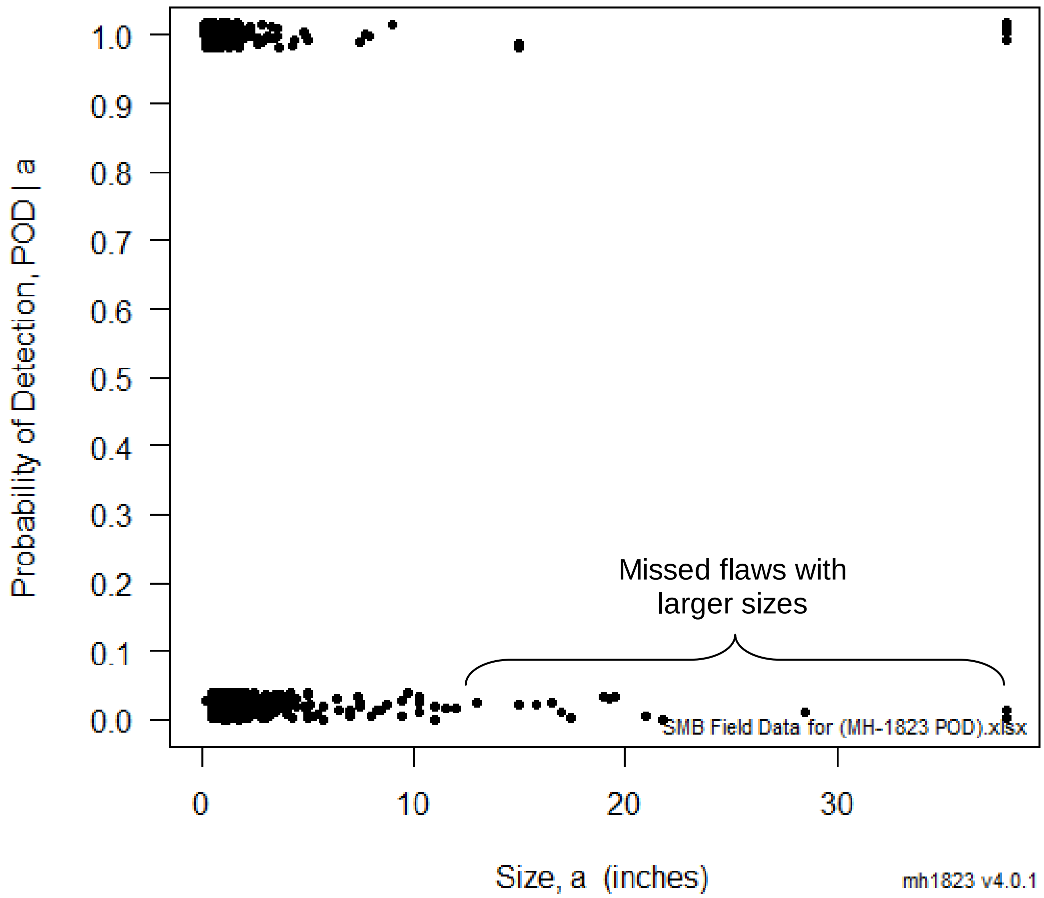


Figure 6-3. RT Hit/Miss binary data, incomplete POD (linear horizontal axis)

6.8 Discussion

The results from POD analysis of both RT and UT by MH-1823 algorithm enabled the following conclusions:

- Overall, the POD curve analysis was considered as an approximate comparison of RT and UT.
- One of the reasons for consideration of the POD as an approximate comparison was due to factors discussed in chapter 2, Table 2-2, regarding the many variables for crack detection.

- Based on the recommendations of MIL-HDBK-1823A, the minimum data points for binary (hit/miss) method should be at least 120 observations to get a good result for a_{50} and $a_{90/95}$. While the 21 core results were accurate, it was not sufficient to produce an accurate POD curve.
- UT seemed to be successful with few missed flaws and a reasonable POD curve (Figure 5-2). This POD was based on logit function, the most common one. The parameters for other link functions are listed in the following table:

Table 6-2. Output data from MH-1823 POD algorithm for UT and RT.

Technique	a_{50}	a_{90}	$a_{90/95}$	n_{hits}	n_{total}	Function
UT	0.5052	1.653	1.97	634	802	logit
	0.459	1.858	2.226	634	802	probit
	0.3218	2.22	2.723	634	802	cloglog
	0.5223	1.643	1.955	634	802	loglog
RT*	0.585	0.08763	0.04695	265	802	logit
	0.5341	0.05706	0.02691	265	802	probit
	0.6303	0.2079	0.1488	265	802	cloglog
	0.3774	0.003504	NA	265	802	loglog
(*) MH-1823 POD, a 2-parameter model algorithm, led to some fictitious values while analyzing RT dataset, confirming that it won't work for all datasets. Comparing with UT results, RT output is the opposite of UT, which is NOT correct. This is due to too many missed flaws by RT.						

- Difficulties in producing a POD curve for RT suggest that, considering this particular dataset from SMB, a POD analysis using a model other than 2-parameter model should be considered.
- The SMB radiography dataset seemed similar to the difficult dataset (A6003H) discussed by Generazio in 2011.
- Design of Experiments for Probability of Detection (DOEPOD), an algorithm developed by Generazio for NASA, may be a proper alternative for MH-1823 to analyze the POD of radiography for this particular SMB dataset.

7 CONCLUSIONS AND FUTURE WORK

7.1 Results

The objective of this research was to compare NDT technologies and to evaluate the inconsistencies between results of different techniques. After thorough analysis of the SMB field inspection and 21 cores data, the following conclusions regarding MT, RT, and UT techniques were made.

7.1.1 Lab vs. Field Core Results for MT

- 3/9 core locations with surface-breaking flaws were detected by MT. Although these 9 cores were located either close to or behind the shelf plates, MT detected the flaws of 3 cores (Table 4-1 and Appendix-F).

7.1.2 Lab vs. Field Core Results for RT and UT

7.1.2.1 <u>Correct Indication of the Methods</u>

- 15 cores were considered for UT
    - o 6 other cores were excluded (cores #2 and #3 due to lack of data and cores #8, #9, #12, and #13 due to their locations behind shelf plates)
- 16 cores were considered for RT
    - o 5 cores were excluded (all the same as shown for UT, except core #9). RT detected the flaw of core #9; therefore, this core was not excluded.
- 11/15 cores (73%) were inspected correctly by UT compared with the lab results.
- 7/16 cores (44%) were inspected correctly by RT compared with the lab results.

7.1.2.2 *Flaw Detectability of the Methods*

- 14 cores had flaws (cores #2 and #3 were not included). 5 cores were healthy.
    - o Out of 14 cores, 10 cores were considered for UT (cores #8, #9, #12, and #13 were excluded due to their locations behind shelf plates).
    - o Out of 14 cores, 11 cores were considered for RT (excluded cores are the same as shown for UT except core #9).
- UT detected flaws of 7/10 cores (70%)
    - o The missed flaws were from cores #4, #10, and #16
- RT detected flaws of 9/11 cores (82%)
    - o The missed flaws were from cores #19 and #21
- Although the RT flaw detection was greater than the UT, RT indicated some volumetric flaws instead of planar flaws for some cores. For example, RT indicated porosity and incomplete fusion for core #1 instead of a crack. Similarly, RT showed slag inclusion for core #11 instead of a crack. These indications of RT can be considered as missed flaws.
- Excluding cores #1 and #11, RT detected 7/11 flaws (64%).
- Flaw detectability of UT was greater than the RT.

7.1.2.3 *Flaw Characterization of the Methods*

- Planar flaw detection of RT was proven weaker than UT.
- 14 cores had planar flaws including surface and subsurface flaws (Figure 4-1).
    - o 10/14 cores were considered for UT (described in 7.1.2.2)
    - o 11/14 cores were considered for RT (described in 7.1.2.2)

- RT detected cracks (planar flaws) of 5/11 cores (45%).
    - o RT missed cracks of 6 cores #1, #11, #15, #16, #19, and #21
- UT detected cracks (planar flaws) of 7/10 cores (70%).
    - o UT missed cracks of 3 cores #4, #10, and #16

7.1.2.4 <u>ROC Analysis Based on the Core Data</u>

- ROC analysis of cores revealed the area under curves of 0.84 and 0.63 for UT and RT respectively. Excluding the gusset plate (shelf plate) locations, ROC indicated AUCs as 0.87 for UT and 0.72 for RT. Consequently, based on ROC curves, UT was shown to be a more reliable technique than the RT method.

7.1.3 Field Data Results for RT and UT

The following conclusions were made based on the analysis of the field data from 352 butt welded joints along the bridge:

- 79% of flaws (634/802), in the overall field inspection, were detected by UT.
- 33% of flaws (265/802), in the overall field inspection, were detected by RT.
- 12% of flaws (96/802), in the overall field inspection, were detected by both UT and RT

7.2 Recommendations and Future Research

According to the data analyses of the Sherman Minton Bridge and the literature survey, the following conclusions may be drawn:

- Based on the comparative study of UT and RT, and according to the assumptions used, UT had successful results when implemented on SMB.

- Observing the data from the SMB 21 cores, RT encountered numerous false positive indications. Therefore, RT image analysis should be done by expert inspectors.

For future research, construction of proper POD and ROC curves for performance of both UT and RT, based on the data from steel highway bridges, is recommended.

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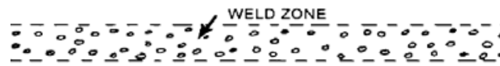
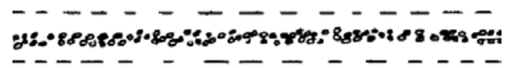
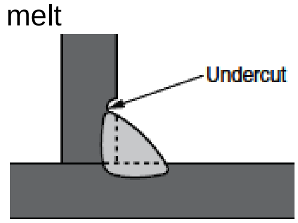
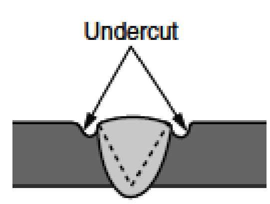
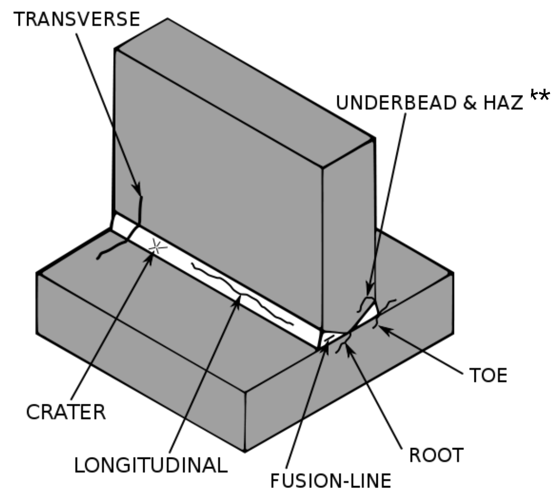
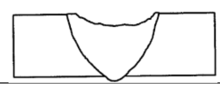
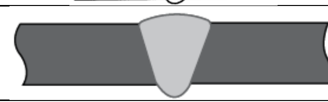
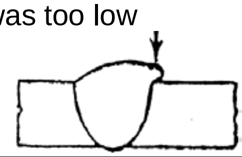
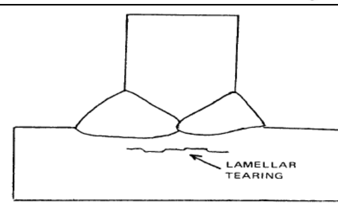
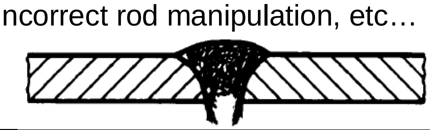
APPENDIX-A: COMMON WELD FLAW TYPES & CATEGORIES

Flaw Category	Flaw Type	Description and Illustration
Porosity	Uniformly Scattered	
	Clustered	
	Linear	
Non-metallic Inclusions	Surface-Breaking Inclusions (Exogenous)	Caused by leaving areas of slag that are trapped in the surface of the weld
	Sulfide Inclusions (Indigenous)	These particles are produced by the combination of oxygen, nitrogen, and/or sulfur present in the cover gas and flux, with the alloying elements in the weld pool. Indigenous inclusions caused by homogeneous reactions during solidification and form as oxides, sulfides and/or nitrides (61).
	Oxide Inclusions (Indigenous)	
	Nitride Inclusions (Indigenous)	
Metallic Inclusions	Tungsten Inclusions	Tungsten inclusions are particles of metallic tungsten embedded in the weld metal, originated from the tungsten electrode, used in tungsten arc welding
Lack of Fusion	Lack of Side Fusion	Due to the presence of slag, oxides, scale, or other non-metallic substances, and due to too low or too high welding current or incorrect edge preparation 
	Lack of Root Fusion	
	Lack of Inter-run Fusion	
Lack of Penetration	Incomplete Root Penetration	caused by the electrode holding at an incorrect angle, having too large diameter, fast travel rate, an insufficient welding current, or an improper joint preparation such as joint misalignment 
Undercut	Undercut in Fillet Welds	During the final or cover pass, the exposed upper edges of the beveled weld preparation tend to melt  
	Undercut in Groove Welds	

Cracks	Transverse Cracks	
	Under-bead Cracks	
	Longitudinal Cracks	
	Crater Cracks	
	Hat Cracks	
	Toe and Root Cracks	
Concavity	Root Concavity	Root concavity is commonly produced by the FCAW* process 
	Surface Concavity	Caused by gravity that causes the molten metal to sag away from the inaccessible upper surface of the weld 
Excessive Penetration	Root Melt-Through Penetration	
Overlap	Toe or Root Overlap	Caused when the welding rod used at an incorrect angle, the electrode travelled too slowly, or the current was too low 
Lamellar Tearing	T-Joints Lamellar Tearing	 Occur in T-Joints where the web plate is welded on both sides with full penetration
Burn-Through	Burn-Through	Caused by factors such as high current, slow rod speed, incorrect rod manipulation, etc… 

(*) FCAW (Flux Cored Arc Welding)
(**) HAZ (Heat Affected Zone)

APPENDIX-B: NOMENCLATURE

S-1 = Span – 1

S-2 = Span – 2

US = Upstream

DS = Downstream

T1 = Tie panel point – 1 (Similarly T2, T3 … T22)

IN = Indiana side of the bridge* (In Fish reports it was shown as only “I”)

KY = Kentucky side of the bridge* (In Fish reports it was shown as only “K”)

BP = Bottom plate of box tie girder

TP = Top plate of box tie girder

UV = Upstream side vertical plate of box tie girder

DV = Downstream side vertical plate of box tie girder

MT = Magnetic particle testing

UT = Ultrasonic testing

NDE = Nondestructive evaluation

RT = Radiographic testing

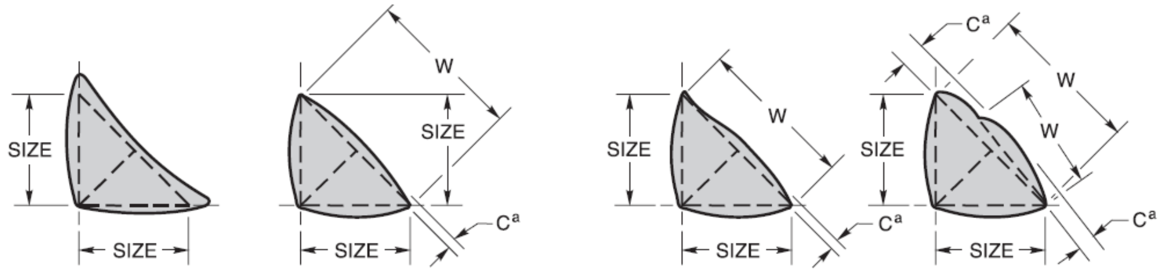
HAZ = Heat affected zone

PSI = Professional Service Industries, Inc.

ATS = Applied Technical Services, Inc.

* In Professional Service Industries, Inc. (PSI) reports Indiana and Kentucky sides were shown differently for some joints. As an example T15 (T14-T15) shows Kentucky side of the tie panel point – 15; while, T4 (T4-T5) shows Indiana side of the tie panel point – 4.

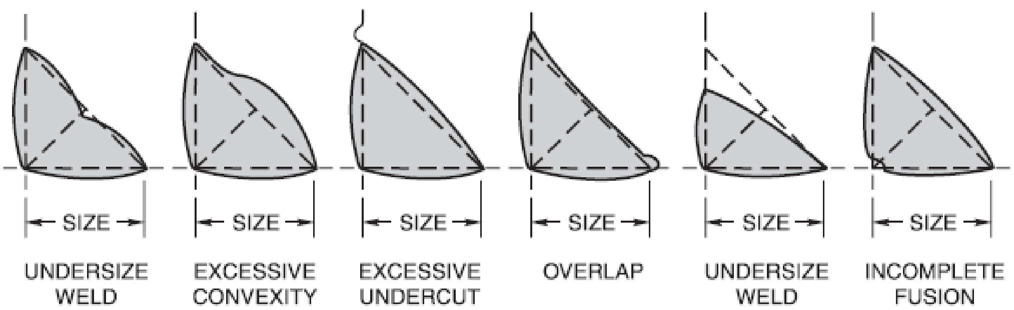
APPENDIX-C: AWS WELDING ACCEPTANCE CRITERIA



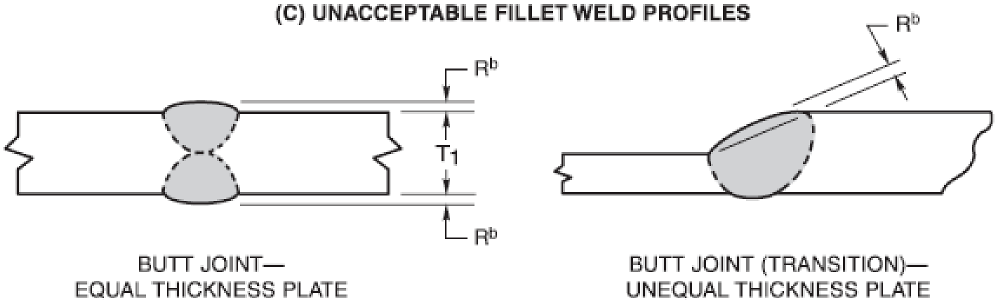
(A) DESIRABLE FILLET WELD PROFILES **(B) ACCEPTABLE FILLET WELD PROFILES**

[a]Convexity, C, of a weld or individual surface bead with dimension W shall not exceed the value of the following table:

WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W	MAX. CONVEXITY, C
W ≤ 5/16 in	1/16 in
W > 5/16 in TO W < 1 in	1/8 in
W ≥ 1 in	3/16 in

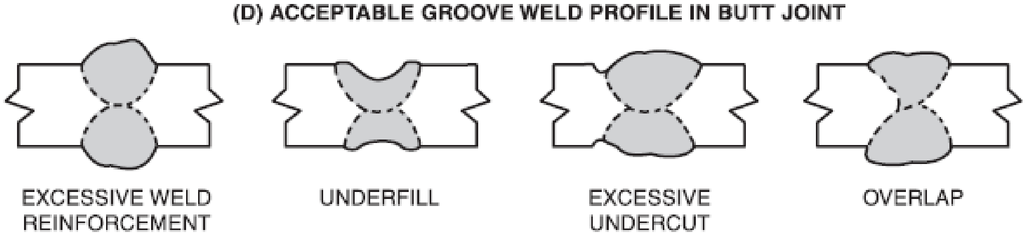


(C) UNACCEPTABLE FILLET WELD PROFILES



[b]Reinforcement R shall not exceed 1/8 in.

(D) ACCEPTABLE GROOVE WELD PROFILE IN BUTT JOINT



(E) UNACCEPTABLE GROOVE WELD PROFILES IN BUTT JOINTS

APPENDIX-D: BINARY (HIT/MISS) DATA FROM SMB

DS-1			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw type
Panel	Side	Plate					
L0	IN	UV	1.75	***1.75***	1	0	B, 9dB
		DV	24.25	1.2	1	1	IF, A, 3dB
T1	KY	DV	1.25	***1.25***	1	0	A, 6dB
	IN	DV	1.75	***1.75***	1	0	A, 4dB
T2	KY	UV	2	***2***	1	0	A, 4dB
		DV	1.87	***1.87***	1	0	A, 5dB
			2.5	***2.5***	1	0	C, 10dB
			1.38	***1.38***	1	0	A, 8dB
			7.5	***7.5***	1	0	A, 6dB
	IN	DV	1.13	38	1	1	A, 0dB
			1.38	38	1	1	B, 9dB
T3	KY	UV	1.75	***1.75***	1	0	C, 11dB
			1.5	***1.5***	1	0	A, 8dB
			2.12	***2.12***	1	0	A, 8dB
		DV	2.75	***2.75***	1	0	A, 5dB
			<u>***1.25***</u>	1.25	0	1	LC
			1.5	***1.5***	1	0	A, 7dB
	IN	DV	19.25	***19.25***	1	0	A, 5dB
T4	KY	UV	<u>***1.125***</u>	1.125	0	1	TC
	IN	DV	3.12	***3.12***	1	0	A, 7dB
T5	KY	DV	3.75	***3.75***	1	0	B, 9dB
			8	***8***	1	0	A, 7dB
			4	***4***	1	0	A, 1dB
	IN	UV	4.25	***4.25***	1	0	A, 4dB
			1.25	***1.25***	1	0	A, 4dB
			1.38	***1.38***	1	0	A, 5dB
		DV	1.5	***1.5***	1	0	A, 7dB
			2.12	***2.12***	1	0	A, 6dB
T6	KY	UV	21.75	***21.75***	1	0	A, 3dB
		DV	38	38	1	1	A, 2dB, PSI
	IN	UV	13	***13***	1	0	B, 9dB
T7	KY	DV	1.5	0.625	1	1	A, 8dB, SI
			0.8	***0.8***	1	0	A, 6dB
			1.2	***1.2***	1	0	A, 8dB
			1	***1***	1	0	A, 6dB
			1	***1***	1	0	A, 6dB
	IN	UV	2	***2***	1	0	A, 4dB
T8	KY	UV	0.8	***0.8***	1	0	A, 8dB
		DV	1.1	***1.1***	1	0	A, 7dB
			1	***1***	1	0	A, 5dB
			0.8	***0.8***	1	0	A, 7dB
	IN	UV	1.7	***1.7***	1	0	A, 8dB
			2.4	***2.4***	1	0	A, 3dB
			1.1	***1.1***	1	0	A, 5dB
			1	***1***	1	0	B, 9dB
			1.1	***1.1***	1	0	A, 6dB
			1.375	***1.375***	1	0	B, 9dB
			1.4	***1.4***	1	0	A, 5dB
		DV	1.5	***1.5***	1	0	A, 8dB
T9	IN	UV	8.5	***8.5***	1	0	A, -3dB

<u>General Notes and Abbreviations:</u>

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

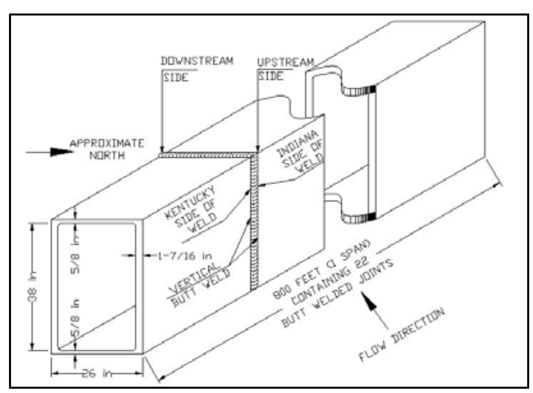
(*Italic,* **Bold,** <u>Underlined</u> format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(LC) Longitudinal Crack
(TC) Transverse Crack
(PSI) Possible Surface Irregularity
(SI) Slag Inclusion

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



DS-1 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw type
Panel Point	Side	Plate					
T9	IN	DV	1.2	***1.2***	1	0	B, 9dB
			0.9	***0.9***	1	0	A, 5dB
T10	KY	DV	0.7	***0.7***	1	0	A, 6dB
			0.8	***0.8***	1	0	B, 9dB
			0.75	***0.75***	1	0	B, 9dB
			1	***1***	1	0	A, -3dB
			0.7	***0.7***	1	0	A, 6dB
			0.75	***0.75***	1	0	B, 9dB
T11	KY	DV	0.5	***0.5***	1	0	B, 9dB
	IN	UV	***0.625***	0.625	0	1	P
		DV	***0.5625***	0.5625	0	1	C
			1	***1***	1	0	A, 4dB
T12	KY	UV	7	***7***	1	0	A, 10dB
		DV	1.5	***1.5***	1	0	A, 1dB
	IN	UV	0.875	***0.875***	1	0	A, 3dB
			1	***1***	1	0	A, -1dB
T13	KY	UV	***1***	1	0	1	C
	IN	UV	3.125	***3.125***	1	0	B, 9dB
			1.125	0.75	1	1	A, 8dB
			1.75	***1.75***	1	0	A, 8dB
		DV	0.625	***0.625***	1	0	B, 8dB
			1.125	***1.125***	1	0	A, 5dB
			1	***1***	1	0	A, 6dB
T14	KY	UV	1.25	***1.25***	1	0	A, 5dB
		DV	7.5	***7.5***	1	0	A, 7dB
			1	***1***	1	0	B, 9dB
			2	***2***	1	0	B, 9dB
			1	***1***	1	0	A, 6dB
			1	***1***	1	0	A, 6dB
			0.75	***0.75***	1	0	A, 6dB
			1.25	***1.25***	1	0	A, -3dB
	IN	UV	0.75	***0.75***	1	0	A, -3dB
			1	***1***	1	0	A, 2dB
			1	***1***	1	0	B, 9dB
T15	KY	UV	2.5	***2.5***	1	0	A, 7dB
			1	***1***	1	0	B, 9dB
			1	***1***	1	0	A, 7dB
			1.4	***1.4***	1	0	A, 7dB
			3.75	***3.75***	1	0	A, 6dB
			0.75	***0.75***	1	0	C, 18dB†
			1.3	***1.3***	1	0	A, 6dB
			6.4	***6.4***	1	0	A, 8dB
		DV	1	***1***	1	0	A, 8dB
			1	***1***	1	0	A, 0dB
			1	0.625	1	1	A, 8dB, IF
			3	***3***	1	0	A, 9dB
			0.75	***0.75***	1	0	A, 4dB
	IN	UV	1	***1***	1	0	A, 4dB

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

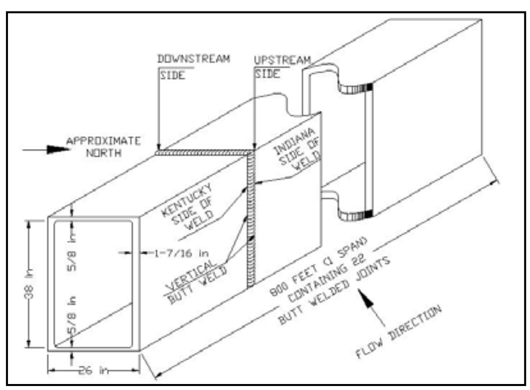
(*Italic,* **Bold,** Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(P) Porosity
(C) Crack
(IF) Incomplete Fusion
(†) Class-C Identified by UT

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



DS-1 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw type
Panel Point	Side	Plate					
T15	IN	UV	0.5	***0.5***	1	0	A, 2dB
T16	KY	UV	5	***5***	1	0	A, 8dB
		DV	1.5	1.5	1	0	A, 5dB
	IN	UV	2.4	***2.4***	1	0	B, 9dB
			1.9	***1.9***	1	0	A, 7dB
			2.1	***2.1***	1	0	A, 1dB
			2.3	***2.3***	1	0	A, 1dB
			2.1	***2.1***	1	0	A, 1dB
			1.5	***1.5***	1	0	A, 8dB
		DV	1.5	***1.5***	1	0	A, 3dB
			1	***1***	1	0	A, 6dB
			0.75	***0.75***	1	0	A, 8dB
T17	KY	UV	2.375	0.27	1	1	A, 5dB, SI
			2.375	1.8	1	1	A, 5dB, IF
			0.4	0.4	0	1	GIW
		DV	1	***1***	1	0	A, 6dB
			1.75	***1.75***	1	0	A, 5dB
			0.75	***0.75***	1	0	A, 8dB
	IN	UV	***7.7***	7.7	0	1	IF†
			1.125	***1.125***	1	0	A, 8dB
			1.25	***1.25***	1	0	A, 4dB
			1	***1***	1	0	A, 7dB
			0.97	0.97	0	1	C
		DV	21.5	0.95	1	1	A, 7dB, SI
			1	***1***	1	0	A, 7dB
			4	***4***	1	0	A, 4dB
T18	KY	UV	***1.3***	1.3	0	1	C
			1.3	1.3	0	1	C
			0.2	0.2	0	1	IF
			1.6	***1.6***	1	0	A, 3dB
			3.5	***3.5***	1	0	A, 5dB
			2.5	***2.5***	1	0	B, 8dB
			1	***1***	1	0	B, 9dB
			1.4	1.4	0	1	C
			2.4	***2.4***	1	0	A, 5dB
			2	***2***	1	0	A, 3dB
			3	***3***	1	0	A, 5dB
			0.65	0.65	0	1	C
		DV	1	***1***	1	0	A, 7dB
			1	***1***	1	0	A, 2dB
			1	***1***	1	0	A, 7dB
			1	***1***	1	0	A, -5dB
			2	***2***	1	0	A, 8dB
			3	***3***	1	0	B, 9dB
			1	***1***	1	0	A, 6dB
	IN	DV	1	***1***	1	0	A, 9dB

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

(*Italic,* **Bold,** Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

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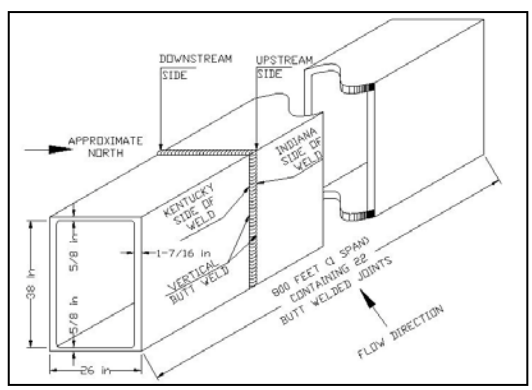
(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(SI) Slag Inclusion
(IF) Incomplete Fusion
(GIW) Gouge in Weld
(C) Crack
(†) Recommendation of Inspection Firm: Ground flush and re-inspect by RT

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



DS-1 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw type
Panel Point	**Side**	**Plate**					
T19	KY	UV	***0.3***	0.3	0	1	IF
T19	KY	UV	2	1.7	1	1	C, 10dB, IF
T19	KY	UV	1.75	***1.75***	1	0	A, 7dB
T19	KY	UV	1.25	***1.25***	1	0	A, 4dB
T19	KY	DV	1	***1***	1	0	A, 3dB
T19	IN	UV	***1.25***	1.25	0	1	TC
T19	IN	UV	1.5	***1.5***	1	0	A, 5dB
T20	KY	UV	1	***1***	1	0	A, 0dB
T20	KY	UV	1	***1***	1	0	A, 4dB
T20	KY	UV	0.75	***0.75***	1	0	A, 4dB
T20	KY	UV	1	***1***	1	0	A, 0dB
T20	KY	DV	22.5	0.75	1	1	A, 5dB, P†
T20	IN	UV	1.25	***1.25***	1	0	A, 2dB
T20	IN	UV	1.25	***1.25***	1	0	A, -3dB
T20	IN	UV	1.25	***1.25***	1	0	B, 9dB
T20	IN	UV	1.25	***1.25***	1	0	A, -6dB
T20	IN	UV	1.5	***1.5***	1	0	A, 2dB
T20	IN	UV	1.25	***1.25***	1	0	A, 7dB
T21	KY	UV	1	***1***	1	0	A, 8dB
T21	KY	UV	1	***1***	1	0	A, 8dB
T21	KY	DV	1.75	***1.75***	1	0	A, 2dB
T21	KY	DV	1	***1***	1	0	A, 7dB
T21	KY	DV	1.25	***1.25***	1	0	A, 1dB
T21	KY	DV	1.25	***1.25***	1	0	A, 6dB
T21	KY	DV	1	***1***	1	0	A, 2dB
T21	KY	DV	1.25	***1.25***	1	0	A, 1dB
T21	IN	UV	3.5	***3.5***	1	0	A, 6dB
T21	IN	UV	2	***2***	1	0	A, 5dB
T21	IN	UV	1	***1***	1	0	A, 6dB
T21	IN	DV	11	***11***	1	0	A, 7dB
L22	KY	UV	2	***2***	1	0	A, 7dB
L22	KY	UV	4	***4***	1	0	A, -3dB
L22	KY	UV	0.75	***0.75***	1	0	A, 5dB
L22	KY	DV	5	***5***	1	0	C, 10dB

General Notes and Abbreviations:

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(*Italic*, **Bold,** Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

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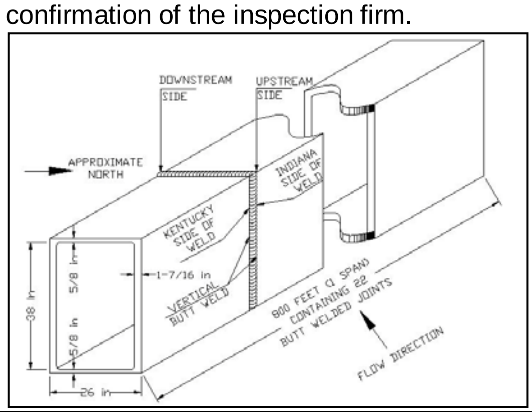
(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(TC) Transverse Crack
(IF) Incomplete Fusion
(C) Associated with Decibel (dB) rating means Class-C identified by UT.
(†) 0.75" diameter cluster porosity

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



US-1			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw type
Panel Point	**Side**	**Plate**					
L0	IN	UV	2.5	***2.5***	1	0	A, -6dB
			5	***5***	1	0	A, 0dB
		DV	2.5	***2.5***	1	0	A, -3dB
			0.6	0.6	0	1	IF
			1.25	***1.25***	1	0	A, -3dB
			4.5	***4.5***	1	0	A, -8dB
T1	KY	DV	17.5	0.4	1	1	A, -4dB, C
			17.5	7.9	1	1	A, -4dB, C, IF
			2.5	***2.5***	1	0	B, 9dB
			0.6	0.6	0	1	SI
			3	***3***	1	0	A, -2dB
			0.2	0.2	0	1	C
T2	KY	UV	5	***5***	1	0	A, 8dB
			1	***1***	1	0	B, 9dB
			4	***4***	1	0	A, 3dB
		DV	1	***1***	1	0	A, 4dB
			2.7	***2.7***	1	0	A, 3dB
			0.9	***0.9***	1	0	A, 6dB
			0.9	***0.9***	1	0	A, 6dB
			1.7	***1.7***	1	0	A, 2dB
			2	***2***	1	0	A, -10dB
	IN	UV	***0.85***	0.85	0	1	IF
			0.6	***0.6***	1	0	A, 7dB
			0.8	***0.8***	1	0	A, 8dB
		DV	1	***1***	1	0	A, 7dB
			0.5	0.5	0	1	C
			0.9	***0.9***	1	0	A, 7dB
T3	KY	UV	1.5	***1.5***	1	0	A, 0dB
			1.25	***1.25***	1	0	A, 1dB
			1.5	***1.5***	1	0	A, 4dB
			1.25	***1.25***	1	0	A, 7dB
			1.25	***1.25***	1	0	B, 9dB
		DV	2.5	0.7	1	1	A, 5dB, IF
			0.5	0.5	0	1	IF
	IN	UV	***0.8***	0.8	0	1	IF
			2.6	***2.6***	1	0	A, 7dB
			0.6	***0.6***	1	0	A, 5dB
		DV	0.9	***0.9***	1	0	A, 8dB
			9	9	0	1	IF
T4	KY	UV	1	***1***	1	0	A, 6dB
			0.9	***0.9***	1	0	A, 6dB
			0.8	***0.8***	1	0	B, 9dB
			1.4	1.4	0	1	TC
			2.4	2.4	0	1	TC
		DV	1	***1***	1	0	B, 9dB
			0.9	1.3	1	1	A, 4dB, TC
	IN	UV	***0.5***	0.5	0	1	IF

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

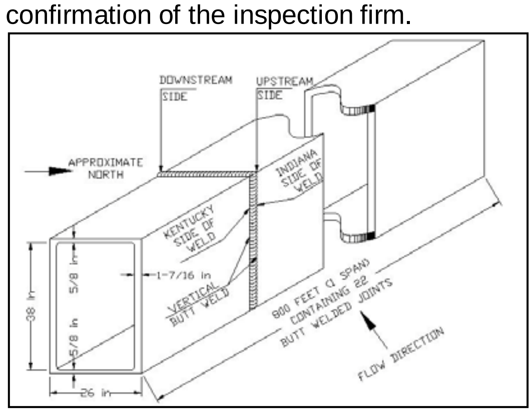
(*Italic*, **Bold,** Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(C) Crack
(SI) Slag Inclusion
(TC) Transverse Crack

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



US-1 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw type
Panel Point	Side	Plate					
T4	IN	UV	0.2	0.2	0	1	IF
		DV	0.9	0.2	1	1	B, 9dB, IF
			0.8	***0.8***	1	0	A, 6dB
T5	KY	UV	0.8	***0.8***	1	0	A, 5dB
			0.8	0.52	1	1	A, 8dB, IF
			0.6	***0.6***	1	0	A, 5dB
			0.3	0.3	0	1	IF
		DV	1	***1***	1	0	A, 8dB
			1	***1***	1	0	A, 7dB
	IN	UV	0.7	***0.7***	1	0	B, 9dB
		DV	3.2	0.2	1	1	A, 8dB, P
			0.8	0.9	1	1	A, 8dB, SI
			2	0.9	1	1	A, 8dB, IF
			0.9	***0.9***	1	0	A, 6dB
			0.8	***0.8***	1	0	A, 7dB
T6	KY	DV	1.75	***1.75***	1	0	A, 7dB
			1	***1***	1	0	A, 7dB
			5	***5***	1	0	A, 8dB
			8.75	4.4	1	1	A, 7dB, IF, SI
	IN	UV	1	***1***	1	0	A, 4dB
			2.7	2.7	0	1	IP†
		DV	1	***1***	1	0	A, -4dB
T7	KY	UV	0.7	***0.7***	1	0	A, 8dB
			1.4	1.4	0	1	GIW
	IN	UV	0.9	***0.9***	1	0	B, 9dB
		DV	1	***1***	1	0	B, 9dB
			0.8	***0.8***	1	0	B, 9dB
T8	KY	UV	0.8	***0.8***	1	0	B, 9dB
			0.8	***0.8***	1	0	B, 9dB
		DV	3	***3***	1	0	A, 0dB
	IN	UV	1.25	***1.25***	1	0	B, 9dB
			1.625	***1.625***	1	0	A, 0dB
			2.5	***2.5***	1	0	A, -1dB
T9	KY	DV	3.25	***3.25***	1	0	A, 6dB
			0.9	0.9	0	1	IF
	IN	UV	0.875	***0.875***	1	0	A, 3dB
			1	***1***	1	0	B, 9dB
		DV	***0.8***	0.8	0	1	SI
T10	KY	DV	0.88	***0.88***	1	0	A, 2dB
			1.25	***1.25***	1	0	A, 6dB
			0.88	***0.88***	1	0	A, 6dB
			1.5	***1.5***	1	0	A, 5dB
			5.25	***5.25***	1	0	A, -4dB
	IN	UV	1.5	***1.5***	1	0	B, 5dB
			2.5	***2.5***	1	0	A, 3dB
			1.8	1.8	0	1	C
			1.7	1.7	0	1	C
			1.6	1.6	0	1	C

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

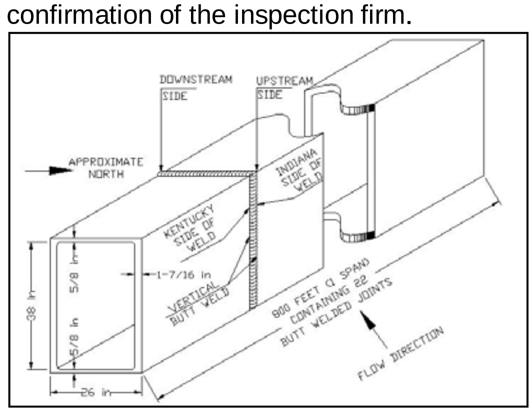
(*Italic*, **Bold**, Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(P) Porosity
(C) Crack
(SI) Slag Inclusion
(IP) Incomplete Penetration
(GIW) Gouge in Weld
(†) Recommendation of Inspection Firm: Grind flush and re-inspect by RT

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



US-1 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw type
Panel Point	**Side**	**Plate**					
T10	IN	DV	2.25	***2.25***	1	0	A, 3dB
			1	***1***	1	0	A, 5dB
			1	***1***	1	0	B, 9dB
			1.25	***1.25***	1	0	B, 9dB
T11	KY	UV	***1***	1	0	1	GIW
		DV	***1.8***	1.8	0	1	SI, IF
			0.7	0.7	0	1	GIW
	IN	UV	2.38	0.5	1	1	B, 9dB, IF
			0.2	0.2	0	1	IF
			1	***1***	1	0	A, -5dB
		DV	2.5	***2.5***	1	0	A, 6dB
			2.1	***2.1***	1	0	B, 9dB
T12	KY	UV	2.1	0.8	1	1	A, 2dB, IF
		DV	1.2	***1.2***	1	0	B, 9dB
			1.2	***1.2***	1	0	A, 6dB
			2.2	***2.2***	1	0	A, 7dB
	IN	DV	1.375	***1.375***	1	0	A, 4dB
			4.875	2.3	1	1	A, 0dB, IF
T13	KY	UV	***1***	1	0	1	GIW
		DV	***2***	2	0	1	IF
	IN	UV	5.75	***5.75***	1	0	A, 4dB
		DV	***1.17***	1.17	0	1	C
			0.215	0.215	0	1	C
			0.226	0.226	0	1	C
			0.298	0.298	0	1	C
			4.2	***4.2***	1	0	A, 7dB
T14	KY	UV	1.875	***1.875***	1	0	B, 9dB
			1	***1***	1	0	B, 13dB
			1.5	***1.5***	1	0	B, 9dB
		DV	19.5	***19.5***	1	0	A, 7dB
	IN	UV	1	***1***	1	0	A, 5dB
			1	***1***	1	0	A, 5dB
			0.6	0.6	0	1	C
		DV	3.5	***3.5***	1	0	A, 0dB
			2.3	***2.3***	1	0	A, -3dB
			4.4	***4.4***	1	0	A, 8dB
			5.1	***5.1***	1	0	A, 6dB
			3.2	***3.2***	1	0	C, 10dB
			16.7	4.3	1	1	A, 4dB, SI
			16.7	4.8	1	1	A, 4dB, SI
			16.7	0.25	1	1	A, 4dB, SI
			0.4	0.4	0	1	C
T15	KY	UV	2.75	1.8	1	1	A, 7dB, SI, IF
			5.75	***5.75***	1	0	B, 9dB
	IN	UV	0.75	***0.75***	1	0	A, 8dB
		DV	0.88	***0.88***	1	0	A, 5dB
T16	KY	UV	***1.35***	1.35	0	1	TC

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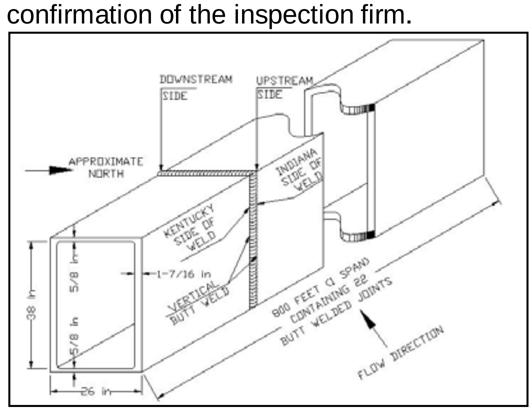
(*Italic*, **Bold**, Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(TC) Transverse Crack
(C) Crack
(C) Associated with Decibel (dB) rating means Class-C identified by UT.
(SI) Slag Inclusion
(GIW) Gouge in Weld

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



US-1 (Cont'd)							
Panel Point	Side	Plate	Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
T16	KY	UV	***1.35***	1.35	0	1	TC
		DV	0.75	***0.75***	1	0	A, 6dB
			0.75	***0.75***	1	0	A, 1dB
			0.75	***0.75***	1	0	A, 2dB
			3.38	***3.38***	1	0	A, 4dB
	IN	UV	***0.44***	0.44	0	1	Crack
			2.3	2.3	0	1	IF
			3	0.25	1	1	A, 4dB, C
		DV	1	***1***	1	0	A, 2dB
T17	KY	UV	2.5	***2.5***	1	0	A, 6dB
			2.5	***2.5***	1	0	A, 7dB
		DV	3.5	3.5	1	1	A, 2dB, P, C†
			3.5	0.9	1	1	A, 2dB, TC‡
			3.5	0.4	1	1	A, 2dB, C
			1.5	***1.5***	1	0	A, 5dB
			11.2	1.2	1	1	A, -5dB, P, IF
	IN	UV	***0.3***	0.3	0	1	TC
		DV	***15***	15	0	1	IF*
T18	KY	UV	1.25	***1.25***	1	0	A, 2dB
			1.5	***1.5***	1	0	A, 6dB
			1.38	***1.38***	1	0	A, 1dB
			2.5	***2.5***	1	0	A, 6dB
	IN	UV	24.5	0.5	1	1	A, 6dB, IF
			9.5	***9.5***	1	0	A, 5dB
		DV	1.5	***1.5***	1	0	A, 8dB
			2.5	15	1	1	A, 7dB, GIW
T19	KY	UV	1	1.2	1	1	A, 2dB, SI
			3.25	***3.25***	1	0	B, 8dB
		DV	1	***1***	1	0	A, -4dB
			1.25	***1.25***	1	0	A, 8dB
	IN	UV	1	***1***	1	0	A, 4dB
			0.2	0.2	0	1	SI
		DV	***0.82***	0.82	0	1	SI
			0.5	***0.5***	1	0	B, 9dB
			1.75	***1.75***	1	0	B, 8dB
			0.8	0.8	0	1	IF
T20	KY	UV	1.87	1.3	1	1	A, 7dB, SI
			1.13	***1.13***	1	0	B, 9dB
			1.5	***1.5***	1	0	A, 3dB
		DV	1.5	***1.5***	1	0	B, 8dB
			1.5	0.35	1	1	A, 1dB, C
			1.25	***1.25***	1	0	A, 3dB
			1.25	***1.25***	1	0	A, 7dB
	IN	UV	1.75	***1.75***	1	0	B, 6dB
			1.75	***1.75***	1	0	B, 6dB
		DV	1.5	***1.5***	1	0	A, 7dB

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

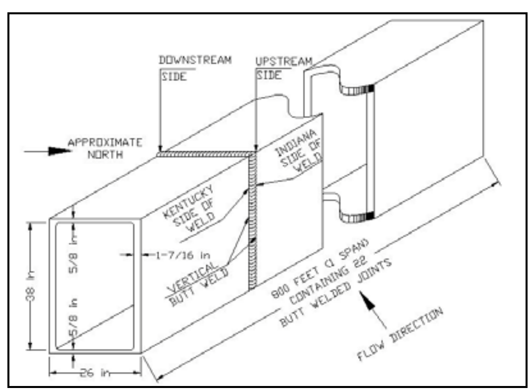
(*Italic*, **Bold**, Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(TC) Transverse Crack
(C) Crack
(†) Crack Between Holes
(‡) Transverse Crack in Base Metal
(*) IF in the region 1"-15" from top. Probably flame cut 0.43".
(SI) Slag Inclusion
(GIW) Gouge in Weld

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



US-1 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
Panel Point	Side	Plate					
T20	IN	DV	2	0.75	1	1	A, 5dB, IF
			1.5	***1.5***	1	0	A, 5dB
			2.5	***2.5***	1	0	A, 5dB
T21	KY	DV	1.62	***1.62***	1	0	A, 7dB
			1.12	***1.12***	1	0	A, 8dB
			0.35	0.35	0	1	SI
			1	1	0	1	C
	IN	UV	***0.65***	0.65	0	1	TC
		DV	***0.52***	0.52	0	1	IF
L22	KY	UV	1.25	***1.25***	1	0	A, 8dB
			1	***1***	1	0	A, 7dB
		DV	2	***2***	1	0	A, 1dB

General Notes and Abbreviations:

(IF) Incomplete Fusion
(TC) Transverse Crack
(C) Crack
(SI) Slag Inclusion

DS-2			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
Panel Point	Side	Plate					
L0	IN	UV	***0.2***	0.2	0	1	P
		DV	17.38	***17.38***	1	0	A, 3dB
			1.38	0.6	1	1	A, 5dB, SI
			15.75	***15.75***	1	0	A, 2dB
T1	KY	UV	0.6	***0.6***	1	0	A, 8dB
		DV	1.2	***1.2***	1	0	A, 7dB
			0.4	0.32	1	1	B, 9dB TC†
	IN	DV	0.5	***0.5***	1	0	A, 8dB
T2	KY	UV	1.3	***1.3***	1	0	A, 6dB
			1.4	***1.4***	1	0	A, 0dB
			1.7	0.2	1	1	A, 4dB, IF
			3.4	0.6	1	1	A, 6dB, IF
		DV	0.6	***0.6***	1	0	A, 5dB
			1.8	***1.8***	1	0	A, 8dB
			0.75	***0.75***	1	0	A, 6dB
			1	***1***	1	0	A, 2dB
			0.6	3.7	1	1	A, 8dB, IF
	IN	UV	2.25	***2.25***	1	0	B, 9dB
			0.75	***0.75***	1	0	A, 4dB
			2	***2***	1	0	A, 4dB
			3.1	3.1	0	1	IF
			0.75	***0.75***	1	0	A, 6dB
		DV	1.25	***1.25***	1	0	A, 0dB
T3	KY	DV	4.1	0.55	1	1	A, 8dB, IF
			0.2	0.2	0	1	P
			0.5	0.5	0	1	SI, P, IF
	IN	UV	2.1	***2.1***	1	0	A, 5dB
			2.8	***2.8***	1	0	A, -1dB
T4	KY	UV	1.75	***1.75***	1	0	A, 5dB
			2.25	***2.25***	1	0	A, 3dB
			3.25	***3.25***	1	0	A, 5dB
		DV	***1.1***	1.1	0	1	P, IF
			1.5	***1.5***	1	0	A, 5dB
			1.7	1.7	0	1	IF
			1.5	***1.5***	1	0	A, 6dB
			1.5	***1.5***	1	0	A, 4dB
	IN	DV	1	***1***	1	0	A, 4dB
T5	KY	UV	***0.15***	0.15	0	1	C
		DV	1.25	***1.25***	1	0	A, 6dB
			1.12	***1.12***	1	0	B, 9dB
	IN	UV	1.25	***1.25***	1	0	A, 6dB
			1.2	1.2	0	1	RA
T6	KY	UV	1.75	***1.75***	1	0	A, 8dB
			1	***1***	1	0	A, 4dB
			11.5	***11.5***	1	0	A, 8dB
		DV	2.25	***2.25***	1	0	B, 9dB
			10.5	3.3	1	1	A, -6dB, IF*
			5.5	***5.5***	1	0	A, 6dB
	IN	UV	1.25	***1.25***	1	0	A, 4dB
			1	***1***	1	0	A, 4dB

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

(*Italic,* **Bold**, Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

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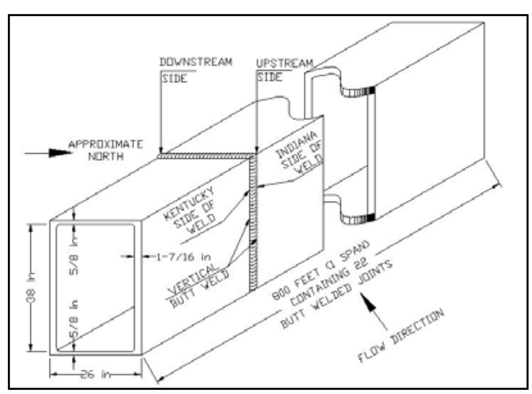
(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(TC) Transverse Crack
(C) Crack
(RA) Rejectable Attribute
(SI) Slag Inclusion
(P) Porosity
(†) Recordable Transverse Crack
(*) Intermittent Incomplete Fusion at the Region

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



DS-2 (Cont'd) Panel Point	Side	Plate	Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
T6	IN	UV	2	***2***	1	0	A, 6dB
			1.25	***1.25***	1	0	A, 7dB
			<u>***0.8***</u>	0.8	0	1	P, IF
			0.5	***0.5***	1	0	A, 2dB
			3.25	1	1	1	A, -3dB, IF
			2	***2***	1	0	A, 0dB
		DV	1.25	***1.25***	1	0	A, -1dB
T7	KY	UV	<u>***0.6***</u>	0.6	0	1	IF
		DV	<u>***7.5***</u>	7.5	0	1	SI, IF[1]
			<u>***1.8***</u>	1.8	0	1	IF
	IN	UV	0.75	***0.75***	1	0	A, 8dB
			0.75	***0.75***	1	0	A, 7dB
		DV	<u>***1.7***</u>	1.7	0	1	TC
			<u>***0.75***</u>	0.75	0	1	P, IF
			2	***2***	1	0	A, 2dB
T8	KY	UV	1	***1***	1	0	A, 4dB
			1	***1***	1	0	A, 7dB
			2.5	***2.5***	1	0	A, 4dB
			1.25	***1.25***	1	0	A, 7dB
			1	***1***	1	0	A, 8dB
			1.25	***1.25***	1	0	A, 7dB
		DV	1	***1***	1	0	A, 5dB
			<u>***1.4***</u>	1.4	0	1	IF
	IN	UV	1	***1***	1	0	A, 7dB
			<u>***0.4***</u>	0.4	0	1	TC
			1	***1***	1	0	A, 8dB
			1.25	***1.25***	1	0	A, 7dB
		DV	0.5	0.5	1	0	A, 7dB
T9	KY	UV	2.5	1	1	1	A, -7dB, C
			<u>***5***</u>	5	0	1	C[2]
		DV	<u>***3.2***</u>	3.2	0	1	C
			<u>***1.7***</u>	1.7	0	1	C
			1	***1***	1	0	B, 9dB
	IN	UV	<u>***0.5***</u>	0.5	0	1	Crack
			<u>***0.3***</u>	0.3	0	1	C
			3.5	***3.5***	1	0	A, 3dB
		DV	<u>***0.4***</u>	0.4	0	1	C
			<u>***0.5***</u>	0.5	0	1	C
T10	KY	UV	38	0.6	1	1	B, 9dB, P, IF
			38	0.5	1	1	B, 9dB, IF
			38	38	1	1	B, 9dB[3]
		DV	<u>***0.8***</u>	0.8	0	1	IF
			7.375	***7.375***	1	0	A, 7dB
			3	***3***	1	0	A, 5dB
	IN	UV	<u>***0.95***</u>	0.95	0	1	SI
			1	***1***	1	0	A, 3dB
			0.75	***0.75***	1	0	A, 5dB

<u>General Notes and Abbreviations:</u>

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

(*Italic,* **Bold**, <u>Underlined</u> format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

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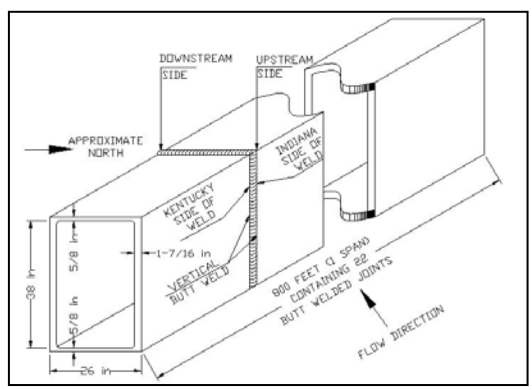
(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(TC) Transverse Crack
(C) Crack
(RA) Rejectable Attribute
(SI) Slag Inclusion
(P) Porosity
([1]) Intermittent Slag Inclusion and Incomplete Fusion at the Region
([2]) Rejectable Crack at this region (0"-5" from bottom)
([3]) Indications are intermittently on screen on 2nd leg and can be referenced with 60 degrees

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



DS-2 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
Panel Point	**Side**	**Plate**					
T10	IN	UV	***1.2***	1.2	0	1	SI
			0.75	***0.75***	1	0	A, 7dB
T11	KY	UV	***2.3***	2.3	0	1	SI
			0.5	***0.5***	1	0	A, 3dB
			4.75	1.2	1	1	A, 6dB, SI
			5	2.7	1	1	A, 6dB, SI
			1.75	***1.75***	1	0	A, 7dB
	IN	UV	12.3	0.7	1	1	A, 2dB, SI, IF
			12.3	1.7	1	1	A, 2dB, SI, IF
T12	KY	UV	2.9	***2.9***	1	0	A, 0dB
			7	1.5	1	1	A, -19dB, C
			5	1.5	1	1	A, 6dB, C
			1.8	***1.8***	1	0	B, 9dB
		DV	1	***1***	1	0	B, 8dB
			1.8	***1.8***	1	0	A, -3dB
			1.6	***1.6***	1	0	A, 2dB
			0.75	2	1	1	A, 4dB, IF
	IN	UV	***1***	1	0	1	IF
			0.6	0.6	0	1	IF
			0.25	***0.25***	1	0	A, 8dB
			5.4	0.4	1	1	A, 2dB, IF
			0.9	0.9	0	1	IF
		DV	1.2	***1.2***	1	0	A, 7dB
			0.5	0.5	0	1	C
			1	***1***	1	0	A, 6dB
T13	KY	UV	1.8	***1.8***	1	0	B, 9dB
		DV	***0.6***	0.6	0	1	SI
			0.4	0.4	0	1	SI
	IN	DV	1.25	***1.25***	1	0	A, 7dB
T14	KY	DV	***1.4***	1.4	0	1	IF
	IN	DV	0.5	***0.5***	1	0	A, 6dB
T15	KY	UV	***1.3***	1.3	0	1	IF
			2.8	2.8	0	1	IF
			0.7	0.7	0	1	IF
		DV	0.75	***0.75***	1	0	A, 2dB
	IN	DV	1	***1***	1	0	B, 9dB
			1	***1***	1	0	B, 11dB
T16	KY	UV	26	0.95	1	1	A, 5dB*, IF
		DV	8.75	***8.75***	1	0	A, 0dB
			0.75	***0.75***	1	0	A, 1dB
			1.5	***1.5***	1	0	A, 6dB
			1	***1***	1	0	B, 8dB
			0.7	0.7	0	1	IF
	IN	UV	9.75	***9.75***	1	0	A, 8dB
		DV	***0.6***	0.6	0	1	IF
T17	KY	UV	2	***2***	1	0	A, 2dB
			4.25	***4.25***	1	0	A, 7dB

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

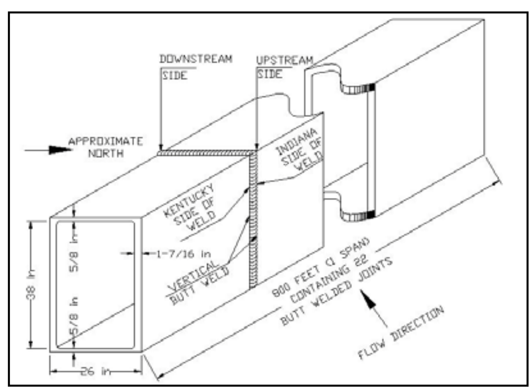
(*Italic,* **Bold**, Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(C) Crack
(SI) Slag Inclusion
(*) Intermittent rejectable Class-A indications by UT at this region

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



DS-2 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
Panel Point	**Side**	**Plate**					
T17	KY	UV	***0.7***	0.7	0	1	IF
			0.3	0.3	0	1	SI
			1	0.45	1	1	A, 4dB, SI
			1.6	1.6	0	1	SI
			2	***2***	1	0	B, 9dB
			2.5	0.1	1	1	A, 8dB, C
		DV	1.25	1.9	1	1	A, 4dB, IF
			1	***1***	1	0	A, 6dB
	IN	DV	1.2	***1.2***	1	0	A, 1dB
T18	KY	UV	***0.2***	0.2	0	1	C
			0.2	0.2	0	1	C
			3.5	***3.5***	1	0	A, 4dB
			3.5	***3.5***	1	0	B, 6dB
			16.5	***16.5***	1	0	A, 4dB
		DV	1.25	***1.25***	1	0	A, 7dB
			1.5	***1.5***	1	0	A, 4dB
	IN	UV	19	***19***	1	0	B, 3dB
		DV	***0.5***	0.5	0	1	C
			7.5	0.3	1	1	A, 2dB, IF
			7.5	1	1	1	A, 2dB, IF
T19	KY	UV	***0.2***	0.2	0	1	SI, P
			0.2	0.2	0	1	SI, P
			0.2	0.2	0	1	SI, P
			0.1	0.1	0	1	VI
			2	***2***	1	0	A, 4dB
		DV	3.25	***3.25***	1	0	A, 5dB
			0.55	0.55	0	1	IF
	IN	UV	3	0.4	1	1	A, 7dB, C
			1.25	0.4	1	1	B, 9dB, C
			1	0.4	1	1	A, 8dB, C
			1.5	***1.5***	1	0	A, 6dB
			1.1	***1.1***	1	0	A, 8dB
			1	***1***	1	0	A, 4dB
			0.4	0.4	0	1	C
		DV	5	***5***	1	0	C, 10dB
			4.5	***4.5***	1	0	B, 9dB
			3	***3***	1	0	B, 0dB
T20	KY	UV	***0.3***	0.3	0	1	IF
			0.4	0.4	0	1	IF
			0.3	0.3	0	1	IF
		DV	1.25	***1.25***	1	0	A, -1dB
			1	***1***	1	0	B, 6dB
			1	***1***	1	0	A, -1dB
			0.5	0.5	0	1	IF
	IN	DV	1	***1***	1	0	A, 5dB
			0.9	0.9	0	1	SI
			0.4	0.4	0	1	SI
			1.75	0.2	1	1	A, 1dB, SI
			1.75	0.2	1	1	A, 1dB, SI
			1.25	***1.25***	1	0	A, -1dB
			1.5	***1.5***	1	0	A, 7dB

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

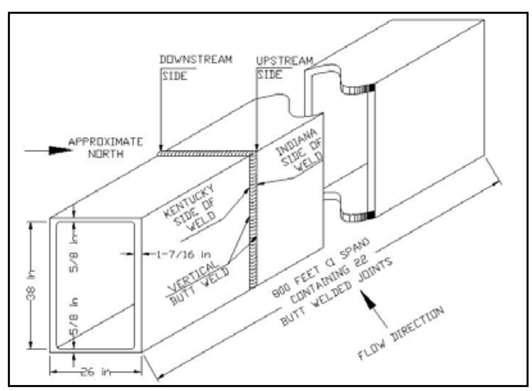
(*Italic,* **Bold**, Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(IF) Incomplete Fusion
(C) Crack
(SI) Slag Inclusion
(P) Porosity
(VI) A volumetric Indication

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



DS-2 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
Panel Point	**Side**	**Plate**					
T21	KY	UV	10.5	0.8	1	1	A, 5dB*, IF
			<u>***0.8***</u>	0.8	0	1	IF
			1.25	***1.25***	1	0	A, -2dB
		DV	2	***2***	1	0	A, 8dB
			3.5	1	1	1	A, 5dB, IF
			1.5	***1.5***	1	0	A, 4dB
			<u>***0.3***</u>	0.3	0	1	IF
	IN	UV	21	***21***	1	0	A, -1dB
			1.5	***1.5***	1	0	A, 8dB
			2.5	***2.5***	1	0	A, 8dB
		DV	1.25	***1.25***	1	0	B, 9dB
			<u>***0.5***</u>	0.5	0	1	CC
L22	KY	UV	1	***1***	1	0	A, 5dB
			1.25	***1.25***	1	0	A, 3dB
			11	***11***	1	0	A, 2dB
			1.75	***1.75***	1	0	A, 1dB
			7	***7***	1	0	A, 1dB
			1.5	***1.5***	1	0	A, 4dB
		DV	1.1	***1.1***	1	0	A, -2dB
			1.25	***1.25***	1	0	A, -2dB
			1.25	***1.25***	1	0	A, 7dB
			0.75	***0.75***	1	0	A, 2dB
			2.75	***2.75***	1	0	A, 0dB
			0.5	***0.5***	1	0	A, 0dB
			1.25	***1.25***	1	0	A, 0dB
			0.5	***0.5***	1	0	A, 6dB

<u>General Notes and Abbreviations:</u>

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

(*Italic,* **Bold**, <u>Underlined</u> format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(IF) Incomplete Fusion
(CC) Crater Crack
(*) Intermittent rejectable Class-A indications at this region detected by UT.

US-2			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
Panel	Side	Plate					
L0	IN	UV	***0.55***	0.55	0	1	TC
			4	***4***	1	0	A, 8dB
			3.75	***3.75***	1	0	A, -1dB
		DV	2.75	***2.75***	1	0	A, 2dB
			8.25	***8.25***	1	0	A, 7dB
			3.5	***3.5***	1	0	A, 4dB
			3.5	***3.5***	1	0	A, 0dB
T1	KY	UV	***0.9***	0.9	0	1	C
			1.2	1.2	0	1	C
		DV	12	***12***	1	0	A, 5dB
	IN	UV	***1.4***	1.4	0	1	GIW
T2	KY	UV	38	***38***	1	0	A, 6dB*
		DV	38	***38***	1	0	A, 1dB*
			38	0.7	1	1	A, 1dB*, IF
	IN	UV	***1.2***	1.2	0	1	SI
			1.3	1.3	0	1	TC
			13.75	0.37	1	1	A, 4dB, IF
			0.4	0.4	0	1	IF
T3	KY	UV	***0.57***	0.57	0	1	IF
		DV	17	***17***	1	0	A, 8dB
T4	KY	UV	0.9	***0.9***	1	0	B, 9dB
			0.6	1.1	1	1	A, 8dB, TC
		DV	1.7	***1.7***	1	0	A, 3dB
			1.44	***1.44***	1	0	A, 8dB
			2.4	***2.4***	1	0	A, 6dB
			2	***2***	1	0	A, -1dB
			2	***2***	1	0	A, 5dB
			1	1	0	1	IF
			3.75	***3.75***	1	0	A, 8dB
	IN	UV	1.5	***1.5***	1	0	A, 2dB
			1.5	***1.5***	1	0	A, 7dB
		DV	10.25	***10.25***	1	0	A, 2dB
T5	KY	UV	1.125	0.6	1	1	A, 4dB, IF
			1.125	***1.125***	1	0	B, 9dB
T6	KY	UV	0.63	***0.63***	1	0	A, 5dB
			0.75	***0.75***	1	0	A, 5dB
			0.63	***0.63***	1	0	A, 8dB
		DV	4.88	***4.88***	1	0	A, 8dB
			0.88	***0.88***	1	0	A, 5dB
	IN	UV	2	***2***	1	0	A, 7dB
			0.5	0.5	0	1	IF
		DV	0.75	***0.75***	1	0	B, 9dB
			0.63	***0.63***	1	0	A, 3dB
T7	KY	DV	***0.5***	0.5	0	1	IF
	IN	DV	3	***3***	1	0	A, 2dB
			3.75	2.4	1	1	A, -4dB, IF, P
			3.75	2.8	1	1	A, -4dB, IF, P
			0.4	0.4	0	1	C
T8	KY	UV	1.4	***1.4***	1	0	A, 3dB
			1.3	***1.3***	1	0	A, 6dB
			2.3	***2.3***	1	0	A, 7dB

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

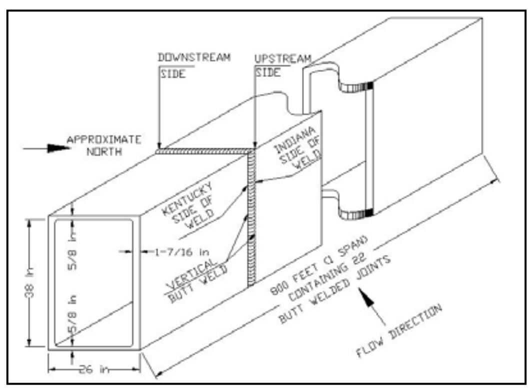
(*Italic*, **Bold**, Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique “hit” or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method “missed” the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(TC) Transverse Crack
(IF) Incomplete Fusion
(C) Crack
(SI) Slag Inclusion
(P) Porosity
(GIW) Gouge in Weld
(*) Intermittent Indications

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



US-2 (Cont'd) Panel Point	Side	Plate	Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
T8	KY	DV	2.8	***2.8***	1	0	A, 7dB
			1.3	***1.3***	1	0	A, 3dB
			2	1.5	1	1	A, 7dB, SI
	IN	DV	2.4	***2.4***	1	0	B, 9dB
			2	***2***	1	0	B, 9dB
			1.1	***1.1***	1	0	A, -5dB
			0.5	***0.5***	1	0	A, 8dB
			0.5	***0.5***	1	0	A, 4dB
			0.8	***0.8***	1	0	B, 9dB
T9	KY	UV	***<u>0.2</u>***	0.2	0	1	C
			<u>0.15</u>	0.15	0	1	LOF
			0.9	***0.9***	1	0	A, 1dB
		DV	1	***1***	1	0	A, -3dB
			0.8	***0.8***	1	0	B, 9dB
			0.9	***0.9***	1	0	A, 0dB
	IN	UV	1.5	***1.5***	1	0	B, 9dB
			1	***1***	1	0	A, 1dB
		DV	1.375	***1.375***	1	0	B, 9dB
			9.5	***9.5***	1	0	A, 4dB
T10	KY	DV	3	***3***	1	0	A, 6dB
			2.6	1	1	1	A, 6dB, IF
			2.6	0.7	1	1	A, 6dB, IF, IP
			1.4	3.6	1	1	A, 7dB, IF, IP
			1.4	3.6	1	1	A, 7dB, IF, IP
			1.4	***1.4***	1	0	A, 6dB
			1.8	***1.8***	1	0	A, 8dB
	IN	UV	***<u>0.2</u>***	0.2	0	1	SI
		DV	1.1	***1.1***	1	0	B, 9dB
			0.9	***0.9***	1	0	A, 6dB
			1.6	***1.6***	1	0	A, 7dB
			1.3	***1.3***	1	0	A, 8dB
			1.6	***1.6***	1	0	A, 4dB
T11	KY	UV	1.3	***1.3***	1	0	A, 8dB
		DV	2.8	***2.8***	1	0	A, 4dB
			1.2	***1.2***	1	0	A, 8dB
			1.3	***1.3***	1	0	A, 8dB
			1	0.2	1	1	A, 8dB, TC
			<u>0.2</u>	0.2	0	1	TC
			<u>0.4</u>	0.4	0	1	TC
			<u>0.4</u>	0.4	0	1	TC
			6.5	***6.5***	1	0	A, 3dB
	IN	UV	1.25	***1.25***	1	0	A, 8dB
		DV	3	***3***	1	0	A, 7dB
			1.25	***1.25***	1	0	A, 7dB
			2.25	***2.25***	1	0	A, 7dB
T12	KY	UV	1.1	***1.1***	1	0	A, 8dB
			0.7	***0.7***	1	0	A, 2dB
		DV	3.9	***3.9***	1	0	A, 3dB
			3.6	***3.6***	1	0	A, 5dB

<u>General Notes and Abbreviations:</u>

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

(*Italic*, **Bold**, <u>Underlined</u> format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

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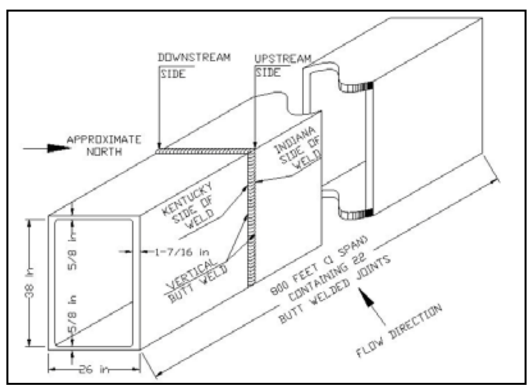
(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(TC) Transverse Crack
(IF) Incomplete Fusion
(C) Crack
(SI) Slag Inclusion
(IP) Incomplete Penetration
(LOF) Lack of Fusion

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



US-2 (Cont'd)							
Panel Point	Side	Plate	Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
T12	KY	DV	1.4	***1.4***	1	0	A, -2dB
	IN	UV	1.1	***1.1***	1	0	A, 7dB
			0.5	***0.5***	1	0	A, 9dB
		DV	1.25	***1.25***	1	0	A, 7dB
T13	KY	UV	1.1	***1.1***	1	0	A, 6dB
		DV	***0.2***	0.2	0	1	SI
			1	0.3	1	1	A, -4dB, SI
			1	0.3	1	1	A, 2dB, SI
			0.9	***0.9***	1	0	A, 4dB
	IN	UV	2.3	***2.3***	1	0	A, 8dB
			0.15	0.15	0	1	SI
			0.2	0.2	0	1	P
		DV	***1.2***	1.2	0	1	IF
			1.25	4.9	1	1	A, 8dB, IF*
			0.4	0.4	0	1	IF
T14	KY	UV	1.3	1	1	1	A, -7dB, IF
			0.6	***0.6***	1	0	A, 5dB
			0.75	***0.75***	1	0	A, 2dB
			0.75	***0.75***	1	0	A, 8dB
			0.15	0.15	0	1	IF
			0.75	0.5	1	1	A, 8dB, C
			15	***15***	1	0	A, 2dB
			1.1	***1.1***	1	0	A, 8dB
			2.1	***2.1***	1	0	A, 5dB
	IN	UV	***0.55***	0.55	0	1	SI
		DV	0.8	***0.8***	1	0	A, 9dB
			1.3	***1.3***	1	0	A, 9dB
			0.75	***0.75***	1	0	A, 7dB
			0.75	***0.75***	1	0	A, 7dB
T15	KY	UV	***0.4***	0.4	0	1	IF
			0.7	0.5	1	1	A, 6dB, C
	IN	UV	0.8	0.75	1	1	A, 5dB, C
		DV	0.7	***0.7***	1	0	A, 6dB
			1	***1***	1	0	A, 7dB
			0.25	0.25	0	1	C
			1	***1***	1	0	A, 8dB
T16	KY	UV	1.8	***1.8***	1	0	B, 9dB
			3	***3***	1	0	A, 6dB
			1	***1***	1	0	A, 5dB
			10.3	***10.3***	1	0	A, 4dB
		DV	1.7	1	1	1	A, 5dB, IF
			0.8	***0.8***	1	0	B, 9dB
			1	***1***	1	0	A, 4dB
	IN	UV	0.7	***0.7***	1	0	A, 4dB
		DV	28.5	***28.5***	1	0	B, 9dB
T17	KY	UV	1	***1***	1	0	A, 8dB
			1	***1***	1	0	A, 5dB
			10.3	***10.3***	1	0	A, 4dB

General Notes and Abbreviations:

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(P) Porosity
(IF) Incomplete Fusion
(C) Crack
(SI) Slag Inclusion
(*) Intermittent Indication

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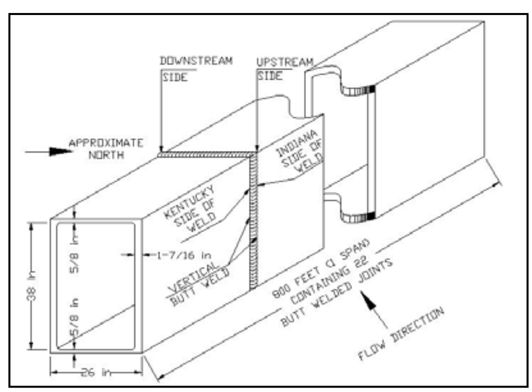


US-2 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
Panel Point	Side	Plate					
T17	KY	DV	1.7	***1.7***	1	0	A, 5dB
			0.8	***0.8***	1	0	B, 9dB
			1	***1***	1	0	A, 4dB
	IN	UV	0.8	***0.8***	1	0	A, 2dB
			0.9	***0.9***	1	0	A, 2dB
			0.65	0.65	0	1	IF
			0.9	***0.9***	1	0	A, 8dB
			1	***1***	1	0	A, 5dB
			1.2	1.2	0	1	IF
		DV	1.25	***1.25***	1	0	B, 9dB
T18	KY	UV	0.8	***0.8***	1	0	B, 9dB
			0.6	***0.6***	1	0	A, 6dB
			0.7	***0.7***	1	0	A, 6dB
			1.7	1.7	0	1	IF
	IN	UV	1.1	***1.1***	1	0	B, 8dB
			1.4	1.4	0	1	IF
			0.4	0.4	0	1	C
T19	KY	UV	1	***1***	1	0	B, 9dB
			3.5	***3.5***	1	0	A, 6dB
			2.5	***2.5***	1	0	A, 4dB
			1	***1***	1	0	B, 9dB
		DV	4.3	***4.3***	1	0	A, 8dB
			0.6	0.6	0	1	IF
	IN	UV	***0.9***	0.9	0	1	IF
			0.75	0.75	0	1	IF
			0.4	0.4	0	1	C
		DV	1.5	***1.5***	1	0	A, 2dB
			1	***1***	1	0	A, 3dB
			1.3	***1.3***	1	0	A, 8dB
T20	KY	DV	0.6	***0.6***	1	0	A, 3dB
	IN	UV	1	0.37	1	1	A, 3dB, SI
			0.75	0.56	1	1	A, 1dB, SI
			0.75	***0.75***	1	0	A, -2dB
			1	1	0	1	SI
			0.25	0.25	0	1	SI
			0.25	0.25	0	1	SI
		DV	***0.5***	0.5	0	1	SI
			1.1	***1.1***	1	0	B, 8dB
			0.6	0.6	0	1	SI
T21	KY	UV	***0.75***	0.75	0	1	TC
			0.75	***0.75***	1	0	A, 8dB
		DV	1	***1***	1	0	A, 8dB
			1.25	***1.25***	1	0	A, 7dB
			1.5	***1.5***	1	0	A, 5dB
	IN	UV	2.3	***2.3***	1	0	A, 7dB
		DV	1	1.5	1	1	A, 7dB, TC
			0.33	0.33	0	1	C
L22	KY	UV	0.5	***0.5***	1	0	A, 6dB
			0.73	0.73	0	1	C

General Notes and Abbreviations:

(*Italic*, **Bold** format) The flaw in the related vertical butt weld location is missed by RT, but UT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by UT in inches.

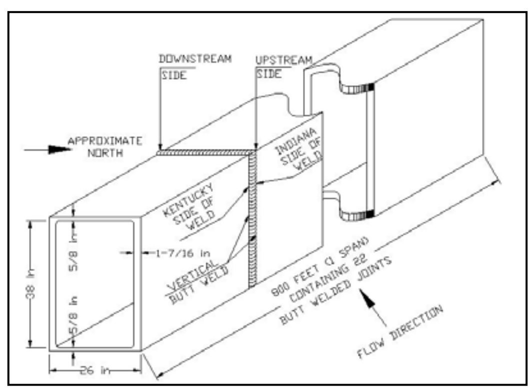
(*Italic,* **Bold**, Underlined format) The flaw in the related vertical butt weld location is missed by UT, but RT picked it and the inspection firm confirmed the existence of the flaw. The attached value shows the measured length by RT in inches.

(1) Binary-based, meaning that the related inspection technique "hit" or detected the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(0) Binary-based, meaning that the related inspection method "missed" the flaw in the specified location (only applicable for H/M UT, and H/M RT columns).

(TC) Transverse Crack
(IF) Incomplete Fusion
(C) Crack
(SI) Slag Inclusion

Typically each T-panel point was supposed to have four and each L-panel point was supposed to have two vertical butt weld locations. Panel points having less than 4 and/or 2 butts in this table mean that they either had no flaws or did not have the confirmation of the inspection firm.



US-2 (Cont'd)			Length (in) UT	Length (in) RT	H/M UT	H/M RT	Flaw Type
Panel Point	Side	Plate					
L22	KY	UV	***0.32***	0.32	0	1	SI
		DV	***0.93***	0.93	0	1	C
			1.7	1.7	0	1	C
			0.75	***0.75***	1	0	A, 4dB
			1.3	1.3	0	1	P
			3	0.92	1	1	B, 6dB, C

(SI) Slag Inclusion
(C) Crack
(P) Porosity

APPENDIX-E: POD CURVES GENERATED BY MH-1823 USING FUNCTIONS OTHER THAN LOGIT

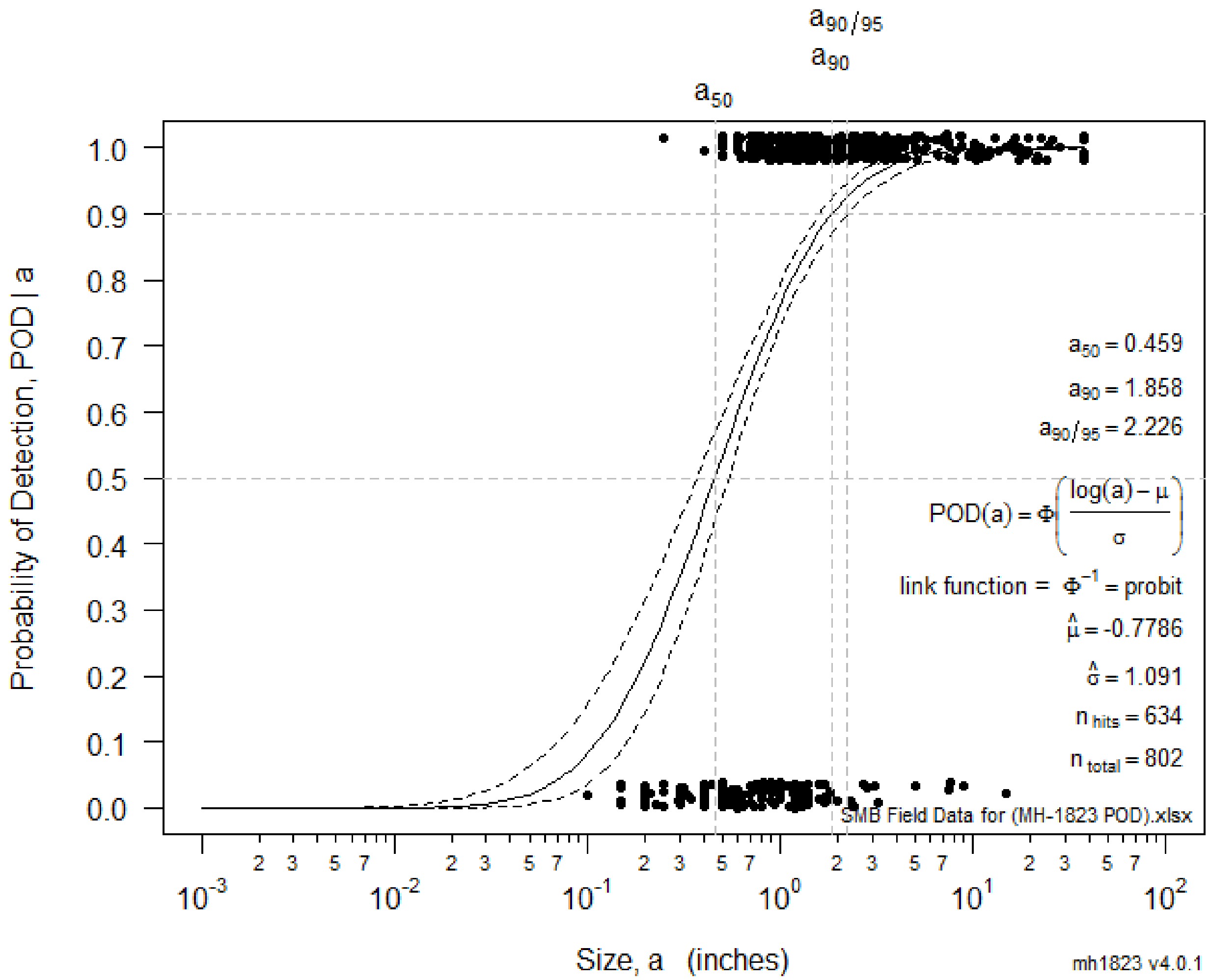


Figure E-1: POD curve based on SMB field UT data using probit function

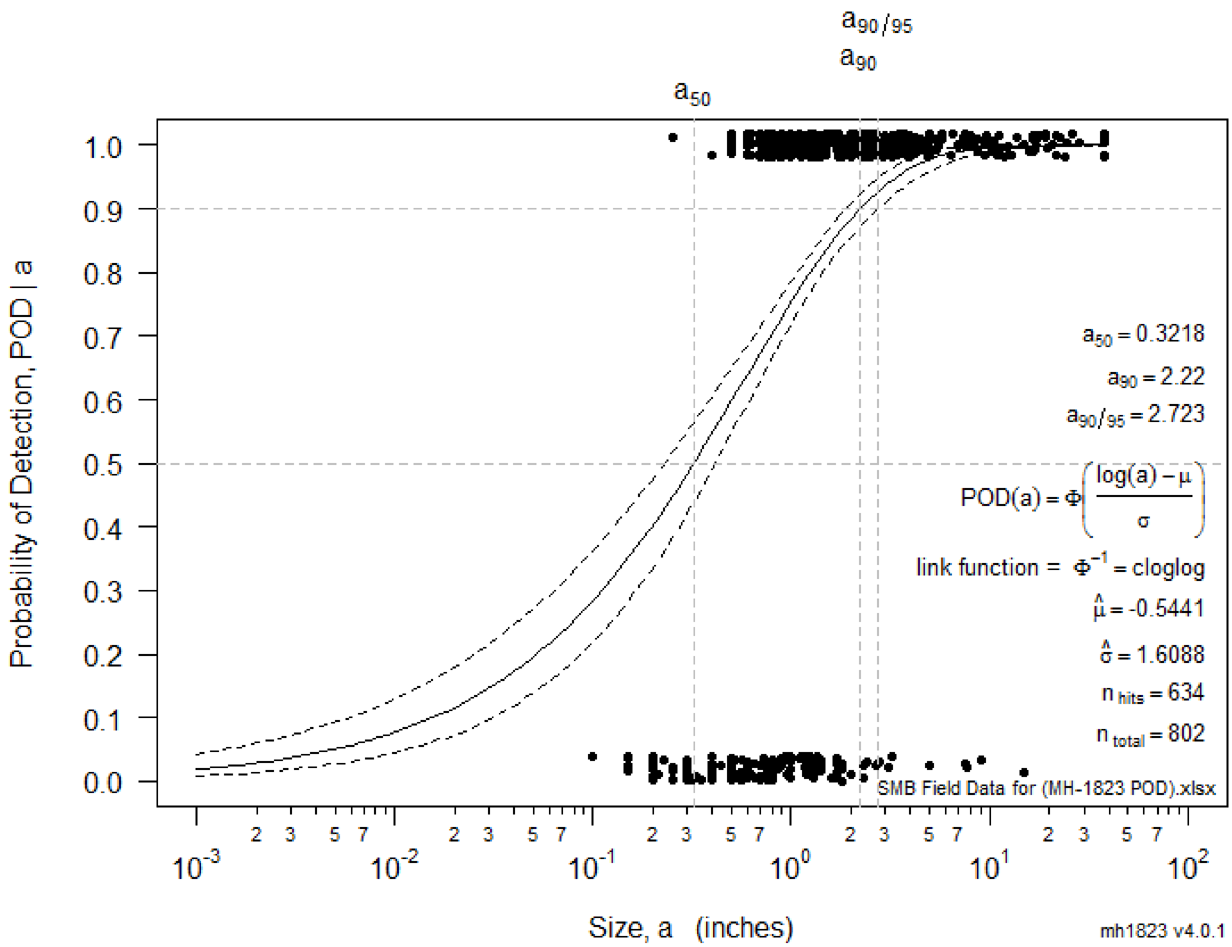


Figure E-2: POD curve based on SMB field UT data using cloglog function

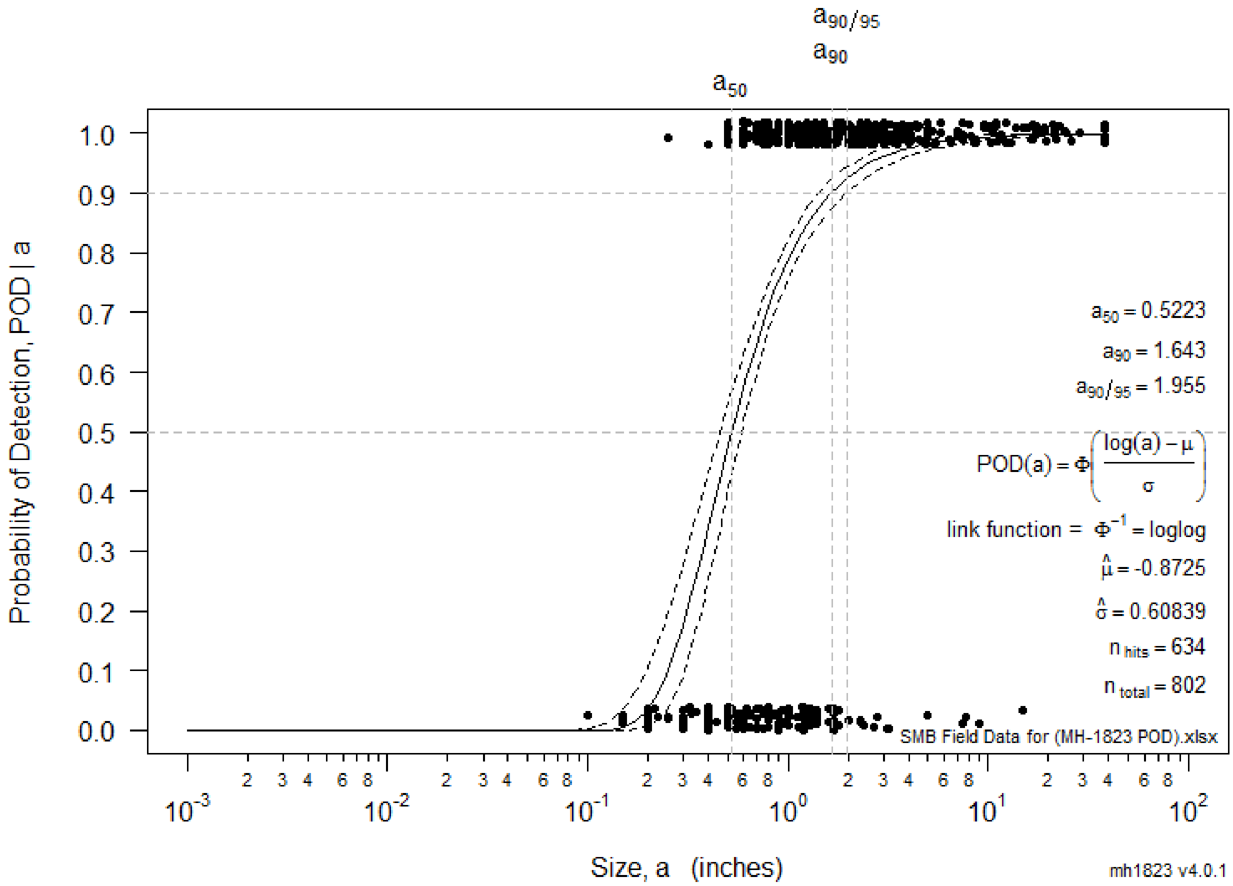


Figure E-3: POD curve based on SMB field UT data using loglog function

APPENDIX-F: FIELD & LAB REPORTS

FOR 21 CORES

CORE #1

Table F1: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #1

Core #1 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %age	Comments
US-1, T17, DV-K **3.7" Dia. Core from Top (21-24")**	MT – PSI	13-16	3	Crack	0	Reject
	RT – ATS	1-15	-	Crack/Porosity	0	Reject
		7	0.9	Transverse Crack	0	Reject
		7	0.4	Crack	0	Reject
		4-6	-	Porosity	0	Reject
		26-28	***1.2***	***Porosity/Inc. Fusion***	***0***	***Reject***
	UT – PSI	10-11.5	1.5	A, 0.79" from surf.	0	Reject
		4-7.5	3.5	A, 0.76" from surf.	0	Reject
		22-33.2	***11.2***	***A, 1.49" from surf.***	***100***	***Reject***
	Visual	-	-	-	-	-
	Core–ATS	***22.34***	***1.61***	***0.62" from surf.***	***NA***	***1Crack, Int. Sur.***

Note: Bold italic rows show the locations corresponded to the core.

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MAGNETIC PARTICLE TESTING REI

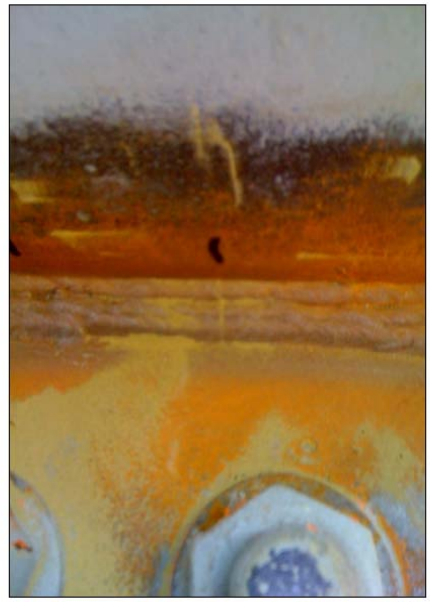
Project: Sherman Minton, Fracture Critical Bridge Inspection **Report No:** 0014672-2 **Contractor/Owner:** INDOT
Quality Requirements: AWS D1.5 - 2008
Weld/Part Location and Identification: Butt Joints (CJP) @ Tie Girder and Fillet Welds @ Lateral Beams & Tie Girder
Pre-Examination Surface Preparation: Media Blast
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 4372
Method of Inspection: Dry, Visible
Media Application: Continuous, AC, Yoke
Direction of Field: Longitudinal

	Interpretation		Repairs		Plate Size	Comments
	Accept	Reject	Accept	Reject		
Date: May 23, 2011 **Tie Girder:** Upstream Span 1 **Panel Point:** T17 (KY) **Weld#:** 3003, 3004, 3005, 5029 Vertical Downstream Web		X				3" Cracked weld between holes, base metal crack. See attached photos (3).

Figure F1. MT report along the Y – axis of the core location

T17, 3003-3004-3005, KY, Downstream Web, Upstream Tie, Span 1

T17, Span 1, 3003-3004-3005, KY, Downstream Web, Upstream Tie



7, Span 1, 3003-3004-3005, KY, Connector Plate for Lateral Beam

Figure F2. Photographs showing Core #1 location

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ULTRASONIC TESTING REPORT

Date: May 23, 2011
Tie Girder: Upstream Span 1
Panel Point: T17 (KY)
Weld#: 3003, 3004, 3005, 5029
Downstream Web

Indication No.	Transducer Angle	From Face	Leg*	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Discontinuity Evaluation	Date	Remarks
				a	b	c	d				From X	From Y			
1	60	A	1	62.3	50.7	7	5	1.5	4.31	.79	-.1	10-11.5	A	5.23.11	
2	60	A	1	54	50.7	1	2.3	3.5	1.48	.76	+1.3	4-7.5	A	5.23.11	
3	60	A	1	49.8	50.7	4	-5	11.2	2.91	1.49	+1.0	22-33.2	A	5.23.11	

Figure F3. PSI-UT report showing 3 class-A cracks along the Y-axis of core #1

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COMPUTED RADIOGRAPHIC INSPECTION REPORT

Job # S172347 PO # WO # Date 9/29/11 Page 1 of 1

CLIENT: **University of Kentucky**
LOCATION: **Sherman Minton Bridge**

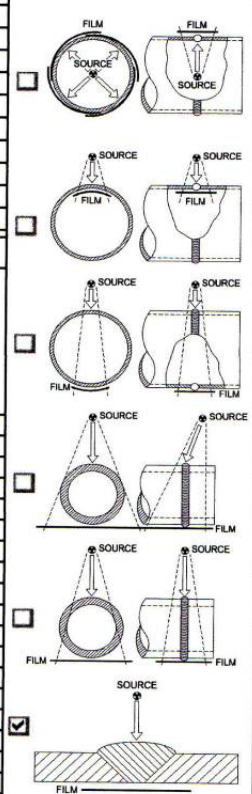
PART NO.: US-S1-T17-KY
PART NAME: Tie Girder
MATERIAL: C/S
THICKNESS: 1.5-2.25
TYPE WELD: BUTT

RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1
Isotope: Ir192
Curies: 96.0
KV: N/A
MA: N/A
Time: 12 min
SFD: 27"
SOD: 25"
OFD: 2"
Source Size (Physical): .126" x .128"
Geometric Unsharpness: 0.013"

Accept/Reject Criteria: AWS D1.5, Figure 6.8
Digital System: Fuji Dynamix Series V
Software Version: VFC1 4.0
IP Type: Fuji ST-VI
Sensitivity: 0.032
Penetrameter: ASTM 1B
Shim(s): N/A
Screen(s): Type Pb Front .010 Back N/A
Focal Size: 0.166
Weld Reinforcement: Ground Flush
Weld Process: N/A

SETUP



SEE ATTACHED SKETCH

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Underout	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US-S1-T17-KY												
UV												
1-15	/											
12-27	/											
25-38	/											
DV												
1-15		X	X			X						Crack b/w stop drill holes
"		X	X									Transverse: 0.9"@7" base metal
"		X	X									Crack: 0.4"@7"
"		X	X									Porosity @ 4"-6"
12-27	/											
23-38		X				X		X				1.2" @ 26"-28"
												Note: Linear Indications are longitudinal with weld except as noted
												Note: Intersecting corner @ top and Bottom of weld has rejectable weld flaws per AWS D1.5. Edge blocks not used

Art.=artifact which is a non-relevant indication

RADIOGRAPHER(S): Jeremy Winkler/Scott Powell Level II RT
INTERPRETER: Jim J. Hills Level III RT

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ATS 120.11, 08/10

Figure F4. ATS Radiographic report for core #1

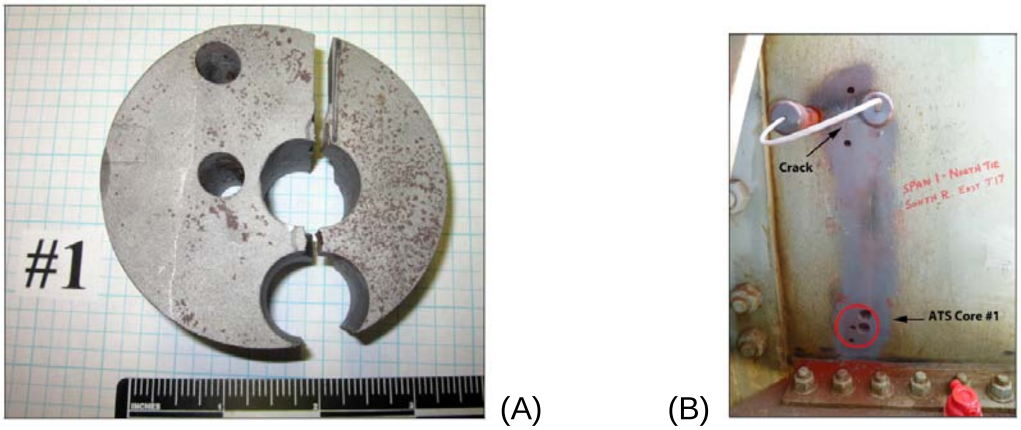


Figure F5. (A) Plan view of the interior surface of the Core #1. (B) Location of Core #1 on the exterior surface of the web

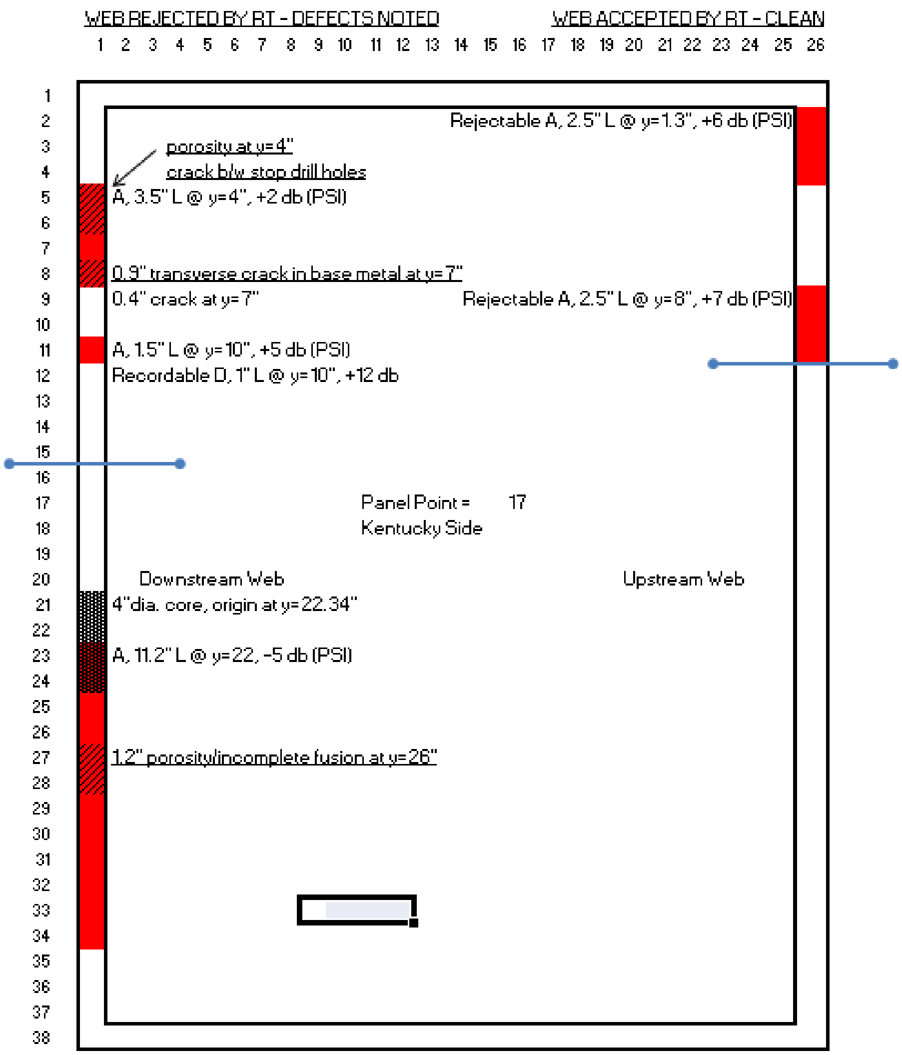
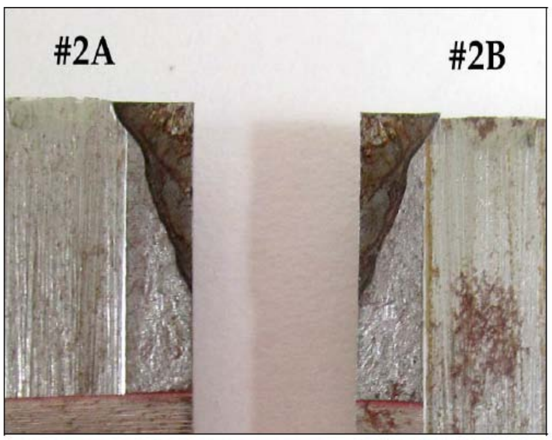


Figure F6. Cross section of the panel point T-17 and core #1 location.

CORES #2 & #3

The locations of these two cores were not specified. Therefore, there are no field data for these cores. Due to their small size it was presumed that those were cores cut at ends of a planar flaw to prevent further growth (i.e. check holes).

The flaw in Core #2 was determined in the lab having length of 0.19 in. Similarly, the flaw in Core #3 was determined in the lab having length of 0.25in. The following pictures show these two cores:



(A)

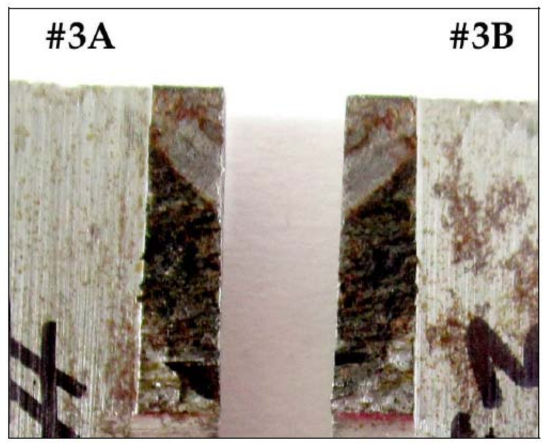
(B)


Figure F7. (A) View of fracture surfaces on Core#2. (B) View of fracture surface on Core#3

CORE #4

Table F2: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #4:

Core #4 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-1, T3, DV-K 3.7" Dia. Core from Top (25-28")	MT – PSI	-	-	-	-	-
	RT – ATS	20-21	0.7	Incomplete Fusion	0	Reject
		26	***0.5***	***Incomplete Fusion***	***100***	***Reject***
	UT – PSI	19.5-22	2.5	A, 0.82" from surf.	0	Reject
	Visual	-	-	-	-	-
	Core–ATS	***26***	***1.125***	***0.31" from surf.***	***NA***	***1Crack, Ext. Sur.***

Note: Bold italic rows show the locations corresponded to the core.

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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton, Fracture Critical Bridge Inspection **Report No:** 0014672-2 **Contractor/Owner:** INDOT
Quality Requirements: AWS D1.5 - 2010
Weld/Part Location and Identification: Butt Joints (CJP) @ Tie Girder and Fillet Welds @ Lateral Beams & Tie Girder
Pre-Examination Surface Preparation: Media Blast
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 4372
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)
Direction of Field: Longitudinal (Circular, Longitudinal)

	Interpretation		Repairs		Plate Size	Comments
	Accept	Reject	Accept	Reject		
Date: June 16, 2011 **Tie Girder:** Upstream Span 1 **Panel Point:** T3 (T2-T3) **Weld#:** 5020 Downstream Web	X*					X* = No rejectable indications were observed. Fails U.T.

Figure F8. PSI MT report showing no crack at Core #4 location

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ULTRASONIC TESTING REPORT

	Indication No.	Transducer Angle	From Face	Leg *	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Discontinuity Evaluation	Date	Remarks
					a	b	c	d				From X	From Y			
Date: June 17, 2011 **Tie Girder:** Upstream Span 1 **Panel Point:** T3 (T2-T3) **Weld#:** 5020 Downstream Web	1	60	A	2	61.3	49.9	6	5	2.5	4.13	.82	-.2	19.5-22	A	6.17.11	Reject

Figure F9. PSI UT report showing once crack at Core #4 location

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COMPUTED RADIOGRAPHIC INSPECTION REPORT

Job # S172347 PO # WO # Date 9/15/11 Page 1 of 1

CLIENT: **University of Kentucky**
LOCATION: **Sherman Minton Bridge**

PART NO.: US.S1.T3.KY
PART NAME: Tie Girder
MATERIAL: C/S
THICKNESS: 1.5-2.25
TYPE WELD: BUTT

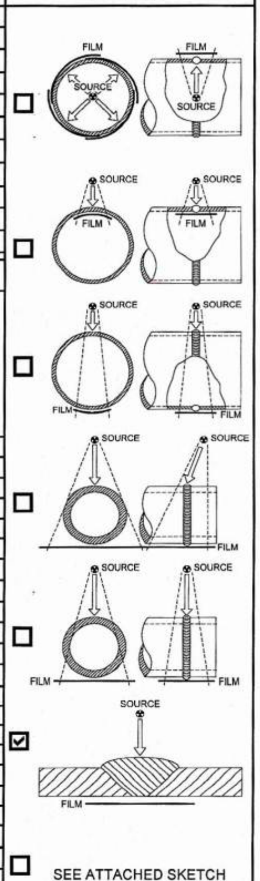
RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1	Accept/Reject Criteria: AWS D1.5
Isotope Ir192	Digital System Fuji Dynamix Series V
Curies 100.0	Software Version VFC1 4.0
KV N/A	IP Type Fuji ST-VI
MA N/A	Sensitivity 0.032
Time 15 min,	Penetrameter ASTM 1B
SFD 27"	Shim(s) N/A
SOD 25"	Screen(s) Type Pb Front .010 Back N/A
OFD 2"	Focal Size 0.166
Source Size (Physical) 0.126 x 0.128	Weld Reinforcement Ground Flush
Geometric Unsharpness 0.013"	Weld Process N/A

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US.S1.T3.KY												
DV RESHOOT												
0-15	/											
8-23		X						X				0.7" long @ 20"-21"
23-38		X						X				0.5" long @ 26"

SETUP



RADIOGRAPHER(S): Scott Powell Level II RT
INTERPRETER: Jim J. Hills Level III RT

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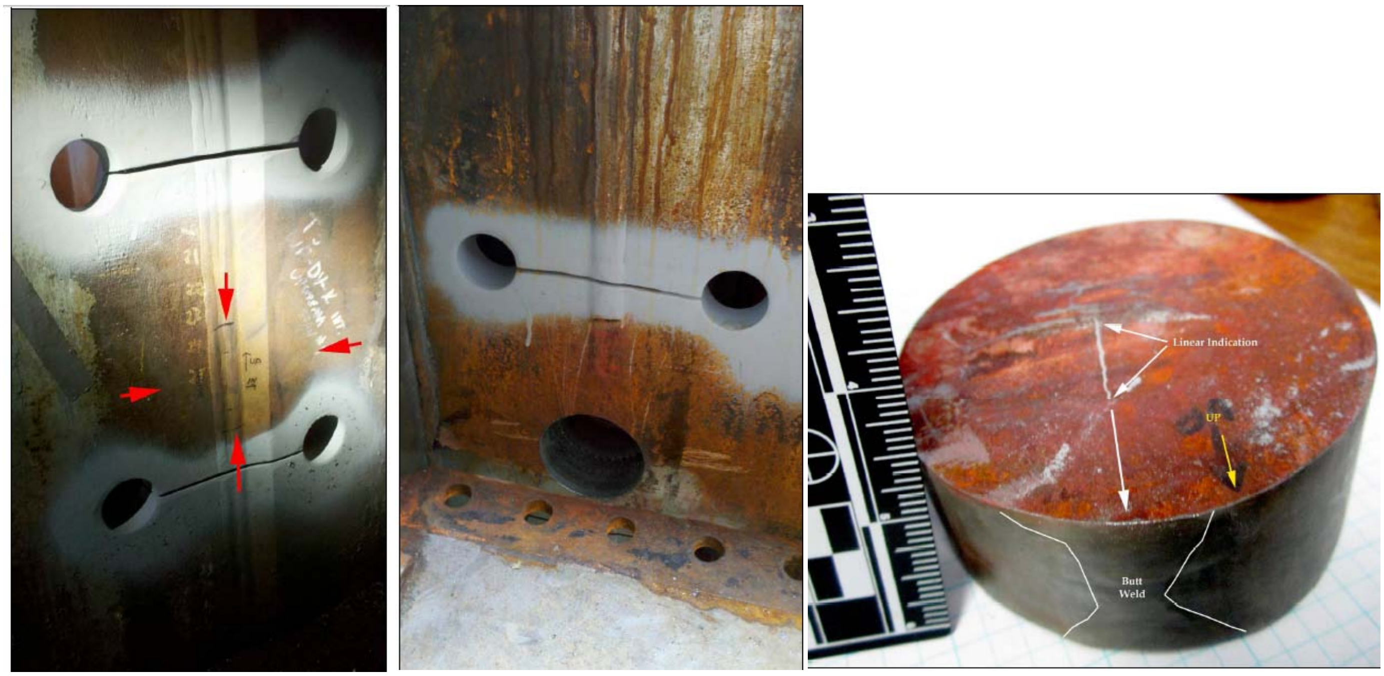
Figure F10. ATS RT report showing one crack at Core #4 location



(A) (B) (C)

Figure F11. (A) Location of Core #4 on the interior surface prior to removal. (B) Location of Core #4 on the exterior surface after removal. (C) Longitudinal crack on the vertical butt weld on the exterior surface.

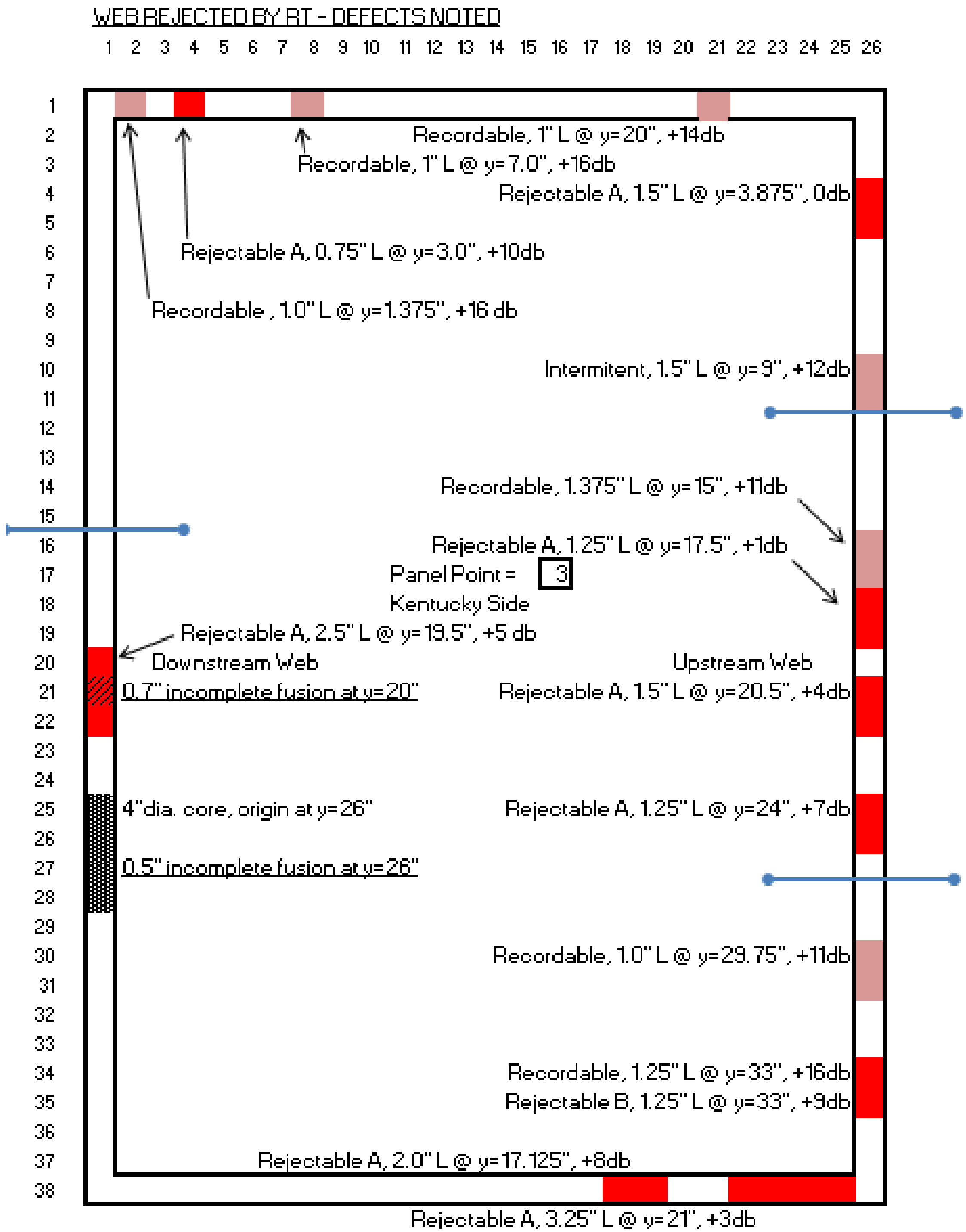


Figure F12. Cross section of the panel point T-3 and Core #4 location on the downstream web.

CORE #5

Table F3: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #5:

Core #5 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %age	Comments
DS-2, T9, UV-K 2.62” Dia. Core from Top (4”)	MT – PSI	-	-	-	-	-
	RT – ATS	***4-5***	***1.00***	***Crack***	***83***	***Reject***
		13-18	3.20	Crack	0	Reject
		20-22	1.70	Crack	0	Reject
		24	0.40	Crack	0	Reject
	UT – PSI	31.75	1.00	B, 0.52” from surf.	0	Reject
	Visual	13.12	0.25	Transverse crack	0	Reject
	Core–ATS	***4***	***1.20***	***0.225” from Int. 0.360” from Ext.***	***NA***	***1Crack, Sub Sur.***

FISH & ASSOCIATES, INC. *Partners in Structural Solutions*

MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton Bridge **Report No:** #T9 Downstream Span 2 **Contractor/Owner:** Indiana DOT
Quality Requirements: ASTM A403 and AWS D1.5 Section 6 and Section 12
Weld/Part Location and Identification: WP-(DV/UV)-K EXT/INT
Pre-Examination Surface Preparation: Needle Scaler finished with Flapper Wheel
Equipment: **Instrument Make:** Parker **Model:** B300 **Serial No:** 6809
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)

Direction of Field: Longitudinal (Circular, Longitudinal)

Date: 9-15-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Downstream Span 2 Panel Point: T9 Weld#: WP (UV-K) - INT	X				1.80" (I) 1.40" (K)	No relevant indications
Visual Inspection		X				Transverse Crack Length=0.25", Y=13.12"

Date: 9-15-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Downstream Span 2 Panel Point: T9 Weld#: WP (UV-K) - EXT	X				1.80" (I) 1.40" (K)	No relevant indications
Visual Inspection	X					Acceptable

Figure F13. Fish MT report showing no relevant indications at Core #5 location

FISH & ASSOCIATES, INC.

Partners in Structural Solutions

ULTRASONIC TESTING REPORT

Date: 9-15-11 Tie Girder: Downstream Span 2 Panel Point: T9 Weld#: WP (UV-K) – EXT Note: Lamination scan acceptable	Indication No.	Transducer Angle	From Face	Leg *	Indication Level a	Reference Level b	Attenuation Factor c	Indication Rating D	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Remarks
	1	70	A	1	52	42	1	9	1.0"	1.5"	0.52"	-0.3"	31.75"	Rejectable indication (Class B)

Date: 9-15-11 Tie Girder: Downstream Span 2 Panel Point: T9 Weld#: WP (DV-K) - EXT Note: Lamination scan acceptable	Indication No.	Transducer Angle	From Face	Leg *	Indication Level a	Reference Level b	Attenuation Factor c	Indication Rating D	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Remarks
	1	70	A	1	38	42	3	-7	2.5"	2.7"	0.9"	0.6"	3.25"	Rejectable indication (Class A)

We the undersigned, certify that the statements in this record are correct and that the welds were prepared and tested in accordance with the requirements of Sectio of AASHTO/ AWS D1.5, Yr. 2010, Bridge Welding Code.

* Use Leg I, II, or III

Signed

Larry Hickman
ASNT Lev II

Figure F14. Fish final UT report showing no relevant indication at the Core #5 location

<u>Note:</u>

The locations, in this report, are not consistenet. Downstream Vertical (DV) is, actually, Upstream Vertical, and vice versa. Considering the DS2 T9 DV-K location, which is actually DS2 T9 UV-K, 2.5 in crack at the core #5 location was found. This labeling error was found out after thorough review of the final reports during this research and personal contact with the FISH & Associates, Inc.

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COMPUTED RADIOGRAPHIC INSPECTION REPORT

Job # S172347 PO # WO # Date 9-20-11 Page 1 of 1

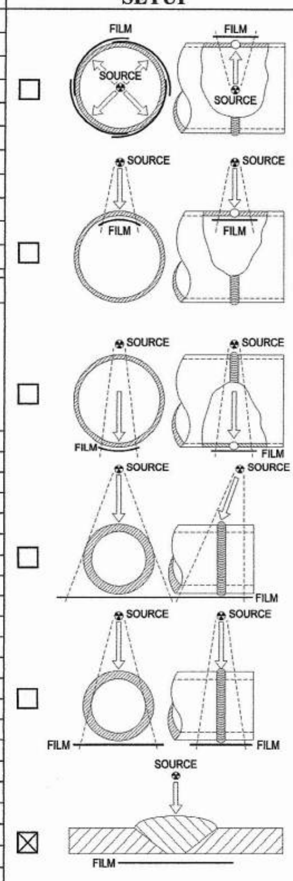
CLIENT: **University of Kentucky**
LOCATION: **Sherman Minton Bridge**

PART NO.: DS-S2-T9-KY
PART NAME: Tie Girder
MATERIAL: C/S
THICKNESS: 1.5"- 2.25"
TYPE WELD: BUTT

RADIOGRAPHIC INSPECTION TECHNIQUE

Specification(s):	ATS 120.19 Rev. 1	Accept/Reject Criteria:	AWS D1.5, Figure 6.8
Isotope	Ir192	Digital System	Fuji Dynamix Series V
Curies	98	Software Version	VFCI 4.0
KV	N/A	IP Type	Fuji ST-VI
MA	N/A	Sensitivity	ASTM 1B
Time	12 min	Penetrameter	0.032
SFD	27"	Shim(s)	N/A
SOD	25"	Screen(s)	Type: Pb Front: X Back:
OFD	2"	Focal Size	0.166
Source Size (Physical)	.126" x .128"	Weld Reinforcement	0.125" or Ground Flush
Geometric Unsharpness	0.013"	Weld Process	N/A

SETUP



☐ SEE ATTACHED SKETCH

INTERPRETATION

PART I.D./ FILM VIEW	Accept	Reject	Crack	Slag Inclusion	Tungsten Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
DS-S2-T9-KY												
UV												
1-16		X	X									1" @ 4"-5" IN HAZ
12-26	/											
30-36	/											
32-37		X	X									
DV												
1-16	/											
12-27		X	X									3.2" @ 13"-18", 1.7" @ 20"-22" *
23-37	/							/				0.4" @ 24"
					☐							
												* Recommend Grind Flush &
												Re-X-Ray
												Note: Intersecting corner @ top and
												Bottom of weld has rejectable weld
												flaws per AWS D1.5

RADIOGRAPHER(S): Dave Storey/Scott Powell Level II R.T.

INTERPRETER: Jim J Hills Level III R.T.

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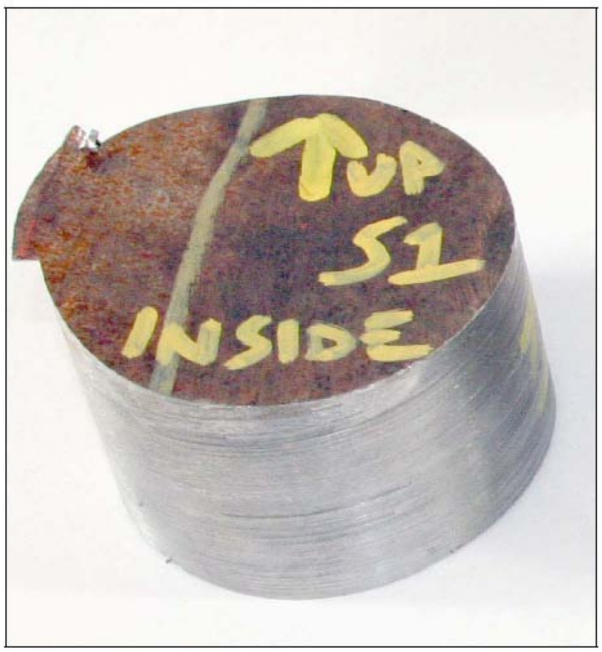
ATS120.11, 08/10

Figure F15. ATS RT report showing one crack at the Core #5 location

(A)

(B)



(C)

Figure F16. (A) Core #5 on the interior surface. (B) Core #5 on the exterior surface. (C) Oblique view of the core #5 on the interior surface

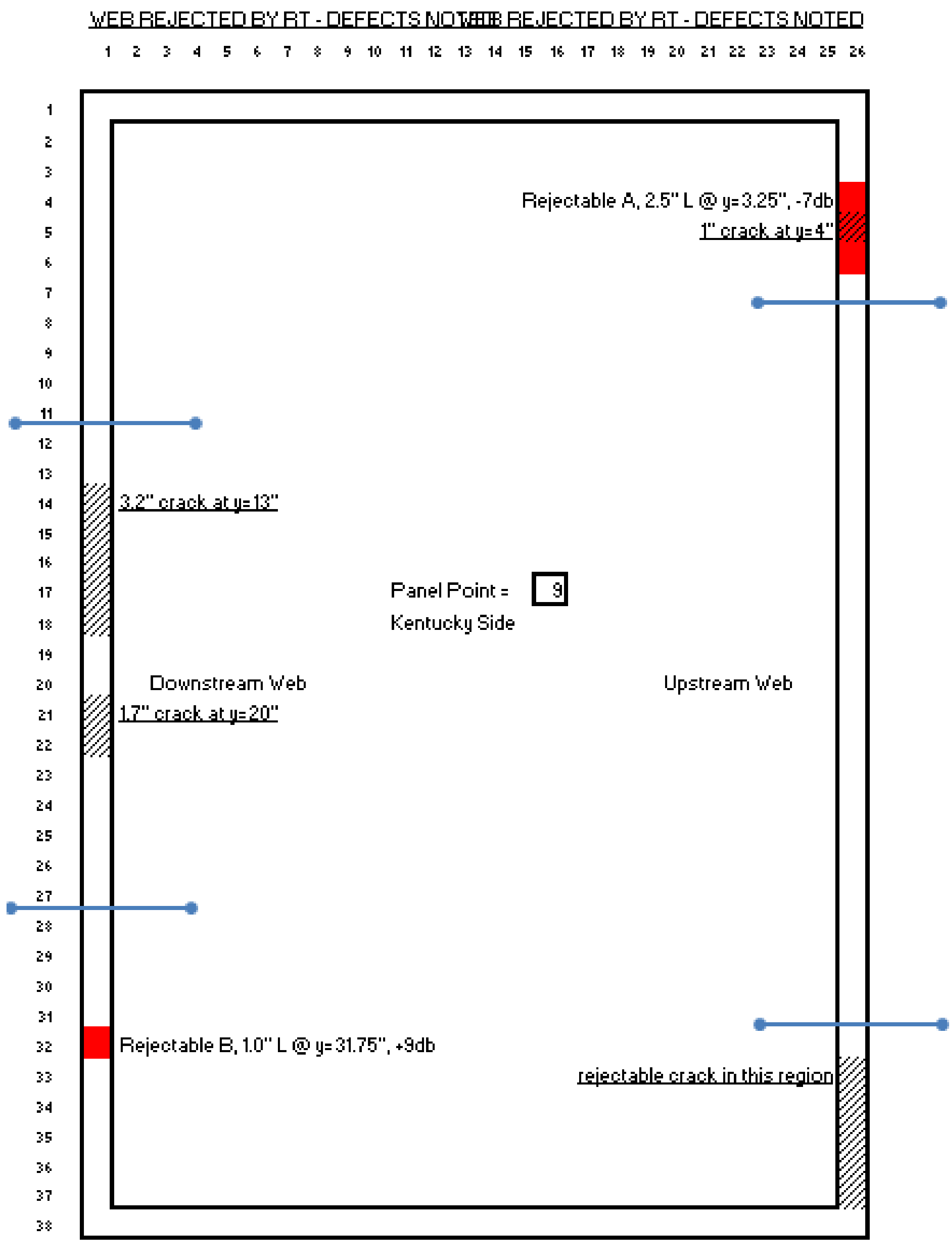


Figure F17. Cross section of the panel point T9 and Core #5 location

CORE #6

Table F4: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #6:

Core #6 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %age	Comments
DS-2, T14, DV-K **2.62” Dia. Core from Top (21”)**	MT – PSI	-	-	-	-	-
	RT – ATS	***21***	***1.40***	***Incomplete Fusion***	***0***	***Reject***
	UT – PSI	-	-	-	-	-
	Visual	-	-	-	-	-
	Core–ATS	***NA***	***NA***	***NA***	***NA***	***No Flaw***

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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton, Fracture Critical Bridge Inspection **Report No:** 0014672-2 **Contractor/Owner:** INDOT
Quality Requirements: AWS D1.5 - 2008
Weld/Part Location and Identification: Butt Joints (CJP) @ Tie Girder and Fillet Welds @ Lateral Beams & Tie Girder
Pre-Examination Surface Preparation: Media Blast
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 4372
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)
Direction of Field: Longitudinal (Circular, Longitudinal)

	Interpretation		Repairs		Plate Size	Comments
	Accept	Reject	Accept	Reject		
Date: July 28, 2011 **Tie Girder:** Downstream Span 2 **Panel Point:** T14 (T13-T14) **Weld#:** 6013 – 4 Sides Top, Bottom and Both Webs	X					

Figure F18. PSI MT report showing no flaws at the Core #6 location

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ULTRASONIC TESTING REPORT

	Indication No.	Transducer Angle	From Face	Leg*	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Discontinuity Evaluation	Date	Remarks
					a	b	c	d				From X	From Y			
Date: July 28, 2011 **Tie Girder:** Downstream Span 2 **Panel Point:** T14 (T13-T14) **Weld#:** 6013 Top, Bottom and Both Webs	---	---	---	---	---	---	---	---	---	---	---	---	---	---	7.28.11	No rejectable indications were observed.

Figure F19. PSI UT report showing no flaws at the Core #6 location

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COMPUTED RADIOGRAPHIC INSPECTION REPORT

Job # S172347 PO # WO # Date 9/17/11 Page 1 of 1

CLIENT: **University of Kentucky**
LOCATION: **Sherman Minton Bridge**

PART NO.: DS.S2.T14.KY
PART NAME: Tie Girder
MATERIAL: C/S
THICKNESS: 1.5-2.25
TYPE WELD: BUTT

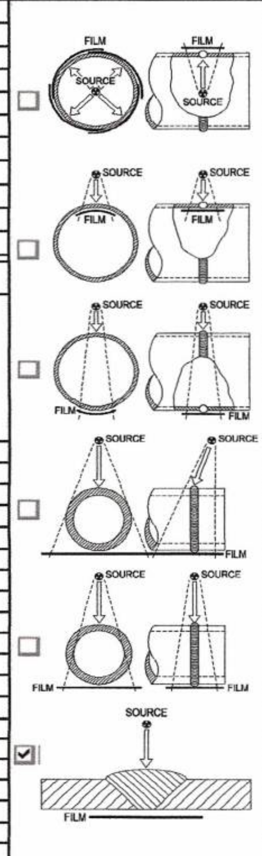
RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1	Accept/Reject Criteria: AWS D1.5, Figure 6.8
Isotope Ir192	Digital System Fuji Dynamix Series V
Curies 98.0	Software Version VFC1 4.0
KV N/A	IP Type Fuji ST-VI
MA N/A	Sensitivity 0.032
Time 12 min	Penetrameter ASTM 1B
SFD 27"	Shim(s) N/A
SOD 25"	Screen(s) Type Pb Front .010 Back N/A
OFD 2"	Focal Size 0.166
Source Size (Physical) .126" x .128"	Weld Reinforcement Ground Flush
Geometric Unsharpness 0.013"	Weld Process N/A

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Underout	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
DS.S2.T14.KY												
UV												
1-15	/											
12-26	/											
23-37	/											
DV												
1-15	/											
12-26		X						X				1.4" long @ 21"-23"
23-37	/											

SETUP

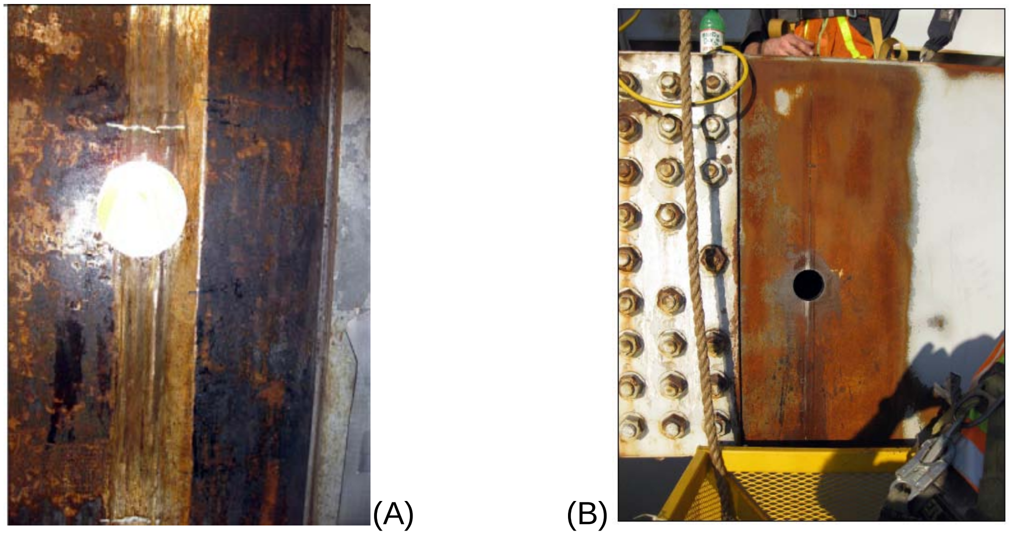


SEE ATTACHED SKETCH

RADIOGRAPHER(S): Dave Storey /Scott Powell Level II RT
INTERPRETER: Jim J. Hills Level III RT

ATS 120.11, 08/10

Figure F20. ATS RT report showing an incomplete fusion at the Core #6 location



(A) (B)

Figure F21. (A) Core #6 on the interior surface of the web. (B) Core #6 on the exterior surface of the web.

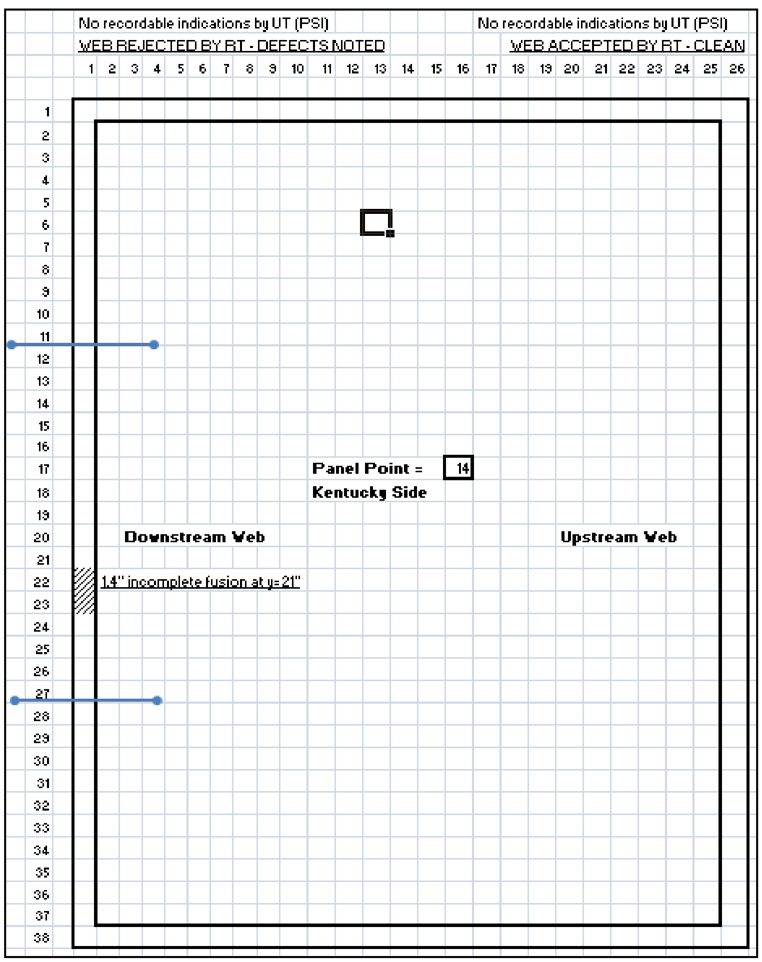


Figure F22. Cross section of the panel point T-14 and the Core #6 location

CORE #7

Table F5: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #7:

Core #7 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %age	Comments
US-1, T8, UV-I 3.72" Dia. Core from Top (26")	MT – PSI	-	-	-	-	-
	RT – ATS	-	-	-	-	-
	UT – PSI	***25.5-28***	***1.625***	***A, 0.8 from surf.***	***0***	***Reject***
	Visual	-	-	-	-	-
	Core–ATS	***NA***	***NA***	***NA***	***NA***	***No Flaw***

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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton, Fracture Critical Bridge Inspection **Report No:** 0014672-2 **Contractor/Owner:** INDOT
Quality Requirements: AWS D1.5 - 2010
Weld/Part Location and Identification: Butt Joints (CJP) @ Tie Girder and Fillet Welds @ Lateral Beams & Tie Girder
Pre-Examination Surface Preparation: Media Blast
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 4372
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)
Direction of Field: Longitudinal (Circular, Longitudinal)

	Interpretation		Repairs		Plate Size	Comments
	Accept	**Reject**	**Accept**	**Reject**		
Date: June 14 & 16, 2011 **Tie Girder:** Upstream Span 1 **Panel Point:** T8 (T8-T9) **Weld#:** 6007 – 4 sides Upstream Web	X*					X* = No rejectable indications were observed. Fails U.T.

Figure F23. PSI MT report showing no flaw at the Core #7 location

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ULTRASONIC TESTING REPORT

Date: June 14, 2011
Tie Girder: Upstream Span 1
Panel Point: T8 (T8-T9)
Weld#: 6007 – 4 Sides
Top Face (Indication No. 1-5)
Upstream Web (Indication No. 1)

Indication No.	Transducer Angle	From Face	Leg*	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Discontinuity Evaluation	Date	Remarks
				a	b	c	d				From X	From Y			
1	70	A	1	59.4	50.5	1	8	2.5	1.3	.42	-.3	8-10.5	A	6.14.11	Reject
2	70	A	1	59.9	50.2	4	6	2.7	2.98	.04	-.6	11-13.7	A	6.14.11	Reject
3	70	A	1	61.8	50.2	4	8	1.7	3.01	.03	-.3	12.3-14	A	6.14.11	Reject
4	70	A	1	63.2	50.2	3	10	2.2	2.63	.15	-.6	17.6-19.8	C	6.14.11	Reject
5	70	A	1	63.6	50.2	2	11	2.0	2.05	.34	-.6	5.8-7.8	D	6.14.11	Reject
1	70	A	1	52.3	50.5	3	-1	---	2.46	.80	.2	25.5-28	A	6.14.11	Reject

Figure F24. PSI UT Report showing a crack at the Core #7 location

RADIOGRAPHIC INSPECTION TECHNIQUE

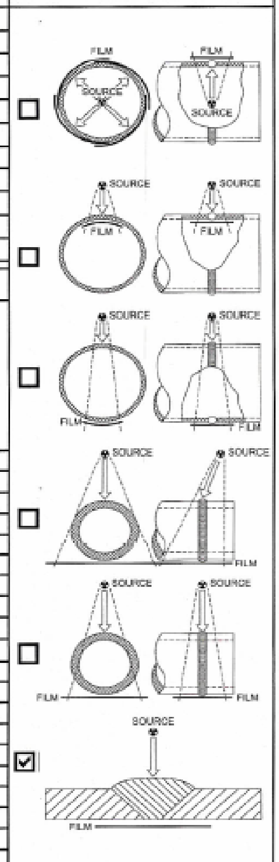
Specifications: ATS 120.19 Rev. 1
Isotope Ir192
Curies 100.0
KV N/A
MA N/A
Time 15 min,
SFD 27"
SOD 25"
OFD 2"
Source Size (Physical) 0.126 x 0.128
Geometric Unsharpness 0.013"

Accept/Reject Criteria: AWS D1.5
Digital System Fuji Dynamix Series V
Software Version VFC1 4.0
IP Type Fuji ST-VI
Sensitivity 0.032
Penetrameter ASTM 1B
Shim(s) N/A
Screen(s) Type Pb Front .010 Back N/A
Focal Size 0.166
Weld Reinforcement Ground Flush
Weld Process N/A

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungsten Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US.S1.T8.IN												
UV												
1-15	/											
12-27	/											
23-38	/											
DV												
1-15	/											
12-27	/											
23-38	/											

SETUP



SEE ATTACHED SKETCH

Figure F25. ATS RT report showing no flaw at the Core #7 location

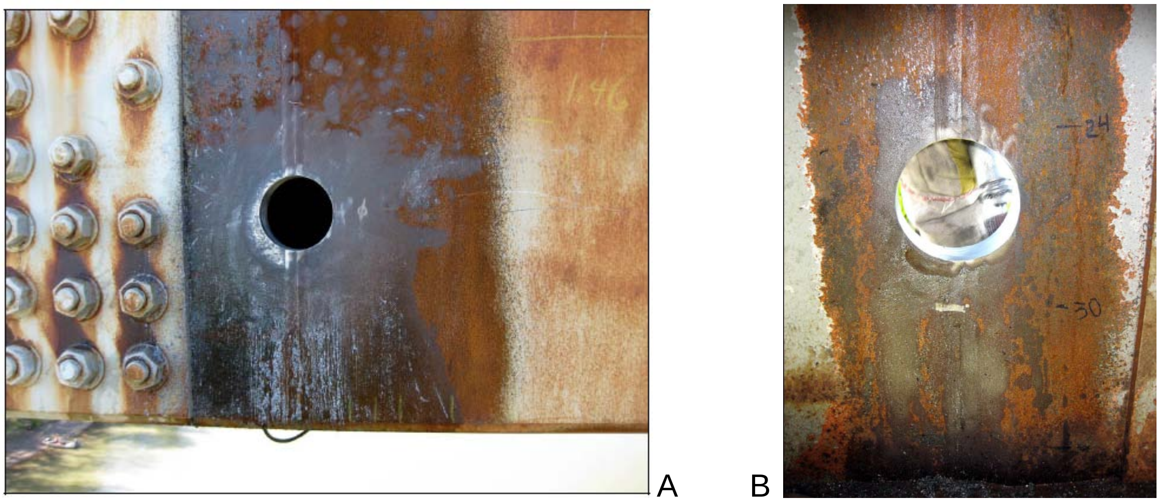


Figure F26. (A) Core #7 location on exterior face. (B) Core #7 location on interior face.

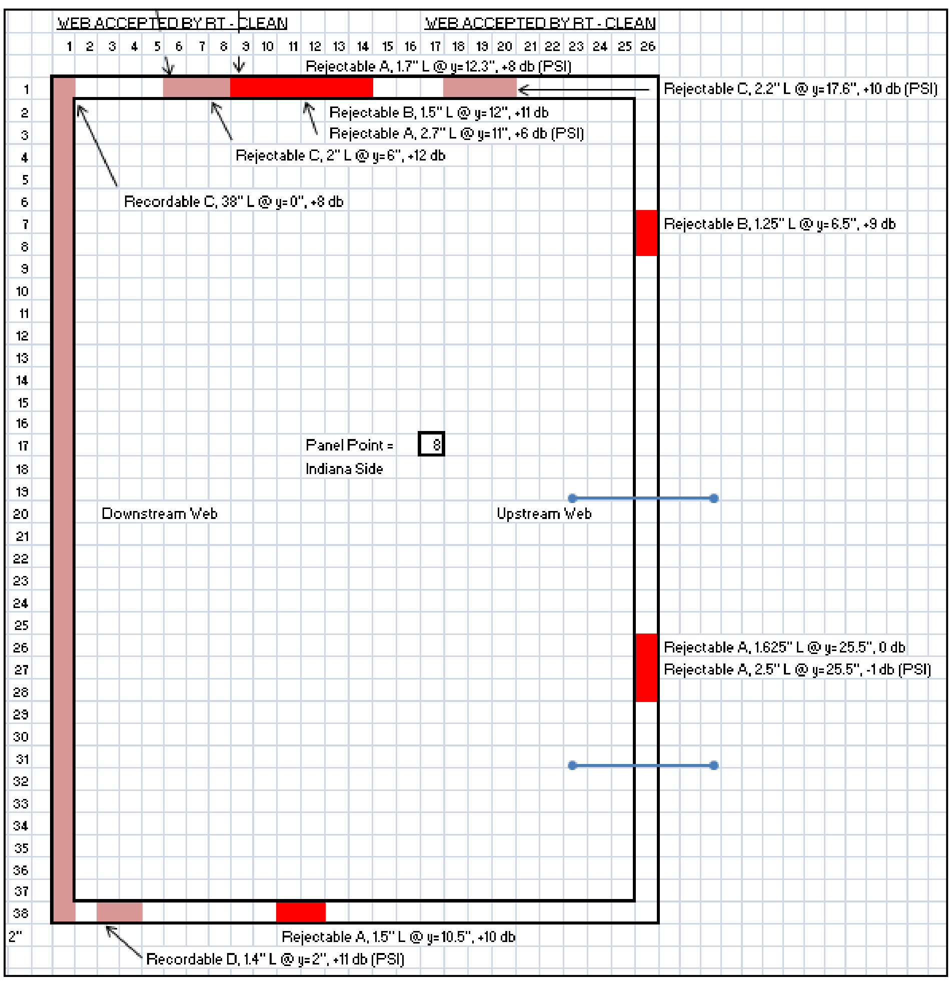


Figure F27. Cross section of panel point T8 and the Core #7 location

CORE #8

Table F6: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #8:

Core #8 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
DS-1, T5, UV-I 2.62" Dia. Core from Top (26")	MT – PSI	***8.375****	***1.25***	***0.75" from surf.***	***100***	***Reject***
		9.25*	***0.50***	***Behind gusset plate***	***100***	***Reject***
	RT – ATS	-	-	-	-	-
	UT – PSI	0.00	4.25	A, 0.75" from surf.	0	Reject
		8.13	1.38	A, 1.23" from surf.	0	Reject
		32.88	1.25	D, 0.96" from surf.	0	Record
		6.25	1.25	A, 0.70" from surf.	0	Reject
	Visual	-	-	-	-	-
	Core–ATS	***Approx. 26"***	***0.68***	***Ext. Surface Flaw***	***NA***	***3 Flaws Ext. Surface***
			0.26	***Ext. Surface Flaw***	***NA***	
			0.49	***Ext. Surface Flaw***	***NA***	

(*) Measured from the bottom of the web plate corresponding to location of Core #8

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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton Bridge **Report No:** # T5 Downstream Span 1 **Contractor/Owner:** Indiana DOT
Quality Requirements: ASTM A403 and AWS D1.5 Section 6 and Section 12
Weld/Part Location and Identification: WP-(DV/UV)-I EXT/INT
Pre-Examination Surface Preparation: Needle Scaling finished with Flapper Wheel
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 10894
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)

Direction of Field: Longitudinal (Circular, Longitudinal)

Date: 9-28-2011	Interpretation Accept	Interpretation Reject	Repairs Accept	Repairs Reject	Plate size	Comments
Tie Girder: Downstream Span 1 Panel Point: T5 Weld#: WP (UV-I) - EXT	X				1.44" (I) 1.83" (K)	No relevant indications
Visual Inspection	X					Acceptable

Date: 9-28-2011	Interpretation Accept	Interpretation Reject	Repairs Accept	Repairs Reject	Plate size	Comments
Tie Girder: Downstream Span 1 Panel Point: T5 Weld#: WP (UV-I) - INT	X				1.44" (I) 1.83" (K)	No relevant indications
Visual Inspection		X				Underfill

Figure F28. FISH MT Report showing no flaws on the Core #8 location

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Ultrasonic Testing Report

Date: 9-27-2011
Tie Girder: Downstream Span 1
Panel Point: T5
Weld#: WP (UV-I) - EXT

Indication No.	Transducer Angle	From Face	Leg *	Indication Level a	Reference Level b	Attenuation Factor C	Indication Rating D	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Remarks
1	70	A	1	63	57	2	4	4.25"	2.21"	0.75"	0	0	Rejectable indication (Class A)
2	70	A	I	67	57	5	5	1.38"	3.6"	1.23"	0.125"	8.13"	Rejectable indication (Class A)
3	70	A	1	76	57	4	15	1.25"	2.8"	0.96"	0	32.88"	Recordable indication (Class D)
4	70	A	1	63	57	2	4	1.25"	2.05"	0.7"	-0.13"	6.25"	Rejectable indication (Class A)

Note: Lamination scan acceptable

Crack in web plate that was found with MT after removal of gusset plate was evaluated. There are two cracks: 1st crack 8 3/8" from face of floor beam web and is 1 ¼" long ¾" is on the surface as reported, 2nd crack is 9 ¼" from face of floor beam is approx. ½" long directly behind gusset plate weld.

Figure F29. FISH UT Report showing no flaws on the Core #8 location

HESCO a division of PTSE. Inc
2501 Monarch St., Alameda, CA 94501, mailing P.O. Box 216, Alameda, CA 94510
Ph#510-523-9488, Fax 510-523-9486, website: www.hescoxray.com

RADIOGRAPHIC INSPECTION REPORT

Job No INT A249-11-320702 **PO#** **WO#** **DATE**

Customer: Michael Baker Jr. Inc.
888 Keystone Crossing,
Suite 1300
Indianapolis, IN 46240

Location: Sherman Minton Bridge
Indiana/Kentucky across the Ohio River

Radiographers:
John Powis Level II
Mike DePinna Level II
Richard Seals Level III

Part ID/ View No	RT REF # on film	Accept	Reject	Trans to Girders	Transverse Crack	Longitudinal Crack	Slag Inclusion	Porosity	Undercut	Incomplete Fusion	Artifact	Remarks
DS-S1-T5-IN												RT Date
INUV TOP	J1	X										26-Sep-11
MID	J1	X										26-Sep-11
BTM	J1	X										26-Sep-11
INDV TOP	J2	X										26-Sep-11
MID	J2	X										26-Sep-11
BTM	J2	X										26-Sep-11

Part Name: Tie Girder	**Weld Type:** Bittweld	**SOD:**	**Shim:** N/A	**Sensitivity:** .032
Specifications: HESCO RT-12 REV/2	**Source:** 6 Mev	**Acceptance Standard:** AWS D1.5 fig 6.8	**Screens: Type:** Pb **Front/Back:** .010	
Material: carbon steel	**Focal Spot Size:** 1.8mm	**Geometric Unsharpness:**	**Film Type:** Fuji 50	
Thickness: 1 1/2 - 2 1/4	**SFD:** 12ft/14ft	**Penetrameter:** AWS 1B	**Size:** 14 x 17	1

Figure F29A. HESCO RT Report showing no flaws on the Core #8 location

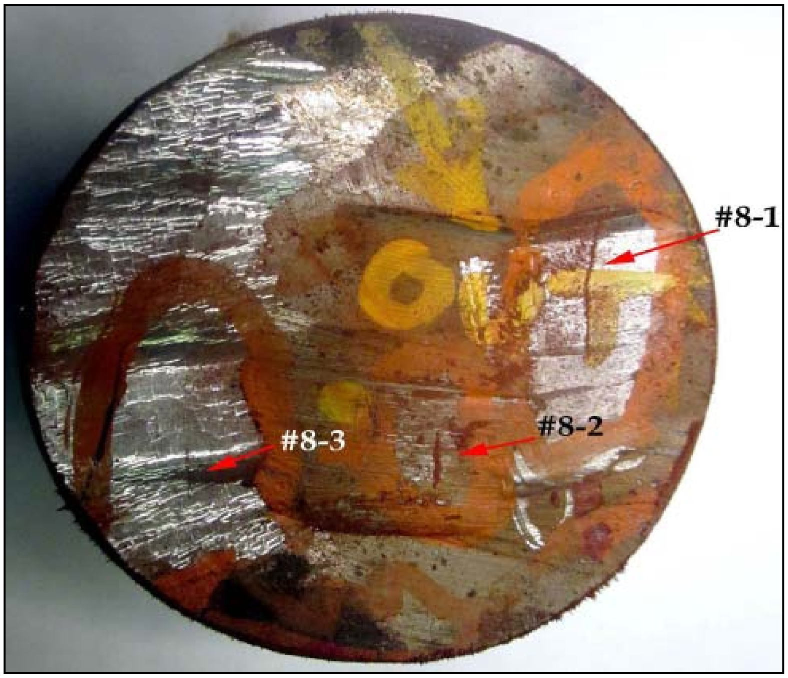

Figure F30. Three vertical cracks found by ATS lab MT method at the Core #8

(A) **(B)**

Figure F31. (A) Core #8 location on the exterior face. (B) Core #8 location on the interior face of web plate.

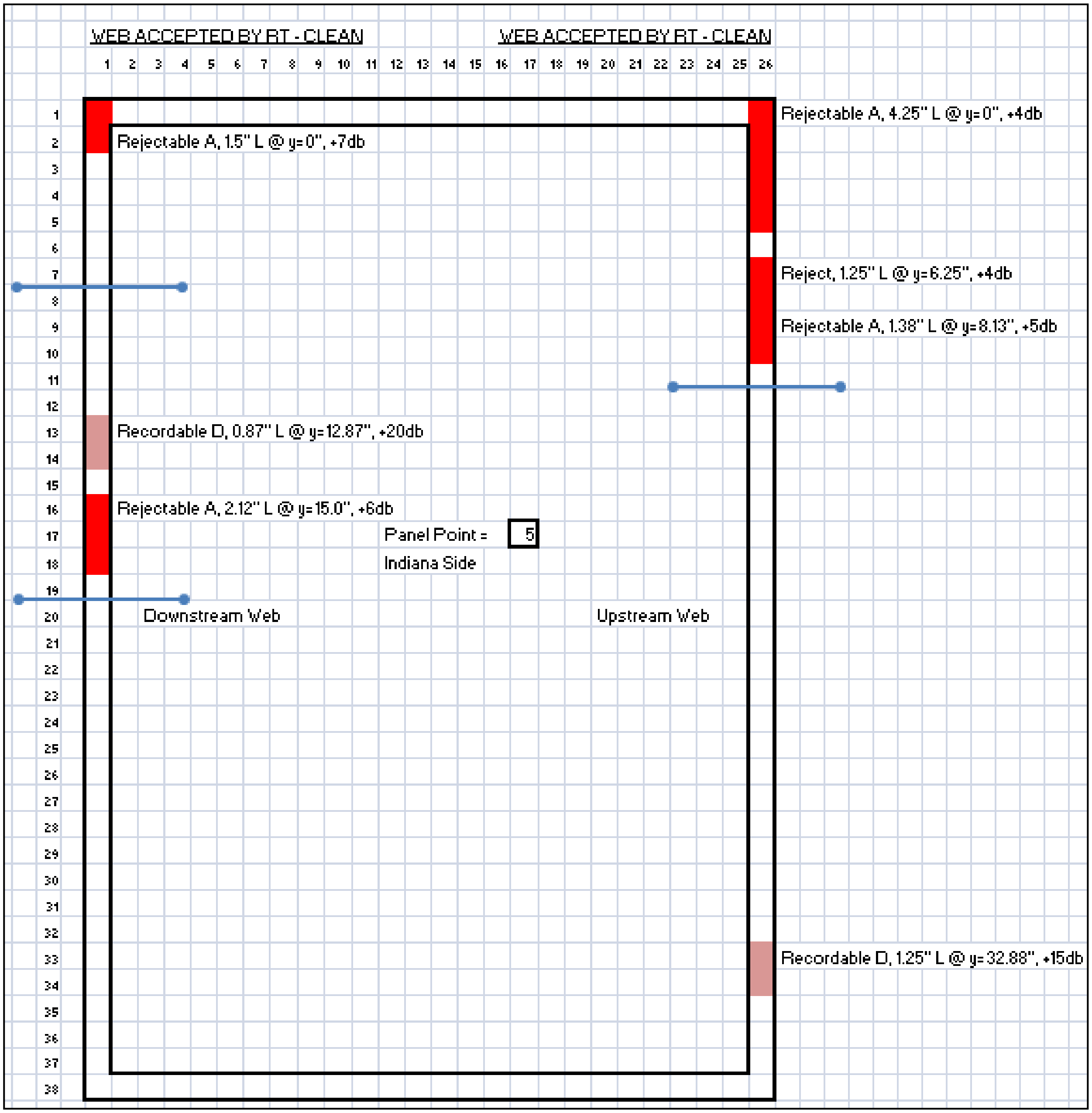

Figure F32. Cross section for the panel point T5 and the Core #8 location

CORE #9

Table F7: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #9:

Core #9 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-1, T21, DV-K **2.62” Dia. Core from Top (26”)**	MT – PSI	-	-	-	-	Accept
	RT – ATS	6.0 – 7.0	0.35	Slag indication	0	Accept
		20 – 21	0.35	Slag indication	0	Reject
		25 – 26	***1.0***	***Crack indication***	***100***	***Reject***
	UT – PSI	2.75	1.62	A, 0.87” from surf.	0	Reject
		6.0	1.12	A, 0.87” from surf.	0	Reject
		19.5	1.38	D, 0.62” from surf.	0	Record
	Visual	-	-	Undercut (DV-K Int.)	0	Reject
	Core–ATS	***Approx. 26”***	***0.63***	***0.16” from surface***	***NA***	***1 flaw Ext. surface***

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MAGNETIC PARTICLE TESTING REPORT

	Interpretation Accept	Interpretation Reject	Repairs Accept	Repairs Reject	Plate size	Comments
Date: 9-22-11 Tie Girder: Upstream Span 1 Panel Point: T21 Weld#: WP (DV-K) - INT	x				1.82” (I) 1.47” (K)	
Visual Inspection		x				Undercut

	Interpretation Accept	Interpretation Reject	Repairs Accept	Repairs Reject	Plate size	Comments
Date: 9-22-11 Tie Girder: Upstream Span 1 Panel Point: T21 Weld#: WP (DV-K) - EXT	x				1.82” (I) 1.47” (K)	
Visual Inspection	x					Acceptable

Figure F33. FISH MT Report showing no flaws at the Core #9 location

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ULTRASONIC TESTING REPORT

Date: 9-22-11 Tie Girder: Upstream Span 1 Panel Point: T21 Weld#: WP (DV-K) – EXT	Indication No.	Transducer Angle	From Face	Leg*	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Remarks
					a	b	C	D				From X	From Y	
	1	70	A	1	63	53	3	7	1.62"	2.54"	0.87"	0	2.75"	Rejectable indication (Class A)
	2	70	A	1	64	53	3	8	1.12"	2.56"	0.87"	0.12"	6.0"	Rejectable indication (Class A)
Note: Lamination scan acceptable	3	60	A	1	66	49	1	16	1.38"	1.24"	0.62"	0	19.5"	Recordable indication (Class D)

Figure F34. FISH UT Report showing no flaws at the Core #9 location

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COMPUTED RADIOGRAPHIC INSPECTION REPORT

Job # S172347 PO # WO # Date 9/27/11 Page 1 of 1

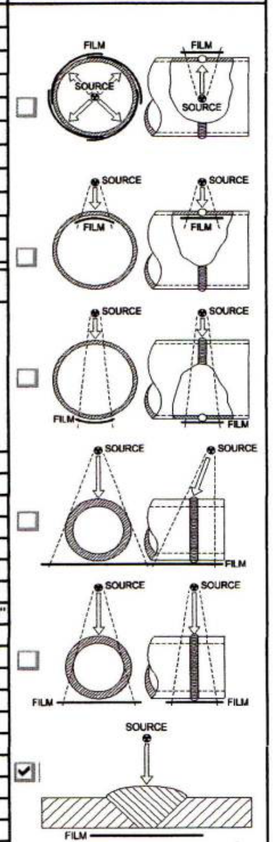
CLIENT: **University of Kentucky**
LOCATION: **Sherman Minton Bridge**

PART NO.: US-S1-T21-KY
PART NAME: Tie Girder
MATERIAL: C/S
THICKNESS: 1.5-2.25
TYPE WELD: BUTT

RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications:	ATS 120.19 Rev. 1	Accept/Reject Criteria:	AWS D1.5, Figure 6.8
Isotope	Ir192	Digital System	Fuji Dynamix Series V
Curies	96.0	Software Version	VFC1 4.0
KV	N/A	IP Type	Fuji ST-VI
MA	N/A	Sensitivity	0.032
Time	12 min	Penetrameter	ASTM 1B
SFD	27"	Shim(s)	N/A
SOD	25"	Screen(s)	Type Pb Front .010 Back N/A
OFD	2"	Focal Size	0.166
Source Size (Physical)	.126" x .128"	Weld Reinforcement	Ground Flush
Geometric Unsharpness	0.013"	Weld Process	N/A

SETUP



SEE ATTACHED SKETCH

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US-S1-T21-KY												
UV												
1-15	/			/								0.22" @ 7"-8"
12-26	/											
23-38	/											
DV												
1-15	/			/								0.35" @ 6"-7"
12-26		X	X	X								S: 0.35" @ 20"-21", C: 1.0" @ 25"-26"
28-34	/											
30-38	/											
												Note: Linear Indications are longitudinal with weld except as noted
												Note: Intersecting corner @ top and Bottom of weld has rejectable weld flaws per AWS D1.5. Edge blocks not used

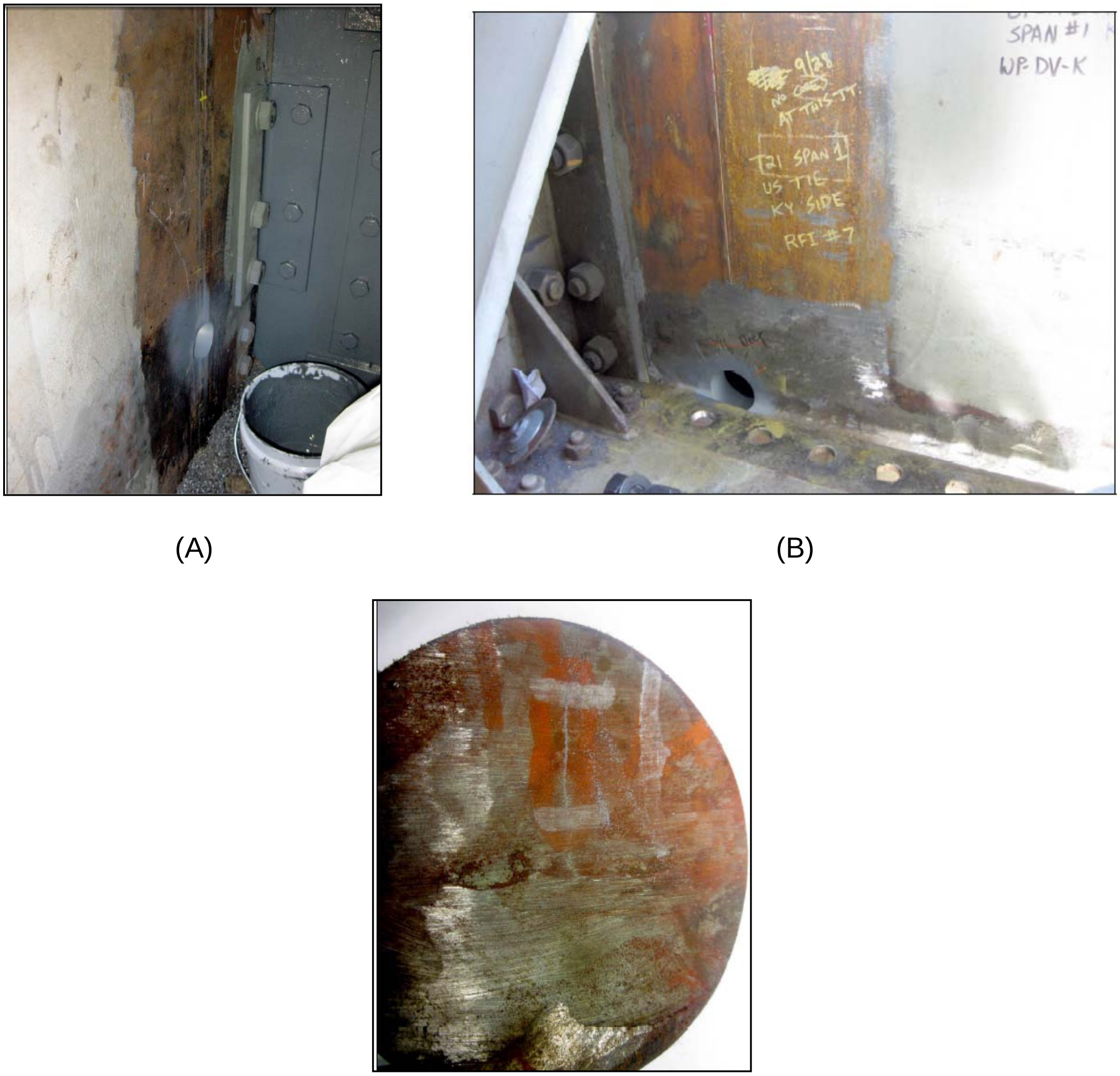
Art.=artifact which is a non-relevant indication

RADIOGRAPHER(S): Jeremy Winkler/Scott Powell Level II RT

INTERPRETER: Jim J. Hills Level III RT

ATS 120.11, 08/10

Figure F35. ATS RT Report showing no flaws at the Core #9 location



(A) (B)

(C)

Figure F36. (A) Location of Core #9 on interior web surface. (B) Location of Core #9 on the exterior web surface. (C) Indication of a vertical flaw by ATS MT lab inspection

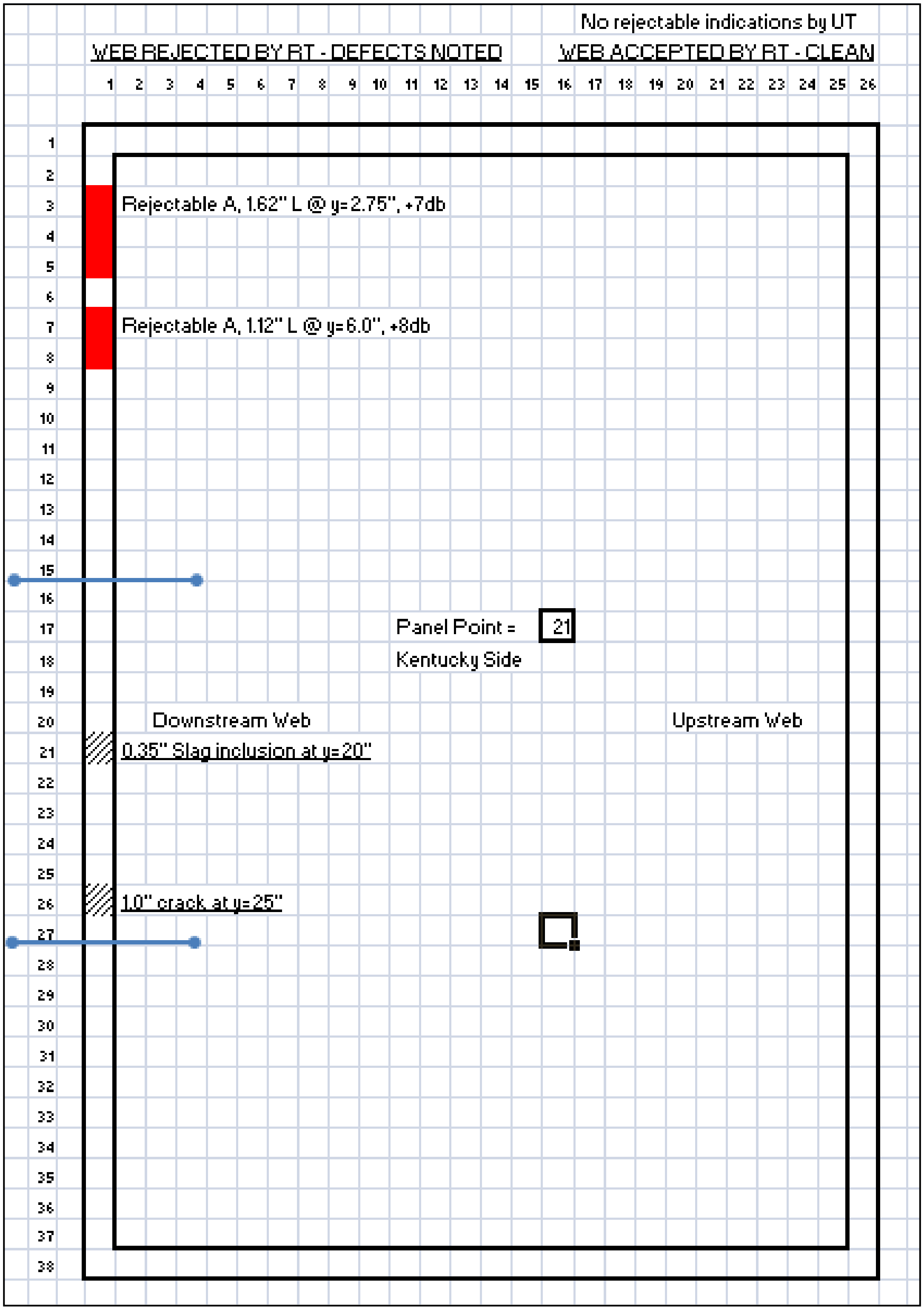


Figure F37. Cross section of panel point T21 and showing of one crack detected by RT at Core #9 location

CORE #10

Table F8: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #10:

Core #10 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
DS-2, T19, UV-I 3.72” Dia. Core from Top (27.5”)	Magnetic Particle Testing	12.0	1.5-2.0	-	-	Reject
		15.5	1.5-2.0	-	-	Reject
		19.0	1.5-2.0	-	-	Reject
		2.0*	1.0	-	-	Reject
	Radiographic Testing	4.0	0.4	Crack, Porosity, Incomplete Fusion	0	Accept
		9.0-24.0	-	Crack b/w drilled holes	0	Accept
		28.0-36.0	***-***	***Crack b/w drilled holes***	***-***	***Accept***
		37.0-38.0	0.4	Porosity	0	Accept
	Ultrasonic Testing	3.5	2.0	D, 0.73” from surf.	0	Record
		29.5-30.5	1.0	D, 0.61” from surf.	0	Record
		2.5-5.5	3.0	A, 0.61” from surf.	0	Reject
		3.4-4.4	1.0	A, 0.75” from surf.	0	Reject
		13.2-14.7	1.5	A, 0.57” from surf.	0	Reject
		16.9-18.0	1.1	A, 0.54” from surf.	0	Reject
	Visual Inspection	-	-	Excessive Convexity UV-I Exterior	-	Reject
	Core–ATS	***Approx. 28”***	***0.94***	***0.26” from surface***	***NA***	***1 flaw Ext. surface***

(*) This crack is located 2.0 inches below the connector plate.

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Magnetic Particle Testing Report

Project: Sherman Minton Bridge **Report No:** #T19 Downstream Span 2 **Contractor/Owner:** Indiana DOT
Quality Requirements: ASTM A403 and AWS D1.5 Section 6 and Section 12
Weld/Part Location and Identification: WP-(DV/UV)-I EXT/INT
Pre-Examination Surface Preparation: Needle Scaling and Flapper Wheel
Equipment: **Instrument Make:** Parker **Model:** B300 **Serial No:** 1622
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cal

Direction of Field: Longitudinal (Circular, Longitudinal)

Date: 9-17-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Downstream Span 2 Panel Point: T19 Weld#: WP (UV-I) - INT	x				1.44" (I) 1.81" (K)	No relevant indications
Visual Inspection	x					Acceptable

Date: 9-17-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Downstream Span 2 Panel Point: T19 Weld#: WP (UV-I) - EXT	x				1.44" (I) 1.81" (K)	No relevant indications
Visual Inspection		x				Excessive Convexity

(A)

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Magnetic Particle Testing Report

Project: Sherman Minton, Fracture Critical Bridge Inspection **Report No:** 0014672-2 **Contractor/Owner:** INDOT
Quality Requirements: AWS D1.5 - 2008
Weld/Part Location and Identification: Butt Joints (CJP) @ Tie Girder and Fillet Welds @ Lateral Beams & Tie Girder
Pre-Examination Surface Preparation: Media Blast
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 4372
Method of Inspection: Dry, Visible
Media Application: Continuous, AC, Yoke
Direction of Field: Longitudinal

	Interpretation		Repairs		Plate Size	Comments
	Accept	Reject	Accept	Reject		
Date: May 25, 2011 **Tie Girder:** Downstream Span 2 **Panel Point:** T19 (IN) **Weld#:** 2006, 2007, 2008 Upstream Vertical		X				1.5" to 2.0" cracks at 12", 15.5" and 19" below top of joint. 1" crack 2" below lateral connector plate. See attached photo.

(B)

(C)

Figure F38. (A) FISH MT report showing no relevant indication at Core #10 location. (B) PSI MT report showing no flaws at Core #10 location. (C) Showing crack below the lateral connector.

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ULTRASONIC TESTING REPORT

Date: 9-17-11

Tie Girder: Downstream Span 2

Panel Point: T19

Weld#: WP (UV-I) – EXT

Note: Lamination scan acceptable

Indication No.	Transducer Angle	From Face	Leg *	Indication Level a	Reference Level b	Attenuation Factor C	Indication Rating D	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Remarks
1	70	A	1	74	58	2	14	2.0"	2.13"	0.73"	-0.4"	3.5"	Recordable indication (Class D)

(A)

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ULTRASONIC TESTING REPOR

Date: May 25, 2011

Tie Girder: Downstream Span 2

Panel Point: T19 (IN)

Weld#: 2006, 2007, and 2008
Upstream Web

Indication No.	Transducer Angle	From Face	Leg*	Indication Level a	Reference Level b	Attenuation Factor c	Indication Rating d	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Discontinuity Evaluation	Date	Remarks
1	70	A	1	63.1	50.1	2	11	1	1.96	.61	+.5	29.5-30.5	D	5.25.11	
2	70	A	1	58.9	50.1	2	7	3	1.97	.61	+.5	2.5-5.5	A	5.25.11	
3	70	A	1	60.9	50.1	3	8	1	2.43	.75	+.1	3.4-4.4	A	5.25.11	
4	70	A	1	58.1	50.1	2	6	1.5	1.86	.57	-.2	13.2-14.7	A	5.25.11	
5	70	A	1	60.3	50.1	2	8	1.1	1.75	.54	-.1	16.9-18	A	5.25.11	

(B)

Figure F39. (A) FISH UT report showing no relevant indication at Core #10 location.

(B) PSI UT report showing no indications at Core #10 location.

APPLIED TECHNICAL SERVICES, INCORPORATED

1049 Triad Court, Marietta, Georgia 30062 • (770) 423-1400 Fax (770) 514-3299 • www.atslab.com • FAA#HC4R227M

COMPUTED RADIOGRAPHIC INSPECTION REPORT

Job # S172347 PO # WO # Date 9-19-11 Page 1 of 1

CLIENT: **University of Kentucky**
LOCATION: **Sherman Minton Bridge**

PART NO.: DS-S2-T19-IN
PART NAME: Tie Girder
MATERIAL: C/S
THICKNESS: 1.5"- 2.25"
TYPE WELD: BUTT

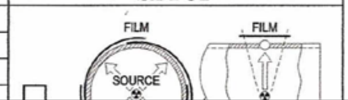
RADIOGRAPHIC INSPECTION TECHNIQUE

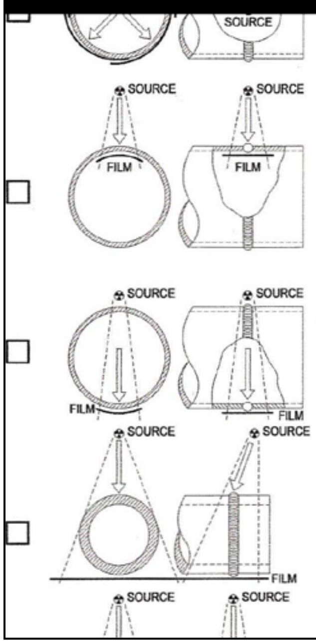
Specification(s): ATS 120.19 Rev. I
Accept/Reject Criteria: AWS D1.5, Figure 6.8
Isotope Ir192
Digital System Fuji Dynamix Series V
Curies 93.2
Software Version VFCI 4.0

[redacted]

MA N/A
Sensitivity ASTM 1B
Time 12 min
Penetrameter 0.032
SFD 27"
Shim(s) N/A
SOD 25"
Screen(s) Type: Pb Front: X Back:
OFD 2"
Focal Size 0.166
Source Size (Physical) .126" x .128"
Weld Reinforcement 0.125" or Ground Flush
Geometric Unsharpness 0.013"
Weld Process N/A

SETUP



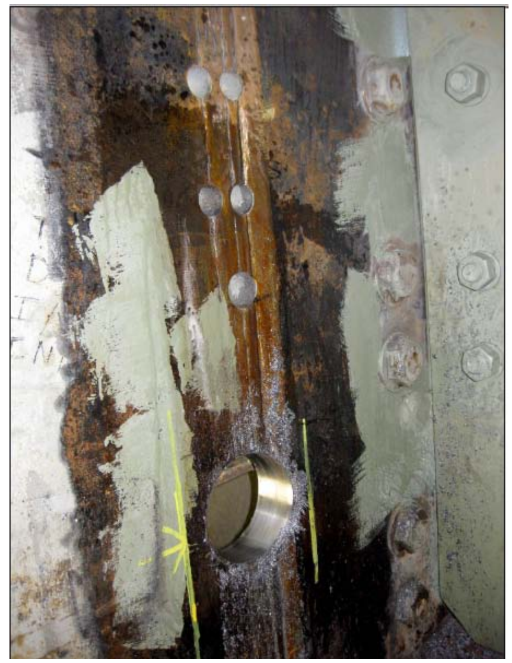


INTERPRETATION

PART I.D./ FILM VIEW	Accept	Reject	Crack	Slag Inclusion	Tungsten Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
DS-S2-T19-IN												
UV												
1-15	/		/			/		/				0.4"@ 4" Crack b/w drill holes
9-24	/		/									Crack b/w drill holes
28-36	/		/									Crack b/w drill holes
30-38	/					/						0.4" @ 37"-38"
DV												
1-15	/											
12-26	/											
23-37	/							/				2 Ind,0.1" @ 27"-29"

Figure F40. ATS RT report showing cracks between drilled holes in the region of Core #10 location.

(A)



(B)

(C)

Figure F41. (A) A vertical flaw was identified by MT method on the exterior surface of the web at Core #10 location. (B) Core #10 location on the interior web surface. (C) Core #10 location on the exterior web surface conflicting with the shelf plate.

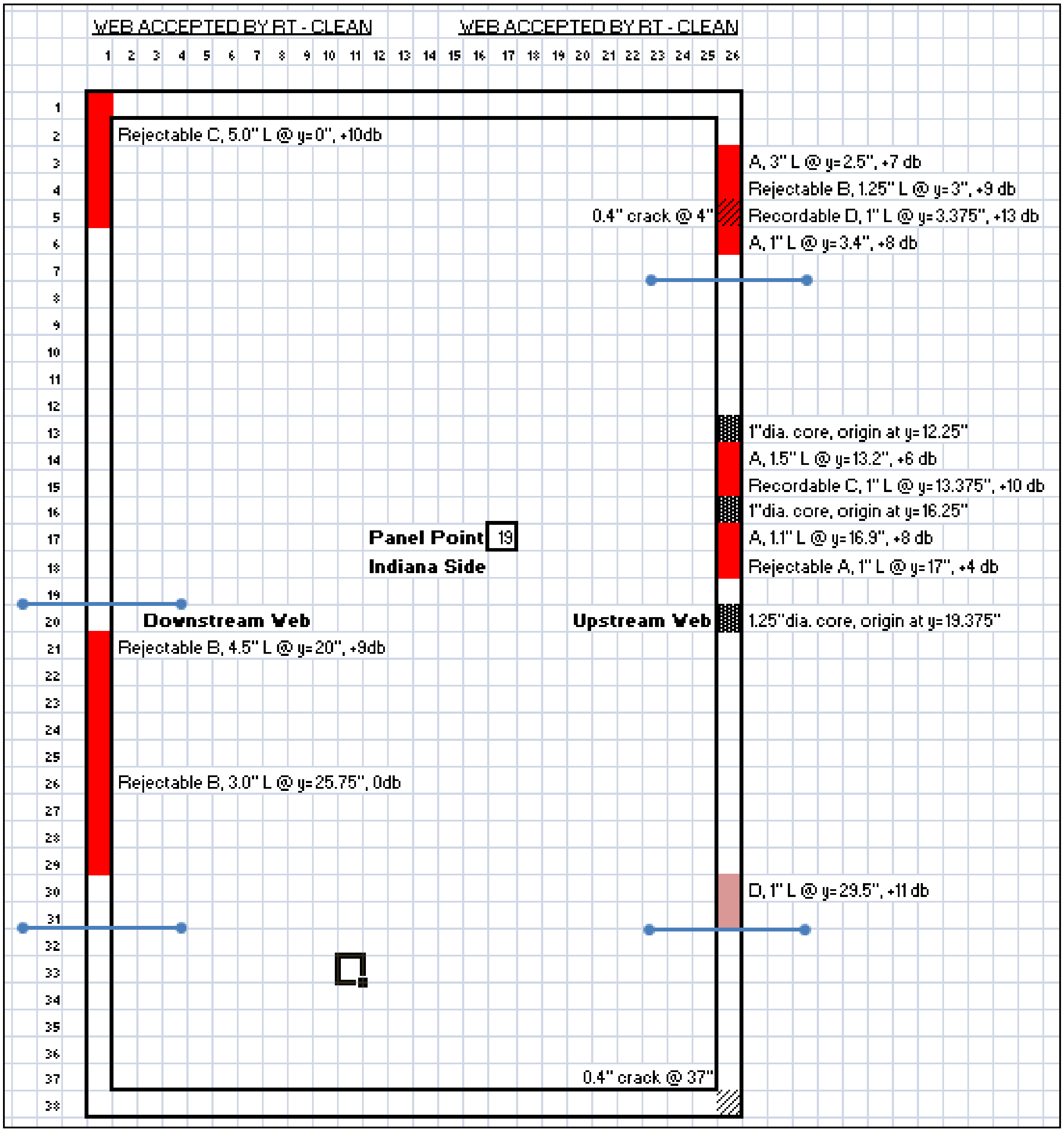


Figure F42. Cross section of panel point T-19 and the upstream web along Core #10 location.

CORE #11

Table F9: Comparison of MT, RT, UT & Visual Inspections with Core Results for Core #11:

Core #11 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-1, T1, DV-K 2.62" Dia. Core from Top (21.75")	MT – PSI	***Core Loc.***	***0.0625***	**-**	**-**	***Reject***
	RT – ATS	0-1 (edge)	0.4	Crack	0	Reject
		4-5	0.2	Slag	0	Accept
		9-11	1.5	Crack	0	Reject
		10-18	6.3	Crack, Inc. Fusion	0	Reject
		30-31	0.6	Slag	0	Reject
		37	0.2	Crack	0	Reject
		34-35	0.3	Slag	0	Accept
	UT – PSI	***22***	***3.62****	***D, 0.75" from surf.***	***~100***	***Record***
		26.75	2.5	B, 0.74" from surf.	0	Reject
		31.25	3.0	A, 0.70" from surf.	0	Reject
		0	17.5	A, 0.75" from surf.	0	Reject
	Visual	DV-K Ext.	-	Excessive Convexity	-	Reject
	Core–ATS	***Approx. 22"***	***1.44***	***0.38" from surface***	***NA***	***1 flaw Ext. surface***

(*) This length could be longer than it was reported because it was behind shelf plate.

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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton Bridge **Report No:** #T1 Upstream Span 1 **Contractor/Owner:** Indiana DOT
Quality Requirements: ASTM A403 and AWS D1.5 Section 6 and Section 12
Weld/Part Location and Identification: WP-(DV/UV)-K EXT/INT
Pre-Examination Surface Preparation: Needle Scaling finished with flapper wheel
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 10894
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)

Direction of Field: Longitudinal (Circular, Longitudinal)

Date: 9-13-2011	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Upstream Span 1 Panel Point: T1 Weld#: WP (DV-K) - EXT		X			1.90" (I) 1.47" (K)	Transverse crack indication in the lateral connection plate weld. This indication is visible in the vertical butt-weld for approximately .0625".
Visual Inspection		X				Excessive convexity

Figure F43. FISH MT report showing one crack at the Core #11 location.

FISH & ASSOCIATES, INC. *Partners in Structural Solutions*

ULTRASONIC TESTING REPORT

Date: 9-13-2011
Tie Girder: Upstream Span 1
Panel Point: T1
Weld#: WP (DV-K)-EXT
Note: Lamination scan acceptable.

Indication No.	Transducer Angle	From Face	Leg *	Indication Level a	Reference Level b	Attenuation Factor c	Indication Rating D	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Remarks
1	70	A	I	71	53	2	16	3.62"	2.20"	0.75"	0"	22"	Recordable indication (Class D) This indication could be longer than reported due to being behind the lateral connection plate.
2	70	A	I	73	53	11	9	2.5"	6.43"	0.74"	0"	26.75"	Rejectable indication (Class B)
3	70	A	I	53	53	2	-2	3"	2.04"	0.70"	0"	31.25"	Rejectable indication (Class A)
4	70	A	I	51	53	2	-4	17.5"	2.20"	0.75"	0"	0"	Rejectable indication (Class A)

Figure F44. FISH UT report showing one class B indication at the Core #11 location.

RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1	Accept/Reject Criteria: AWS D1.5, Figure 6.8
Isotope Ir192	Digital System Fuji Dynamix Series V
Curies 91.0	Software Version VFC1 4.0
KV N/A	IP Type Fuji ST-VI
MA N/A	Sensitivity 0.032
Time 12 min	Penetrameter ASTM 1B
SFD 27"	Shim(s) N/A
SOD 25"	Screen(s) Type Pb Front .010 Back N/A
OFD 2"	Focal Size 0.166
Source Size (Physical) .126" x .128"	Weld Reinforcement Ground Flush
Geometric Unsharpness 0.013"	Weld Process N/A

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US-S1-T1-KY												
UV												
1-15	/											
12-26	/											
23-38	/											
DV												
1-15		X	X	/								C: 0.4" @ edge b/w 0"-1", S: 0.2"@4"-5", C:1.6"@9"-11"*
5-20		X	X					X				6.3"@ 10"-18"*
25-32		X		X								0.6"@ 30"-31"
29-37		X	X	/								C: 0.2"@ 37", S: 0.3"@34"-35"
												*Same Indication
												Note: Linear Indications are
												longitudinal with weld except as
												noted
												Note: Intersecting corner @ top and
												Bottom of weld has rejectable weld
												flaws per AWS D1.5

Art.=artifact which is a non-relevant indication

SETUP

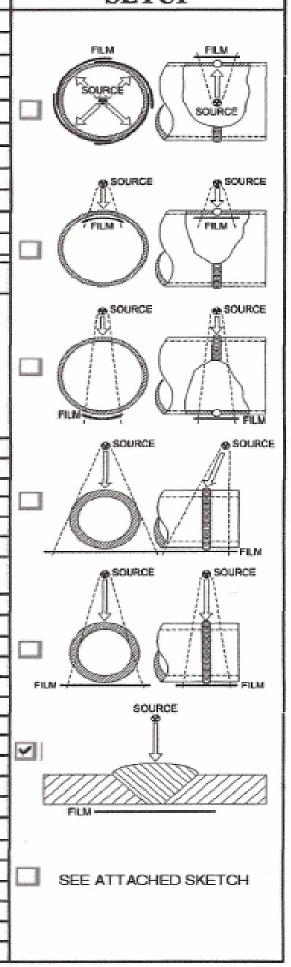
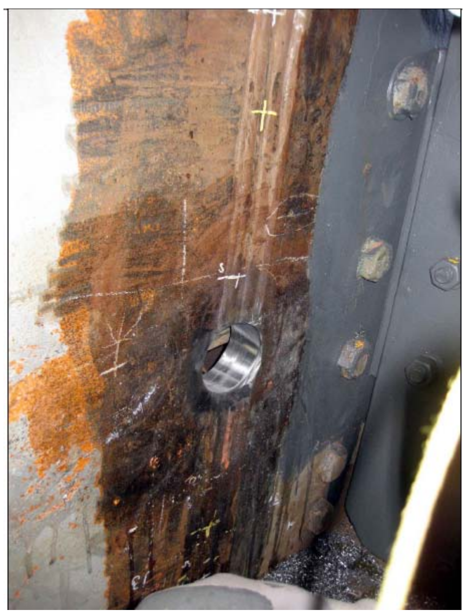


Figure F45. ATS RT report showing flaws at the Core #11 location.

(A)

(B)



(C)

Figure F46. (A) Vertical falw indication at Core #11 on exterior surface. (B) Core #11 location on the exterior surface of the web. (C) Core #11 location on the interior web surface.

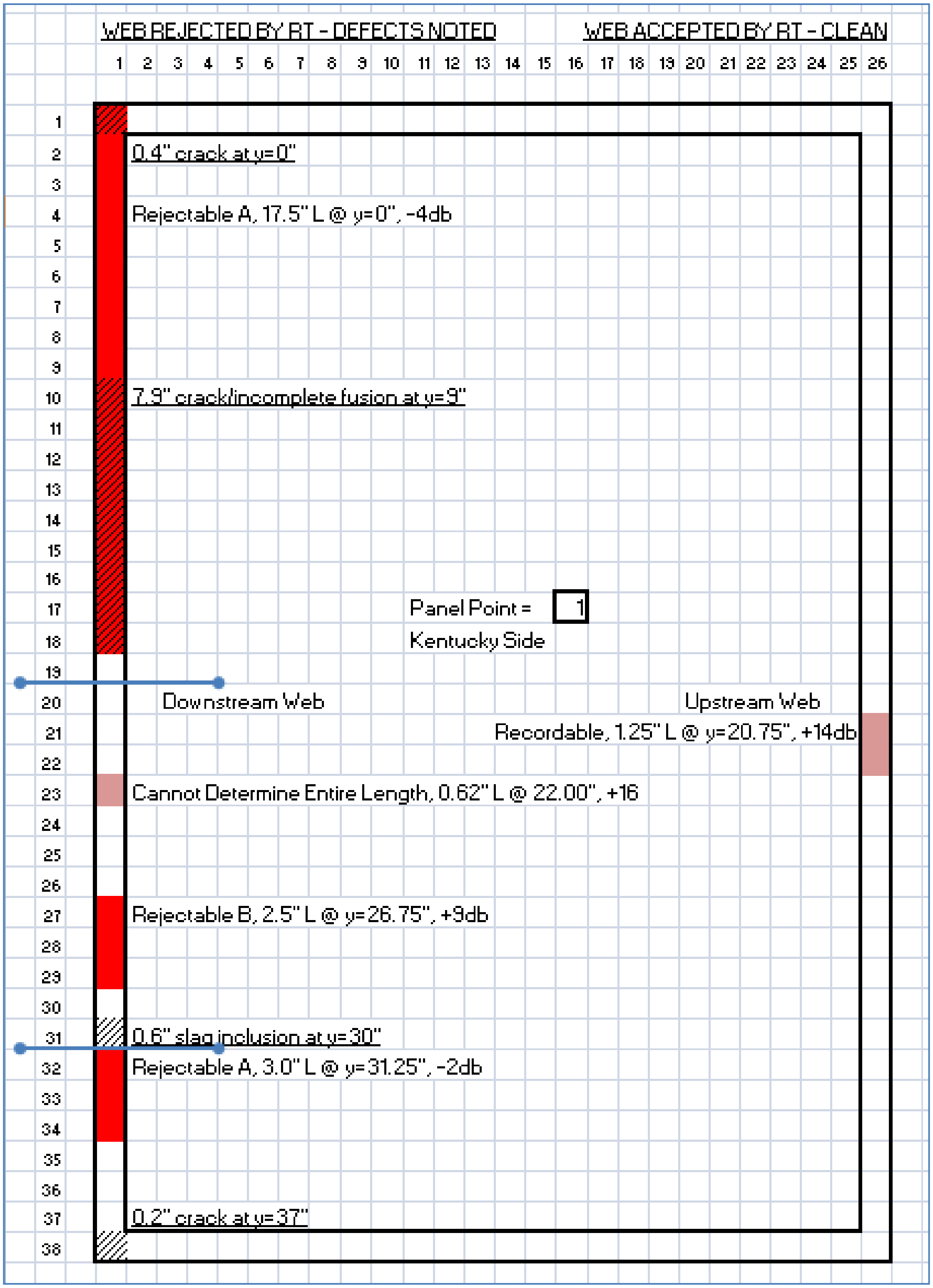


Figure F47. Cross section of the panel T-1 (Kentucky side) showing flaws along the Core #11 location.

CORE #12

Table F10: Comparison of MT, RT, UT & VI with Core Results for Core #12:

Core #12 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-1, T12, UV-K **1.68" Dia. Core from Top (27")**	MT – PSI	-	-	-	-	Accept
	RT – ATS	8.0-9.0	0.8	Incomplete Fusion	0	Reject
		14.0-15.0	Art.*	Incomplete Fusion	0	Reject
	UT – PSI	8.7-11	2.3	C, 0.84" from surf.	0	Reject
		9.0-10.2	1.2	B, 0.79" from surf.	0	Reject
		14.5-15.7	1.2	A, 0.80" from surf.	0	Reject
		22.3-24.5	2.2	A, 0.81" from surf.	0	Reject
		17.5-20.2	2.7	A, 0.13" from surf.	0	Reject
		6.7-8.8	2.1	A, 1.12" from surf.	0	Reject
	Visual	-	-	-	-	-
	Core–ATS	***~27.0***	***1.44***	***0.22" from surf.***	***NA***	***1 flaw Ext. Surf.***

(*) Art. stands for artifact which is a non-relevant indication.

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MAGNETIC PARTICLE TESTING REPORT

	Interpretation		Repairs		Plate Size	Comments
	Accept	Reject	Accept	Reject		
Date: June 12-13, 2011 **Tie Girder:** Upstream Span 1 **Panel Point:** T12 (T11-T12) **Weld#:** 6008 – 4 sides Upstream Web	X*					X* = No rejectable indications were observed. Fails U.T.

Figure F48. PSI MT report showing no flaws at the Core #12 location.

Information To Build On
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ULTRASONIC TESTING REPORT

Date: June 13, 2011
Tie Girder: Upstream Span 1
Panel Point: T12 (T11-T12)
Weld#: 6008 – 4 Sides
Downstream Web (Indication No. 1-4)
Bottom (Indication No. 1)
Upstream Web (Indication No. 1)

Indication No.	Transducer Angle	From Face	Leg*	Indication Level a	Reference Level b	Attenuation Factor c	Indication Rating d	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Discontinuity Evaluation	Date	Remarks
1	70	A	1	63.5	50.1	3	10	2.3	2.70	.84	-.25	8.7-11	C	6.13.11	Reject
2	70	A	1	58.9	50.1	0	9	1.2	2.56	.79	+.25	9-10.2	B	6.13.11	Reject
3	70	A	1	56	50.1	0	6	1.2	2.58	.80	+.25	14.5-15.7	A	6.13.11	Reject
4	70	A	1	58.8	50.1	2	7	2.2	2.63	.81	+.25	22.3-24.5	A	6.13.11	Reject
1	70	B	3	59.8	50.1	3	7	2.7	4.43	.13	-.1	17.5-20.2	A	6.13.11	Reject
1	70	A	1	54	50.1	2	2	2.1	3.62	1.12	-.2	6.7-8.8	A	6.13.11	Reject

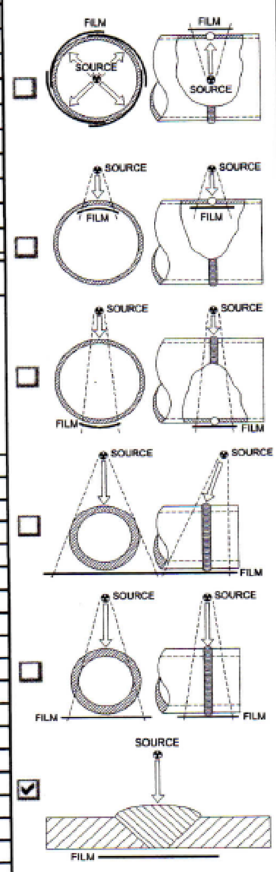
Figure F49. PSI UT report showing no flaws at the Core #12 location.

RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1
Isotope: Ir192
Curies: 96.0
KV: N/A
MA: N/A
Time: 12 min
SFD: 27"
SOD: 25"
OFD: 2"
Source Size (Physical): .126" x .128"
Geometric Unsharpness: 0.013"

Accept/Reject Criteria: AWS D1.5, Figure 6.8
Digital System: Fuji Dynamix Series V
Software Version: VFC1 4.0
IP Type: Fuji ST-VI
Sensitivity: 0.032
Penetrameter: ASTM 1B
Shim(s): N/A
Screen(s): Type Pb Front .010 Back N/A
Focal Size: 0.166
Weld Reinforcement: Ground Flush
Weld Process: N/A

SETUP



SEE ATTACHED SKETCH

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungsten Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US-S1-T12-KY												
UV												
1-15		X						X				0.8" @ 8"-9", Art. @ 14"-15"
12-26	/											
24-37	/											
DV												
1-15	/											
11-26	/											
24-37	/											
												Note: Linear Indications are longitudinal with weld except as noted
												Note: Intersecting corner @ top and Bottom of weld has rejectable weld flaws per AWS D1.5. Edge blocks not used

Art.=artifact which is a non-relevant indication

Figure F50. ATS RT report showing no flaws at the Core #12 location.

(A) (B)

Figure F51. (A) Indicated vertical flaw was determined by MT method at the ATS lab on the exterior surface of the web (Core #12). (B) Core #12 location on the exterior surface of the web.

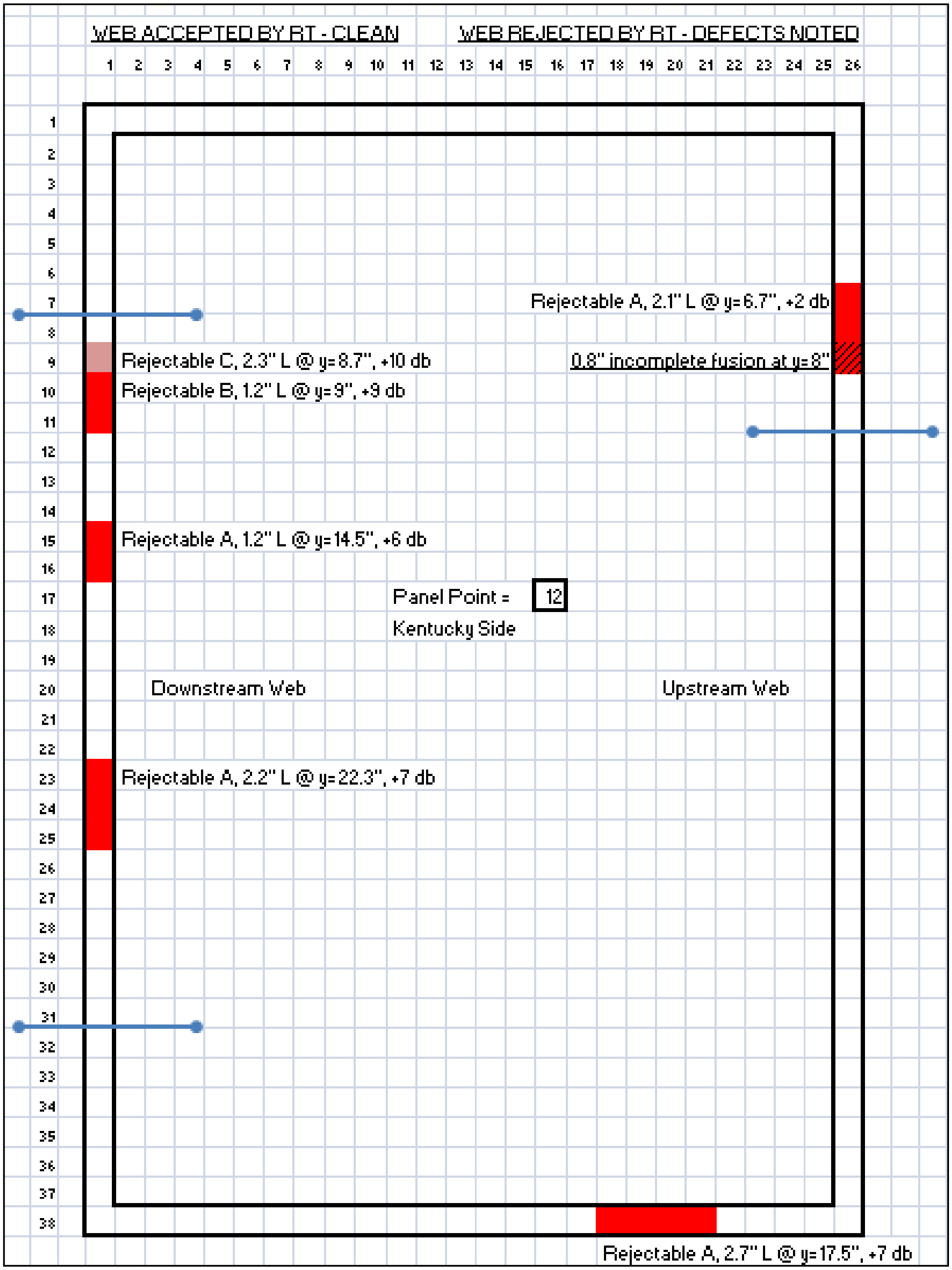


Figure F52. Cross section of the panel point T-12 and flaw indications along the web that Core #12 was located.

CORE #13

Table F11: Comparison of MT, RT, UT & VI with Core Results for Core #13:

Core #13 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
DS-2, T9, UV-I 2.62” Dia. Core from Top (27”)	MT – PSI	-	-	-	-	Accept
	RT – ATS	1.0	0.5	Crack	0	Reject
		15.0-16.0	0.3	Crack	0	Reject
	UT – PSI	19.0	3.5	A, 1.02” from surf.	0	Reject
	Visual	***UV-I (Int.)***	***-***	***Undercut, Arc Strike***	***-***	***Reject***
	Core–ATS	***~27.0***	***1.5***	***0.35” from surf.***	***NA***	***1 flaw Ext. Surf.***

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MAGNETIC PARTICLE TESTING REPORT

Date: 7-28-2011	Interpretation Accept	Interpretation Reject	Repairs Accept	Repairs Reject	Plate size	Comments
Tie Girder: Downstream Span 2 Panel Point: T9 Weld#: WP (UV-I) - INT	X				1.52" (I) 1.875" (K)	No relevant indications
Visual Inspection		X				Undercut, Arc strikes

Date: 7-28-2011	Interpretation Accept	Interpretation Reject	Repairs Accept	Repairs Reject	Plate size	Comments
Tie Girder: Downstream Span 2 Panel Point: T9 Weld#: WP (UV-I) - EXT	X				1.52" (I) 1.875" (K)	No relevant indications
Visual Inspection	X					Acceptable

Figure F53. FISH MT and Visual reports. MT shows no relevant indications, but Visual shows an undercut and arc strikes along the Core #13 location.

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ULTRASONIC TESTING REPORT

Date: 7-28-2011

Tie Girder: Downstream Span 2

Panel Point: T9

Weld#: WP (UV-I) – EXT

Note: Lamination scan acceptable

Indication No.	Transducer Angle	From Face	Leg *	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Remarks
				a	b	c	D				From X	From Y	
1	70	A	1	62	55	4	3	3.5"	2.98	1.02"	-.25"	19"	Rejectable indication (Class A)

Figure F54. FISH UT report showing no relevant indication at Core #13 location.

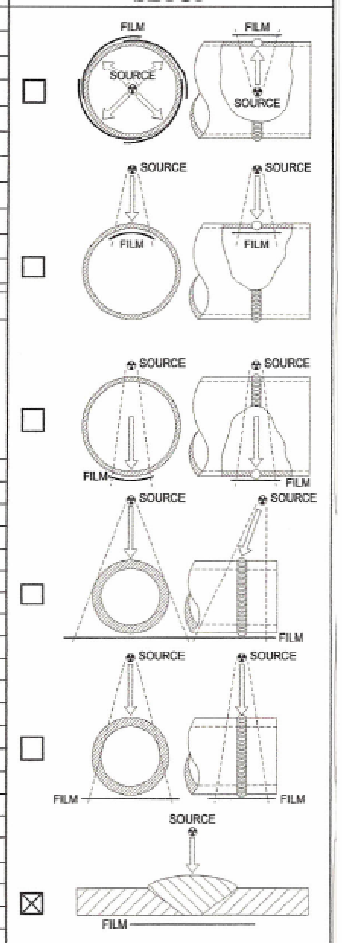
RADIOGRAPHIC INSPECTION TECHNIQUE

Specification(s):	ATS 120.19 Rev. 1	Accept/Reject Criteria:	AWS D1.5, Figure 6.8
Isotope	Ir192	Digital System	Fuji Dynamix Series V
Curies	98	Software Version	VFCI 4.0
KV	N/A	IP Type	Fuji ST-VI
MA	N/A	Sensitivity	ASTM 1B
Time	12 min	Penetrameter	0.032
SFD	27"	Shim(s)	N/A
SOD	25"	Screen(s)	Type: Pb Front: X Back:
OFD	2"	Focal Size	0.166
Source Size (Physical)	.126" x .128"	Weld Reinforcement	0.125" or Ground Flush
Geometric Unsharpness	0.013"	Weld Process	N/A

INTERPRETATION

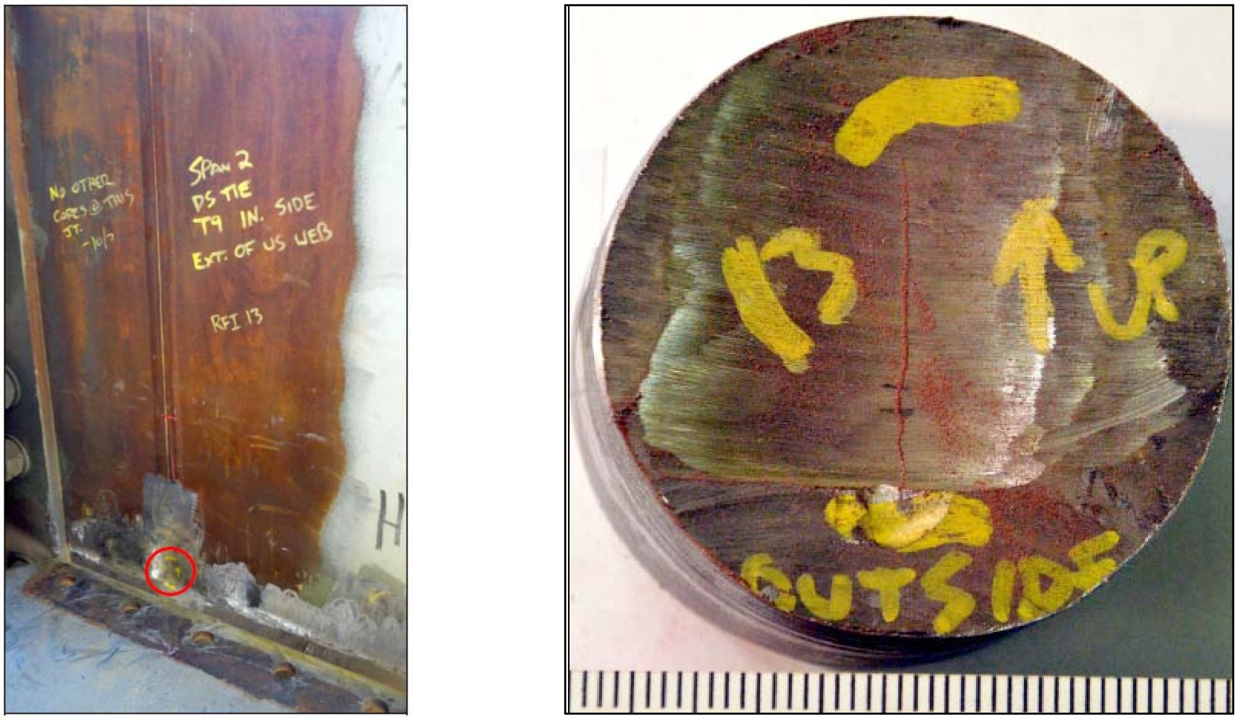
PART I.D./ FILM VIEW	Accept	Reject	Crack	Slag Inclusion	Tungsten Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
DS-S2-T9-IN												
UV												
1-16		X	X									0.5" @ 1", 0.3" @ 15"-16"
12-26	/											
30-36	/											
32-37	/											
DV												
1-16	/											
12-26	/							/				0.4" @ 22"-23"
23-37		X	X									0.5" @ 37"
												Note: Intersecting corner @ top and Bottom of weld has rejectable weld flaws per AWS D1.5

SETUP



☐ SEE ATTACHED SKETCH

Figure F55. ATS RT report showing nothing at the Core #13 location.



(A) (B)

Figure F56. (A) Location of Core #13 on the exterior surface of the web. (B) Vertical flaw detected by MT at the ATS lab on the exterior surface of the core.

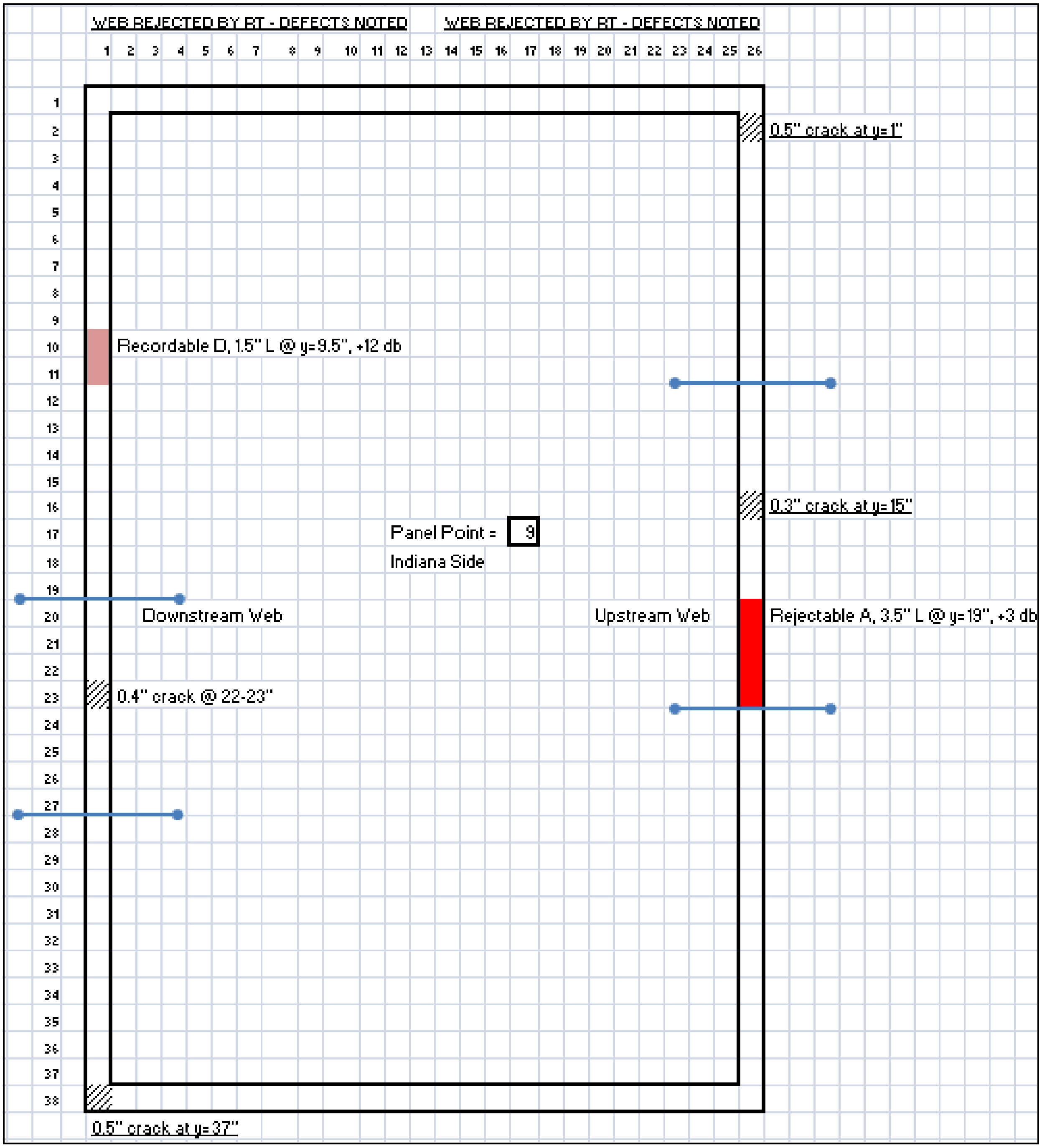


Figure F57. Cross section of the panel point T-9 (UV-I)

CORE #14

Table F12: Comparison of MT, RT, UT & VI with Core Results for Core #14:

Core #14 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-1, T13, DV-I 2.75" Dia. Core from Top (27")	MT – PSI	-	-	-	-	Accept
	RT – ATS	***28.0***	***1.17***	***Crack***	***~78***	***Reject***
		28.0	***0.215***	***Crack***	***~22***	***Reject***
		28.0	***0.226***	***Crack***	***~23***	***Reject***
		28.0	***0.298***	***Crack***	***~30***	***Reject***
	UT – PSI	***19.0-27.5***	***8.5***	***C, 0.65" from surf.***	***~40***	***Reject***
		11.9-13.4	1.5	C, 0.72" from surf.	0	Reject
		33.8-38.0	4.2	A, 0.63" from surf.	0	Reject
	Visual	-	-	-	-	-
	Core–ATS	***~27.0***	***1.5***	***0.27" from surf.***	***NA***	***2 flaws Ext. Surf.***
			1.0	***0.24" from surf.***	***NA***	

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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton, Fracture Critical Bridge Inspection **Report No:** 0014672-2 **Contractor/Owner:** INDOT
Quality Requirements: AWS D1.5 - 2010
Weld/Part Location and Identification: Butt Joints (CJP) @ Tie Girder and Fillet Welds @ Lateral Beams & Tie Girder
Pre-Examination Surface Preparation: Media Blast
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 4372
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)
Direction of Field: Longitudinal (Circular, Longitudinal)

	Interpretation		Repairs		Plate Size	Comments
Date: June 12, 2011 **Tie Girder:** Upstream Span 1 **Panel Point:** T13 (T13-T14) **Weld#:** 5024 Downstream Web	**Accept**	**Reject**	**Accept**	**Reject**		
	X*					X* = No rejectable indications were observed. Fails U.T.

Figure F58. PSI MT reprot showing no relevant indications at Core #14 location

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ULTRASONIC TESTING REPORT

Date: June 12, 2011
Tie Girder: Upstream Span 1
Panel Point: T13 (T13-T14)
Weld#: 5024
Downstream Web (Indication No. 1-3)

Indication No.	Transducer Angle	From Face	Leg*	Indication Level a	Reference Level b	Attenuation Factor c	Indication Rating d	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Discontinuity Evaluation	Date	Remarks
1	70	A	1	61.9	50.2	2	10	8.5	2.01	.65	-.2	19-27.5	C	6.12.11	Reject
2	70	A	1	63.3	50.2	3	10	1.5	2.31	.72	-.2	11.9-13.4	C	6.12.11	Reject
3	70	A	1	61.5	50.2	4	7	4.2	3.05	.63	-.1	33.8-38	A	6.12.11	Reject

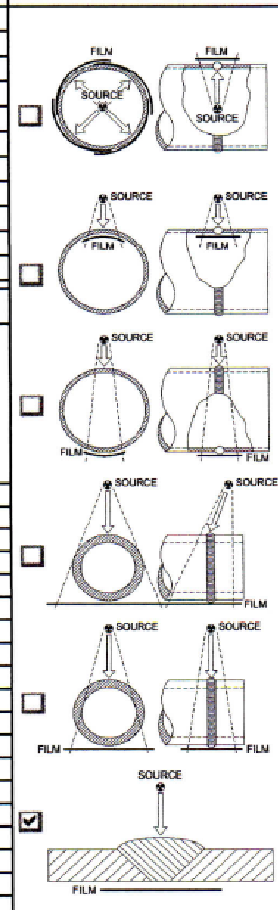
Figure F59. PSI UT reprot showing one Class-C indication at Core #14 location

RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1
Isotope Ir192
Curies 96.0
KV N/A
MA N/A
Time 12 min
SFD 27"
SOD 25"
OFD 2"
Source Size (Physical) .126" x .128"
Geometric Unsharpness 0.013"

Accept/Reject Criteria: AWS D1.5, Figure 6.8
Digital System Fuji Dynamix Series V
Software Version VFC1 4.0
IP Type Fuji ST-VI
Sensitivity 0.032
Penetrameter ASTM 1B
Shim(s) N/A
Screen(s) Type Pb Front .010 Back N/A
Focal Size 0.166
Weld Reinforcement Ground Flush
Weld Process N/A

SETUP



SEE ATTACHED SKETCH

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US-S1-T13-IN												**Second shot for information**
DV												
22-37		X	X									C: 1.17" @ 28"
		X	X									C: 0.215" @ 28"
		X	X									C: 0.226" @ 28"
		X	X									C: 0.298" @ 28"
Area radiographed again, determine condition after grinding linear indication.												
												Note: Linear Indications are
												longitudinal with weld except as
												noted
												Note: Intersecting corner @ top and
												Bottom of weld has rejectable weld
												flaws per AWS D1.5. Edge blocks
												not used

Art.=artifact which is a non-relevant indication

Figure F60. ATS RT report showing four cracks at the Core #14 location.

Figure F61. (A) Vertical flaws on the exterior surface of the Core #14 detected by MT. (B) Core #14 location on the exterior surface of the web.

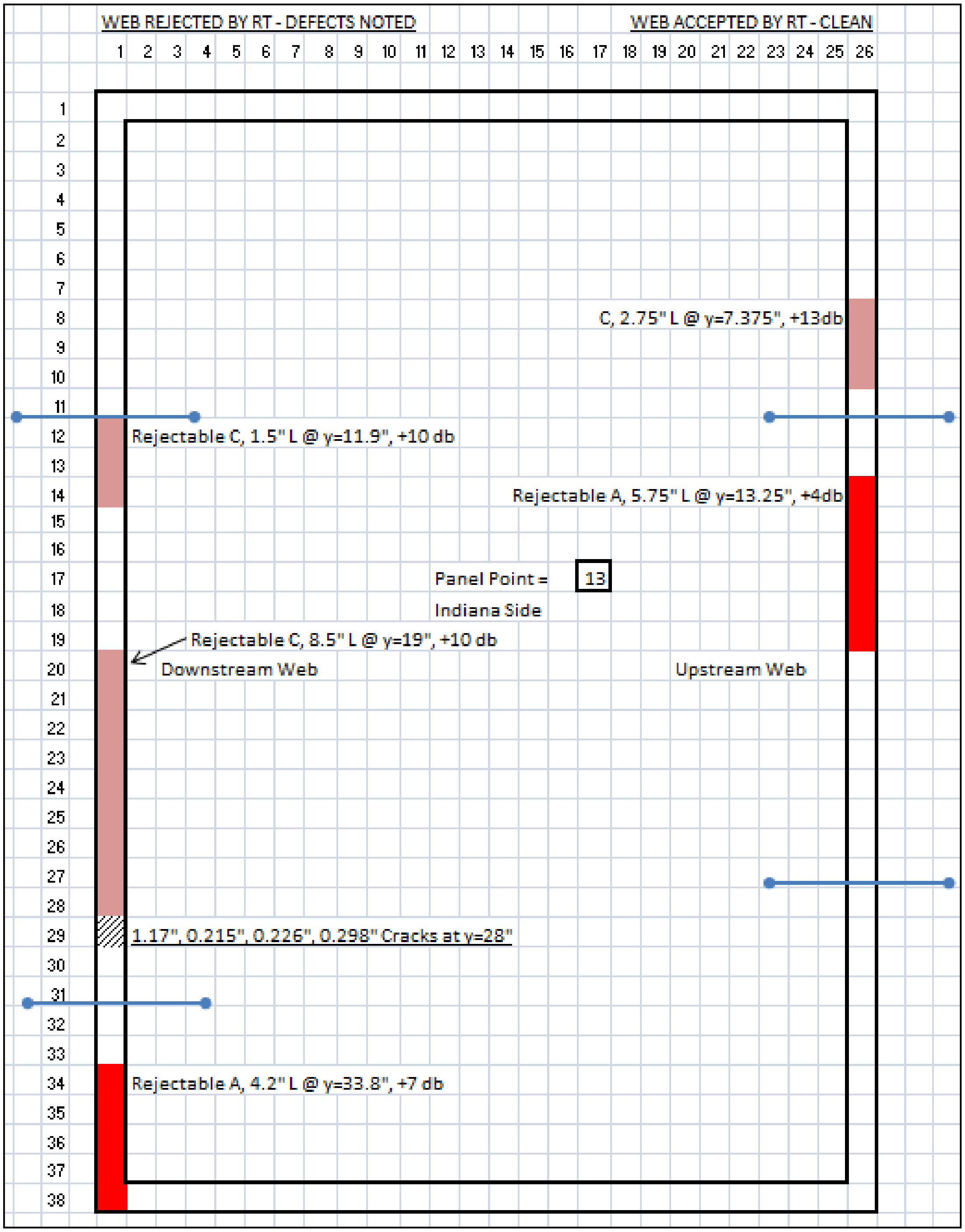


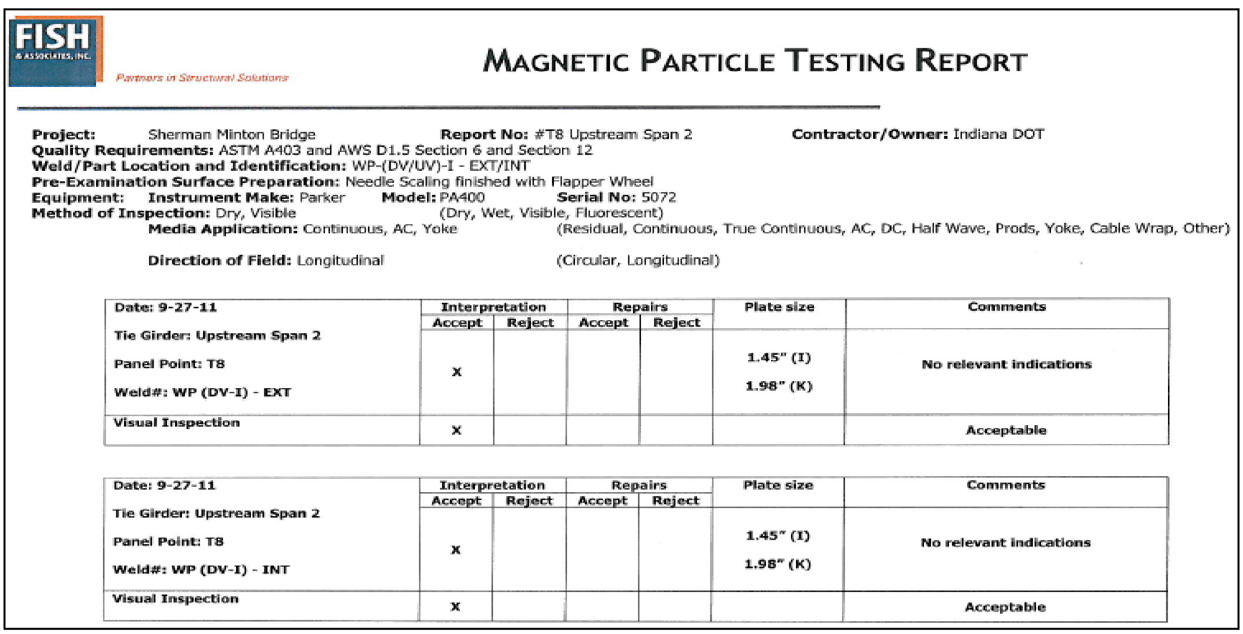
Figure F62. Cross section of the panel point T-13 (Indiana side).

CORE #15

Table F13: Comparison of MT, RT, UT & VI with Core Results for Core #15:

Core #15 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-2, T8, DV-I 2.17" Dia. Core from Top (15")	MT – PSI	-	-	-	-	Accept
	RT – ATS	***15.0-16.0***	***0.35***	***Incomplete Fusion***	***100***	***Accept***
	UT – PSI	1.8	0.8	D, 0.92" from surf.	0	Record
		6.0	2.4	B, 0.65" from surf.	0	Reject
		9.3	2.0	B, 1.04" from surf.	0	Reject
		14.4	***1.1***	***A, 0.71" from surf.***	***~95***	***Reject***
		19.3	0.5	A, 0.49" from surf.	0	Reject
		24.3	0.5	A, 0.96" from surf.	0	Reject
		33.5	0.8	B, 1.06" from surf.	0	Reject
	Visual	-	-	-	-	Accept
	Core–ATS	***~15***	***0.086***	***0.78"-I* & 0.78"-E****	***NA***	***1 Subsurf.***

(*) I and E mean interior and exterior surfaces, respectively. The subsurface flaw locates 0.78 inches from both surfaces of the plate.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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton Bridge **Report No:** #T8 Upstream Span 2 **Contractor/Owner:** Indiana DOT
Quality Requirements: ASTM A403 and AWS D1.5 Section 6 and Section 12
Weld/Part Location and Identification: WP-(DV/UV)-I - EXT/INT
Pre-Examination Surface Preparation: Needle Scaling finished with Flapper Wheel
Equipment: **Instrument Make:** Parker **Model:** PA400 **Serial No:** 5072
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)
Direction of Field: Longitudinal (Circular, Longitudinal)

Date: 9-27-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Upstream Span 2 Panel Point: T8 Weld#: WP (DV-I) - EXT	x				1.45" (I) 1.98" (K)	No relevant indications
Visual Inspection	x					Acceptable

Date: 9-27-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Upstream Span 2 Panel Point: T8 Weld#: WP (DV-I) - INT	x				1.45" (I) 1.98" (K)	No relevant indications
Visual Inspection	x					Acceptable

Figure F63. FISH MT & visual reports accepting the Core #15 location.

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ULTRASONIC TESTING REPORT

Date: 9-27-11
Tie Girder: Upstream Span 2
Panel Point: T8
Weld#: WP (DV-I) - EXT

Indication No.	Transducer Angle	From Face	Leg *	Indication Level a	Reference Level b	Attenuation Factor c	Indication Rating D	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Remarks
1	70.5	A	1	64.4	46.7	4	14	0.8"	2.76"	0.92"	0.2"	1.8"	Recordable indication (Class D)
2	70.5	A	1	57.6	46.7	2	9	2.4"	1.95"	0.65"	0.1"	6.0"	Rejectable indication (Class B)
3	70.5	A	1	60	46.7	4	9	2	3.14"	1.04"	0.3"	9.3"	Rejectable indication (Class B)
4	70.5	A	1	43.3	46.7	2	-5.0	1.1"	2.13"	0.71"	0.2"	14.4"	Rejectable indication (Class A)
5	70.5	A	1	56.1	46.7	1	8	0.5"	1.47"	0.49"	0	19.3"	Rejectable indication (Class A)
6	70.5	A	1	54.8	46.7	4	4	0.5"	2.89"	0.96"	-0.1"	24.3"	Rejectable indication (Class A)
7	70.5	A	1	59.7	46.7	4	9	0.8"	3.19"	1.06"	-0.2"	33.5"	Rejectable indication (Class B)

Note: Lamination Scan Acceptable

Figure F64. FISH UT report showing one flaw at Core #15 location.

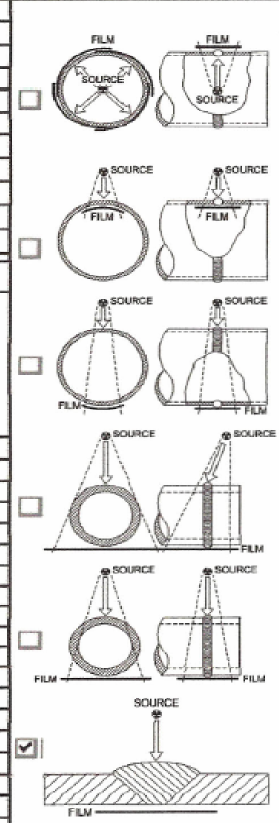
RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1	Accept/Reject Criteria: AWS D1.5, Figure 6.8
Isotope Ir192	Digital System Fuji Dynamix Series V
Curies 91.0	Software Version VFC1 4.0
KV N/A	IP Type Fuji ST-VI
MA N/A	Sensitivity 0.032
Time 12 min	Penetrameter ASTM 1B
SFD 27"	Shim(s) N/A
SOD 25"	Screen(s) Type Pb Front .010 Back N/A
OFD 2"	Focal Size 0.166
Source Size (Physical) .126" x .128"	Weld Reinforcement Ground Flush
Geometric Unsharpness 0.013"	Weld Process N/A

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slag Inclusion	Tungsten Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US-S2-T8-IN												
UV												
1-15	/											
11-26	/							/				0.2" @ 13"-14"
23-37	/											
DV												
1-15	/							/				0.35" @ 15"-16" *
11-25	/							/				0.35" @ 15"-16" *
23-37	/											
												* Same Indication
												Note: Linear Indications are
												longitudinal with weld except as
												noted
												Note: Intersecting corner @ top and
												Bottom of weld has rejectable weld
												flaws per AWS D1.5

SETUP



SEE ATTACHED SKETCH

Figure F65. ATS RT report showing 2 Inc. fusions at Core #15 location.

(A)

(B)

Figure F66. (A) Core #15 location on the exterior surface of the web. (B) Transverse metallographic section through the indication at Core #15.

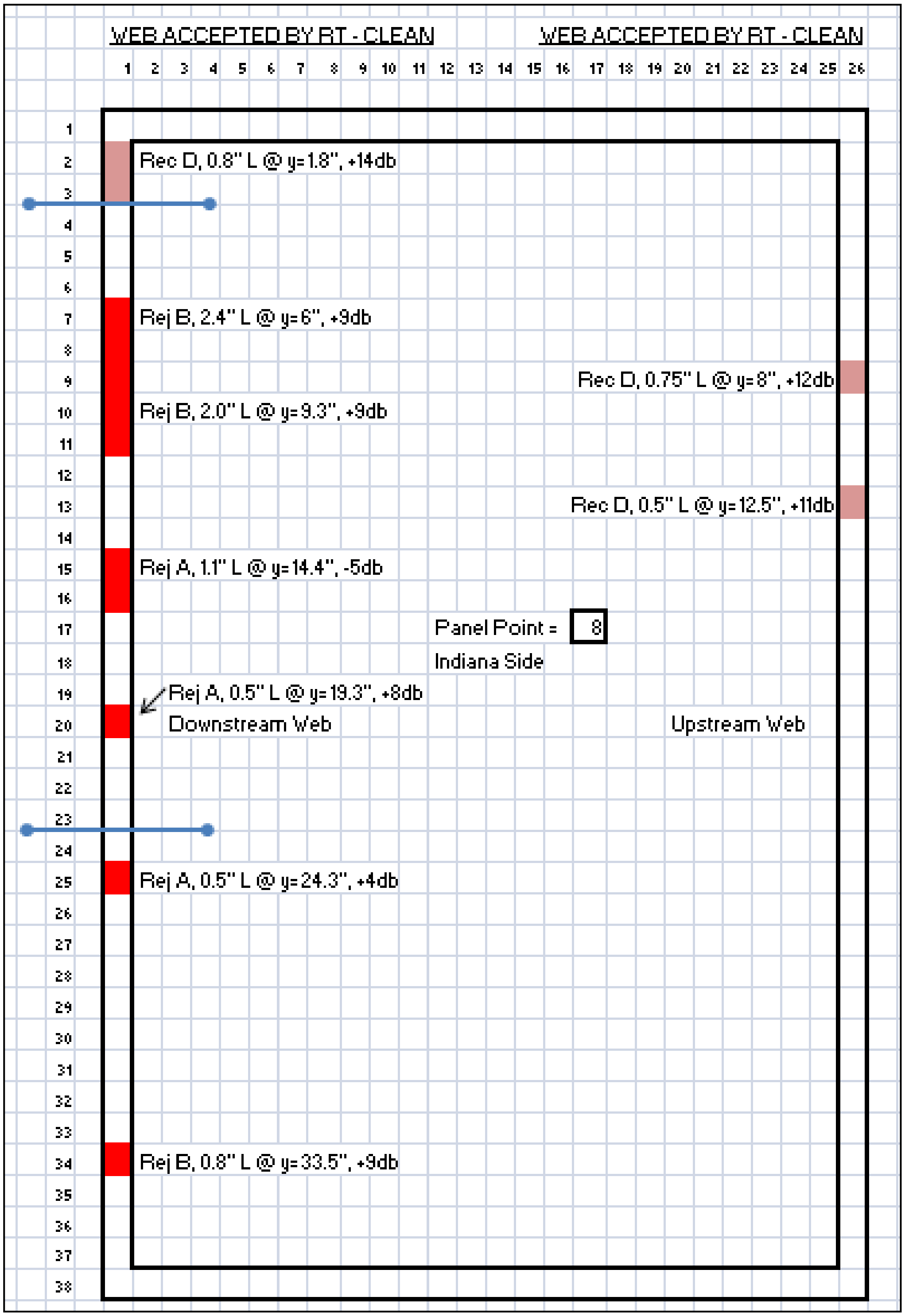


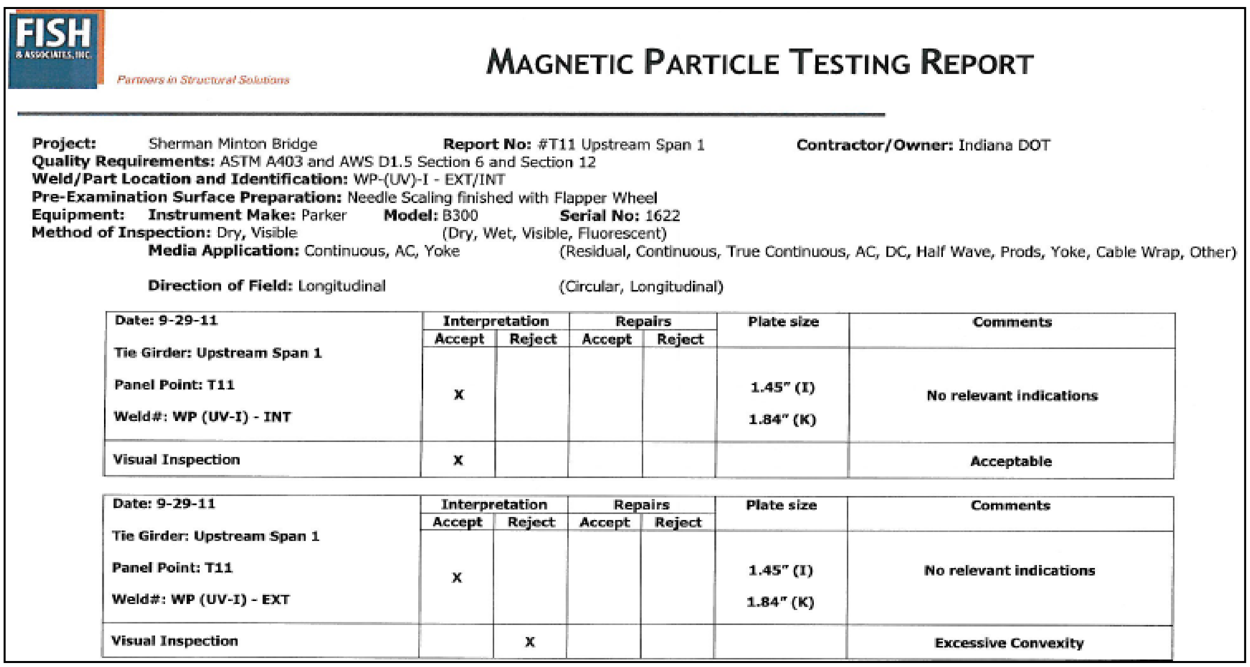
Figure F67. Cross section of panel point T-8 (Indiana side)

CORE #16

Table F14: Comparison of MT, RT, UT & VI with Core Results for Core #16:

Core #16 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-1, T11, UV-I 2.16" Dia. Core from Top (3")	MT – PSI	-	-	-	-	Accept
	RT – ATS	1.2	0.5	Incomplete Fusion	0	Reject
		3.0-4.0	***0.2***	***Incomplete Fusion***	***100***	***Reject***
	UT – PSI	0.0	2.38	B, 0.95" from surf.	0	Reject
		15.75	1.9	A, 0.92" from surf.	0	Reject
	Visual	UV-I (Ext)	-	Excessive Convexity	-	Reject
	Core–ATS	***~3***	***0.1***	***0.90"-I* & 0.68"-E****	***NA***	***1 Subsurf.***

(*) I and E mean interior and exterior surfaces, respectively. The subsurface flaw locates 0.9 inches from inside and 0.68 inches from outside of the web plate.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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton Bridge **Report No:** #T11 Upstream Span 1 **Contractor/Owner:** Indiana DOT
Quality Requirements: ASTM A403 and AWS D1.5 Section 6 and Section 12
Weld/Part Location and Identification: WP-(UV)-I - EXT/INT
Pre-Examination Surface Preparation: Needle Scaling finished with Flapper Wheel
Equipment: **Instrument Make:** Parker **Model:** B300 **Serial No:** 1622
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)

Direction of Field: Longitudinal (Circular, Longitudinal)

Date: 9-29-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Upstream Span 1 Panel Point: T11 Weld#: WP (UV-I) - INT	X				1.45" (I) 1.84" (K)	No relevant indications
Visual Inspection	X					Acceptable

Date: 9-29-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Upstream Span 1 Panel Point: T11 Weld#: WP (UV-I) - EXT	X				1.45" (I) 1.84" (K)	No relevant indications
Visual Inspection		X				Excessive Convexity

Figure F68. FISH MT and visual reports.

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ULTRASONIC TESTING REPORT

Date: 9-29-11
Tie Girder: Upstream Span 1
Panel Point: T11
Weld#: WP (UV-I) - EXT

Indication No.	Transducer Angle	From Face	Leg *	Indication Level a	Reference Level b	Attenuation Factor c	Indication Rating D	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance From X	Distance From Y	Remarks
1	70	A	1	68	55	4	9	2.38"	2.77"	0.95"	0	0	Rejectable indication (Class B)
2	70	A	1	53	55	3	-5	1.0"	2.7"	0.92"	0	15.75"	Rejectable indication (Class A)

Note: Lamination scan acceptable

Figure F69. FISH UT report.

RADIOGRAPHIC INSPECTION TECHNIQUE

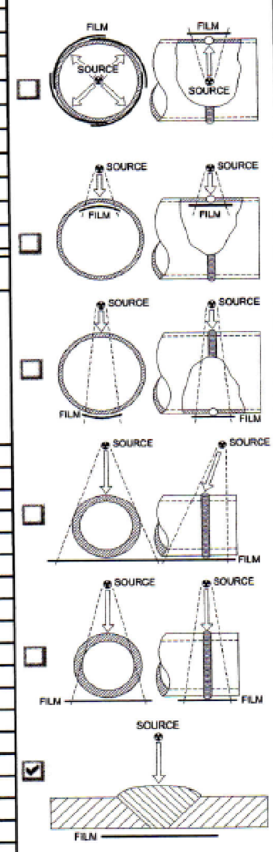
Specifications: ATS 120.19 Rev. 1	Accept/Reject Criteria: AWS D1.5, Figure 6.8
Isotope Ir192	Digital System Fuji Dynamix Series V
Curies 96.0	Software Version VFC1 4.0
KV N/A	IP Type Fuji ST-VI
MA N/A	Sensitivity 0.032
Time 12 min	Penetrameter ASTM 1B
SFD 27"	Shim(s) N/A
SOD 25"	Screen(s) Type Pb Front .010 Back N/A
OFD 2"	Focal Size 0.166
Source Size (Physical) .126" x .128"	Weld Reinforcement Ground Flush
Geometric Unsharpness 0.013"	Weld Process N/A

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US-S1-T11-IN												
UV												
0-15		X						X				0.50" @ 1.2", 0.2"@3"-4"
11-26	/											
24-37	/											
DV												
0-15	/											
6-21	/											
30-36	/											
31-37	/											Art. @ 31"-34"
												Note: Linear Indications are
												longitudinal with weld except as
												noted
												Note: Intersecting corner @ top and
												Bottom of weld has rejectable weld
												flaws per AWS D1.5. Edge blocks
												not used

Art.=artifact which is a non-relevant indication

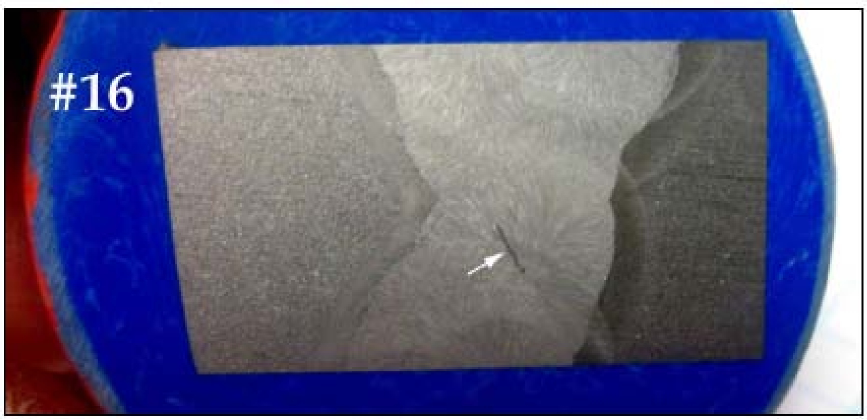
SETUP



SEE ATTACHED SKETCH

Figure F70. ATS RT report.

(A)



(B)

Figure F71. (A) Core #16 location on the exterior surface of the web. (B) Transverse metallographic section through indication at Core #16.

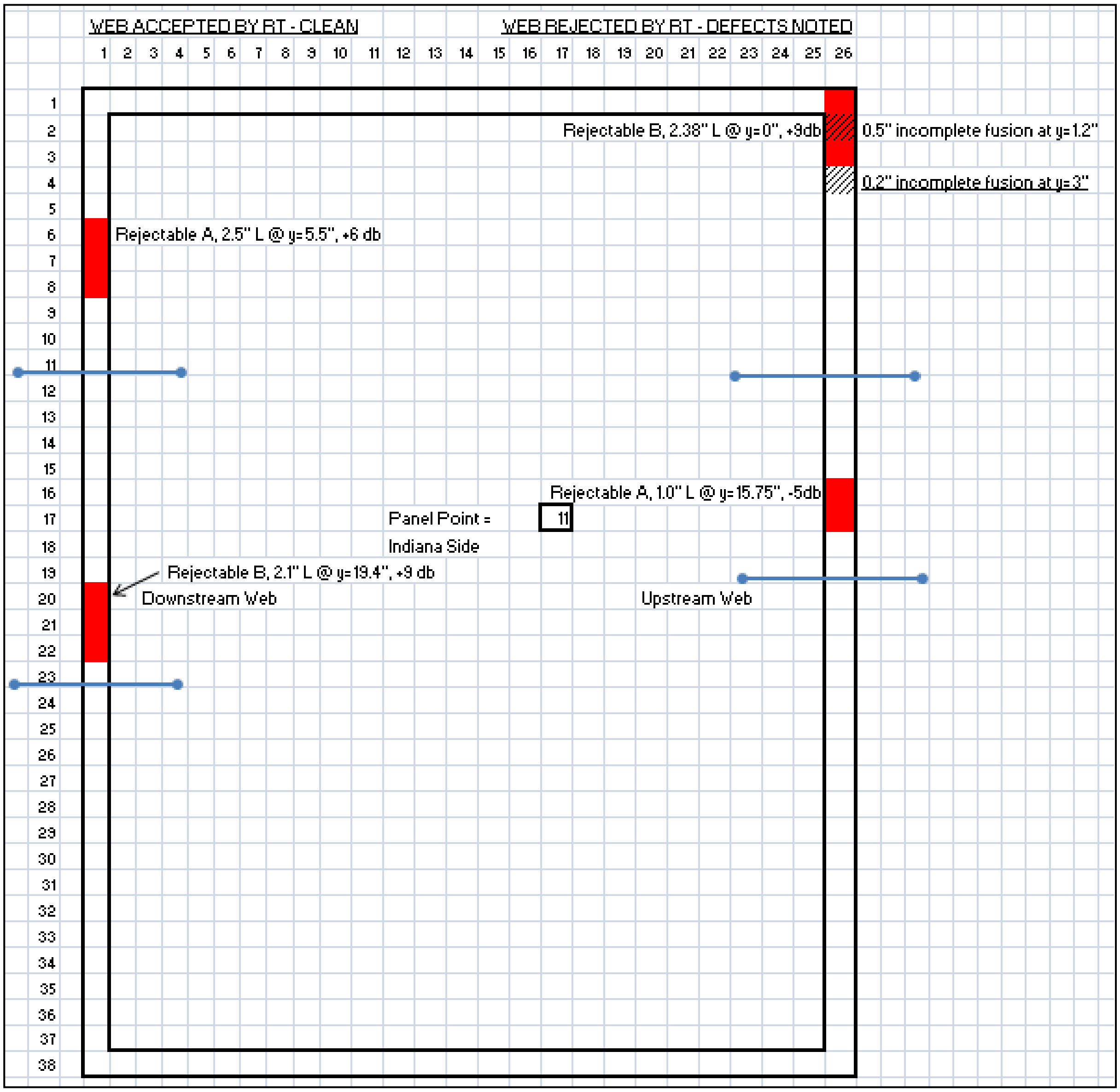


Figure F72. Cross section of panel point T-11 (Indiana side) at Core #16 location

CORE #17

Table F15: Comparison of MT, RT, UT & VI with Core Results for Core #17:

Core #17 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
DS-2, T3, DV-K 2.16" Dia. Core from Top (18")	MT – PSI	-	-	-	-	Accept
	RT – ATS	14.0	0.55	Incomplete Fusion	0	Reject
		18.0	***0.20***	***Porosity***	***0***	***Reject***
		25.0-26.0	0.50	Inc. F., Porosity, Slag	0	Reject
	UT – PSI	6.0-7.1	1.1	C, 0.72" from surf.	0	Accept
		12.7-16.8	4.1	A, 0.70" from surf.	0	Reject
		15.0-16.7	1.7	C, 0.72" from surf.	0	Accept
	Visual	-	-	-	-	-
	Core–ATS	***No Flaw***	**-**	***No flaw found***	***NA***	***0 flaws***

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MAGNETIC PARTICLE TESTING REPORT

	Interpretation		Repairs		Plate Size	Comments
	Accept	Reject	Accept	Reject		
Date: June 8, 2011 **Tie Girder:** Downstream Span 2 **Panel Point:** T3 (T2-T3) **Weld#:** 6004 – 4 sides Downstream Web	X*					X* = No rejectable indications were observed. Fails U.T.

Figure F73. PSI MT report showing no rejectable falws.

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ULTRASONIC TESTING REPORT

Date: June 8, 2011

Tie Girder: Downstream Span 2

Panel Point: T3 (T2-T3)

Weld#: 6004 – 4 Sides
Downstream Web (Indication No. 1)
Downstream Web (Indication No. 2)
Upstream Web (Indication No. 1)
Top and Bottom Faces

Indication No.	Transducer Angle	From Face	Leg*	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Discontinuity Evaluation	Date	Remarks
				a	b	c	d				From X	From Y			
1	70	A	1	64	50.7	3	10	1.1	2.33	.72	-.5	6-7.1	C	6.8.2011	Acceptable
2	70	A	1	62.1	50.7	3	8	4.1	2.27	.70	-.4	12.7-16.8	A	6.8.2011	Reject
1	70	A	1	63.6	50.7	3	10	1.7	2.34	.72	-.5	15-16.7	C	6.8.2011	Acceptable
---	---	---	---	---	---	---	---	---	---	---	---	---	---	6.8.2011	No rejectable indications were observed.

Figure F74. PSI UT report.

APPLIED TECHNICAL SERVICES, INCORPORATED

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COMPUTED RADIOGRAPHIC INSPECTION REPORT

Job # S172347 PO # WO # Date 9/24/11 Page 1 of 1

CLIENT: **University of Kentucky**
LOCATION: **Sherman Minton Bridge**

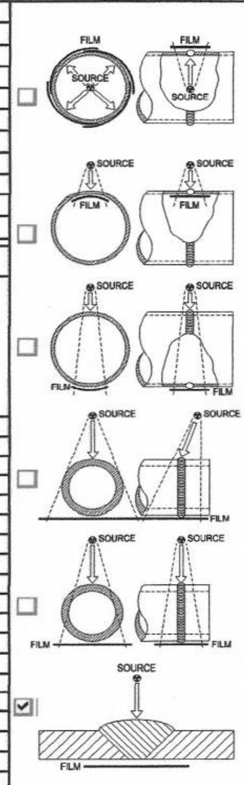
PART NO.: DS-S2-T3-KY
PART NAME: Tie Girder
MATERIAL: C/S
THICKNESS: 1.5-2.25
TYPE WELD: BUTT

RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1
Isotope Ir192
Curies 91.0
KV N/A
MA N/A
Time 12 min
SFD 27"
SOD 25"
OFD 2"
Source Size (Physical) .126" x .128"
Geometric Unsharpness 0.013"

Accept/Reject Criteria: AWS D1.5, Figure 6.8
Digital System Fuji Dynamix Series V
Software Version VFC1 4.0
IP Type Fuji ST-VI
Sensitivity 0.032
Penetrameter ASTM 1B
Shim(s) N/A
Screen(s) Type Pb Front .010 Back N/A
Focal Size 0.166
Weld Reinforcement Ground Flush
Weld Process N/A

SETUP



☐ SEE ATTACHED SKETCH

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
DS-S2-T3-KY												
UV												
1-16	/											
10-24	/											
28-35	/											
32-37	/											
DV												
1-16	/											
12-27		X				X		X				LOF: 0.55"@14", P: 0.2"@18"
23-37		X		X		X		X				0.5"@25"-26"
												Note: Linear Indications are
												longitudinal with weld except as
												noted
												Note: Intersecting corner @ top and
												Bottom of weld has rejectable weld
												flaws per AWS D1.5

Art.=artifact which is a non-relevant indication

RADIOGRAPHER(S): Dave Storey/Scott Powell Level II RT
INTERPRETER: J. J. Hills Jim J. Hills Level III RT

ATS 120.11, 08/10

Figure F75. ATS RT report showing no flaws at Core #17 location.

(A)

(B)

Figure F76. (A) Location of Core #17 on exterior surface of the web. (B) Macro-etched section of Core #17 (No cracks found).

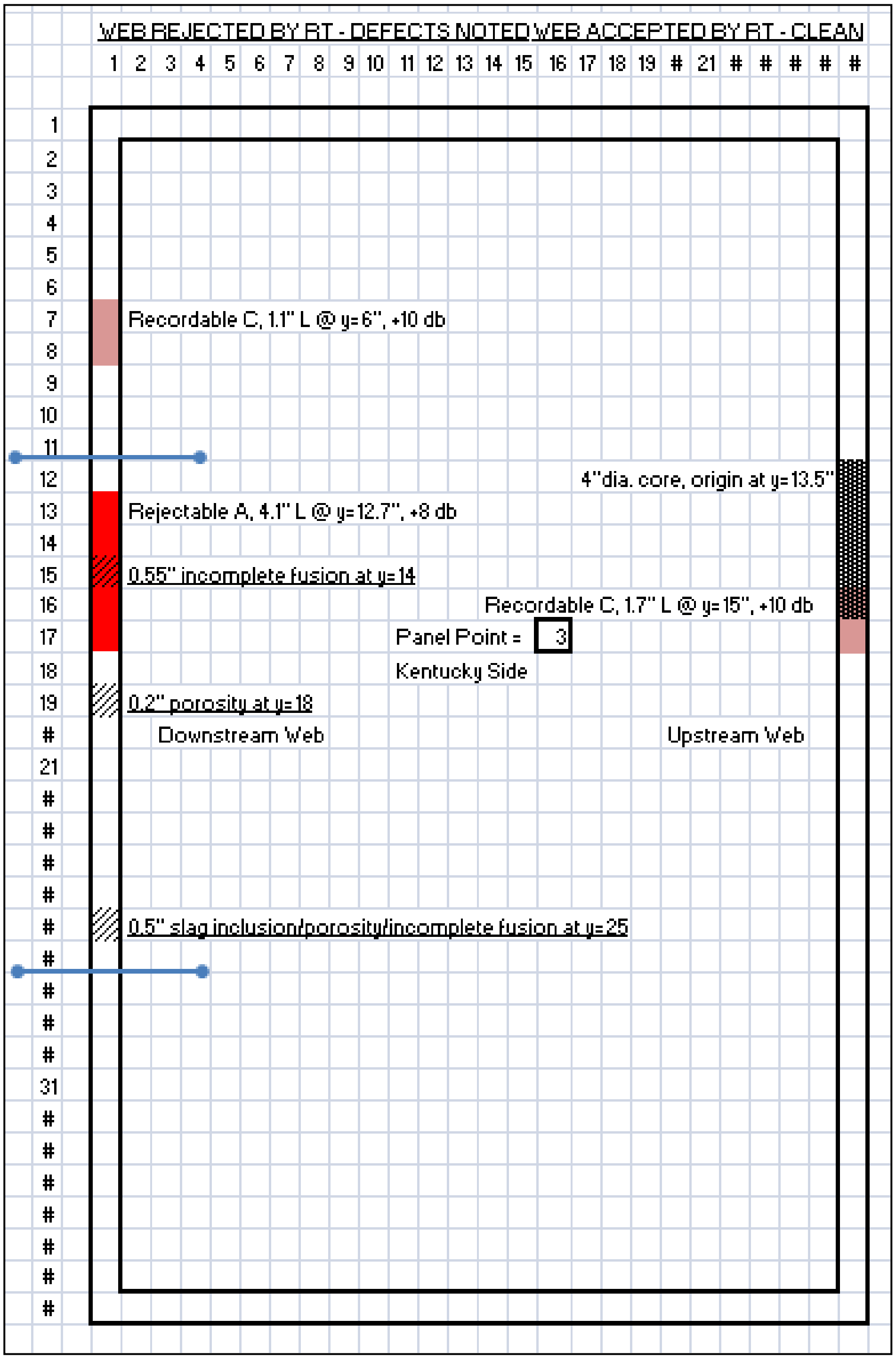


Figure F77. Cross section of panel point T-3 (Kentucky Side).

CORE #18

Table F16: Comparison of MT, RT, UT & VI with Core Results for Core #18:

Core #18 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-1, T9, DV-I **2.17" Dia. Core from Top (12")**	MT – PSI	-	-	-	-	Accept
	RT – ATS	***12.0-13.0***	***0.8***	***Slag***	***0***	***Reject***
	UT – PSI	-	-	-	-	Accept
	Visual	-	-	-	-	-
	Core–ATS	***No Flaw***	**-**	***No flaw found***	***NA***	***0 flaws***

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MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton, Fracture Critical Bridge Inspection **Report No:** 0014672-2 **Contractor/Owner:** INDOT
Quality Requirements: AWS D1.5 - 2010
Weld/Part Location and Identification: Butt Joints (CJP) @ Tie Girder and Fillet Welds @ Lateral Beams & Tie Girder
Pre-Examination Surface Preparation: Media Blast
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 4372
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)
Direction of Field: Longitudinal (Circular, Longitudinal)

	Interpretation		Repairs		Plate Size	Comments
	Accept	Reject	Accept	Reject		
Date: June 14, 2011 **Tie Girder:** Upstream Span 1 **Panel Point:** T9 (T9-T10) **Weld#:** 5022 Downstream Web	X*					X* = No rejectable indications were observed.

Figure F78. PSI MT report showing no rejectable indications.

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ULTRASONIC TESTING REPORT

	Indication No.	Transducer Angle	From Face	Leg *	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Discontinuity Evaluation	Date	Remarks
					a	b	c	d				From X	From Y			
Date: June 14, 2011 Tie Girder: Upstream Span 1 Panel Point: T9 (T9-T10) Weld#: 5022 Downstream Web	---	---	---	---	---	---	---	---	---	---	---	---	---	---	6.14.11	No rejectable indications were obsereved.

Figure F79. PSI UT report showing no rejectable indications.

APPLIED TECHNICAL SERVICES, INCORPORATED

1049 Triad Court, Marietta, Georgia 30062 • (770) 423-1400 Fax (770) 514-3299 • www.atslab.com

COMPUTED RADIOGRAPHIC INSPECTION REPORT

Job # S172347 PO # WO # Date 9/17/11 Page 1 of 1

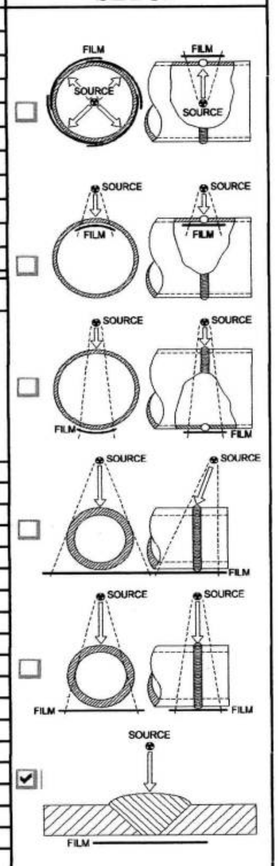
CLIENT: **University of Kentucky**
LOCATION: **Sherman Minton Bridge**

PART NO.: US.S1.T9.IN
PART NAME: Tie Girder
MATERIAL: C/S
THICKNESS: 1.5-2.25
TYPE WELD: BUTT

RADIOGRAPHIC INSPECTION TECHNIQUE

Specifications: ATS 120.19 Rev. 1	Accept/Reject Criteria: AWS D1.5, Figure 6.8
Isotope Ir192	Digital System Fuji Dynamix Series V
Curies 98.0	Software Version VFC1 4.0
KV N/A	IP Type Fuji ST-VI
MA N/A	Sensitivity 0.032
Time 12 min	Penetrameter ASTM 1B
SFD 27"	Shim(s) N/A
SOD 25"	Screen(s) Type Pb Front .010 Back N/A
OFD 2"	Focal Size 0.166
Source Size (Physical) .126" x .128"	Weld Reinforcement Ground Flush
Geometric Unsharpness 0.013"	Weld Process N/A

SETUP



INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US.S1.T9.IN												
UV												
1-15	/							/				0.3" long @ 10"-11"
12-26	/											
23-38	/			/								0.3" long @ 35"-36"
DV												
1-15		X		X								*0.8" long @ 12"-13"
12-26		X		X								*0.8" long @ 12"-13"
30-36	/											
31-38	/					/						
												*Same Indication

RADIOGRAPHER(S): Scott Powell Level II RT
INTERPRETER: Jim J. Hills Level III RT

ATS 120.11, 08/10

Figure F80. ATS RT Report showing no flaws at the Core #18 location.

(A)

(B)

Figure F81. (A) Core #18 location on the exterior surface of the web. (B) Macro-etched cross section of the Core #18.

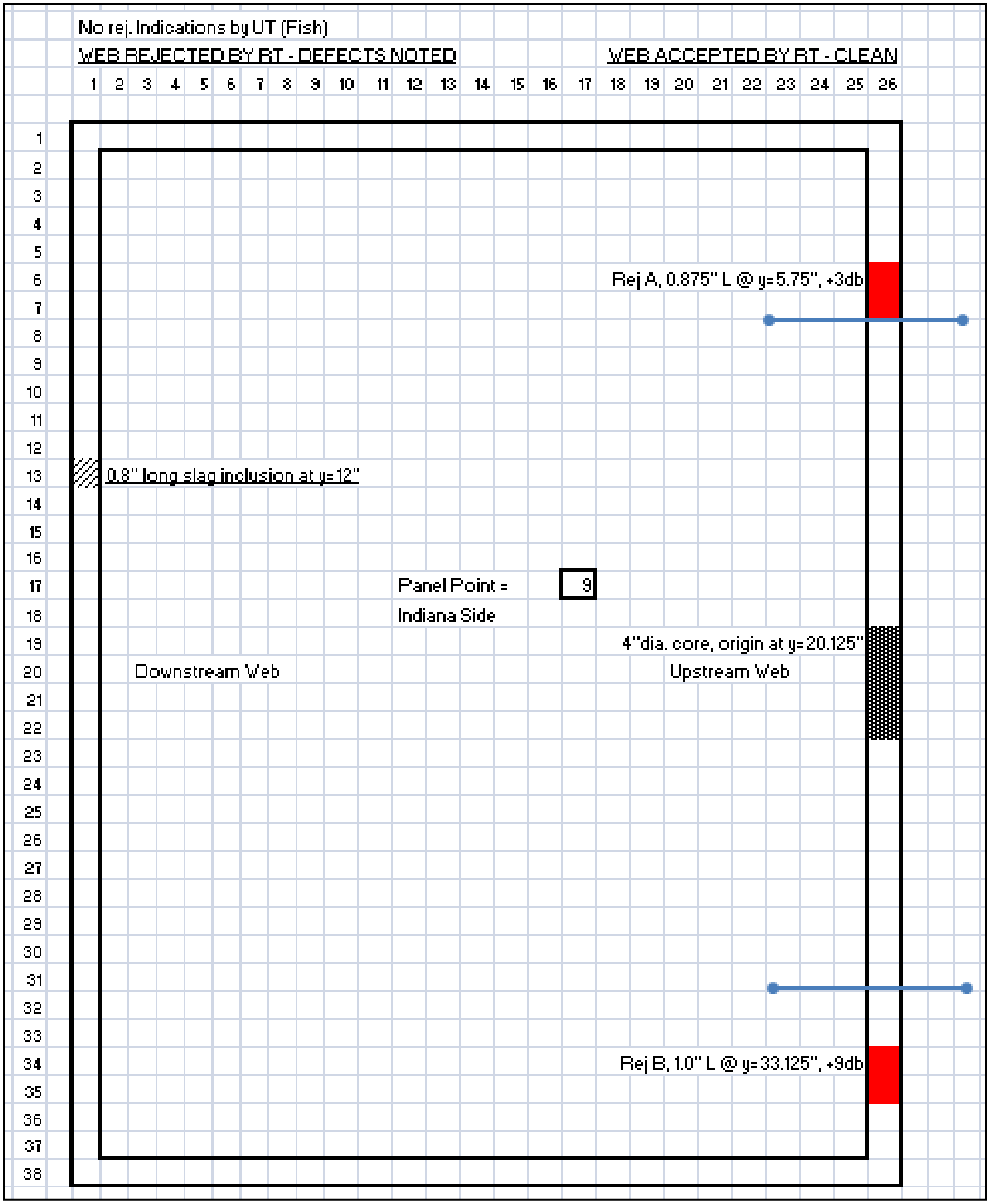


Figure F82. Cross section of panel point T-9 (Indiana side) at Core #18 location

CORE #19

Table F17: Comparison of MT, RT, UT & VI with Core Results for Core #19:

Core #19 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
DS-1, T20, UV-I 2.16" Dia. Core from Top (27")	MT	-	-	-	-	Accept
	RT	-	-	-	-	Accept
	UT (09/26/11)	33.5	1.00	A, 0.82" from surf.	0	Reject
		31.5	1.00	D, 0.45" from surf.	0	Record
		28.25	***0.75***	***A, 0.56" from surf.***	***~90***	***Reject***
		18.5	1.00	A, 0.64" from surf.	0	Reject
		13.5	0.75	D, 0.90" form surf.	0	Record
		11.5	1.25	A, 0.71" from surf.	0	Record
		9.75	1.00	A, 0.90" from surf.	0	Reject
		8.0	1.25	C, 0.67" from surf.	0	Reject
	UT (05/21/11)	6.25	1.25	A, 0.66" from surf.	0	Reject
		19.75	1.25	A, 0.72" from surf.	0	Reject
		32.5	1.50	A, 0.70" from surf.	0	Reject
		26.34	***1.25***	***A, 0.60" from surf.***	***~100***	***Reject***
		34.5	1.25	A, 0.80" from surf.	0	Reject
		20.5	1.25	B, 0.68" from surf.	0	Reject
		22.0	1.25	0.90" from surf.	0	Record
	Visual	UV-I (Ext)	-	Undercut, Under-filled	-	Reject
	Core–ATS	***27***	***0.08***	***I-0.89", E-0.71"***	***NA***	***1 flaw Subsurface***

FISH & ASSOCIATES, INC.
Partners in Structural Solutions

ULTRASONIC TESTING REPORT

Date: 9-26-11

Tie Girder: Downstream Span 1

Panel Point: T20

Weld#: WP (UV-I)– EXT

Note: Lamination scan acceptable

Indication No.	Transducer Angle	From Face	Leg*	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Remarks
				a	b	C	D				From X	From Y	
1	70	A	1	43	40	3	0	1.0"	2.5"	0.82"	0	33.5"	Rejectable indication (Class A)
2	70	A	1	51	40	1	10	1.0"	1.5"	0.45"	0.6"	31.5"	Recordable indication (Class D)
3	70	A	1	45	40	1	4	0.75"	1.7"	0.56"	-0.6"	28.25"	Rejectable indication (Class A)
4	70	A	1	46	40	2	4	1.0"	1.9"	0.64"	0	18.5"	Rejectable indication (Class A)
5	70	A	1	56	40	3	13	0.75"	2.7"	0.9"	0	13.5"	Recordable indication (Class D)
6	70	A	1	50	40	2	8	1.25"	2.1"	0.71"	-0.1"	11.5"	Recordable indication (Class A)
7	70	A	1	43	40	3	0	1.0"	2.6"	0.9"	0	9.75"	Rejectable indication (Class A)
8	70	A	1	52	40	2	10	1.25"	2.0"	0.67"	-0.1"	8.0"	Rejectable indication (Class C)

FISH & ASSOCIATES, INC.
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ULTRASONIC TESTING REPORT

Date: 5-21-2011

Tie Girder: Downstream Span 1

Panel Point: T20

Weld#: WP (UV-I) – EXT

Note: Lamination scan acceptable

Indication No.	Transducer Angle	From Face	Leg*	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Remarks
				a	b	C	D				From X	From Y	
1	70	A	I	59	55	2	+2	1.25"	1.93"	.663"	-.125"	6.25"	Rejectable indication (Class "A)
2	70	A	I	54	55	2	-3	1.25"	2.1"	.72"	0"	19.75"	Rejectable indication (Class "A)
3	70	A	I	59	55	2	+2	1.50"	2.04"	.699"	-.125"	32.5"	Rejectable indication (Class "A)
4	70	A	I	51	55	3	-6	1.25"	1.75"	.597"	-.25	26.375"	Rejectable indication (Class "A)
5	70	A	I	55	55	3	+7	1.25"	2.35"	.804"	0"	34.5"	Rejectable indication (Class "A)
6	70	A	I	55	55	2	+9	1.25"	2"	.68"	0"	20.5"	Rejectable indication (Class "B)
7	60	A	I	62	47	2	+13	1.25"	1.98"	.99"	+.50	22"	Recordable indication

Figure F83. FISH UT reports (different dates, the same location) showing one flaw at the Core #19 location (26.375 in from top, Y)

FISH & ASSOCIATES, INC.
Partners in Structural Solutions

MAGNETIC PARTICLE TESTING REPORT

Date: 5-21-2011	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Downstream Span 1 Panel Point: T20 Weld#: WP (UV-I) - EXT	X				1.51" (IN) 2.00" (KY)	No relevant indications
Visual Inspection		X				Undercut and under filled joint.

Date: 5-21-2011	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Downstream Span 1 Panel Point: T20 Weld#: WP (UV-I) - INT	X				.520" (IN) .651" (K)	No relevant indications
Visual Inspection	X					

Figure F84. FISH MT report showing no flaw at the Core #19 location

HESCO a division of PTSE. Inc
2501 Monarch St., Alameda, CA 94501, mailing P.O. Box 216, Alameda, CA 94510
Ph#510-523-9488, Fax 510-523-9486, website: www.hescoxray.com

RADIOGRAPHIC INSPECTION REPORT

Job No INT A249-11-320702 PO# WO# DATE

Customer: Michael Baker Jr. Inc.
888 Keystone Crossing,
Suite 1300
Indianapolis, IN 46240

Location: Sherman Minton Bridge
Indiana/Kentucky across the Ohio River

Radiographers:
John Powis Level II
Mike DePinna Level II
Richard Seals Level III

Part ID/ View No	RT REF # on film	Accept	Reject	Trans to Girders	Transverse Crack	Longitudinal Crack	Slag Inclusion	Porosity	Undercut	Incomplete Fusion	Artifact	Remarks
DS-S1-T20-IN												RT DATE
INUV TOP	M7	X										21-Sep-2011
MID	M7	X										21-Sep-2011
BTM	M7	X										21-Sep-2011
INDV TOP	M8	X										21-Sep-2011
MID	M8	X										21-Sep-2011
BTM	M8	X										21-Sep-2011

Part Name: Tie Girder	Weld Type: Bittweld	SOD:	Shim: N/A	Sensitivity: .032
Specifications: HESCO RT-12 REV/2	Source: 6 Mev	Acceptance Standard: AWS D1.5 fig 6.8	Screens: Type: Pb Front/Back: .010	
Material: carbon steel	Focal Spot Size: 1.8mm	Geometric Unsharpness:	Film Type: Fuji 50	
Thickness: 1 1/2 - 2 1/4	SFD: 12ft/14ft	Penetrameter: AWS 1B	Size: 14 x 17	18

Figure F85. HESCO RT report showing no flaw at the Core #19 location

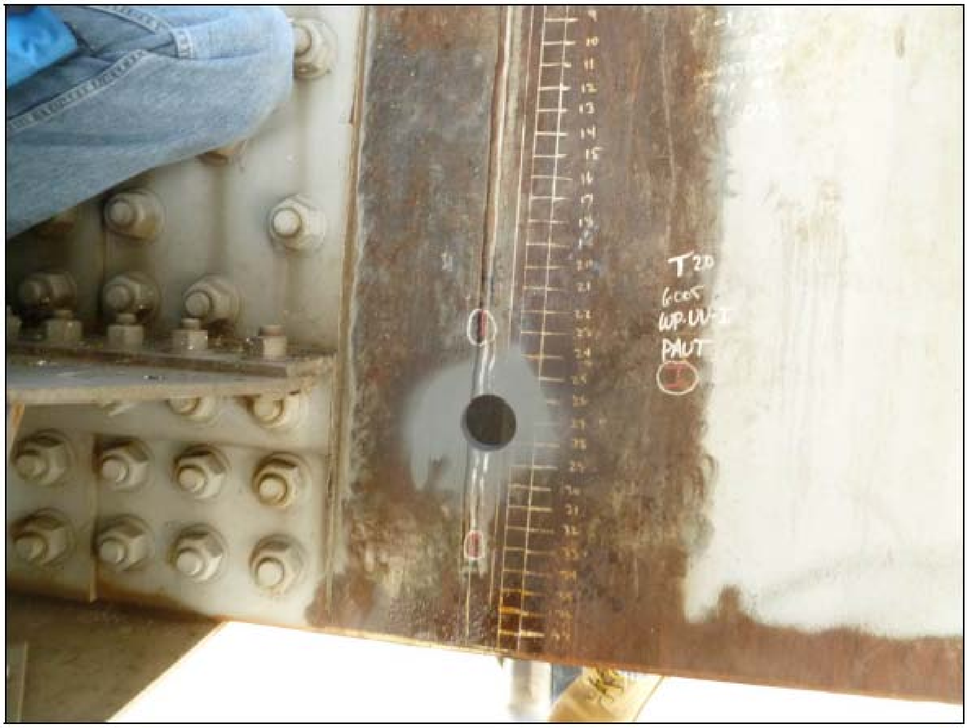


Figure F86. Core #19 location on the exterior surface of the web

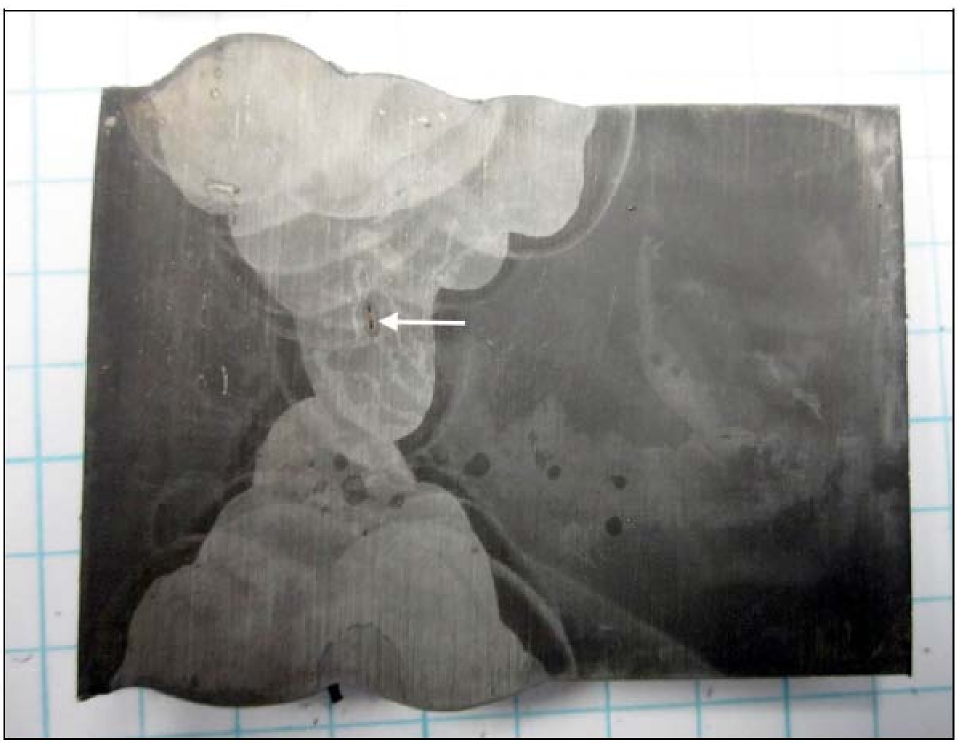


Figure F87. Macro-Etched cross section of the Core #19 indicating a flaw

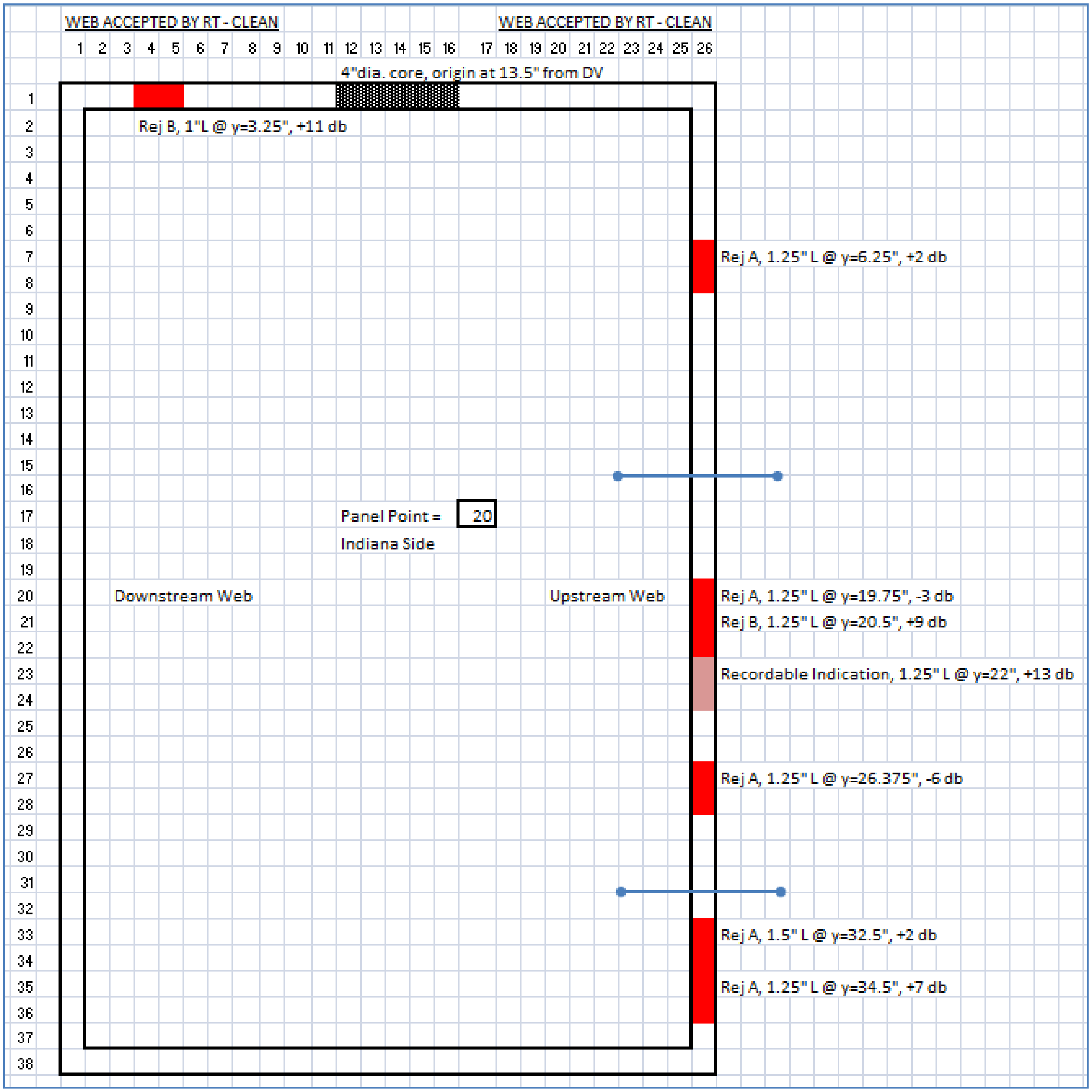
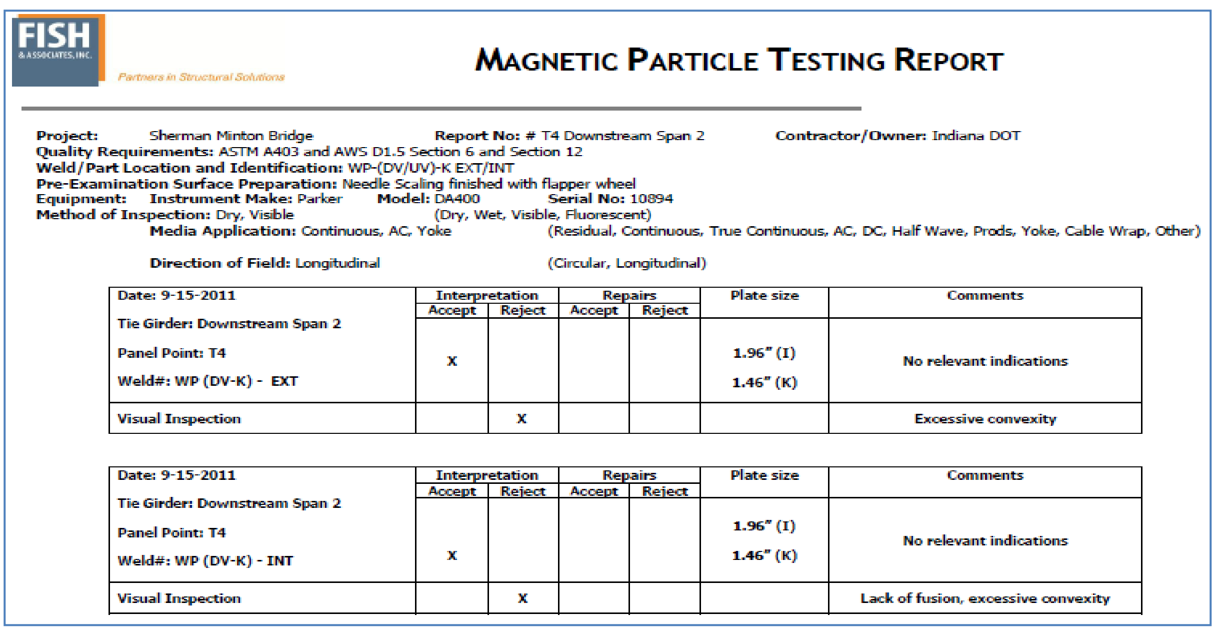


Figure F88. Cross section of panel point T-20 (Indiana side) at Core #19 location

CORE #20

Table F18: Comparison of MT, RT, UT & VI with Core Results for Core #20:

Core #20 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
DS-2, T4, DV-K 2.16" Dia. Core from Top (7")	MT	-	-	-	-	Accept
	RT	***7 - 9***	***1.1***	***Inc. fusion & porosity***	**-**	***Reject***
		20 - 22	1.7	Inc. fusion	-	Reject
	UT	30.75	1.5	A, 0.70" from surf.	0	Reject
		24.0	1.5	A, 0.60" from surf.	0	Reject
		2.78	1.0	C, 0.62" from surf.	0	Record
		11.5	1.5	A, 0.78" from surf.	0	Reject
	Visual	DV-K (Ext)	-	Excessive Convexity	-	Reject
		DV-K (Int)	-	Excessive Convexity & Lack of Fusion	-	Reject
	Core–ATS	***No Flaw***	**-**	***No flaw found***	***NA***	***0 flaws***



FISH & ASSOCIATES, INC.
Partners in Structural Solutions

MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton Bridge **Report No:** # T4 Downstream Span 2 **Contractor/Owner:** Indiana DOT
Quality Requirements: ASTM A403 and AWS D1.5 Section 6 and Section 12
Weld/Part Location and Identification: WP-(DV/UV)-K EXT/INT
Pre-Examination Surface Preparation: Needle Scaling finished with flapper wheel
Equipment: **Instrument Make:** Parker **Model:** DA400 **Serial No:** 10894
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)

Direction of Field: Longitudinal (Circular, Longitudinal)

Date: 9-15-2011	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Downstream Span 2 Panel Point: T4 Weld#: WP (DV-K) - EXT	X				1.96" (I) 1.46" (K)	No relevant indications
Visual Inspection		X				Excessive convexity

Date: 9-15-2011	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Downstream Span 2 Panel Point: T4 Weld#: WP (DV-K) - INT	X				1.96" (I) 1.46" (K)	No relevant indications
Visual Inspection		X				Lack of fusion, excessive convexity

Figure F89. FISH MT report at Core #20 location

ULTRASONIC TESTING REPORT

FISH & ASSOCIATES, INC. *Partners in Structural Solutions*

Date: 9-15-2011 Tie Girder: Downstream Span 2 Panel Point: T4 Weld#: WP (DV-K)-EXT	Indication No.	Transducer Angle	From Face	Leg *	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Remarks
					a	b	c	D				From X	From Y	
	1	70	A	I	59	53	2	4	1.5"	2.06"	0.70"	0.187"	30.75"	Rejectable indication (Class A)
	2	70	A	I	61	53	2	6	1.5"	1.77"	0.60"	0.125"	24.0"	Rejectable indication (Class A)
Note: Lamination scan acceptable	3	70	A	I	65	53	2	10	1.0"	1.80"	0.62"	0.25"	2.75"	Recordable indication (Class C) *Not rejected due to length.
	4	60	A	II	61	49	7	5	1.5"	4.29"	0.78"	0.187"	11.5"	Rejectable indication (Class A)

Figure F90. FISH UT report at Core #20 location

RADIOGRAPHIC INSPECTION TECHNIQUE

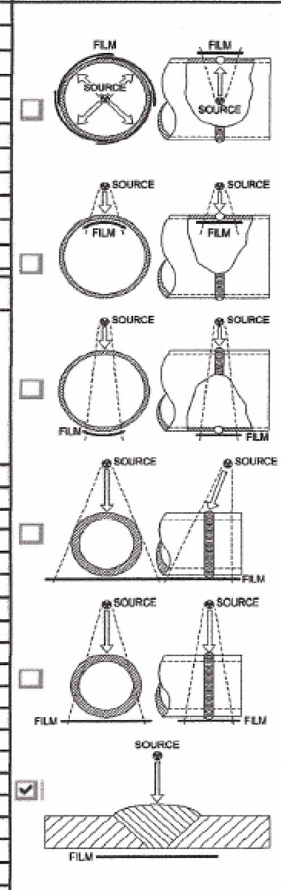
Specifications: ATS 120.19 Rev. 1	Accept/Reject Criteria: AWS D1.5, Figure 6.8
Isotope Ir192	Digital System Fuji Dynamix Series V
Curies 98.0	Software Version VFC1 4.0
KV N/A	IP Type Fuji ST-VI
MA N/A	Sensitivity 0.032
Time 12 min	Penetrameter ASTM 1B
SFD 27"	Shim(s) N/A
SOD 25"	Screen(s) Type Pb Front .010 Back N/A
OFD 2"	Focal Size 0.166
Source Size (Physical) .126" x .128"	Weld Reinforcement Ground Flush
Geometric Unsharpness 0.013"	Weld Process N/A

INTERPRETATION

PART ID/ FILM VIEW	Accept	Reject	Crack	Slage Inclusion	Tungston Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
DS-S2-T4-KY												
UV												
1-16	/											
12-27	/											
23-37	/							/				0.31" @ 34"
DV												
1-16		X				X		X				1.1" @ 7"-9"
12-26		X						X				1.7" @ 20"-22"
23-37	/											
												Note: Linear Indications are
												longitudinal with weld except as
												noted
												Note: Intersecting corner @ top and
												Bottom of weld has rejectable weld
												flaws per AWS D1.5

Art.=artifact which is a non-relevant indication

SETUP



☐ SEE ATTACHED SKETCH

Figure F91. ATS RT report showing no rejectable indications at Core #20

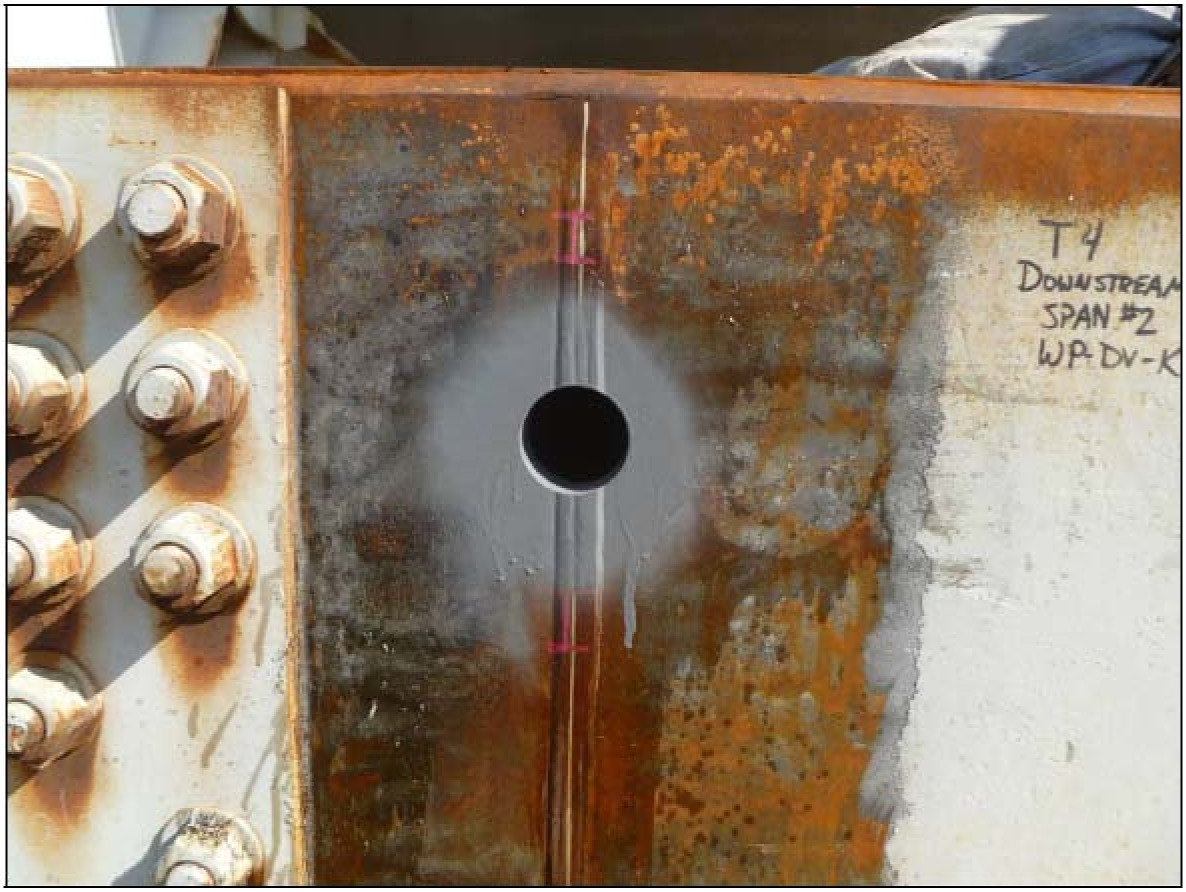


Figure F92. Core #20 location at the exterior surface of the web

Figure F93. Core #20 Macro-Etched cross section showing no flaws

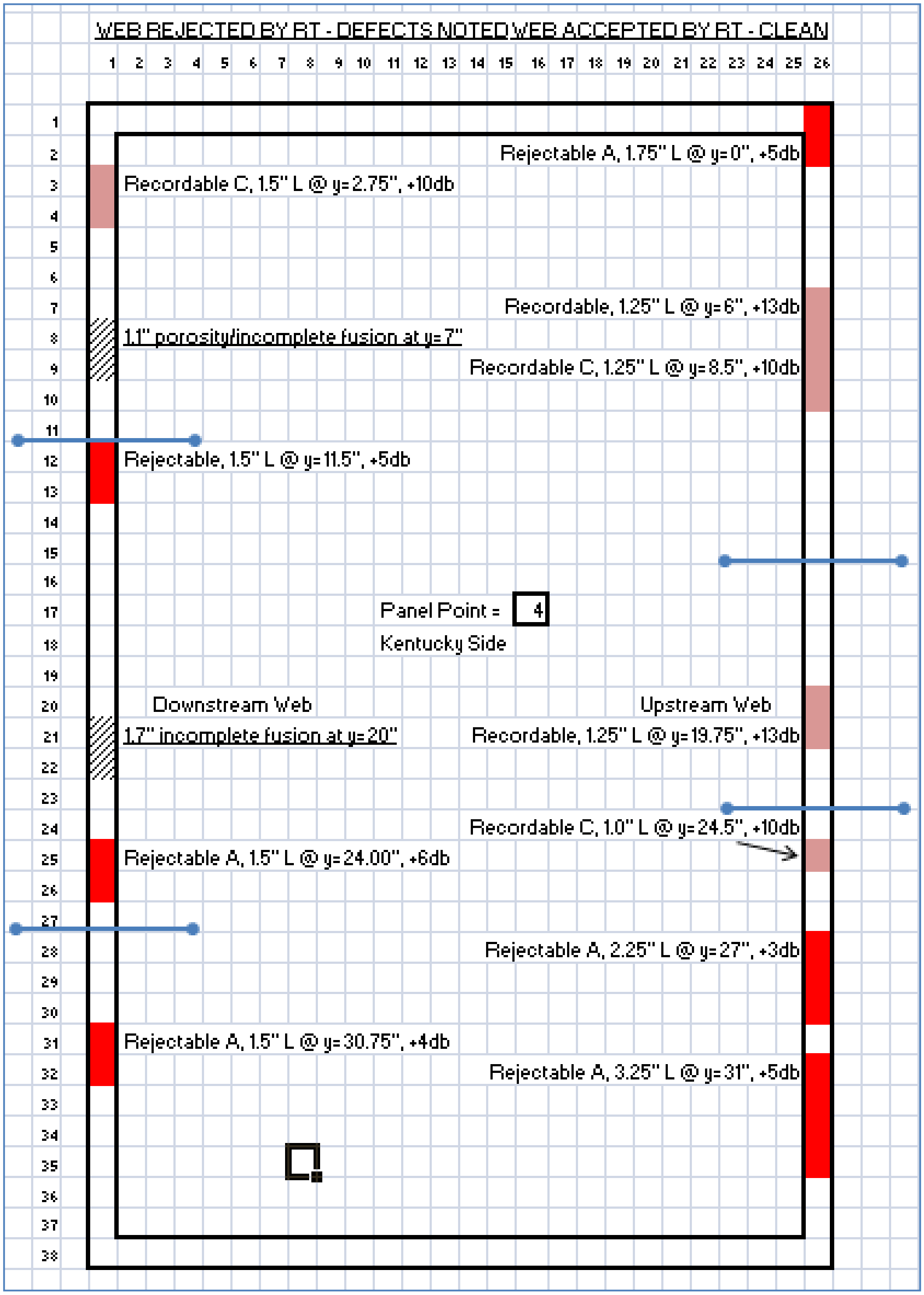


Figure F94. Cross section of panel point T-4 (Kentucky side)

CORE #21

Table F19: Comparison of MT, RT, UT & VI with Core Results for Core #21:

Core #21 Location	Inspection Method	Flaw Location from Top – Y (in)	Flaw Length (in)	Flaw Disposition	Flaw Overlap %	Comments
US-2, T9, DV-K 1.59" Dia. Core from Top (5")	MT	-	-	-	-	Accept
	RT	8 - 9	0.15	Inc. fusion	-	Accept
		16 - 17	0.35	Inc. fusion	-	Accept
	UT	***5.2***	***1***	***A, 1.34" from surf.***	***~100***	***Reject***
		9.8	0.8	B, 0.98" from surf.	0	Reject
		23	0.9	A, 1.27" from surf.	0	Record
	Visual	-	-	-	-	Accept
	Core–ATS	***~5***	***0.01***	***I-0.28", E-1.28"***	***NA***	***1 flaw subsurface***

FISH & ASSOCIATES, INC.
Partners in Structural Solutions

MAGNETIC PARTICLE TESTING REPORT

Project: Sherman Minton Bridge **Report No:** #T9 Upstream Span 2 **Contractor/Owner:** Indiana DOT
Quality Requirements: ASTM A403 and AWS D1.5 Section 6 and Section 12
Weld/Part Location and Identification: WP-(DV/UV)-K - EXT/INT
Pre-Examination Surface Preparation: Needle Scaling finished with Flapper Wheel
Equipment: **Instrument Make:** Parker **Model:** PA400 **Serial No:** 5072
Method of Inspection: Dry, Visible (Dry, Wet, Visible, Fluorescent)
Media Application: Continuous, AC, Yoke (Residual, Continuous, True Continuous, AC, DC, Half Wave, Prods, Yoke, Cable Wrap, Other)
Direction of Field: Longitudinal (Circular, Longitudinal)

Date: 9-28-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Upstream Span 2 Panel Point: T9 Weld#: WP (DV-K) - EXT	x				1.83" (I) 1.45" (K)	No relevant indications
Visual Inspection	x					Acceptable

Date: 9-28-11	Interpretation		Repairs		Plate size	Comments
	Accept	Reject	Accept	Reject		
Tie Girder: Upstream Span 2 Panel Point: T9 Weld#: WP (DV-K) - INT	x				1.83" (I) 1.45" (K)	No relevant indications
Visual Inspection	x					Acceptable

Figure F95. FISH MT report showing no flaw at the Core #21 location

FISH & Associates, Inc. — Partners in Structural Solutions	ULTRASONIC TESTING REPORT														
Date: 9-28-11 Tie Girder: Upstream Span 2 Panel Point: T9 Weld#: WP (DV-K) - EXT	Indication No.	Transducer Angle	From Face	Leg *	Indication Level	Reference Level	Attenuation Factor	Indication Rating	Length	Angular Distance (Sound Path)	Depth from "A" Surface	Distance		Remarks
					a	b	c	d				From X	From Y	
	1	70	A	1	48.7	46.1	6	-3	1.0"	3.9"	1.34"	0.7"	5.2"	Rejectable indication (Class A)
	2	70	A	1	59.1	46.1	4	9	0.8"	2.88"	0.98"	0.2"	9.8"	Rejectable indication (Class B)
Note: Lamination scan acceptable	3	70	A	1	50.9	46.1	5	0	0.9"	3.7"	1.27"	0	23.0"	Rejectable indication (Class A)

Figure F96. FISH UT report for Core #21 location

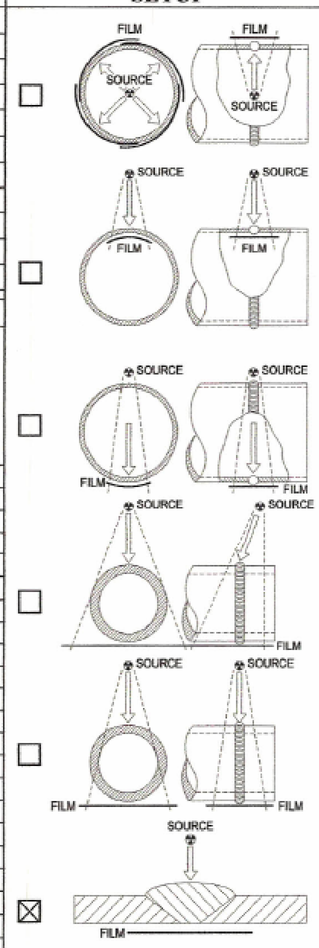
RADIOGRAPHIC INSPECTION TECHNIQUE

Specification(s):	ATS 120.19 Rev. 1	Accept/Reject Criteria:	AWS D1.5, Figure 6.8
Isotope	Ir192	Digital System	Fuji Dynamix Series V
Curies	91.7	Software Version	VFCI 4.0
KV	N/A	IP Type	Fuji ST-VI
MA	N/A	Sensitivity	ASTM 1B
Time	13 min	Penetrameter	0.032
SFD	27"	Shim(s)	N/A
SOD	25"	Screen(s)	Type: Pb Front: X Back:
OFD	2"	Focal Size	0.166
Source Size (Physical)	.126" x .128"	Weld Reinforcement	0.125" or Ground Flush
Geometric Unsharpness	0.013"	Weld Process	N/A

INTERPRETATION

PART I.D./ FILM VIEW	Accept	Reject	Crack	Slag Inclusion	Tungsten Inclusion	Porosity	Undercut	Incomplete Fusion	Incomplete Penetration	Root Concavity	Root Convexity	REMARKS
US-S2-T9-KY												
UV												
1-15	/											
11-26	/							/				0.4" @ 25"-26"
22-37		X	X					/				C: 0.2", LOF: .15" @ 22-23, 0.25" @ 24"-25"
DV												
1-15	/							/				0.15"@ 8"-9"
12-26	/							/				0.35"@ 16"-17"
30-36	/											
31-38	/											
												Note: Linear Indications are longitudinal with weld except as noted
												Note: Intersecting corner @ top and Bottom of weld has rejectable weld flaws per AWS D1.5

SETUP



SEE ATTACHED SKETCH

Figure F97. ATS RT report at the Core #21 location

Figure 98. Core #21 location on the exterior surface of the web

Figure F99. Core #21 Macro-Etched cross section

APPENDIX-G: NDT AND LAB DATA FOR FIGURE 2-11:

	NDT results					Sectioning results		
	Radiography		Ultrasonics					
No	Flaw type	Length, mm	Flaw type	Length, mm	Height, mm	Flaw type	Length, mm	Height, mm
1	CP 2	14	NE			Porosity	<9	2.6
2	CP 6	13	Th	23	HNM	Lack of inter–run fusion	13	0
3	CP 10	10	Is	<5	5.5	Porosity/slag	>24	5
4	Crk 1	22	Ps	30	HNM	Multiple cracks	28	4.1
5	Crk 2	35	Ps	33	HNM	Multiple cracks, Crk 2 and	38	5.7
6	Crk 3					Crk 3 are the same flaw		
7	Crk 4	41	Ps	40	HNM	Lack of root/sidewall fusion	39	2.6
8	Crk 5	50	Vl	60	3.5	Slag	48	4
9	Crk 6	41	Th	57	<3	Lack of sidewall fusion/slag	43	1
10	Crk 7	41	Th	35	<3	Lack of root fusion/slag	38	5.4
11	IL 1	48	Pl	52	9	Slag	47	3.4
12	IL 2	42	M	41	3	Slag	38	3.5
13	IL 6	7	Ps	13	<3	Lack of root fusion	4	1.9
14	IL 7	6	Pl	31.5	4	Lack of sidewall fusion	16	13.5
15	IL 10	13	NE			Lack of sidewall fusion	12	0.7
16	IP 1	10	Th	23	<3	Slag/lack of fusion	10	15
17	IP 2	5	Pl	41	3.5	Multiple lack of fusion	>60	1
18	IP 3	4	Ps	8	HNM	Slag/lack of fusion	14	8.4
19	IP 4	4	Ps	23	HNM	Slag/lack of fusion	10	9.8
20	IP 5	4	Th	14	HNM	Lack of sidewall fusion	<10	0.6
21	IP 7	4	Th	18	<3	Lack of fusion	>30	1.3
22	LSF 1	65	M	87	10	Crack	63	3.5
23	LSF 2	55	M	65	13	Crack	56	5.5
24	LSF 3	55	M	71	7	Crack/porosity	44	8.5
25	LSF 4	33	M	93	25	Crack/lack of fusion/slag	46	8
26	LSF 5	24	Th	27	<3	Lack of sidewall fusion	17	4.8
27	LSF 6	22	Vl	27.5	11.5	Lack of sidewall fusion	16	10.5
28	LSF 7	12	M	107	12	Crack/slag	11	5
29	LSF 8	9	Rt	15.5	HNM	Lack of root fusion/slag	13	4.1
30	PL 1	192	NE			Lack of inter–run fusion	LNM	1.9

FLAW TYPE LEGEND

Radiography (BS 2600 Parts 1 and 2)		Ultrasonics (BS 3923, Part 1, Level 2B)	
Crk	- Crack	*Th*	- Threadlike
LSF	- Lack of sidewall fusion	Pl	- Planar longitudinal
IL	- Linear inclusions	Is	- Isolated
PL	- Linear porosity	Ps	- Planar surface
IP	- Isolated porosity	Rt	- Root concavity
CP	- Cluster of pores	Vl	- Volume
		M	- Multiple
		NE	- Not evaluated (i.e. echo <DAC –14dB)
		HNM	- Height not measurable (although attemted)
		LNM	- Lenght not measurable (visible only on one slice)

Figure G-1. NDT and lab data for 30 out of 55 flaws (*48*)

No	NDT results: Radiography: Flaw type	Radiography: Length, mm	Ultrasonics: Flaw type	Ultrasonics: Length, mm	Ultrasonics: Height, mm	Sectioning results: Flaw type	Sectioning results: Length, mm	Sectioning results: Height, mm
31	IL	4	Pl 1	31.5	10.5	Lack of sidewall fusion	13	8.1
32	NE		Pl 3	25	6	Lack of fusion	36	2
33	NE		Pl 4	24	4	Lack of fusion	17	1.7
34	NE		Pl 5	20	8	Lack of fusion	36	1.7
35	LSF	25	Pl 7	39	7	Crack	25	3
36	LSF	20	Pl 8	27.5	7.5	Crack	19	5.5
37	LSF	25	Pl 9	21.5	6	Lack of sidewall fusion	16	13.2
38	IL	4	Ps 2	16.5	HNM	Slag/lack of root fusion	6	1.8
39	Ru	6	Ps 3	13	HNM	Lack of root fusion	<10	0.9
40	NE		Ps 5	8	HNM	Lack of fusion	<12	0.7
41	CP	7	Ps 6	8	HNM	Lack of side fusion	23	1.1
42	LSF	41	Ps 7	88	8	Crack	74	5.5
43	NE	30	Ps 9	11.5	HNM	Lack of root/sidewall fusion	20	1.9
44	LSF	25	Ps 10	25	HNM	Crack	27	5.3
45	NE		Pt 2	10	HNM	Lack of fusion	>1	0.4
46	NE		Pt 3	8.5	HNM	Root crack	>1	0.7
47	NE		Pt 4	8.5	HNM	Small segregation	>1	0.4
48	IL	49	Th 2	38	<3	Lack of fusion/slag	38	3.2
49	LSF	47	Th 3	35	<3	Lack of side fusion/slag	28	1.9
50	IP	2	Th 4	10	HNM	lack of fusion	9.5	0.7
51	IL	31	Th 5	31	<3	Slag/lack of fusion	39	3.3
52	IL	30	Th 6	32	<3	Slag/lack of fusion	20	4.6
53	CP	7.5	Th 7	18	HNM	Slag/lack of fusion	10	10.8
54	CP	5	Th 9	6	HNM	Lack of fusion	3	1.6
55	CP	2.5	Th 10	72	<3	Crack/lack of sidewall fusion	>89	5.9

FLAW TYPE LEGEND

Radiography (BS 2600 Parts 1 and 2)		Ultrasonics (BS 3923, Part 1, Level 2B)	
LSF -	Lack of sidewall fusion	Th -	Threadlike
IL -	Linear inclusions	Pl -	Planar longitudinal
IP -	Isolated porosity	Pt -	Planar transverse
CP -	Cluster of pores	Ps -	Planar surface
Ru -	Undercur	HNM -	Height not measurable (although attemted)
NE -	Not evaluated (not seen by radiography)		

Figure G-2. NDT and lab data for 25 out of 55 flaws (48)