September 4, 2008

PROJECT INFORMATION

04-0120F4
Self Anchor Suspension Bridge (SAS)

SUBJECT

Detection of Cracks in Closed-rib PJP Tack Welds after completion of welding Using Ultrasonic Testing

EXECUTIVE SUMMARY

Based upon macro-etch specimens taken during Production Monitoring Tests (PMT) and both visual, and magnetic particle testing of tack welds prior to welding, there is a possibility that cracks may exist in tack welds of production deck panels. METS was tasked with the development of both a conventional Ultrasonic Testing (UT) or Phased Array Ultrasonic Testing (PAUT) procedures to be used in conjunction with conventional UT to detect cracks in tack welds of completed panels. The Department purchased deck panels DP-564-001 and DP-164-001 for procedural development. Both of these deck panels had been rejected by the Contractor, American Bridge / Flour JV (ABF), due to having failed PMT's. These deck panels are representative of panels welded prior to the existence of known cracks, DP-164-001 (welded 29 March, 2008), and panels welded after known cracking existed, DP-564-001 (welded 25 May, 2008).

Development using PAUT began on DP-564-001, since it was deemed the quickest approach to identify indications that have crack-like characteristics. Initially twenty-four (24) tack welds on weld joint 10 were tested and seven (7) tack welds removed and macro-etch tested. Of these areas, six (6) had suspect signals and one (1) had an indication indicative of a "C" shaped fusion type discontinuity previously identified in deck panel tack welds. Results of this testing made it possible to isolate the signal corresponding to the crack, while filtering out spurious signals caused by melt-through, lack of penetration (LOP), and other weld type discontinuities.

Forty-eight (48) tack welds on weld joints 2 and 3 of DP-564-001 were then tested by PAUT to select four (4) tack weld samples with cracks, two (2) tack weld samples with "C" shaped discontinuities, and one (1) tack weld sample with melt-through and un-fused LOP for use in developing a conventional UT procedure. By using electronic gates on the conventional UT instrument to measure the distance from the top of the deck panel to the UT indication, it was possible to identify discontinuities at locations of suspect cracking.

The forty-eight (48) tack welds on weld joints 5 and 6 of DP-564-001 were then tested with this conventional UT procedure and seventeen (17) tack welds with signals indicative of cracks were

identified. All of the tack welds on weld joints 5 and 6 where then tested using PAUT. Three (3) of the seventeen (17) locations identified by the conventional UT were deemed not to be cracks by PAUT, the remaining fourteen (14) locations being confirmed as cracks. PAUT did not identify any additional tack welds as having cracks. All seventeen (17) locations were then cut and macro-etched. Three (3) additional tack welds were also selected, which represented two (2) acceptable tack welds and one (1) tack weld identified with a discontinuity other than a crack. The macro-etch testing confirmed the results of the PAUT for all seventeen (17) samples and no cracking was found in the samples of acceptable tack welds.

All one-hundred seventy (170) tack welds on Deck Panel DP-164-001 were then tested with conventional UT. Forty-two (42) suspect tack welds were identified by conventional UT. Of these discontinuities, PAUT testing identified only eight (8) as being cracks. Four (4) of these locations were cut out of the deck panel for further evaluation, but one (1) sample was damaged during the removal process and was discarded. The remaining three (3) samples were saw-cut and macro-etched, confirming the presence of cracks. The remaining four (4) tack welds identified by PAUT as cracks were left within the weld for use in training technicians in the application of the procedures.

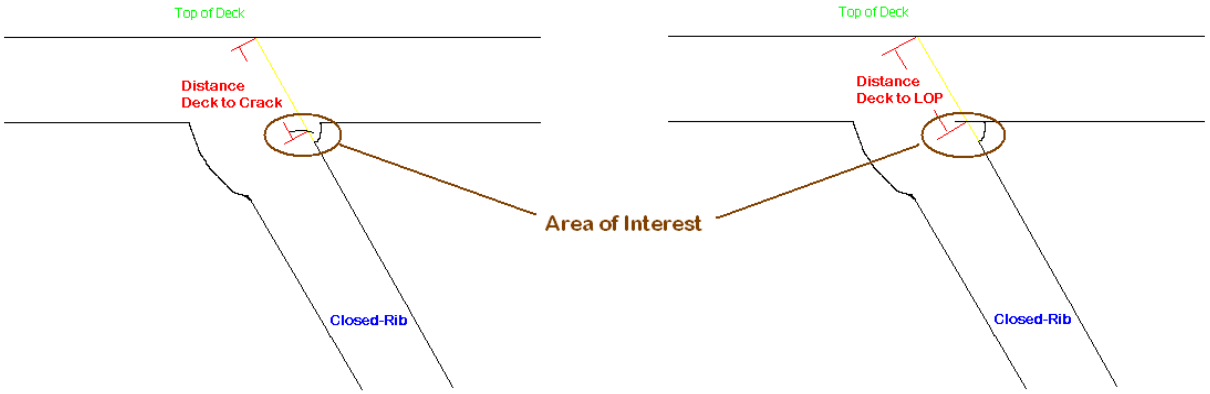
Based upon the procedural development performed, it is practical to utilize the Conventional Ultrasonic Testing (UT) as a prescreening technique to identify suspect tack welds locations followed by Phased Array Ultrasonic Testing (PAUT) to positively identify cracks. Prescreening with Conventional UT is advantageous due to the speed and ease of use for typical Level II UT technicians. The Conventional UT can be performed using the same equipment currently being used by the State and the Contractor to determine the depth of penetration on the Closed-rib welds. Only tack welds positively identified with PAUT should be reported as cracks. With additional procedure development, Phased Array Ultrasonic Testing should be able to determine the size, location and orientation of cracks. Such determinations are outside the scope of the current procedure, which was limited to the positive verification of the existence of cracks in tack welds.

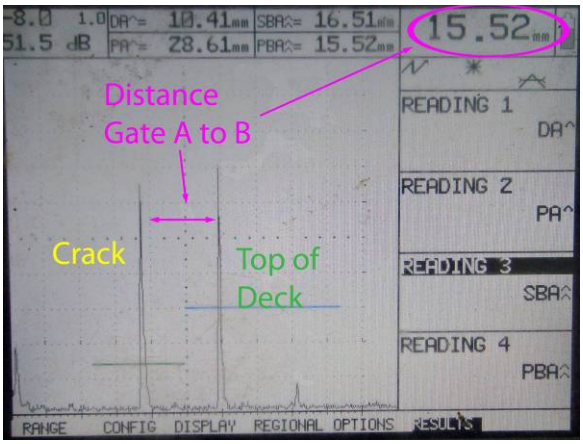
DISCUSSION

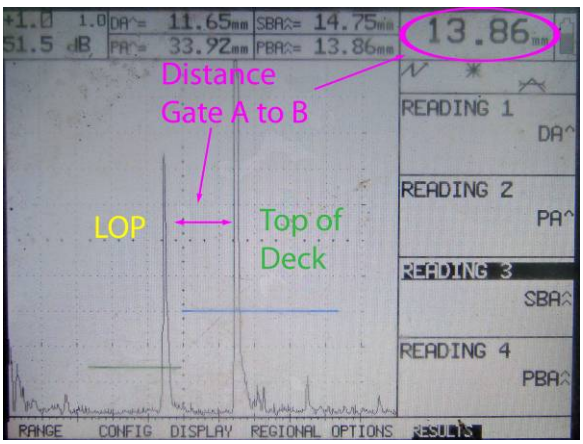
Cracks found with UT, PAUT, and Macro-etch testing appear to be in areas where melt-through occurred during the tack welding process. The cracks observed in macro-etch specimen generally occur in the centerline area of the tack weld cross-section and extend from just subsurface of the melt-though (ID of Rib) through the tack weld and root pass. In macro-etch specimen, the cracks appear to be arrested approximately 8-9mm deep at the Submerged Arc Welding (SAW) fill/cover pass. The cracks typically average 10mm in length, as determined by UT, and can occur anywhere along the length of the tack weld (no isolation to start or stop areas was observed). The location data from UT coincides with that observed during Magnetic Particle Testing (MT) of current tack welds prior to welding. This location data is based upon testing of tack weld locations only, and no investigation of the remainder of the weld has been conducted.

Conventional Ultrasonic Testing (pre-screening)

The Conventional Ultrasonic Testing (UT) technique consists of performing UT of the closed-rib PJP weld using a shear wave transducer with a nominal frequency and angle of 3.5MHz and 70 degrees. This is the same equipment used for determining the depth of penetration for Closed-rib welds. The UT is performed to locate signals with planar type characteristics within the area of interest were cracks have been found in production welds (see sketch below). This "area of interest" is approximately 1.5 to 4 mm further from the top of the deck than where un-fused areas of the partial joint penetration weld (LOP) are found. The location of the signal (either LOP or Crack) is determined by measuring the distance from the top of the deck plate to the signal within the weld. This is accomplished using a dual gate system which measure the distance between signals in the "A" gate (LOP or Crack) to signals in the "B" gate (top of deck plate). Signals detected in the area of interest should be further evaluated by Phased Array Ultrasonic Testing (PAUT) to ensure the suspect signals are not being caused by variations in thickness, reflections from melt-through areas or other geometry and weld discontinuities.



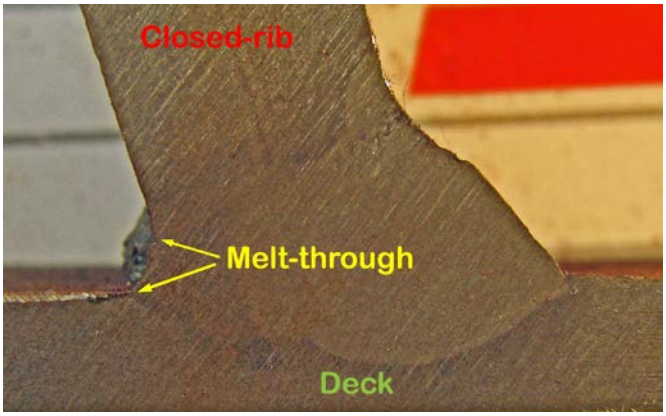


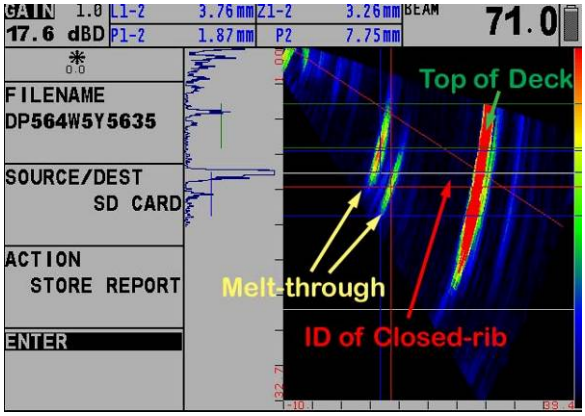


Phased Array Ultrasonic Testing (PAUT)

PAUT is utilized to further evaluate suspect signals detected during the UT pre-screening and to eliminate those indication that are not clearly indicative of cracks. Testing is being conducted utilizing a GE Phasor XS, ultrasonic flaw detection unit capable of operating in either phased array or conventional ultrasonic modes. PAUT is being conducted using an 8 element array transducer with a nominal frequency of 2 MHz, with a size of 7mm x 9mm and 36 degree wedge capable of producing a sectoral scan from 50 and 80 degrees refracted shear waves within the part being tested. The unit is calibrated for distance and a TCG (Time Corrected Gain) established to normalize the signal from each angle. Since PAUT displays a cross-section of the weld within the 50 to 80 degree arc defined during set-up, cross-sectional location of the discontinuities is more easily distinguished than in conventional ultrasonic testing where only reflections from one angle are displayed. This additional understanding of the location within the weld allows for the differentiation between signals caused by cracks from those caused by geometry or other weld discontinuities.

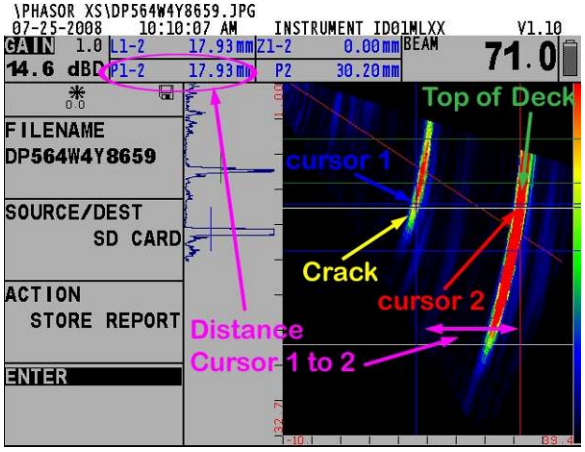
Signals caused by weld geometry (melt-through) are typified by signals starting before or after the location where LOP indications would be found (further from the top of the deck), are located at the inside surface of the closed-rib and typically appear faint. They are typically detected in the scan region between 55 and 60 degrees. These signals can usually be detected while scanning longitudinally along the weld and may have one or more areas with sufficient reflectivity that it would be detectable with the 70 degree shear wave transducer during the initial UT screening. These signals can be considered non-relevant and the area of weld determined to be free of cracks.

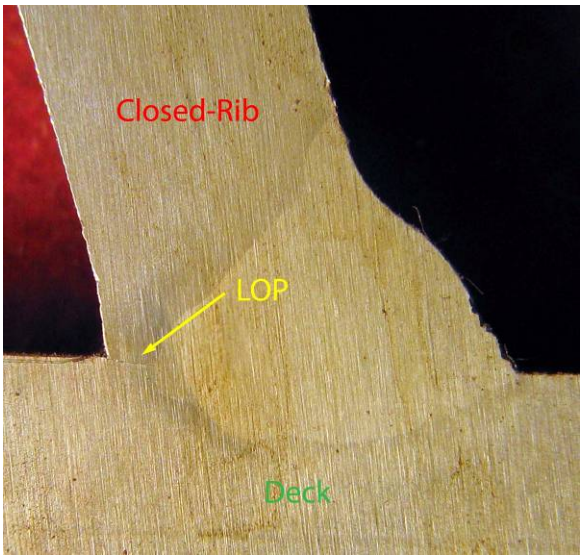


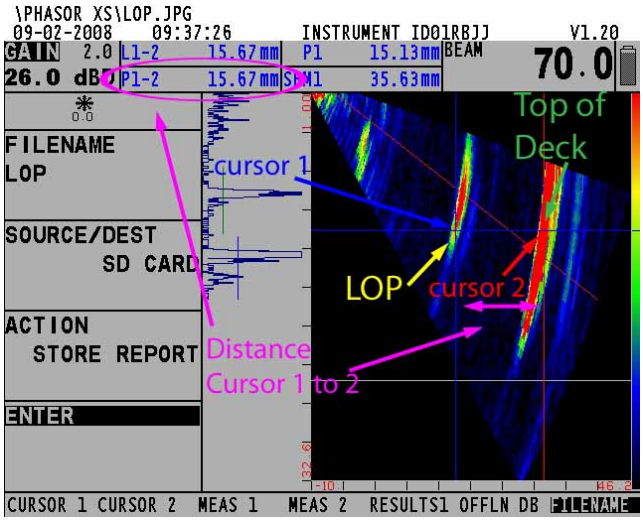


Signals from cracks display properties of planar type discontinuities during scanning. Although not mutually exclusive, most often no LOP signals will be present in the location of maximum amplitude of the crack signal. There may be areas where both LOP and crack signals are both visible which is often observed at the beginning or end of the crack. Larger crack signals can also result in either a partial or complete loss of signal from the top of the deck due to the majority of the PAUT scan being reflected by the crack. The location of the crack is typically slightly below the inside surface of the closed-rib (due to melt-through) and extend into the weld

4mm to 8mm. The determination of the location is accomplished during the freeze mode. The PAUT unit has the ability to measure various distances (horizontal, vertical, or absolute) between two controllable crosshairs displayed during the freeze mode. For determination of the location within the weld relative to the top of the deck plate, the horizontal component for both cursors 1 and 2 is located at the inside surface depth of the closed-rib. The vertical components of cursor 1 is then place at the center of the signal from the suspect discontinuity at the location were it crosses the horizontal cursor component. The vertical component of cursor 2 is placed at the center of the signal from the top of the deck plate at the location were it crosses the horizontal cursor component. This allows measurement between the two vertical components (P1-P2) and results in the cross-sectional distance from the inside of the deck plate to the suspect discontinuity.







Signals from LOP are located either at or slightly into the deck from the rib to deck intersection (due to fit-up and shrinkage) the thickness of the deck plate. Signals from cracks are typically located 1.5mm to 4mm further from the top of the deck plate. Determination of the depth of indications as well as height of the discontinuity can also be measured. However, accurate measurements such as these would require further procedural development to determine the amplitude necessary to ensure the correct limits of the signals are located.

Specific settings for phased array instruments will differ based upon the manufacturer and model. However, the basic principles behind the testing will remain the same. These include:

1. Setting up the instrument to "normalize" signals from all angles using TCG (Time Corrected Gain) or similar amplitude correction according to the manufacturer's recommendations.
2. Defining a scan from 50 to 80 degrees.
3. Defining a sensitivity level based upon LOP calibration blocks and samples with known defects.
4. Measuring discontinuity location relative to the top of the deck and inside of the closed-rib to determine if they are within the area of interest for known cracks.
5. Investigating signal responses to confirm planar characteristics.
6. Observing signals caused by melt-through re-entrant corners during scanning to disregard isolated areas of greater signal response caused by this geometry.

Weld samples, photographs and macro-etches of various discontinuities found within the closed-ribs are available on-site for aid in the understanding of the detection techniques. Also, both John Kinsey and David McClary are available to answer question regarding the application of either Conventional or Phased Array Ultrasonic Testing in relation to the detection of cracks within closed-rib tack welds.

Please contact the undersigned at +86-13621724452 for any questions.

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