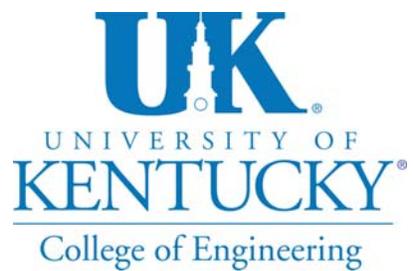




KENTUCKY TRANSPORTATION CENTER

NONDESTRUCTIVE TESTING OF A WELD REPAIR ON THE I-65 BRIDGE OVER THE OHIO RIVER AT LOUISVILLE





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Research Report

KTC-09-17A/SPR 364-07-1F

Nondestructive Testing of a Weld Repair on the I-65 Bridge over
The Ohio River at Louisville

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Commonwealth of Kentucky

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EXECUTIVE SUMMARY

PROJECT OBJECTIVES AND APPROACH

The main project objective was to evaluate a weld/crack repair of an upper chord member of the East truss on the I-65 JFK Memorial Bridge over the Ohio River at Louisville. The original weld cracked in service and was repaired in 1994. KYTC officials were concerned about the effectiveness of the repair and the possibility of crack growth outside of the repair that might pose a threat to the structural integrity of the bridge. The crack was in an upper chord H beam that is a fracture critical member (FCM) made from high strength quenched and tempered (QT) steel.

Nondestructive evaluation methods (acoustic emission monitoring, penetrant testing, ultrasonic testing and radiographic testing) were employed to investigate the inboard flange and web of the H beam (where the weld/crack repair was located) to ensure that the 1994 weld repair had effectively arrested further crack growth.

The nondestructive evaluation work was performed by experienced firms/organizations. Conventional penetrant testing, ultrasonic testing and radiographic testing were conducted by Huntington Testing and Technology and the acoustic emission monitoring by Northwestern University Infrastructure Technology Institute researchers. The work was performed in April and May 2008.

CONCLUSIONS

Within the limits of human error and equipment accuracy, all of the factors related to this study support the conclusion that there are no additional cracks in the vicinity of the 5-1/16 inch crack near Panel Point U28 and that the original weld/crack repair by H & E was properly affected arresting further crack growth.

Subsequently Palmer Engineers Inc. conducted an annual fracture critical inspection on the bridge including magnetic particle testing (MT) on FCMs in the upper chords of bridge. They reported that “- Five (MT indications) were located at U28 (East Truss), which exhibits the most cause for concern”. Based upon KTC work done under this study, the finding warrants further review and resolution.

RECOMMENDATIONS

The first recommendation relates to resolving any contradictions that might exist related to the exact condition of the East truss upper chord H beam near Panel Point 28. The other recommendation relates to conducting structural reliability review/analyses of the bridge FCMs made from QT steel.

1. KYTC bridge maintenance officials should meet with Palmer inspection personnel and KTC researchers to review their respective findings related to the repair area

- near Panel Point U28. Contradictions in findings can be resolved in follow-on field inspection to determine whether the MT surface indications are actually cracks.
2. Conduct an in-depth structural reliability assessment of the I-65 JFK Memorial Bridge upper chord FCMs made from T-1 or equivalent steel. This assessment should include the following tasks:
 - a. Identification of all pertinent structural members,
 - b. Review of past inspections/work conducted on those members and other pertinent data,
 - c. Review design stresses for FCMs,
 - d. Inspect all past repair sites on FCMs,
 - e. Selection and instrumentation of several structural members on both trusses to identify live stresses/cycles with the bridge under traffic,
 - f. In-situ testing/evaluation of QT steel in FCMs to determine consistency of specific material properties (e.g. hardness and microstructure replication),
 - g. Extract samples QT steel from FCMs and perform laboratory evaluations to assess material properties and fracture toughness,
 - h. Prepare a structural reliability review based upon subtasks 2a-g and related approaches (by others) addressing structural reliability of steel bridge QT steel FCMs. This review will provide:
 - i. the current structural condition of all QT steel FCMs on the bridge including any concerns that cannot be addressed by periodic inspections,
 - ii. summaries of dead and live load stresses and fatigue/fracture mechanics evaluations for all QT steel FCMs on the bridge (including repair details and critical maximum crack sizes), and
 - iii. recommended actions to assure structural reliability of all QT steel FCMs on the bridge including those for NDE inspections (beyond the mandated annual arms-length inspections) incorporating NDE methods, operator prequalification and inspection frequency.

SUMMARY

There are no fracture problems in the weld/crack repair area near Panel Point U28 on the East truss of the JFK Memorial Bridge. However, sufficient concerns remain about the structural reliability of the FCMs on the bridge incorporating QT. Those members warrant further investigation and testing.

1. INTRODUCTION

Long span steel bridges typically contain fracture critical members (FCMs) that pose risks to bridge owners due to the increased probability/consequences of their failure (structure collapse or disablement/closure). It is very difficult to eliminate such members from structures. Therefore, bridge owners now apply stringent design and fabrication guidelines to preclude failures from common causes such as weld defects and fatigue. Additionally, they employ special (arms length) inspections and occasionally nondestructive evaluations (NDE) using equipment-assisted procedures to detect small or subsurface discontinuities not readily discerned by visual inspection. Close or NDE-augmented inspections constitute a “buy-down” of risk to a level acceptable to the owner and an increase in motorist safety (assuming the inspection work is effective/properly done). This can be achieved in many circumstances including follow-up inspections of retrofits/repairs.

There are some uncommon circumstances where inspections are not effective for risk reduction and other approaches are necessary (e.g. brittle steel or Hoan Bridge defects). In those cases design retrofits or component replacements are the only viable options to ensure acceptable structure risks. In several cases, owners have replaced bridges when significant concerns existed about their structural integrity (e.g. the St. Mary’s, WV US 33 Bridge over the Ohio River (1971), the Covington, KY US 25 Bridge over the Ohio River (1972) and the Portsmouth, OH US 23 Bridge over the Ohio River (2001).

Concerns about structure reliability can arise about FCMs when there are clear indications that fabrication shop quality control/quality assurance (QC/QA) are compromised, when designs introduce circumstances that promote brittle pop-in cracking (e.g. Hoan Bridge defects) or when material qualification testing is inadequate. When several of those factors occur together, structural reliability concerns increase and extraordinary actions may be warranted. Such a situation occurred relevant to a location on the I-65 JFK Memorial Bridge over the Ohio River at Louisville in 2007 that resulted in its in-depth inspection. That work is the subject of this report.

1.1 BACKGROUND

The I-65 JFK Bridge (MP-056-0065-136.723 (B00214)) was designed in 1961 and opened to traffic in 1963. It is a 2,500 ft. multi-span cantilever truss structure with 5 spans. Originally, the bridge had 6 traffic lanes, but was subsequently modified to provide two additional lanes in the 1990s. The bridge carries high traffic volumes with ADTs in excess of 100,000 vehicles.

The design incorporated the innovative use of welded fabrication of structural shapes along with the use of high-strength quenched and tempered (QT) steel (100,000 psi yield strength). That steel was originally a proprietary product marketed by United

States Steel Corporation as *T-1* steel (later incorporated into ASTM A 514). Purportedly, the JFK Bridge also contained some QT steel from another manufacturer that no longer exists. For that matter, United States Steel Corporation no longer makes structural steel plate of the type used in the JFK Bridge. For several decades, QT steels were widely used, especially on truss bridges where it could provide significant reductions in structure weight due to its high strength, especially for truss tension members including FCMs.

Several concerns have arisen over the years relating to the welded fabrication of QT steel. Welding of bridge steel was still relatively new when the JFK Bridge was built and designers/owners were not familiar with some significant potential problems. Shop and owner quality control/quality assurance (QC/QA) procedures were nonexistent or lacking and defects could readily be introduced during fabrication operations. Additionally, AASHTO had yet to investigate steel toughness and issue related specifications. In the 1960s, it was unlikely that any toughness requirements (e.g. Charpy impact testing) were imposed, and if they were, they would probably have been inadequate for *T-1* steel. Loose fabrication practices, inadequate inspection and poor steel toughness led to significant findings of cracks on relatively new bridges, several near catastrophic failures and construction delays due to fracturing or steel members during erection. Those incidents began in the 1960s and continued into the 1970s until the FHWA, AASHTO and individual state highway agencies stepped in and instituted significant improvements in steel quality and fabrication shop QC/QA practices.

The JFK Bridge was not immune to such problems. In the early 1990s, NDE inspections were conducted on welds in FCMs on the bridge (1). November 1993, *Hazelet + Erdal, Inc. (H & E)*, an engineering consulting firm, conducted arm's length visual inspections of the FCMs and other locations on the bridge that had showed significant problems in prior inspections. Several deficiencies were found including cracking in several upper chord members on both the upstream and downstream trusses. Those cracks were found in or near welds in the chord tension members – built-up H beams made from *T-1* steel and fabricated by welding. In December 1993, emergency repairs were made at the four locations and further inspections were conducted.

The follow-on inspections included the use of magnetic particle testing (MT) and ultrasonic testing (UT). MT was used on all butt welds in the H- beam tension members and in suspended span hanger members. UT was used on butt weld in gusset plates of suspended span hangers and on upper chord members found to contain rejectable UT indications in the 1991 tests. UT was also used to further evaluate all new MT indications.

KTC researchers assisted in providing strain gaging on the downstream (West) truss at Panel Point 63 (2). Acoustic emission (AE) testing was also used to detect possible crack growth activity at several locations that possessed previous subsurface UT indications. Later those locations were cored and subjected to metallurgical examination at a local laboratory.

All of that work was performed from March-May 1994 by *H & E* personnel. A total of 628 sites were tested by MT and/or UT. Those tests revealed 88 cracks at 35 locations. Subsequent metallurgical evaluations revealed that most of the cracks were welding hot cracks that occurred during fabrication. Only one showed signs of fatigue crack growth, but apparently once that crack broke the surface of the beam, it became benign. Additionally, the KTC strain gage testing revealed low live stress ranges in the upper chord members (approx. 1.5 ksi or below). Those low live stresses are usually inadequate to cause fatigue problems. However, with large cracks or brittle steel they may be a concern.

Subsequently, *H & E* and a metallurgy technician used a grinding wheel and burr to repair most of the cracks by applying check holes at the crack tips. Several large cracks were lapped with bolted splice plates. In the *H & E* report, some discussion was provided of a repair on Panel U27-U28 near Panel Point U28 on the East truss where 2 parallel transverse cracks measuring 2 inches and 1-1/4 inches in length were found in the base metal of the H-beam web running into the flange to web longitudinal fillet weld (Figure 1). The cracks were apparently due to incorrectly located saw cuts in the web that were made at the fabrication shop. Apparently, the shop welded over the saw cuts in an effort to eliminate them without beveling them to ensure complete penetration of the filler metal. The resulting incomplete penetration repair welds created large, crack-like defects which eventually turned into fatigue cracks and grew to the surface of the web once the beam was placed in service. At the time of their detection the cracks had not traversed far across the web and on the other end, they had run into the tough weld metal in the full-penetration flange-to-web fillet welds. One crack was completely removed by grinding and the ends of the other crack were reported to have been ground out (op. cit. 1 pp. 9-10).

After the weld repairs were affected, the bridge's upper chord members were known to have been subjected to some follow-on NDE work later in the 1990s, but documentation of that work has not been obtained by KTC researchers. Thereafter, upper chord members were subjected to the mandated fracture-critical inspections that included "arms-length" visual inspections conducted on an annual basis, but no additional NDE-enhanced inspections were known to have occurred on the upper chord members prior to this study.

KYTC personnel inspecting the upper chord in 2007 found that the crack near Panel Point U28 previously repaired in 1994 had grown in length to 5-1/16 inches (Figure 2). The crack was readily visible despite painting operations on the bridge. There was a check hole at one end of the crack and what appeared to be a longitudinal saw cut at its other end running along the toe of the flange-to-web fillet weld which was apparently used to dead head the other end of the crack. At the check hole, the crack appeared to penetrate from the top face of the web to about its mid-thickness (Figure 3). A schematic representation was prepared of the H beam in the area of concern along with component terminology and relevant dimensions (Figure 4). The fact that the crack was highlighted by rust along most of its length relates to: 1) the spray painting of the

bridge and 2) the viscous coatings applied which did not penetrate into the crack. At the time of these pictures, the bridge had been painted within 6 months and the presence of rust in the crack is probably not indicative of a working crack.

1.2 PROPOSED WORK PLAN

Due to the concentration and nature of flaws near Panel Point U28 on the East truss, KYTC officials had significant concern about this site. They requested that KTC researchers investigate it more thoroughly to ensure the repair had been properly executed that no other concerns existed. KTC researchers developed an SPR work plan with the following objectives:

1. Conduct NDE tests on the East upper chord of the I-65 JFK Bridge to evaluate the subject transverse and longitudinal cracks and other portions of the upper chord in the immediate crack area.
2. Assess the potential for problems posed by the transverse cracks and provide recommendations for follow-on work.
3. Provide a record of the work performed and analysis to facilitate future KYTC decision making relevant to the flaws.

To address those objectives the following tasks were identified:

Task 1. Conduct nondestructive evaluations [acoustic emission (AE), radiography (RT) and ultrasound (UT)] on the subject cracks and portions of the upper chord in the crack area. The RT and UT work will be performed by Huntington Testing, a qualified NDE test firm with an ANST Level III certified inspector to plan and review the work. The Northwestern University Infrastructure Technology Institute (ITI) has experienced experts to conduct the AE tests. Kentucky Transportation Center personnel will provide logistical coordination with the inspection firm, Northwestern ITI, the manlift provider and KYTC Central Office and District 5 personnel. Work will include removing existing paint in the crack area prior to UT testing and replacing it after completion of the NDE work.

Task 2. Test results will be reviewed and findings will be analyzed. Recommendations for additional KYTC actions will be prepared based upon those results/findings.

Task 3. A report will be prepared and provided to KYTC on the work performed, test results/analyses, and recommendations for future KYTC actions related to the cracks.

2. FIELD NONDESTRUCTIVE EVALUATIONS

2.1 MOBILIZATION AND FIELD TESTING

Mobilization began after receiving quotes from the various test parties and arranging with KYTC District 5 for traffic control. The work was to be performed on the northbound lanes of the bridge to access the East truss. Panel 28 was located near the second tower on the bridge at pier 3. Due to some intervening cross members on the upper chord, a direct extension of a man-lift boom could not be effected and the man-lift had to be repositioned several times to allow the work basket to access the upper chord (Figure 5). This required a manlift with a 125 ft. reach and the wheels of the man lift had to be extended as well to provide proper support. That required closure of two lanes of traffic and the extended track of the manlift partially extended into the second lane.

The field work took five days to complete over a six-week interval with work beginning on April 14, 2008. Typically, the lane closures did not begin until about 8:30 am to accommodate peak morning traffic. KYTC District 5 personnel would cone the outer two lanes and the man lift would be slowly driven onto the bridge from the first Indiana exit ramp. One of the exit ramp's lanes was shut down to allow the vehicle to travel up the ramp against the normal flow of traffic. The manlift would be driven to the test site and deployed and thereafter other service vehicles would enter the lane closure area. Test personnel would deploy on the bridge in the mid-mornings. In the afternoons, District 5 officials required that the work cease at about 2:45 pm to enable the manlift to exit the bridge via the Indiana exit ramp and subsequently allow the lane closure to be lifted by about 3:15 pm. This limited access to the test site and somewhat extended the period over which the work was required for completion of the field work.

Several site access problems were encountered during the radiographic tests that extended the duration of the field testing. However, those issues were successfully addressed and the field testing was completed on May 30, 2008.

2.2 INITIAL SITE VISUAL ASSEMENT

At the onset of the NDE field work KYTC and KTC personnel accessed the test site at Panel Point 28 to inspect the crack/repair. Viewing the upper face of the H-beam web, they determined that there were no apparent changes at the site since the KYTC inspectors took the 2007 pictures (Figure 6).

On accessing the underside of the H beam they found that the 5-1/16 inch long crack had opened sufficiently where it intersected the 1-3/16 inch long saw cut at the flange-to-web fillet weld to allow sun light through the crack. They also encountered a deep repair gouge in the inner face of the inboard flange just under the web (Figure 7). The gouge was apparently part of the field repair conducted in 1994.

After taking some field measurements to size the H beam and locate the crack, they marked the outer face of the inboard flange to locate where the 5-1/16 inch crack would be anticipated if it had penetrated into the flange. Prior to the follow-on NDE work, the paint was removed from the upper face of the web and the outer face of the inboard flange by grinding. As previously noted, the bridge had been recently painted and the new paint was difficult to remove. However this was necessary for both PT and UT work.

2.3 NONDESTRUCTIVE TESTING

2.3.1 Huntington Testing and Technology

The Louisville office of Huntington Testing and Technology (HTT) assisted in performing the conventional NDE work on the bridge. Testing included a surface method, dye penetrant testing (PT) added at the suggestion of HTT personnel, and two volumetric (subsurface) methods, ultrasonic shear wave testing (UT) and radiographic testing (RT). The work was performed by ASNT Level II and III certified personnel with extensive experience in commercial nondestructive testing.

PT was performed to 1) ensure that any shallow surface cracks would not be overlooked and 2) pinpoint locations for follow-up volumetric NDE. Its use was limited to the outer face of the inboard flange of the H beam and the upper face of its web in the area of the crack/repair (Figures 8 and 9). A red visible penetrant was sprayed on the exposed steel and allowed to saturate into any tight crevices, such as cracks. Then, a white developer was sprayed onto the test surface to extract any red dye that had penetrated into a crevice to contrast with the white developer which remained in the background. No indications were found. After these initial tests, the remaining NDE work involved the use of volumetric (UT and RT) and defect activity (AE) methods.

Shear wave UT was performed over the same general surface locations to detect any cracks in the web and the outboard flange (Figure 10). The test equipment included a portable UT flaw detector, capable of longitudinal and shear wave testing and straight and angle-beam transducers (sensors). UT is widely used to detect both surface-breaking and subsurface discontinuities such as cracks. Prior to scanning for cracks, the operator used a straight beam transducer to scan the steel for delaminations which could interfere with the testing for cracks. Then the operator manipulated the angle-beam transducer over the test surface. It alternatively created a directed ultrasonic shear wave into the steel and then passively detected any waves reflected back by discontinuities. The reflected waves are discerned by the operator as peaks on an LCD screen that is calibrated for distance between the transducer and the discontinuity. UT readily detected the 5-1/16 inch crack bounded by a check hole on one end and a saw cut on the other, but did not detect any cracking elsewhere on the web and inboard flange.

RT provides detection capabilities somewhat similar to UT. RT was also performed at Panel Point 28. Huntington Testing personnel used a gamma ray source of iridium 192 housed in a lunch-box sized container called a “camera” (Figure 11). A yellow guide tube was extended from the camera to a collimator that guides gamma rays along a path into a face of the test piece (Figure 12). A film pack was placed on the opposite face to the test piece and exposed by the gamma radiation that passed through it (Figure 13). The camera contained a flexible cable run by a hand crank. This allowed the operator to operate the camera at a safe distance from the gamma ray. The operator turned the crank which extended another flexible cable mounted inside the camera. At the end of that cable was a small pellet of iridium 192. The cable/gamma ray source traveled along the guide tube stopping at the collimator. The operator timed the exposure ending the shot by cranking the cable/gamma ray source back into the camera. He then removed the film pack from the test piece and developed it. Afterward, he inspected the developed film on a light table looking for overdeveloped/dark lines/shapes that would indicate flaws. The resulting radiographs revealed the 5-1/16 inch crack, but no other significant flaws in either the web or the inboard flange.

The Huntington Testing and Technology report is contained in Appendix A.

2.3.2 Northwestern University Infrastructure Technology Institute

The Northwestern University Infrastructure Technology Institute (ITI) provided AE testing for the project. AE testing/monitoring is a passive test similar to seismic testing for earthquakes. With AE testing, sensitive “listening” devices (i.e. piezoelectric transducers) are placed in known arrays on the face/surface of a test piece. When the test piece is stressed, flaws in the test piece that are dynamically affected emit stress waves in the material. Those waves are propagated to the surface of the test piece where they expand as circular surface waves. Those waves can be detected by the transducers (normally in the ultrasonic spectrum above 100 kHz). By placing the transducers in a known array on a test piece, the location of the discontinuity can be determined on the face of the test piece by planar flaw location.

On bridges, the test pieces (steel beams) are usually stressed by traffic going over a bridge including normal vehicular traffic or heavy proof loads in large trucks. For this project normal traffic loading was used. Typically AE bridge monitoring is used to either detect cracks or evaluate crack growth (3, 4). AE monitoring can detect ambient noise, typically from fretting, and also AE activity from non-crack flaws.

ITI personnel began work on April 14, 2008 by removing paint where the transducers were to be placed. Then, they laid out the transducer array locations on the surface of the steel (Figure 14). The battery operated AE monitor was housed in a protective case along with a ruggedized laptop PC that was used to program the monitor and retrieve test data (Figure 15). Thereafter the transducer array was attached

to the H beam using grease between the faces of the transducers and the steel to promote acoustic coupling. The transducers were held in place with magnetic mounts. They were wired to the AE monitor inside the protective case which was located on the H beam web during the monitoring work (Figure 16). Once the system had been installed, ITI personnel programmed the AE monitor to begin testing. A total of four tests were conducted on the web in the crack/repair area and on the outer face of the inboard flange. Test intervals were short, ranging from 12 minutes to about 3-1/2 hours. After each test was completed, ITI personnel accessed the site and used the PC to stop the test run and download the test data. ITI personnel post processed the data to perform planar flaw location and other analytical procedures. The ITI AE monitoring did not detect any discernable data that could be related to a significant defect other than the pre-existing 5-1/16 inch crack.

The Northwestern University Infrastructure Technology Institute report is contained in Appendix B.

3. SUMMARY OF TEST RESULTS

Neither the Huntington Testing and Technology who conducted extensive conventional NDE work, nor the ITI who used a very sensitive NDE method, found any cracks or indications thereof near Panel Point U28 outside of the 5-1/16 inch crack that had been previously repaired by terminating its ends with a saw cut and hole. No other signs of significant distress were detected during the inspection work.

4. CONCLUSIONS

Within the limits of human error and equipment accuracy, all of the factors related to this study support the conclusion that there are no additional cracks in the vicinity of the 5-1/16 inch crack near Panel Point U28 and that the original weld/crack repair by *H & E* was properly affected arresting further crack growth.

At the completion of this project, KTC researchers and the NDE teams involved were and remain confident in our findings/conclusions. However, at the onset of report preparation, we became aware that Palmer Engineers Inc. conducted an annual fracture critical inspection on the bridge. That inspection was primarily visual. It was supplemented with magnetic particle testing (MT) on FCMs in the upper chords of the trusses on the bridge. A review of the Palmer inspection report indicated that they had conducted visual inspections/NDE in the same area near Panel Point 28 inspected by KTC (5). In October 2010, Palmer had additional magnetic particle and ultrasonic testing performed at the location previously tested by KTC and no new flaws were detected (6).

An important concern is the structural reliability of all of the FCMS containing QT steel. Pertaining to the structure as it was fabricated, the following is known:

- The bridge used welded shop fabrication of FCMS at a time predating the use of fracture control plans by DOTs.
- In fact, the I-65 Bridge predates the wide recognition of FCMS by DOTs and many relevant code-authoring agencies.
- QT steel predates AASHTO requirements for fracture toughness testing. Charpy impact tests were not required for any steel used on this bridge (an early application of Charpy testing was on the I-275 Combs-Hehl twin bridges in the late 1970s).
- Despite the omission of fracture toughness tests, some idea of the QT steel properties could be gained if the original steel mill heat certifications were still available, but that is highly unlikely.
- RT was employed by the fabrication shop to inspect H beam tension butt welds and MT was specified for web-to-flange fillet welds.
- Numerous cracks were subsequently found in the H beams in 1993-94. The majority of those were ascribed to welding (e.g. hot cracks) though some may have been exacerbated by hydrogen embrittlement. These findings indicate definite shortcomings in shop welding processes and probable shortcomings in the QA process.

The I-65 JFK Memorial Bridge represents an early use of welded high-strength steel on a major structure. It extended the technology of the day, but lacked code-based safeguards that are considered essential for a modern-day equivalent structure. The contrast with past and present practice is evident in the extensive cracking in the bridge's FCMS. Such occurrences are exceedingly rare in modern welded steel bridges.

After the bridge was placed in service follow-on inspections/testing revealed numerous cracks. The following findings were obtained from field/laboratory work:

- Low live stresses in the upper chord longitudinal load bearing members (H beams) during the 1994 KTC work.
- Most cracks were shop-related but there was evidence of fatigue crack growth on one of the few cored cracks taken from the bridge H beams. That was determined by laboratory examination of the fracture morphology.

Those findings need to be revisited and updated. Since the original strain gage testing, the number of lanes on the bridge has been increased from 6 to 8. Traffic volumes/loadings have probably changed as well. Fatigue cracking identified on one cracked core extracted from the bridge in 1994 was only briefly addressed in the *H + E* report. The original metallurgical analyses/report were made by a Louisville test firm, *Metallurgical Services Company*, which is no longer in business. Its parent company, *Stork Materials Technology*, may have the original files related to the laboratory analyses of the cores. KTC researchers are planning to seek those files and review those to obtain any further information on the 1994 analyses. Along with fatigue, atmospheric impacts pose a potential concern.

Defective A 514 (QT) steel was encountered on the I-275 Combs-Hehl twin bridges over the Ohio River near Newport. That steel was found to be susceptible to hydrogen stress cracking. Brittle QT steel may be susceptible to cracking when subject to static tensile or low-amplitude cyclic loadings. If defective steel was used in bridges built in the late 1970s, it is possible that some could have been introduced in a bridge built in the early 1960s when fewer preventive controls were in place.

After the condition of the test area on the H beam near Panel Point U28 is resolved, significant concerns will persist related to the FCMs containing welded QT steel. Those warrant further in-depth investigations of those. The primary focus of that work would be to assess the condition of those members relative to all potential failure mechanisms and to develop an action plan to ensure the continued structural reliability of the I-65 JFK Memorial Bridge over its remaining service life.

5. RECOMMENDATIONS

The one recommendation relates to conducting structural reliability review/analyses of the bridge FCMs made from QT steel.

1. Conduct an in-depth structural reliability assessment of the I-65 JFK Memorial Bridge upper chord FCMs made from T-1 or equivalent steel. This assessment should include the following tasks:
 - a. Identification of all pertinent structural members,
 - b. Review of past inspections/work conducted on those members and other pertinent data,
 - c. Review design stresses for FCMs,
 - d. Inspect all past repair sites on FCMs,
 - e. Selection and instrumentation of several structural members on both trusses to identify live stresses/cycles with the bridge under traffic,
 - f. In-situ testing/evaluation of QT steel in FCMs to determine consistency of specific material properties (e.g. hardness and microstructure replication),
 - g. Extract samples of QT steel from FCMs and perform laboratory evaluations to assess material properties and fracture toughness,
 - h. Prepare a structural reliability review based upon subtasks 2a-g and related approaches (by others) addressing structural reliability of steel bridge QT steel FCMs. This review will provide:
 - i. the current structural condition of all QT steel FCMs on the bridge including any concerns that cannot be addressed by periodic inspections,
 - ii. summaries of dead and live load stresses and fatigue/fracture mechanic's evaluations for all QT steel FCMs on the bridge (including repair details and critical maximum crack sizes), and

- iii. actions necessary to assure structural reliability of all QT steel FCMs on the bridge including those for NDE inspections (beyond the mandated annual arms-length inspections) incorporating NDE methods, operator prequalification and inspection frequency.

6. REFERENCES

1. Hazelet +Erdal, Inc., "Fracture Critical Member Report Inspection/Repair/Analysis – JFK Memorial Bridge over the Ohio River at Louisville", September 1994.
2. Hopwood, T. and Oberst C. "Stress Measurements on the I-65 Bridge over the Ohio River at Louisville", Kentucky Transportation Center, Report No. KTC 94-16, July 1994.
3. Prine, D.W. and Hopwood T., "Detection of Fatigue Cracks in Highway Bridges with Acoustic Emission," Journal of Acoustic Emission, Volume 4, No. 2/3, April - September 1985.
4. Hopwood, T. "Acoustic Emission Inspection of Steel Bridges", Public Works, May 1988, pp 66-68.
5. Bridge Inspection Report Form (TC 71-118) for the JFK Memorial (I-65) Bridge, MP-056-0065-B00214, over the Ohio River in Louisville, Kentucky, Palmer Engineering February 26, 2009.
6. E-mail from C. Wood of Palmer Engineering to T. Hopwood "RE: NDT of the JFK Bridge at U 28 Upstream dated January 5, 2010.

7. FIGURES



Figure 1. Panel Point 28 on the Upper Chord of the East Truss of the I-65 JFK Memorial Bridge.

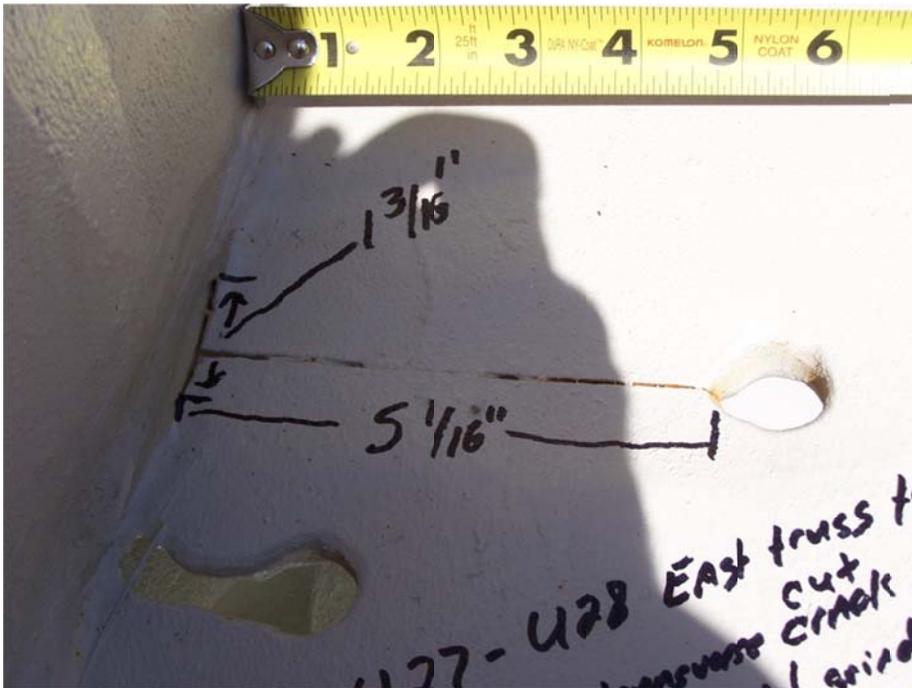


Figure 2. Weld/Crack Repair in H Beam Web Near Panel Point 28 on East Truss.



Figure 3. Panel 28 Web Crack Shown to Penetrate about Halfway Into the Web Plate in the Through-Thickness Direction.

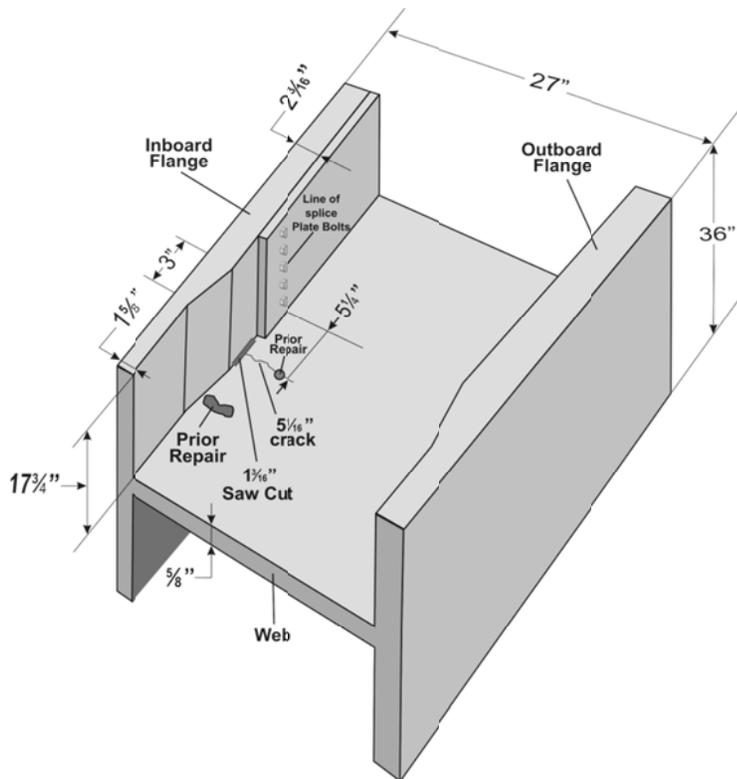


Figure 4. Schematic of H beam in Test Area Showing Locations of Crack, Repairs and Beam/Crack Relevant Dimensions.



Figure 5. Intervening Bridge Members that Impacted Sizing and Siting of Manlift to Access Panel Point 28.



Figure 6. View of Crack/Repair Looking Down on Upper Face of Web at Panel Point 28 Prior to the Onset of NDE Work.



Figure 7. Gouge in Inboard Flange Due to Past Weld Repair. Note Light Passing Through Crack at the Flange-to-Web Fillet Weld Location.

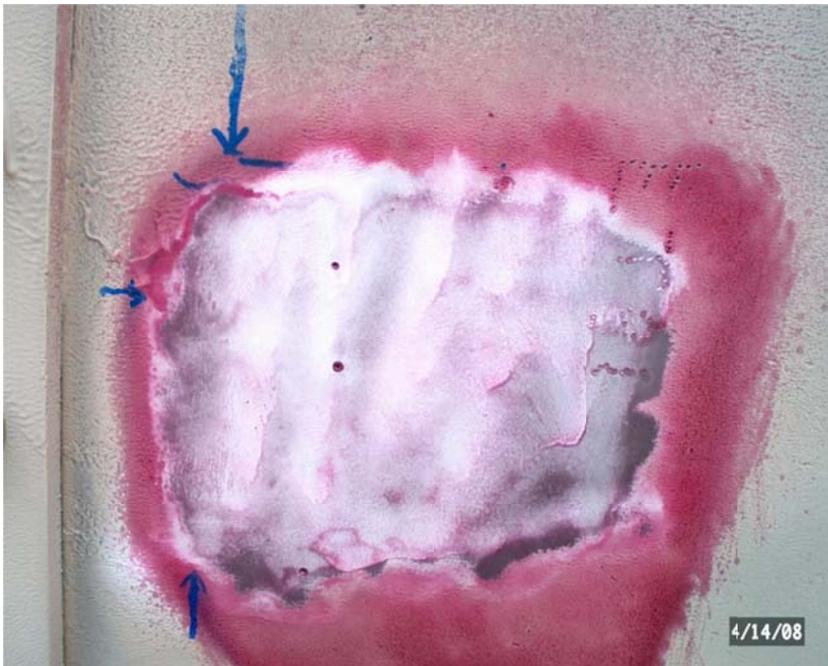


Figure 8. Dye Penetrant Test on Outside Face of Inboard Flange.



Figure 9. Dye Penetrant Test on Cracked Area on Upper Face of H beam Web.



Figure 10. Operator Performing Ultrasonic Shear Wave Testing (UT) on the Outer Face of the Inboard Flange of the H Beam at Panel 28.



Figure 11. RT Camera (Arrow) Mounted on H beam. Note Yellow Guide Tube Running from Camera to Location Under the Beam.



Figure 12. Upward View Showing RT Guide Tube and Collimator Aimed at 5-1/16" Crack in H beam Web for Radiograph from Underside of W



Figure 13. RT Film Pack Mounted on Outer Face of Inboard Flange for Radiograph of Flange-to-Web Fillet Weld and Flange at 5-1/16" Crack Terminus.



Figure 14. Upper Face of H-Beam Web (Looking Downward) Showing Layout for the Transducer Array.



Figure 15. Battery Powered AE Monitor Mounted in Protective Case with Ruggedized Laptop PC.



Figure 16. Transducers on H Beam Web Wired to AE Monitor Located in the Protective Case.

8. APPENDIX A

REPORT # K08D14-1

June 24, 2008

INSPECTION

OF

JFK BRIDGE PIER UPPER STRUCTURE U27-U28 Trusses

Location: Louisville, KY to Jeffersonville, IN

**Methods: ULTRASONIC SHEAR WAVE
RADIOGRAPHY
LIQUID PENETRANT**

INSPECTION DATES: 4-21-08 & 5-29-08

**REPORT FOR:
Theodore Hopwood II, P.E.
Kentucky Transportation Center
University of Kentucky
176 Raymond Building
Lexington, Ky 4-506-0281
859-257-2501 PH
859-257-8177 FX
thopwood@engr.uky.edu**

**REPORT BY:
Ken Rogers, Level III
Huntington Testing & Technology
925 Ulrich Ave
Louisville, Ky 40219
502-964-0500ph/3999fx**

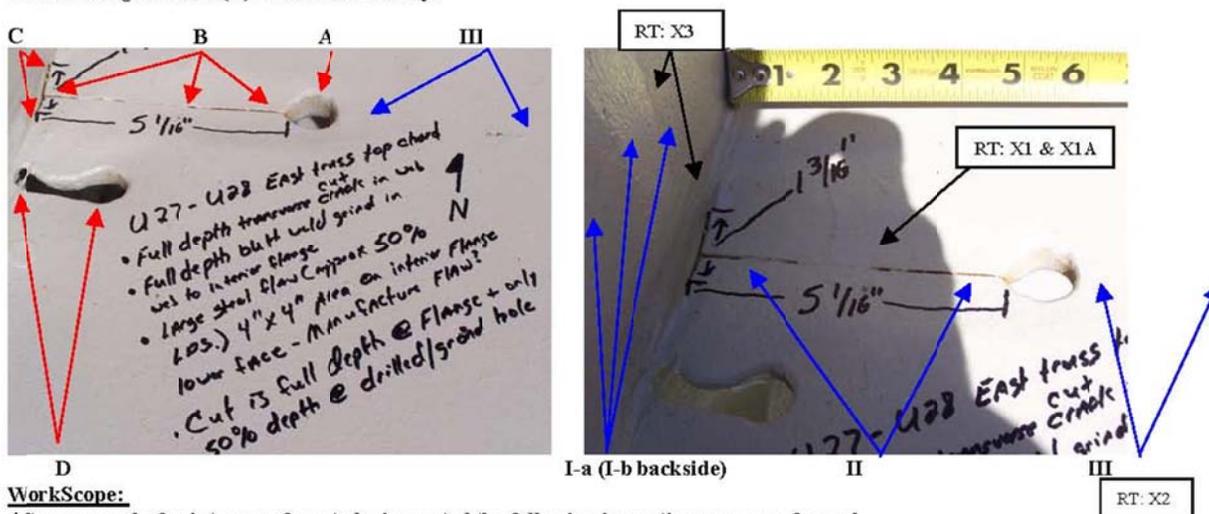
REPORT # K08D14-1

ULTRASONIC-LIQUID PENETRANT-RADIOGRAPHY INSPECTION

of JFK Bridge Truss U27-U28 Area with Original Fab. Defect

SUMMARY

The following is a summary of the U27-U28 Truss Area containing "original construction" defects which were explored for size and growth and particularly for any subsurface cracking in the area resulting from the presence of the defects. Defects visibly present (see below) are a drilled hole (A) with an apparent transverse crack (B) running to the inner flange with a longitudinal saw cut (C) at the inner web-flange corner perpendicular to the transverse crack and an elongated hole (D) in the near vicinity.



WorkScope:

After removal of paint on surfaces to be inspected the following inspections were performed.

UT Inspection, Liquid Penetrant Inspection and Radiography for surface and subsurface crack detection.

- Ultrasonic Inspection: Straight Beam Inspect with Dual Element transducer for defect and Loss of Back Wall Shear wave inspect with 45 degree angle and 60 degree angle
- Liquid Penetrant Inspection the Solvent removable Visible Dye Method
- Radiograph Web and Inner Flange Area with IR192 radiation source.

Summary: Ultrasonic Inspection scanning was performed on Areas I-a, I-b, II and III. Area III had no significant Indications. Area II revealed the crack is full thickness with length equal to visible surface length. No other Indications were found. Area "I-a" (downstream Flange inner surface) and "I-b" (downstream Flange outer surface) revealed (by UT) many varied depth inclusions attributed to the original manufacturing process with many being in the "area of interest" (crack/saw cut area). These indications did not "travel" and could be picked up with straight beam inspection typical of inclusions and not of cracks. Radiography was also performed to complete a thorough inspection. Radiography did not reveal any significant indications. In conclusion there is no evidence of internal or external cracking beyond that which is already visibly present.

Ken Rogers

Ken M. Rogers, ASNT Level III #52399 - Huntington Testing

HUNTINGTON TESTING

Shop or Field Service
Preheat and Post Weld Heat Treat
Product Testing
Research and Development

925 Ulrich Ave
Louisville, Kentucky 40219
Tel.: 502-964-0500
Fax.: 502-964-3999

Chemical Analysis
Weld Engineering
Mechanical Testing
Non-destructive Testing

ULTRASONIC INSPECTION REPORT

Customer: University of Kentucky P.O. No. _____
Date of Inspection: 4-21-08 Project Number: K08D14-1

IDENTIFICATION

Job Site	<u>JFK (Kennedy) Bridge, Lou., Ky</u>	Location	<u>Louisville-to-Jeffersonville</u>
Type of Item	<u>Bridge U27-U28 Truss UT</u>	P/N	<u>JFK "Kennedy Bridge"</u>
Material Type	<u>Carbor Steel</u>	Procedure	<u>SP-UT-001 Rev. 0 w/Attach 3</u>
Specification	<u>AWS C5.1</u>		<u>SP-UT-008 Rev. 0 w/Attach D</u>

TECHNIQUE TYPE

Straight Beam 0 dg Shear Wave: 45° 60° 70° Defect detection

TRANSDUCER TYPE

Frequency 1 MHz 2.25 MHz 5 MHz 10 MHz
Transducer Single Element Dual Element
Diameter 1/4" 3/8" 1/2" 3/4" 1"

CALIBRATION METHOD

(1/16" DIA. X .600" DP HOLE & 3/64" DIA. X 1.25" DEEP HOLE)

DSC IIW ASME Basic Back Wall Tech. Flat Bottom Hole Side Holes V-Notch

TYPES OF INDICATIONS

See UT Section

INSPECTION PERFORMED BY: Ken Rogers Level II Date: 4-21-08

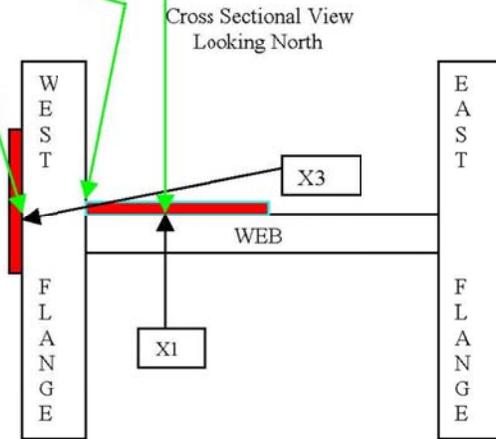
REPORT# K08D14-1

RADIOGRAPHY INSPECTION

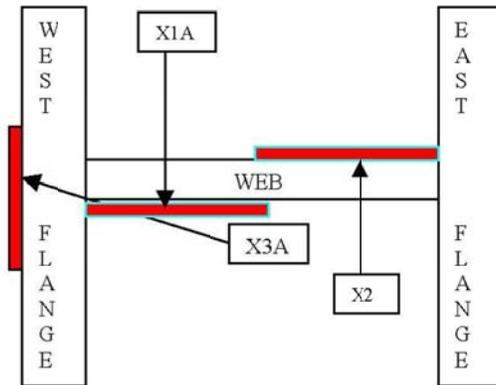
of JFK Bridge Truss U27-U28 Area with Original Fab. Defect

Liquid Penetrant Inspection performed on these areas after paint removal – No Significant Indications

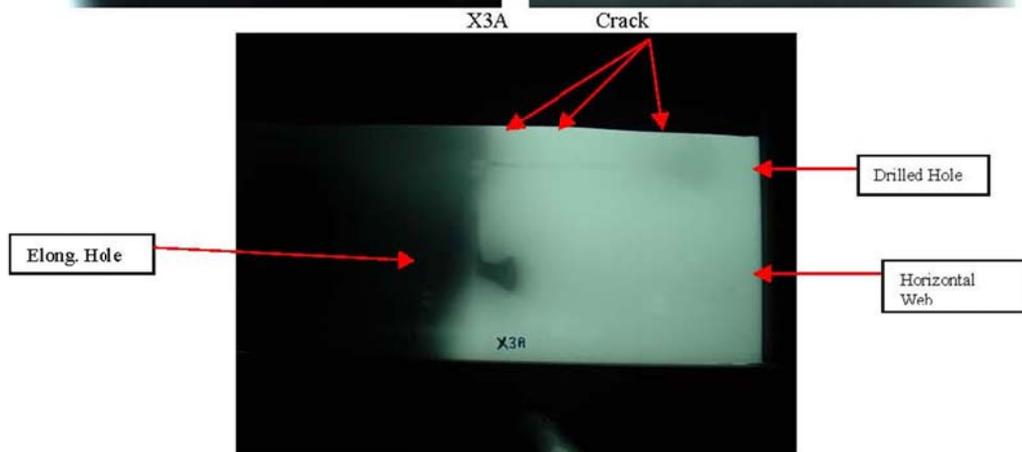
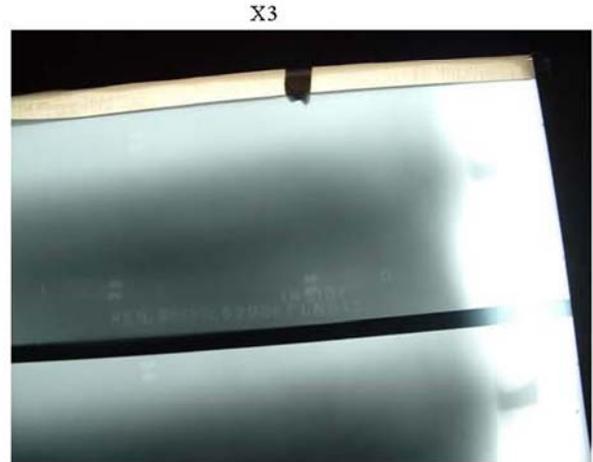
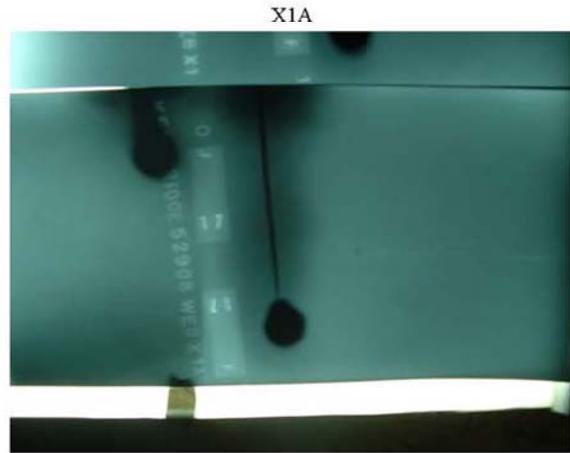
Noah Garrow RT-II



Radiography performed by Charles Barnes RT-LII & Noah Garrow RT-LII



REPORT# K08D14-1
RADIOGRAPHY INSPECTION
of JFK Bridge Truss U27-U28 Area with Original Fab. Defect



ULTRASONIC EXAMINATION REPORT

STATION JFK Bridge UNIT NO. U27-U28 East Truss DATE 4/21/2008
 EQUIPMENT TYPE / NO. U27-U28 Truss Area
 PROCEDURE NO. SP-UT-008 REV. 1 WORK ORDER NO. K08D14-1

UT INSTRUMENT DATA--**See Calib. Sheets**

INSTRUMENT: MAKE _____ MODEL _____ SERIAL NO. _____
 FREQUENCY _____ RANGE _____ REP. RATE _____
 REJECT _____ DAMPING _____ MATERIAL CAL. _____
 ZERO /P.D _____ D-DELAY _____ GAIN _____ Db+ _____ Db
 VELOCITY _____ POWER _____ DAC / TCG _____
 VIDEO _____ CABLE JACK _____
 CALIBRATION DATE _____ CALIBRATION DUE DATE _____
 SYSTEM CALIBRATION BLOCK TYPE _____

TRANSDUCER: MAKE _____ TYPE _____ SERIAL NO. _____
 FREQUENCY _____ SIZE _____ WEDGE/ ANGLE _____
 CONNECTOR TYPE _____ CABLE TYPE _____ LENGTH _____

MATERIAL INFORMATION

MATERIAL TYPE A-36 PIPE _____ CASTING _____ PLATE X BOILER TUBES _____
 SHAFTS _____ STUDS _____ TANK _____ OTHER _____ REMARKS _____

M = monitor SW = Shear Wave(Angle Beam) & SB = Straight Beam (Long. Wave)

EQUIP / COMP / ETC.		ACCEPT REJECT	FINDINGS
1. Horizontal Web Area	M		Crack has no apparent growth. Crack is full depth
Area with visible tranverse crack			UT shear Wave from topside surface, transverse and long. scanning-2 directions
2. Horizontal Web Area	X		No Significant Indications
Area east of 1 above			UT shear Wave from topside surface, transverse and long. scanning-2 directions
3. Down Stream Flange Area	X		No Significant Indications (multiple inclusions/laminations found-SW & SB)
14" Hx 8" W Area			UT shear Wave from inside/outside surfaces, trans. and long. scanning-2 directions
			Straight Beam performed for defect detection (IIV block side drilled holes used)
			Shear Wave Scanning with 45/60 deg. wedges (1/2" element), 5 Mhz
			1/2" wedges and 5 Mhz best for this application for crack detection (inc. sensitivity)
			(based on comparison with typical referenced 2.25 Mhz with large wedge)

INSPECTOR(S) / NDE LEVEL Ken Fogers -LIII PAGE 1 OF 4

ULTRASONIC CALIBRATION DATA SHEET

IIW 1018 CAL. BLOCK

Station / Location	Kennedy Bridge	Procedure	SP-UT-008 R1	Date	4/21/2008
Unit Number	U27-U28	Cal. Block	IIW 1018 Steel	Thickness of Part	.769"-2.215"nom

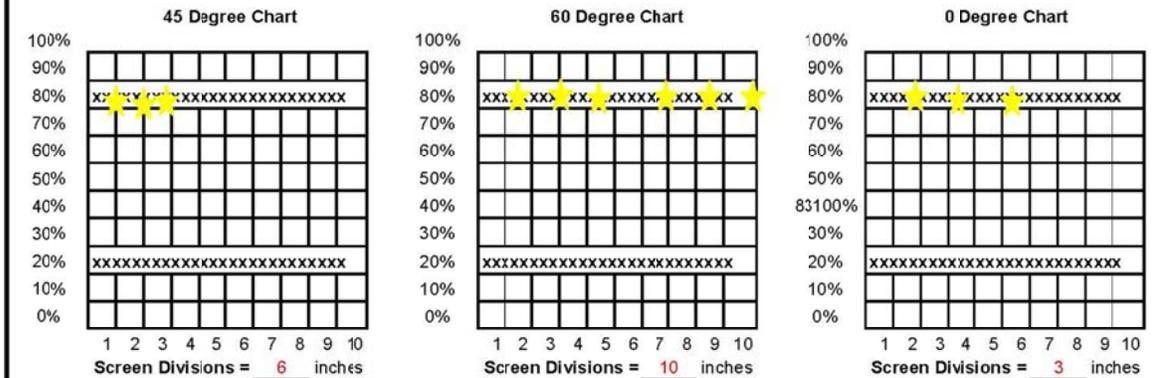
TRANSDUCER DATA

Make	K-B	S/N	00P4VT	Make	K-B	S/N	00P4VT	Make		S/N	
Type	BCHMK	Mode	Shear	Type	BCHMK	Mode	Shear	Type		Mode	
Freq.	5	Size	1/2"	Freq.	5	Size	1/2"	Freq.		Size	
Angle	45	M. Angle	45	Angle	60	M. Angle	60	Angle		M. Angle	

Make		S/N		Make		S/N	SNF16700	Make		S/N	
Type		Mode		Type		Mode	Dual, long	Type		Mode	
Freq.		Size		Freq.		Size	1/4"	Freq.		Size	
Angle		M. Angle		Angle		M. Angle	0	Angle		M. Angle	

SCREEN PATH DISTANCES & DEPTH READOUTS FROM THE INSTRUMENT

SDH Dia.	% of Block Thickness	Sound Path Distance					Instrument Depth and Amplitude					
		30	45	60	70	80	45 D	45 A	60 D	60 A	70 D	70 A
1/16"	.600" dp							80%		80%		
3/64"	1.25" dp							80%		80%		
								Min		Min		



Instrument Data (1/16" SDH's)

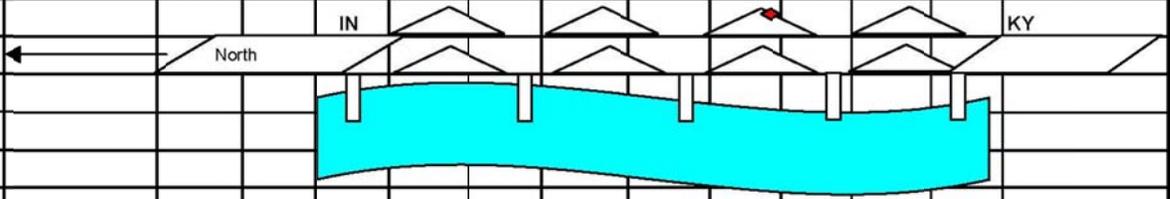
Make	KBI	Angle	45	Angle	60	Angle	0
Model	USN52L	Freq.	5 MHZ	Freq.	5 MHZ	Freq.	5 Mhz
Serial #	L4-TCG-1998	Gain Db	53	Gain Db	55	Gain Db	82
Cable Jack	SINGLE	Scan Db	21+	Scan Db	21+	Scan Db	NA
Prf-Mod	LOW	Rejec.	OFF	Reject	OFF	Reject	OFF
Prf-Val	120	Damping	50 ohms	Damping	50 ohms	Damping	50 ohms
DAC/TCG	ON	Range	6"	Range	10"	Range	3
Calibration	2/26/2006	Velocity	.1269 in/us	Velocity	0.127 in/us	Velocity	.232 in/s
Cal. Due	3/26/2006	Zero/ P-delay	5.3046 us	Zero/ P-delay	6.3831	Zero/ P-delay	3.752 us
Video	Full - W	Delay	0	Delay	0	Delay	0
Power	High	Power	HIGH	Power	HIGH	Power	HIGH
				TCG Set		TCG Set	

DUAL **VEL. -** **PROBE DELAY** **3" RANGE 150 OHMS** **RRP - LOW 1275 Hz** **DB GAIN**
TRANS.
 INSPECTOR(S) / NDE LEVEL _____ Ken Rogers LII PAGE 2 OF 4

ULTRASONIC INDICATION DATA SHEET

Station / Loc	Top of Bridge-East Side #2 Pk from KY	Unit Number	JFK	Date	4/21/2008
Procedure	SP-UT-008 Rev. 1	Job Number	K08D14-1		
Item #	U27-U28 East Truss Top Chord	Datum "0"			
Thick.	.769" Web & 2.215"-1.660" DS Flange	W Measure	DS = down stream		

weld # & Ind. #	Scan Direction Top or Bottom Axial or Circ.	ampl. %	DB Setting	Trans. Angle	Distance in Inches			W Distance Inches			L Distance Inches		Type of indicator
					MP1	MP	MP2	W1	W	W2	L1	L2	
Scan 1	0 Deg. Calibration			0									
Scan 2	60 Deg. Calibration			60									U27-U28 East Truss
Scan 3	45 Deg. Calibration			45									Top Chord -South Side



Indication #	Indication Length	Depth of ind	Radial length	Location			Type of Indication					Acc.	Rej.	Remarks			
				weld	base metal	H.A.Z.	por.	slag	Inclus.	crack	fus.						
	Horiz. Pit	0.769" Thk															
																	Vert. Pit IN Side 2.215" thk. Vert. Pit KY Side 1.660" thk.

WELD PROFILE

	West Vert. Plate	Flat Web Plate
Dist.	2.215'	Thk. .769"
1/2	Taper	
1	Taper	
1 1/2	Taper	
2	Taper	
2 1/2	Taper	
3	1.660'	

Crown Width **NA**
Crown Height **NA**

Abbreviations

1. Por. = porosity
2. Dimens = Dimensional
3. Circ. = Circumferential
4. MP = Metal Path

INSPECTOR(S) / NDE LEVEL Ken Rogers LIII PAGE 4 OF 4

9. APPENDIX B

**Acoustic Emission Monitoring of a Top Chord on
The John F. Kennedy Memorial Bridge
Over the Ohio River at
Louisville, Kentucky**

July, 2008

By
Daniel R. Marron and David E. Kosnik
Infrastructure Technology Institute
Northwestern University

Purpose: The purpose of this task is to use acoustic emission (AE) monitoring to provide additional information on the nature of an area near U27-U28 on the East truss top chord.

Background: Kentucky Transportation Cabinet Bridge # B00214 carries I-65 traffic over the Ohio River between Louisville, Kentucky and Jeffersonville, Indiana. The structure consists of a single through cantilevered truss carrying seven lanes of traffic and has an ADT of approximately 132,000 vehicles. The bridge was opened to traffic in 1963. There is an area near U27-U28 on the East top chord which has a five inch full depth transverse crack in the web with a one inch diameter stop hole, an adjacent irregular hole of unknown origin, and a partial depth saw cut along the web to flange weld at the crack as shown in **Figure 1**.

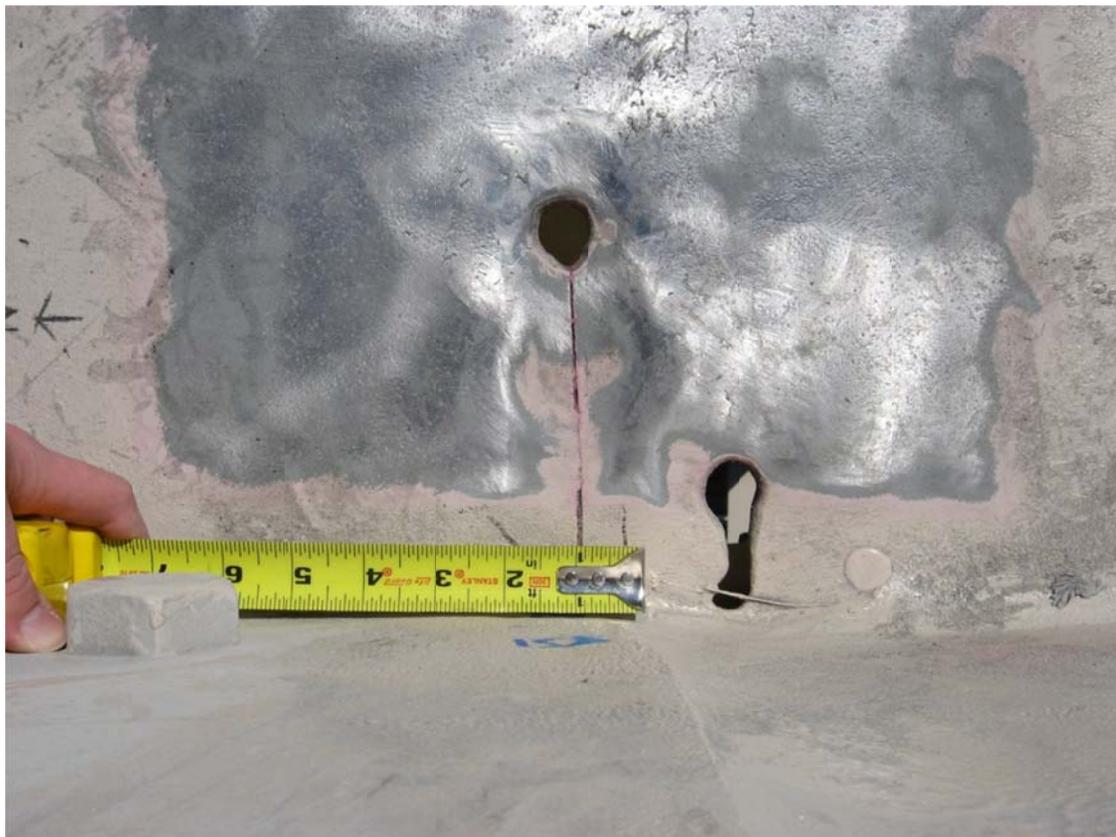


Figure 1: View Down Into Top Chord

Procedure: An AMSY5 acoustic emission system and six VS150-RIC piezoelectric 150 KHz resonant sensors with integrated pre-amplifiers, all from Vallen Systeme GmbH of Icking Germany, were used for this testing. A recording threshold of 40dB was used for all tests. This threshold value is the minimum threshold for reliable detection of early fatigue cracks in mild steel under high cycle fatigue conditions as determined in laboratory experiments. The system's internal calibration function and manual pencil lead breaks were performed at the beginning and end of each run to confirm adequate coupling of the sensors. Additionally, a displacement sensor capable of micro inch resolution was installed across the crack with the

intent to correlate AE and crack opening. The displacement sensor was damaged in transit and no useful data was collected from it.

A small area (<1" diameter) of bridge paint was removed by hand grinder and then wiped with a clean rag soaked in mild solvent to remove debris at each location. Sensors were then acoustically coupled to the structure with Dow Corning high vacuum silicone grease and held in place with Vallen magnetic hold-downs. ITI engineers integrated the AMSY5 into a custom sealed enclosure along with a rugged laptop computer and support electronics. Sensors were connected to the AE monitor by short cables run to bulkhead pass through connectors on the enclosure. The entire system within that enclosure was placed on the top chord for the duration of the testing. Cabling was run down to the deck where power was supplied by a small gasoline generator. An ITI engineer operated the system from a second laptop computer from the deck.

Two separate test configurations were necessary due to the geometry of the location and its proximity to a large bolted connection. The first test configuration monitored only the vertical flange on the west side of the chord adjacent to the crack. Sensor one was placed on the web as a guard channel so that acoustic events originating in the web could be filtered out. Sensor two was placed on the flange immediately opposite the crack, and the remaining four sensors were placed on the flange in a rectangular array around sensor two, as shown in **Figure 2** below.



Figure 2: AE Sensors on Vertical Flange

The second test configuration monitored only the web of the chord near the crack. Channel two was placed on the outside of the west flange opposite the crack and served as the guard channel so that acoustic events originating in the flange could be filtered out. Channel one

was placed on the web near the stop hole opposite the crack with the remaining channels placed in a rectangular array around it as shown in **Figure 3** below.

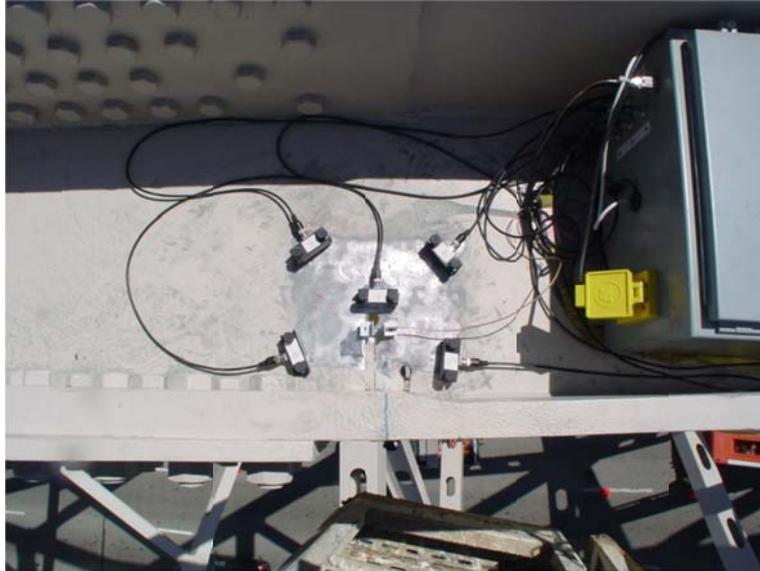


Figure 3: AE Sensors on Horizontal Web

A total of four test intervals, two on the web and two on the flange, were recorded during the two days of monitoring as shown in **Table 1** below.

Run Number	Location	Start Date	Start Time	Duration
1	Horizontal / Web	04/15/2008	13:32	12 min
2	Vertical / Flange	04/15/2008	13:49:58	3 h 23 min
3	Horizontal / Web	04/16/2008	10:27:27	52 min
4	Vertical / Flange	04/16/2008	11:31:51	36 min

Table 1: AE Test Runs

Results: ITI engineers applied three different AE analysis techniques to the collected data. The first technique used was a simple multi-channel approach with first hit channel (FHC) analysis to examine the acoustic activity level of the crack. This approach was developed and proven during previous AE testing of steel structures by ITI. The FHC analysis evaluates the order of receipt of an AE signal at each of the sensors in the array. When the sensor mounted on or near the crack is the channel that receives the first hit, the AE signal must have originated at the crack. All other first hits are the result of extraneous noise sources and can be ignored. During test runs 2 and 4, the channel two sensor, located on the vertical flange opposite the crack in the web, was considered the “crack” channel. Similarly, during test runs 1 and 3, the channel one sensor at the stop hole in the web opposite the crack was considered the “crack” channels.

FHC analysis was used to determine the total number of crack-related hits per data recording session. Further analysis showed that, although there were a significant number of acoustic events originating from the transverse crack, all first hit counts were of low amplitude and went effectively to zero when a 45dB filter was applied. ITI has previously used the ratio of crack first hits to total hits during a test as a relative indicator of crack activity between test runs over time. This ratio allows for a numerical comparison of crack activity between tests conducted months to years apart or before and after a retrofit installation. Unfortunately, the ratio was not consistent from run to run, so the method is not appropriate for this site. The unfiltered FHC analysis results are summarized in **Table 2** below.

Run Number	Location	Crack First Hits	Crack FH Rate	Ratio Crack FH to Total Hits
1	Horizontal / Web	2477	206 hits/min	85%
2	Vertical / Flange	0	0 hits/min	0%
3	Horizontal / Web	12425	377 hits/min	57%
4	Vertical / Flange	477	10 hits/min	0.3%

Table 2: First Hit Channel (FHC) Analysis

The second technique employed a two-dimensional location analysis using the known position of each sensor and the features of interest on the upper chord. Due to the geometry of this site and the conservative nature of the location determination algorithms, not all acoustic events will yield a location. None of the acoustic events for either of the two vertical flange test runs produced any locatable indications. Both runs on the horizontal web, however, yielded many events whose locations were able to be determined, as seen in **Figure 4**.

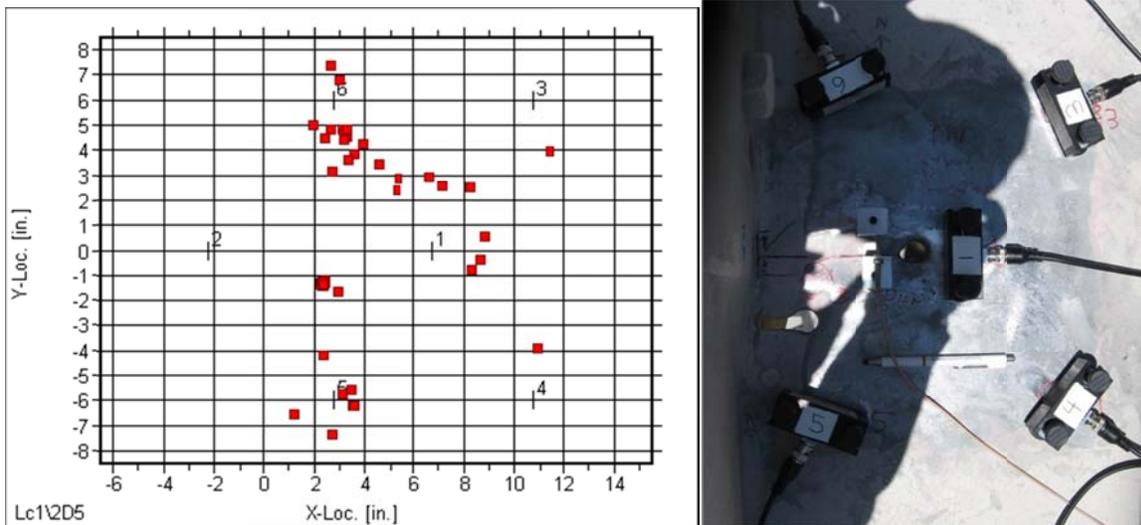


Figure 4: AE Locations on Horizontal Web

The third and final analysis technique further refines the locations derived above through a combination of spatial and temporal clustering. This clustering filter requires a minimum of

three AE events within a 1 inch location window to occur within a one second time interval¹. The temporal clustering technique that was applied to the data recorded in these tests was originally developed by David W. Prine for application to in-process weld monitoring. It has been well proven both in the laboratory and in the field to be a very effective filter criterion to allow reliable detection of crack growth in noisy environments.

The plot in **Figure 5** shows AE events plotted vs. source location in inches. The events have been subjected to both an energy and amplitude threshold to minimize background noise. The plot shows the locations of groups of filtered events that satisfy the clustering criteria (3 events within 1 inch of each other occurring within a one second interval). A group of clusters centered at (2.62", -1.24") can be observed in the green circle. This observation was confirmed by subsequent radiography to be a slag inclusion introduced during original fabrication. **Figure 6** defines the coordinate system used and gives the precise location of the cluster group due to AE from the slag inclusion.

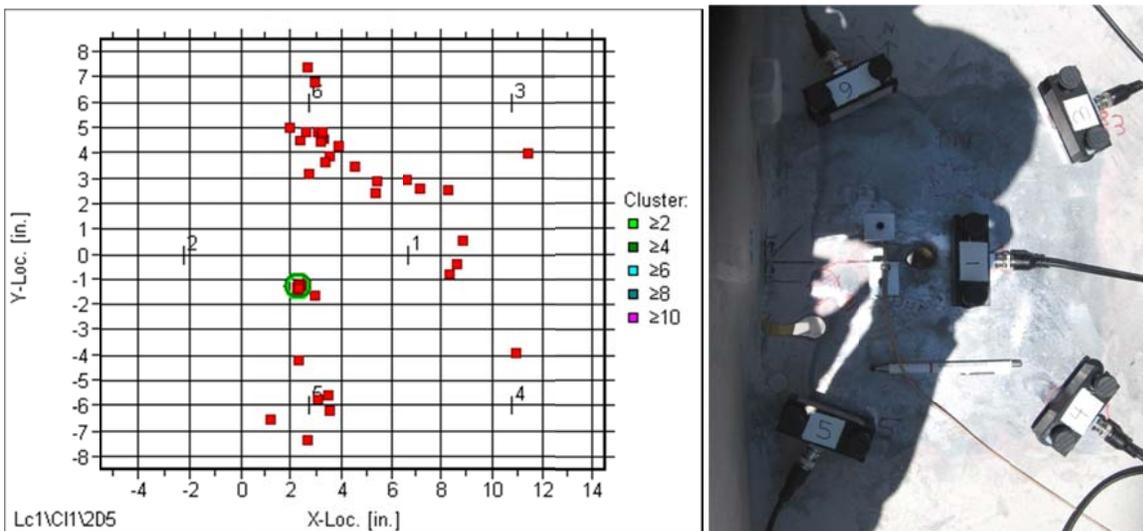


Figure 5: AE Cluster Location

¹ "Acoustic Emission Monitoring of the Trunnion Shafts on Oregon DOT Bridge #1377A, the I-5 Columbia River Bridge East Lift Span, Portland, Oregon," David W. Prine, Report to Oregon DOT, November, 1994.

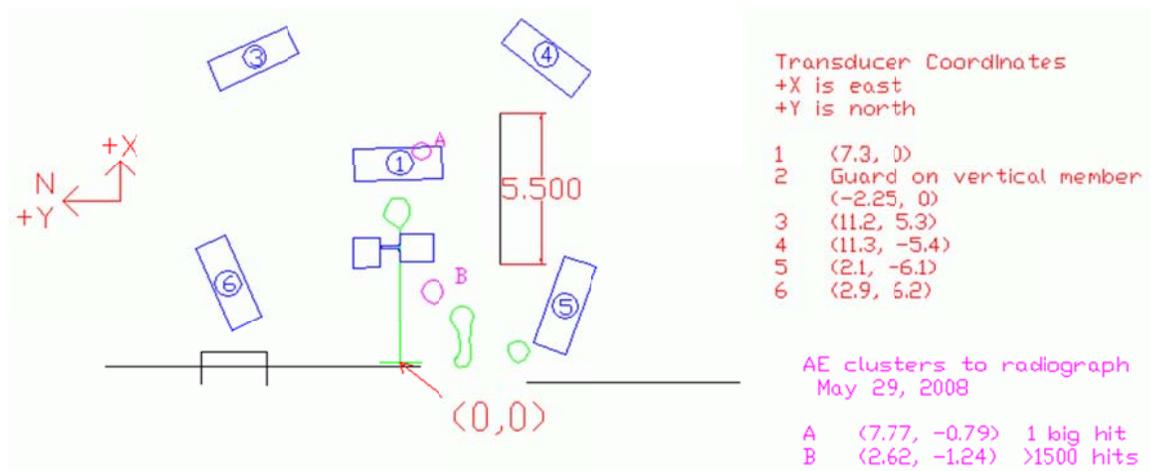


Figure 6: Horizontal Web Layout

Conclusions: The AE data collected in April of 2008 shows no significant acoustic sources on the vertical flange in the area of interest on the east truss top chord near U27-U28. The horizontal web in that area does show a significant number of acoustic events along the transverse crack, but they are of low amplitude and are most likely the result of fretting between the existing crack faces. It is not possible to determine if the crack is actively growing based solely on this AE test, but AE location analysis suggests that it has not jumped the stop hole. Only one location generated AE activity which passed the clustering filter. This detail was later confirmed by radiography to be a slag inclusion in the horizontal web.

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