RESEARCH REPORT
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ACOUSTIC EMISSION MONITORING OF BASCULE BRIDGE COMPONENTS

by

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INTRODUCTION

During September 4-16, 1986, Kentucky Transportation Research Program (KTRP) personnel conducted a two-week inspection of welding operations on bascule bridge components for the Wisconsin Department of Transportation (WisDOT). Welding was performed by the Phoenix Steel Company at Eau Clair, Wisconsin. The inspection was conducted using acoustic emission (AE) monitoring on in-process welds.

KTRP investigative experience with AE weld monitoring and testing of bridges began in 1973. Since that date, KTRP has performed nine series of laboratory and fabrication shop weld monitoring tests and conducted 20 field tests of bridges using a series of increasingly sophisticated AE devices. Over the past four years, KTRP has had success with the Acoustic Emission Weld Monitor (AEWM) developed by GARD, Inc. of Niles, Illinois. That device was originally intended to monitor in-process welding operations to detect defect formation. KTRP has determined that the unit is also suitable for detecting fatigue-crack growth on in-service bridges. The operation of the AEWM and a summary of KTRP/GARD bridge experience with that device is contained in a technical paper, which is included in the Appendix.

The AEWM is a microprocessor-based AE system that operates on an event-based, AE pattern-recognition principle. The AE signals are detected by sensitive sensors attached to the weldment. Those sensors convert stress-wave energy from flaw formation and/or growth into electrical signals. The AEWM is capable of detecting electrical signal patterns characteristic of cracks and of concurrently rejecting large amounts of electrical signals from mechanical noise. Mechanical noise pervades most slag-type welding processes and in-service bridges. It is the primary obstacle to conducting such tests using conventional AE equipment and techniques. The AEWM is the only AE device that can detect crack activity in high-noise environments.

There are several attendant benefits of the AEWM's microprocessor configuration. It is capable of detecting and locating flaws automatically, eliminating operator error. It detects AE flaw activity in near-real time, allowing a correlation to be made between events during a weld deposition (i.e., weld "rolls") or on a bridge (i.e., vehicle loads) and any AE events the AEWM characterizes as being flaw-related. Once the sensors (piezoelectric transducers) are mounted and the AEWM is calibrated, the unit may be operated in a stand-alone (unattended) mode.

A red indicating lamp on the front of the instrument panel will extinguish if the AEWM detects crack activity. The approximate location of the defect between the two sensors will be shown on a 16-element light-emitting diode (LED) on the instrument panel. The amount of crack activity may be determined from the number of indications detected by the AEWM that correspond to the crack or unclassified (i.e., slag or porosity) model. That information also is displayed on the LED panel.

Recently, the Federal Highway Administration initiated two studies using the AEWM. In one study, GARD, Inc. will develop an updated AEWM using the latest microprocessor technology. That device will be lighter and less expensive than the current AEWM. Operating principles will remain unchanged. The unit will be used for inspecting bridges. In the second study, KTRP has installed the AEWM used in this project at High Steel Structures Inc. fabrication shop in Lancaster, Pennsylvania, to monitor production-welding operations for a six-month period, which began in January 1987. Results will be used to determine if the device is a viable NDT tool for welding-shop operations.

WELDING OPERATIONS AT PHOENIX STEEL CO.

Weldments being fabricated at Phoenix Steel were four pieces to be incorporated into girders for a WisDOT bascule bridge (State Project No. 1508-04-71) (see shaded area in Figure 1). The weldments were made from thick-sectioned (2 1/2-inch typically) ASTM A 36 steel. The stiffener and web plates were made of common "as rolled" steel. The flange material was normalized.

Full-penetration welds were used for both flange-to-web welds and stiffener-to-flange welds. The stiffener-to-web welds were partial-penetration welds. Flanges were made from three plates that were welded together. The assembled one-piece flanges were subsequently attached to the webs. Flange-to-web full-penetration welds consisted of three straight welds deposited using automatic submerged-arc welding (SAW) and two corner welds deposited by manual SAW (Figures 2 and 3). Stiffener-to-web welds were made using manual shielded metal-arc welding (SMAW). Stiffener-to-flange welds were made using both manual SAW and SMAW (Figures 4 and 5).

The four assemblies were welded at two adjacent stations in the plant. Two flange-to-web welding operations were performed concurrently with welding operations being conducted for several shifts.

The flanges were attached to the webs with continuous SMAW tack welds. The weld groove was formed by two bevels cut in the edge of the web. The groove angle was about 50 degrees (Figure 6). The weldments were torch heated to 150^{o}F prior to welding. Several SAW weld passes were applied on one side of the weldment. It was then turned and several weld passes were deposited on the opposite groove after it was back-gouged. Once the weld was approximately one-half complete, it was ultrasonically inspected using a straight-beam shot from the backside of the flange. The weldment was then completed with alternating welds of both sides of the weldments to provide balanced welding stresses and to prevent distortion. The completed welds were ultrasonically inspected with an angle-beam shot into the weld from the web.

The 50-degree weld groove presented some problems with the initial weld passes. In some cases, it was difficult for the operator to control where the welding head would deposit the weld metal. Minor variations in head movement would occasionally result in slag inclusions or "rolls" in weld metal. After the first welds were built up to about one-third the final size, problems ceased. The high (150^{o}F) preheat probably prevented many incidents of restraint cracking. The welders were careful in depositing weld metal and in inspecting each completed weld pass. Subsequently, the amount of weld repairs were minimal.

Full-penetration stiffener-to-flange welds also were completed with few problems. The weldments had three pairs of 2 1/2-inch thick stiffeners. Each stiffener pair was attached symmetrically to the webs using partial-penetration fillet welds. The stiffeners were then welded to the flanges at one weld station. The other station was used to complete the final flange-to-web welds.

Root passes were made using manual SMAW. When possible, welding operators were eventually assigned to concurrently weld the stiffeners. The opposite stiffeners were welded simultaneously during most of the two-man welding operations.

While KTRP personnel were still at the shop, those type of welds proved to be relatively trouble-free. The 150°F preheat also was effective in preventing potential restraint cracking problems in the stiffener-to-flange welds and the care taken by the Phoenix Steel welders also contributed to the low number of defects encountered.

ACOUSTIC EMISSION TESTING

During flange-to-web welding operations, AE transducers were mounted on the backside of the flange, some 6 inches offset from the weld line (Figure 7). Magnetic hold downs were used to affix the transducers. Preheat torches were located under the flange to keep flames from damaging the transducers. In Figure 7, the end transducers were the active units that compose a linear array. A center transducer also was employed as a pulser to calibrate the two active transducers. Transducer linear array spacings of 42, 50, and 78 inches were used for the three straight portions of the weldment (where automatic SAW was employed). An active transducer spacing 18 inches from each corner was used for the manual SAW corner locations (Figure 8).

The flange-to-web weld AE monitoring was initially conducted at 60 dB signal amplification. Welding operations in the root area produced many AE defect indications. Some of those were caused by undercuts in the base metal. Undercuts may cause defect indications by trapping slag tightly against the weld-groove walls. Also, they may promote embedded slag in the completed weld. The other routine source of AE defect indications was "fish-eyes" or surface-breaking porosity filled with slag. Those defects were identified and easily remedied by grinding between passes.

The main problem encountered in the AE monitoring was due to the high sensitivity of the GARD AEWM. Frequently, the AEWM detected small flaws that were not readily detectable by radiography or ultrasound.

That problem was alleviated at Phoenix Steel by two steps: 1) the AE system gain was lowered 6-10 dB midway through the testing, and 2) AE defects having low activity levels were ignored unless they were detected at the same location in a subsequent weld pass.

The first step eliminated many of the low-energy defect indications caused by minor weld undercuts. The second step eliminated consideration of defects placed in the weld on one pass and melted out on a succeeding pass. Those steps greatly reduced the number of AE defect indications that were subsequently inspected or repaired. Unfortunately, by the time those actions had been effected, most of the root area flange-to-web welds were complete and no useful comparison was obtained. AE testing in the top weld passes had already proved to be uneventful prior to making those changes (using the earlier test criteria).

AE monitoring had to be limited to one particular weldment (2JL2) during most of the flange-to-web welding. During that time, the AEWM detected two major cracks that formed at different times in the first (root) portion of the welds. Those were surface-breaking cracks that were detected visually. One was about 1/2 inch long and the other was about 2 1/2-inches long. No known cracks were detected by other means and not by the AEWM.

The AEWM also detected a subsurface flaw indication that was later determined to be rejectable by ultrasonic inspection. Ultrasonic inspections were conducted using the AWS building code. That code was used as the welds in question were to be used in compression. The AEWM detected single flaw indications every two or three passes at the higher gain settings (usually undercuts). Most of those sources became inactive in succeeding weld passes, especially after thorough slag removal. Occasionally, an AEWM indication would be a shallow surface crack or fold in the weld metal that could be easily removed by grinding. Due to the lack of depth of those defects, it is highly likely they would have been eliminated by subsequent weld passes.

After the AE monitoring changes were instituted, few defect indications were detected. When they met the newly adopted defect criteria (i.e., lower gain and repeatability at one location), their locations as indicated by the AEWM were visually inspected. They were marked as to location. The original weld metal was then removed and new welds were deposited. Often, during those repairs, surface or subsurface defects were not detected visually. This indicates the AEWM was still detecting very small, but active, flaws. In each instance, as when the repair welds were deposited, they did not produce active AE flaw indications.

The AEWM was shifted to monitor several deep weld repairs on another complete assembly (2DL1) after most of the previously monitored flange-to-web welds had been completed on two assemblies at the other work station. By that time, the welds had been built-up and routine flange-to-web welding had become problem and flaw free. While the change precluded 100 percent monitoring of any weldment, it was felt that deep repairs might prove troublesome and would warrant AEWM inspection. Historically, weld repairs have been sites of subsequent cracking problems.

Repairs were effected by air-arc back-gouging and surface grinding of the gouged-out area. The weld was then preheated to 150^{o}F. The repair grooves were 1 and 2 inches deep and 9 and 12 inches long, respectively. Transducers were set 48 inches apart and the repair welds were monitored at 59 dB gain. New weld metal was deposited using manual SAW (Figure 9). Sixteen weld passes were required to fill the longer, deeper gouge. Thirteen passes were required to fill the smaller gouge. No defect indications were detected by the AEWM during the weld repairs.

After the final flange-to-web weld repairs were completed on that assembly, stiffeners were attached to the webs and flanges. Once all web-to-flange welds for the four assemblies had been completed, a second welding operator was free to assist in the stiffener welding. The decision was made to weld two opposite stiffeners concurrently on a single weldment. Essentially, this is similar to welding on a single line, except two welding sources are concurrently active. The AE transducers were usually placed on the outer flange face opposite the welding operation. Sometimes, the lack of access to that face required placement of the transducers on the same flange face as the weld, but on the other side of the stiffener being welded. Typically, transducer spacing was 24 inches and the AE system gain was set at 48-52 dB (Figure 10).

The AEWM proved capable of monitoring concurrent welding operations. The only problems occurred when one welder was chipping or grinding while the other was welding. Then, the amplitude of the mechanical noise generated by the grinding exceeded the preset AEWM threshold and all incoming signals were rejected. Also, one particular grinding wheel could occasionally create "false calls" in the adjacent weld. That fact was quickly recognized and accounted for in subsequent work.

One welding operator was eventually able to use manual SAW on his welds while the other welder was limited to stick welding (due to the lack of a second SAW machine). At that point, the AEWM was monitoring two concurrent welds deposited by two different processes. Later in the stiffener welding operations, one welder had to shift to a different stiffener than the one being welded by his counterpart. A lockout feature on the GARD device was utilized for that operation. A third transducer (normally used as the calibrating pulser) was placed between the two welding operations (Figure 11). The third transducer was connected to the third GARD amplifier and the circuitry and computer program in the GARD AEWM automatically employed that amplifier's signals as a "lock-out" for out-of-array (noise) sources. The active array was on the weld line of the operator shown seated in Figure 11. The AE signals from his weld were monitored by the AEWM and those of his counterpart were rejected.

A few slag-related defects were detected and removed during stiffener welding operations. There appeared to be some slight differences in the abilities of the welding operators to make SMAW welds (especially at the root openings where the weld throat was narrow). The AEWM picked up more background AE activity and defect indications from some welders than from others during the SMAW operations. Also, SAW welding tended to be more acoustically "quiet" than SMAW. A few problems were caused by slag trapped at fit-up edges between the stiffener and flange. Those areas could not be cleaned and the entrapped slag created some false calls during subsequent welding operations. However, those false indications came from the same known location each time they occurred and were easily identified.

The only unusual occurrence happened during the flange-to-web welds. One web plate on a weldment being AE monitored was known to contain many laminations (from ultrasonic inspection). During the SAW operation on the middle portion of the assembly (No. B3597), multiple AE flaw indications were detected. Most of those occurred when the welding head was depositing metal on the web side of the weldment. Those indications were suspicious. They all occurred at the center of the array. As the weld was built up, the frequency of AE flaw-indication became unrealistically high. Ultrasonic inspection revealed no defects in or adjacent to the weld. The AE activity was probably caused by delamination activity in the plate away from the weld area. That type activity will normally be located in the center of a linear array. That is the first time such behavior had been experienced by either KTRP or GARD personnel. If necessary, that problem may be eliminated in the future by the use of noise-rejection techniques not presently incorporated in the FHWA AEWM.

TEST RESULTS AND CONCLUSIONS

During the course of the KTRP AE inspection work, 52 separate set-ups and tests were conducted. Forty-one of those were for the flange-to-web welds and 11 were for stiffener-to-flange welds. A total of 267 welding passes were monitored during the flange-to-web welding operations. Those entailed monitoring some 750 feet of deposited weld metal. Similar data were not obtained for the stiffener-to-flange welds due to the extensive use of manual SMAW. The AEWM detected flaw indications during 34 of the 267 flange-to-web weld passes. Nine of those AEWM indications corresponded with visibly observable flaws on the surface of welds. Five AE flaw indications were produced during the stiffener-to-flange welds. Several of those were visibly detected slag stringers. In all cases, the flaw locations indicated by the AEWM were either repaired or inspected by ultrasonic testing and found to be defect free.

The AEWM functioned well in the Phoenix Steel tests. It detected all known planar defects (i.e., cracks) that occurred in the welds on which it was used. It also detected several other defects whose nature was usually slag-related. AEWM results have not always correlated well with ultrasonics. This is due to two reasons: 1) the AEWM has sometimes failed to detect some porosity or bridging of the welds in the root area, and 2) the AEWM has sometimes detected flaws that are too small to be detected visually or to be considered rejectable by the ultrasonic standard used for weldments. However, the AEWM achieved its purpose -- to ensure that the welding procedures used by Phoenix Steel were suitable for welding thick plates. If weld-procedure controls employed by Phoenix Steel had been unsatisfactory, more cracks would have been generated and the AEWM would have been of more benefit (in a negative sense). That is one of the four advantages of the AEWM over other NDT methods: it allows assessment of weld-procedure control. Also, it should be noted that the AEWM monitored hundreds of linear feet of welding (in-process). If costs for the AE inspection were calculated on the basis of per foot of weld deposited, and if only the KTRP operator's shop costs were considered, the inspection price would have been relatively inexpensive.

Several firsts were achieved for the AEWM and several for the AE monitoring of welds in general. Those were:

1. The first AEWM monitoring of grooved full-penetration web-to-flange welds.
2. The first large-scale AEWM monitoring of heavy-section, bounded weldments for highway use.
3. The first known AE test on concurrent independent welding operations.
4. The first concurrent known AE monitoring of two different types of welding.
5. The first use of the AEWM on manual welding operations for highway steels.

Early results of the KTRP tests of the AEWM at High-Steel have supported some preliminary KTRP suppositions made during the Phoenix Steel tests, especially about the reduction in test sensitivity and the repeatability of AE activity on succeeding weld passes. To date, that work has provided additional evidence indicating that the AEWM is both an effective and useful shop NDT tool. Work performed for WisDOT at Phoenix Steel proved very helpful in preparing for the FHWA project and KTRP will endeavor to keep WisDOT personnel abreast of the progress of the current project.

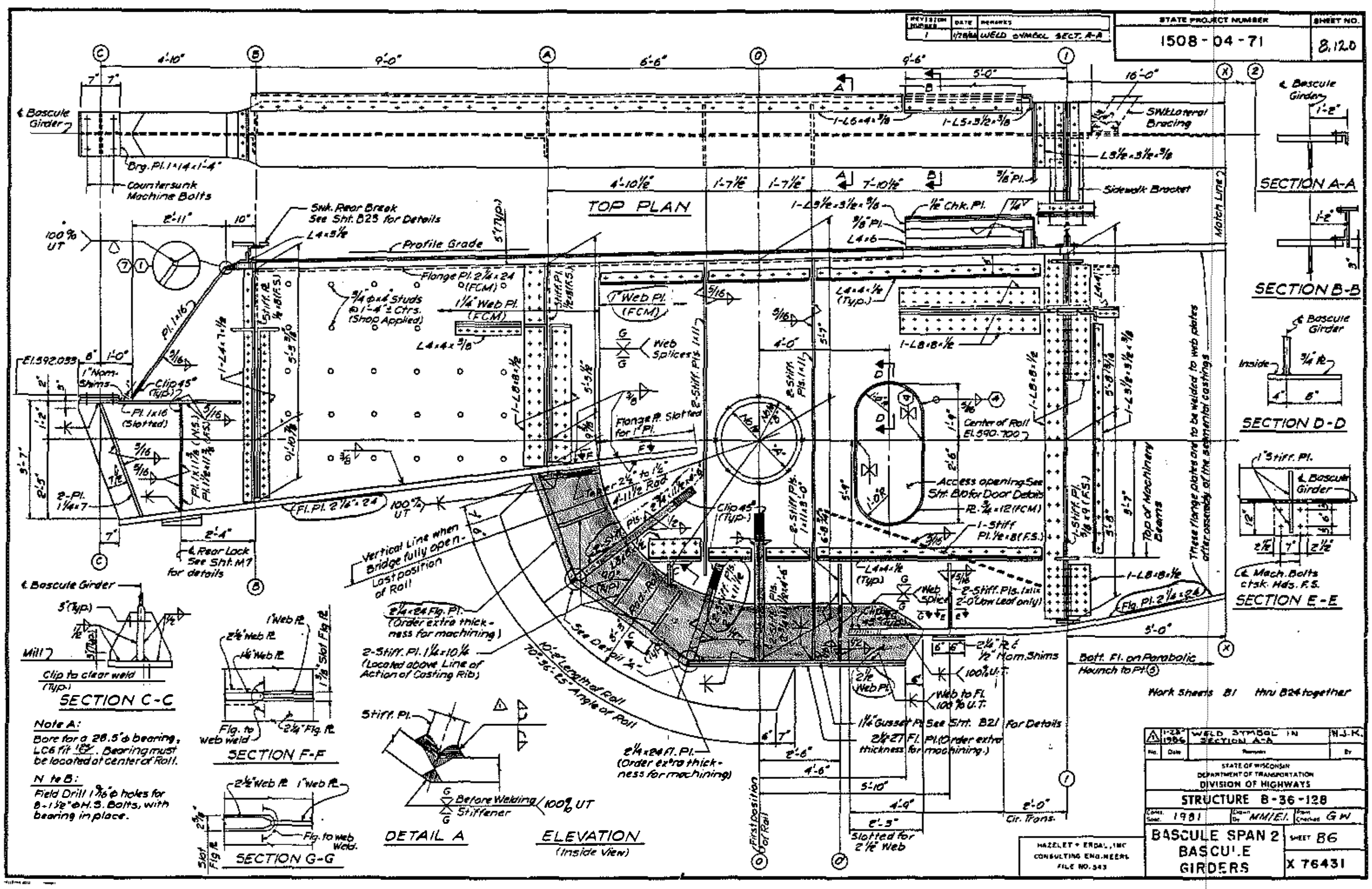

Figure 1. WisDOT Bascule Bridge Girder - Weldment Shown in Shaded Area.

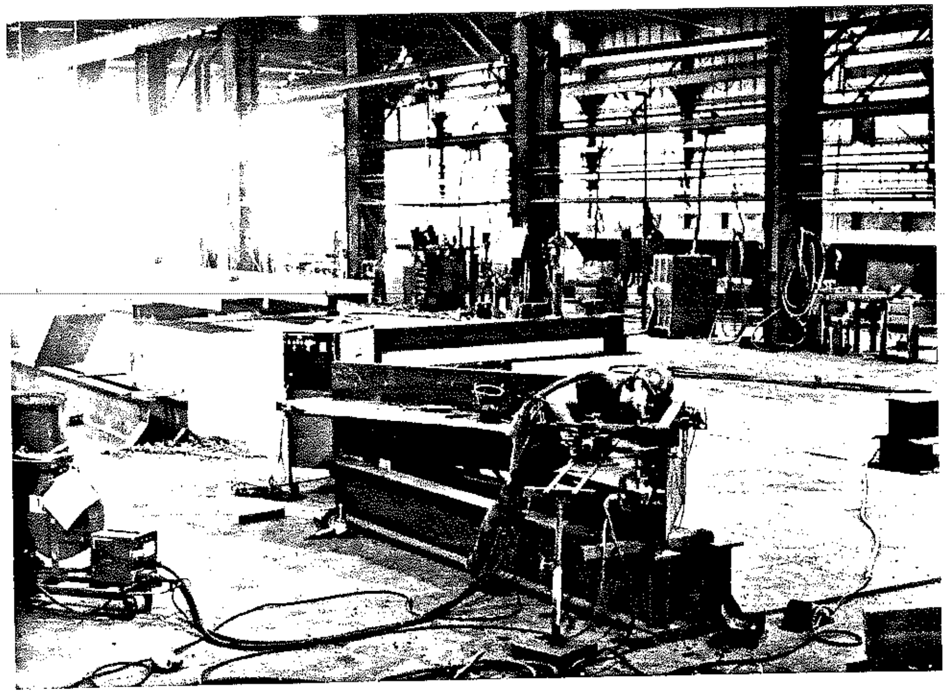

Figure 2. Automatic SAW for Straight Flange-to-Web Welds. Note the Acoustic Emission Weld Monitor to the Left of the Weldment.

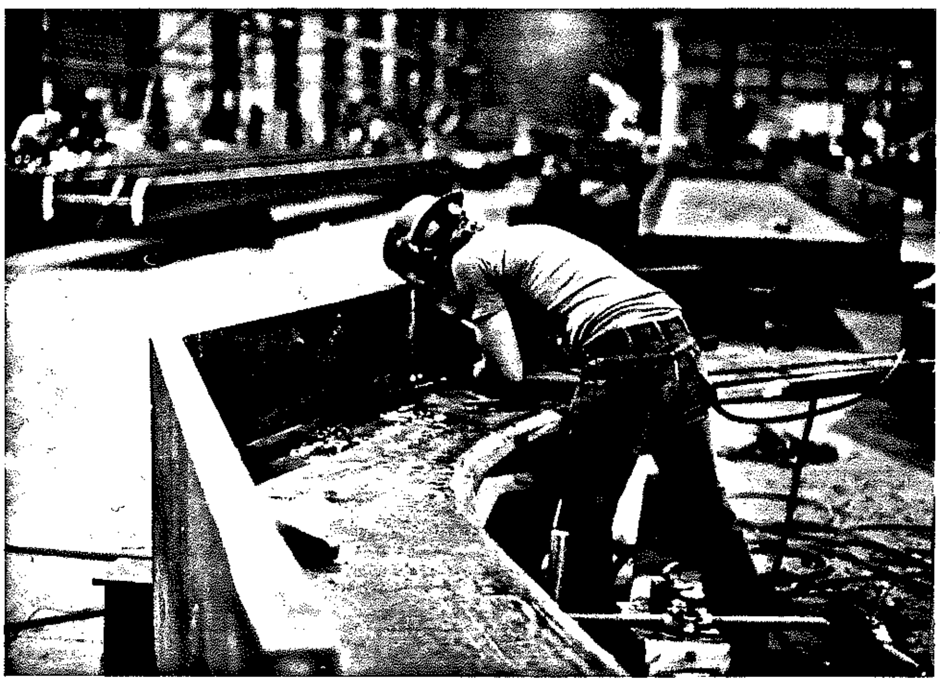

Figure 3. Manual SAW Being Deposited on the Flange-to-Web Corner Welds.

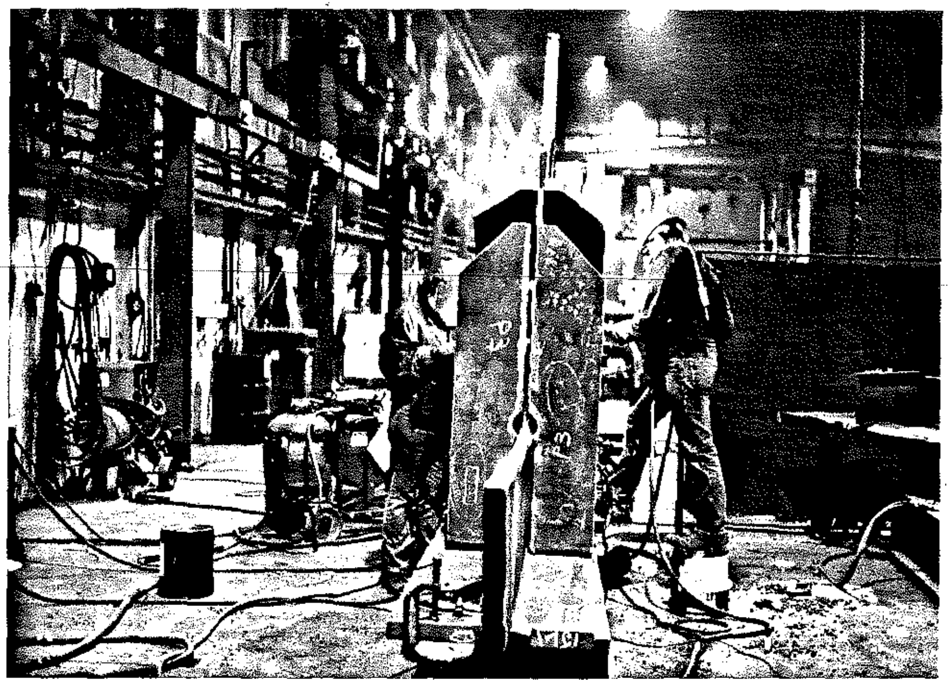

Figure 4. Depositing Full-Penetration Stiffener-to-Flange Welds Using Manual SAW (Welder on Right).

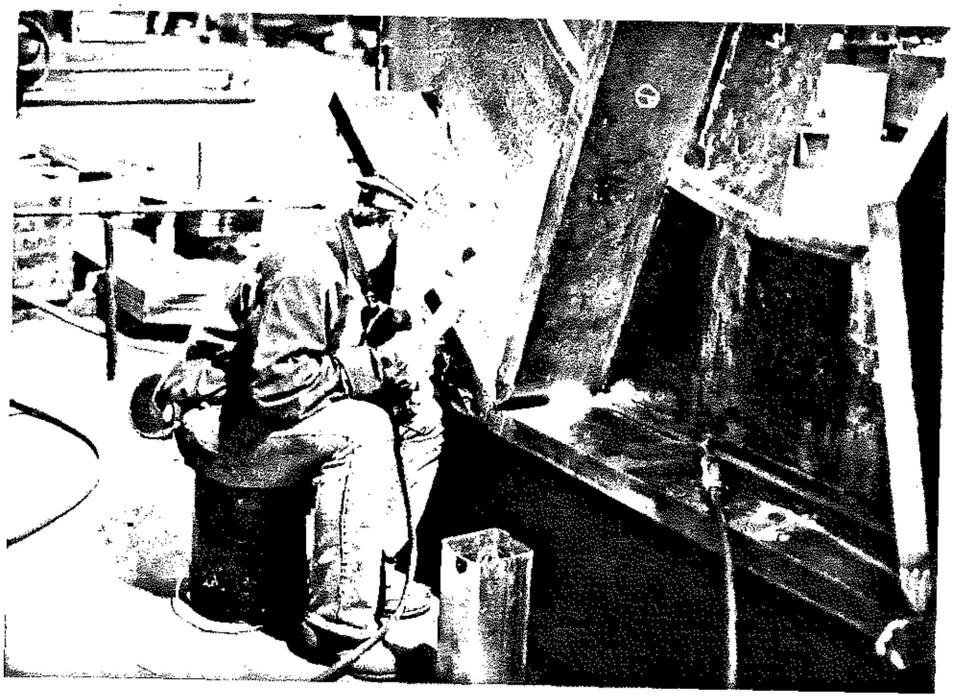

Figure 5. Depositing Full-Penetration Stiffener-to-Flange Welds Using Manual SMAW.

Figure 6. Fit-up Flange-to-Web Assembly Prior to Welding.

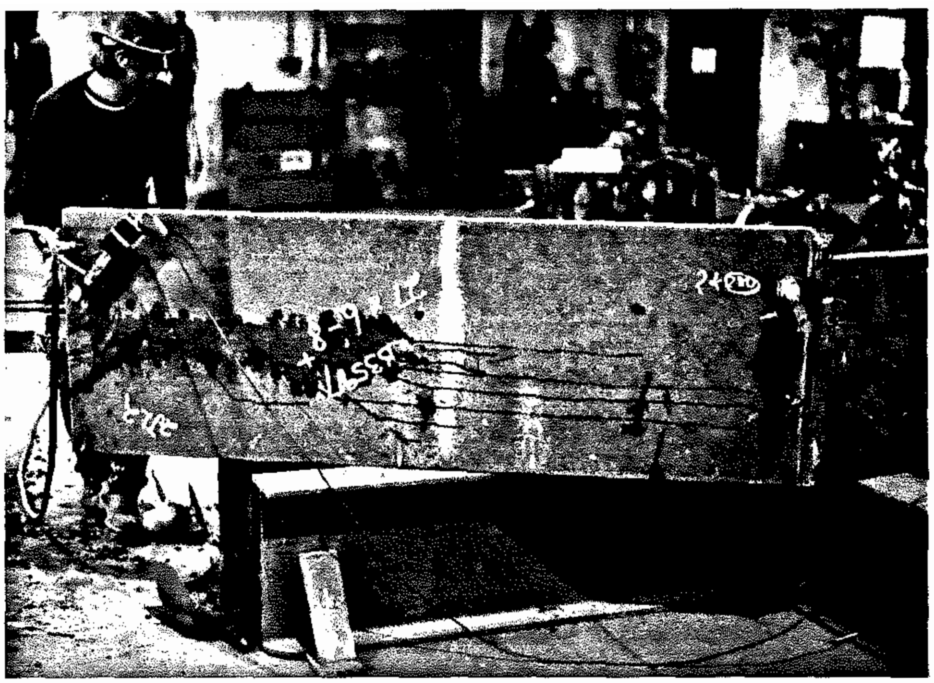

Figure 7. The Two Active AE Transducers Mounted on the Backside of the Flange.

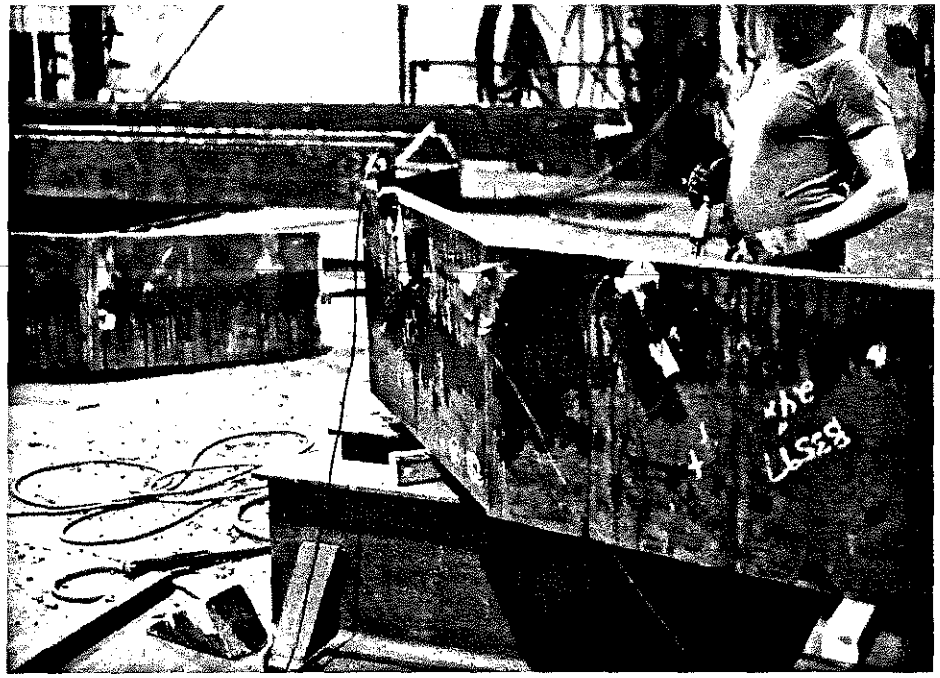

Figure 8. AE Transducers Mounted to Monitor a Corner Weld (Note the Centrally Located Pulser Used for Calibration).

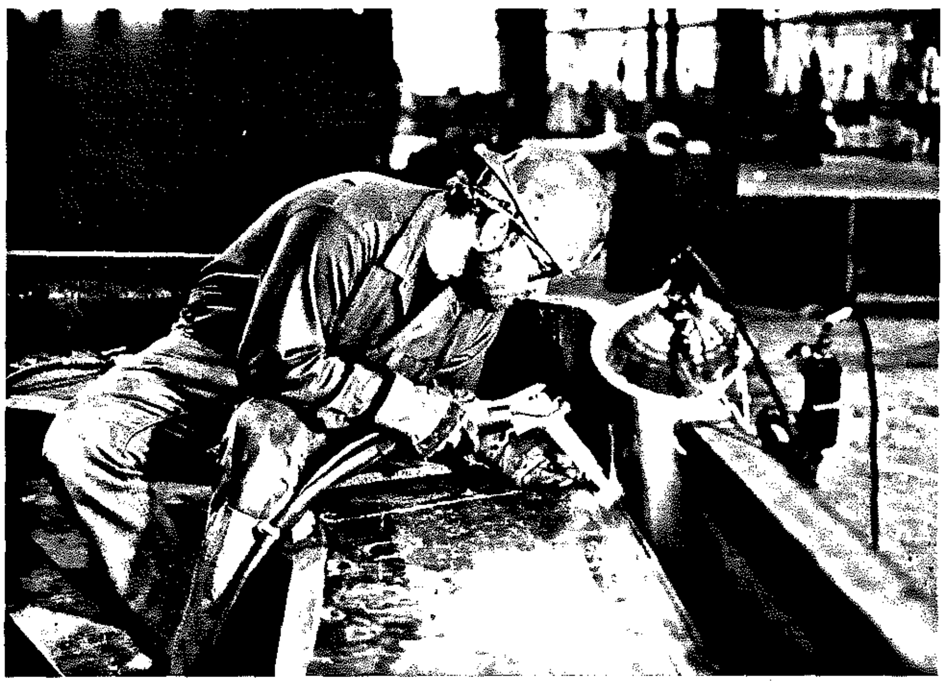

Figure 9. Manual SAW Used in a Short Weld Repair (Note Transducer Assembly on Backside of the Flange on the Right Corner of the Photograph).

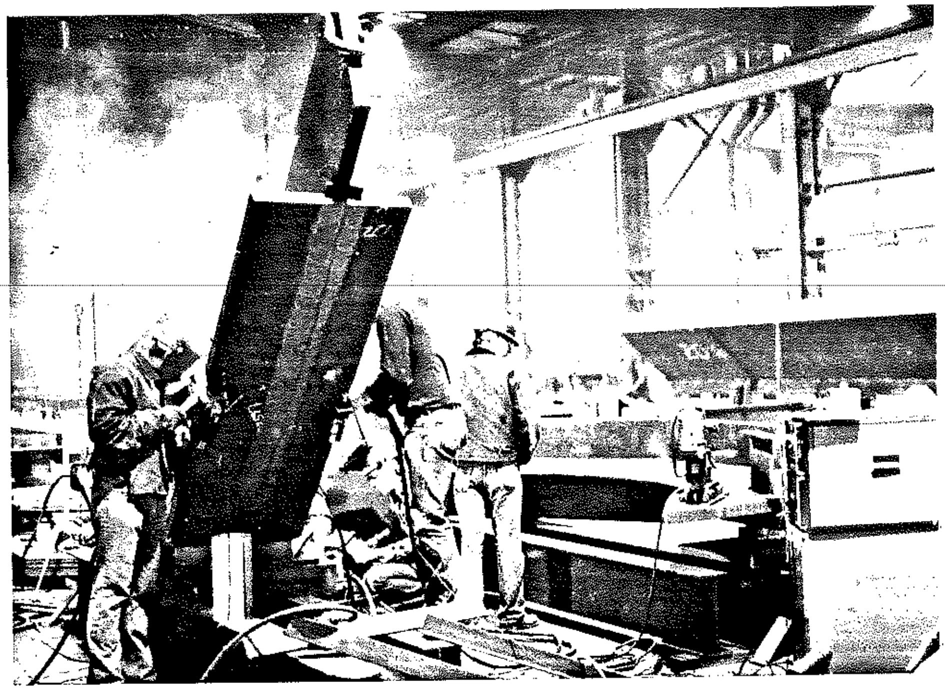

Figure 10. Concurrent Stiffener-to-Flange Welding with Transducers Located Opposite the Welds on the Backside of the Flange (Note the AEWM Located in the Right Corner of the Photograph).

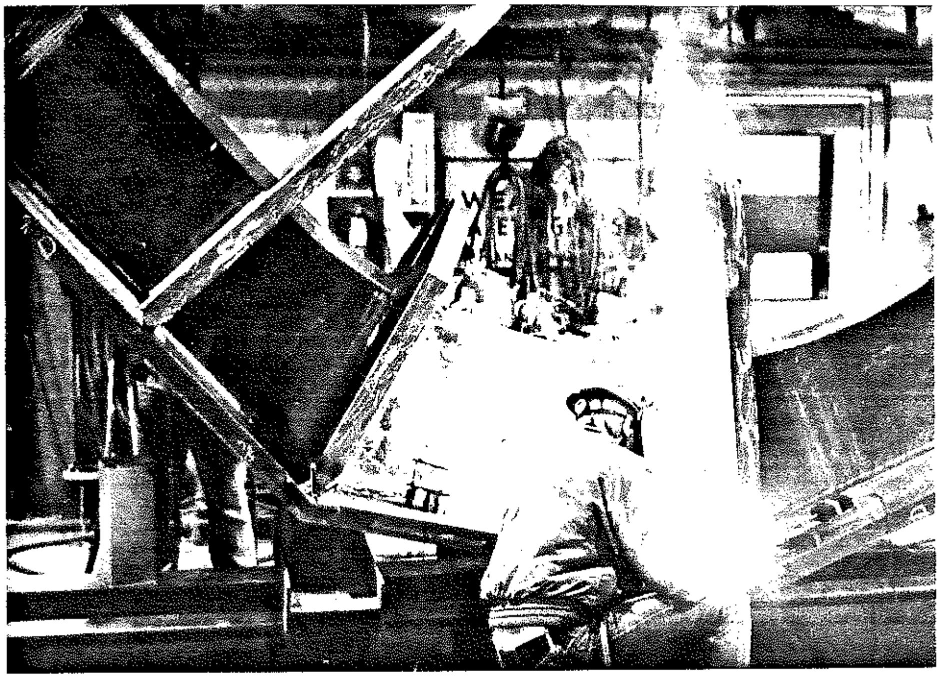

Figure 11. Lock-Out Transducer Mounted on Top of Flange. The Active Array is Monitoring the Welding of the Seated Operator.

APPENDIX

ACOUSTIC EMISSION STRUCTURAL MONITORING IN NOISY ENVIRONMENTS USING EVENT BASED PROCESSING

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ABSTRACT

An acoustic emission (AE) system which employs event-based signal processing has been successfully tested on structures (bridges) which typically have high-noise environments.

The AE system employs a three-step sequential test to discriminate between noise sources (pattern recognition). The AE system processes those signals "on-the-fly" and notifies the AE operator in real-time of AE flaw activity. The AE system also indicates the flaw's relative location between two active transducers (linear flaw location).

The AE system has been used on a variety of structural configurations on eight welded and riveted steel bridges. The structures were cyclically loaded by normal traffic. On structures containing visible cracks, the AE system was able to detect AE flaw activity eminating from the crack locations based on the three-step sequential test. During typical one-hour AE tests, the AE system was able to discriminate between one flaw-related AE event and up to 3,000 noise events.

Based on those tests, the AE system shows the ability to detect AE flaw activity in structures such as bridges which have high-noise environments.

ACOUSTIC EMISSION has shown much promise for inspecting large structures such as bridges. To date, the widespread use of this method has been precluded by the high amount of mechanical noise emitted by those structures when stressed. That noise mimics AE defect-source activity and cannot be discriminated by conventional AE techniques.

The Acoustic Emission Weld Monitor (AEWM) was originally developed by GARD to detect flaw activity generated during in-process slag-type welding operations (1,2). That type of welding process generates a large amount of AE noise due to: 1) slag cracking, 2) oxide cracking, and 3) welding-arc impact. The ability of the AEWM to successfully monitor slag-type welding operations and the similarty between background AE noise problems in those welding operations and the operational environment of bridges led to its application as a structural monitoring tool.

EQUIPMENT DESCRIPTION

The AEWM uses conventional analog electronics to acquire and pre-process AE activity. This includes the use of analog signal amplification and bandpass filtering from signals produced by standard resonant transducers. Also the conventional time-of-arrival (Δt) technique is employed for linear flaw location using two active transducers. The unique portion of the GARD AEWM is its microprocessor-based multiparametric filtering program, which analyzes the AE data, rejects noise-related activity, and locates and characterizes flaws in real-time.

Consecutive AE events are subjected to a three-step sequential test or AE pattern-recognition filtering program (Figure 1). First, the analog pre-processing circuitry computes the ringdown count (RDC) and time of arrival. Then, the microprocessor portion of the system tests the collected analog information for each event. As the first step in the filtering program, the ring-down count must lie within fixed limits. If this is satisfied, the second filtering step is imposed wherein the AE event must occur within a predetermined minimum event rate with other AE events preceding or following it (which have also passed the ring-down test). The third step determines whether all the events passing the first two filtering tests were located by time-of-arrival from within a tight locational tolerance. All AE event data that fail to pass any one of the tests are discarded. Additionally, the frequency content of each AE event is analyzed using a comb filter. Valid AE events having high-frequency biases are classified as cracks. Other data that satify the model are characterized by the AEWM as unclassified defects

The AEWM can continuously process large numbers of AE events occurring at rates too fast for an operator to analyze. The microprocessor circuitry also determines when valid flaw activity occurs. The operator is informed of flaw-related events by an indicating lamp on the AEWM and by a LED panel which displays the relative location of the flaw between the two active transducers. The unit is also capable of data storage by floppy discs and direct hardcopy output subsequent to a test.

FIELD TEST PROGRAM

GARD and Kentucky Transportation Research Program personnel first tested the AE System on the I-24 bridge over the Tennessee River near Paducah, Kentucky, in December 1982 (Figure 2) (3). The bridge possessed out-of-plane bending cracks in the deck beams. Of five sites monitored, only one produced AE flaw indications. At that test site, several 2-3 inch-long cracks were present in the web between the deck beam upper flange and a bolted angle splice plate which connected the deck beam to tie-chords.

A two-transducer array was aligned parallel and adjacent to the splice angle with a 64" spacing (Figure 3). The crack site was offset in the array, being located 16" from the upper transducer. A pulsing transducer was mounted adjacent to the crack and used to periodically check the function of the active transducers.

The monitoring was performed with 150kHz resonant transducers at a total system gain of 80 db. The transducers were coupled to the beam with a silicone grease.

The test site was monitored for several 2-1/2-hour periods while the deck beam was loaded by normal traffic. Valid AE flaw indications were detected from the crack locations during the tests. AE activity was proportional to the volume and weight of traffic on the bridge. The bolted splices produced high amounts of background noise occurring in a ratio of about 1,000-to-1 to valid AE flaw data. Typical noise rates for this structure were 800-1,000 AE events per hour. The AEWM System was able to reject this large quantity of noise.

Four follow-up AE monitoring tests on this bridge over a twenty-two month period showed a diminishing amount of valid AE activity. Also, the crack-growth rate was measured and found to be decreasing with time. The last test, conducted in August 1984, included a 48-hour continous monitoring of the crack site with no valid AE flaw activity detected. Out-of-plane bending cracks at those sites are typically auto-extinguishing. Crack growth measurements and the AE monitoring support that conclusion.

The second bridge monitored was the I-75 bridge over the Ohio River at Covington, Kentucky. Cracks were previously detected in the paint on the toes of fillet welds at cover-plate termini. The cover plates were situated on the lower flanges of the approach-span girders. The transducer array was placed on the lower flange, spanning the cover-plate termini. Guard transducers were employed to prevent fretting noises, created at the upper flange-to-concrete deck interface, from interferring with the monitoring process. Twelve sites were monitored and no valid AE flaw indications were received. High AE noise rates (up to 1,000 events per hour) were also encountered during those tests. Follow-up nondestructive testing by dye-penetrant and magnetic-particle testing revealed no defect indications at the AE test sites.

In November 1984, under contract to Wisconsin DOT, GARD monitored several deck beams on the I-94 overpass in South Milwaukee, Wisconsin. The deck beams were double-cantilever, box-type structures which extended outward from a central pier. Transverse cracks were present in tension areas of welds at the pier. The Wisconsin Department of Transportation wished to know if those cracks were subject to fatigue-crack growth. GARD monitored two sites which possessed cracks using a 64" active transducer spacing and a four-guard transducer array. Due to the high traffic volume on the bridge, up to 3,000 noise events were detected in a 20-minute monitoring period. However, no false AE indications were triggered. In one of the eight-hour monitoring sessions conducted at the two test sites, one valid AE flaw indication was detected from a location which contained a visible crack. This crack was the largest visible crack, approximately 1-1/4" long. This information was used by the Wisconsin Department of Transportation to plan repairs for the bridge.

Also, in November 1984, GARD and Kentucky Transportation Research Program personnel performed an inspection on the I-24 bridge over the Ohio River. The tests were performed to confirm expected growth of ultrasonically detected subsurface defects in the butt welds on a tie-girder which had been reinforced with splice plates (Figure 4). The AEWM detected AE flaw-related activity at one location coinciding with an ultrasonic flaw indication. The tie chords produced relatively low AE rates of 50-100 events per hour. Additionally, a six-inch long out-of-plane bending crack in a deck beam was monitored. The crack, which had jumped two check holes, was very active and produced AE flaw indications every 15 minutes. That was the most active flaw encountered in the AE inspection to date.

The fifth bridge evaluated by GARD, was the U.S. 18 bridge over the Mississippi River near Prairie du Chien, Wisconsin. Like the I-94 Milwaukee bridge, this was an evaluation of an existing flaw in a structure. Third party AWS code U. T. detected several code rejectable subsurface indications in electroslag welds in both the upper and lower flanges of fracture critical girders. GARD monitored two of the longer indications over a two day period and detected no valid AE indications at either site. Due to low traffic volumes, low AE rates were encountered (100-200 events per hour).

The I-471 bridge at Cincinnati, Ohio, a 720-ft. main-span tied-arch structure was the next bridge tested. Transition butt-welds similar to those on I-24 Ohio River bridge were monitored using a new technique. Instead of monitoring single flange or web welds individually, those contiguous weld lines around the periphery of the tie-chords were monitored using one active 42-inch transducer array (Figure 5). While that method is flaw-location inexact, it can be used to determine the existence of an active flaw somewhere on the weld line. Four weld lines were monitored over a three day period. No AE flaw indications were detected using the AEWM. As with the I-24 Ohio River bridge, low AE rates were encountered at the tie-chord welds (typically 50-100 events per hour).

The seventh bridge tested was the U.S. 25 bridge over the Rockcastle River, near Corbin, Kentucky. This was a riveted twin-girder bridge. The active transducer array was placed on a web along the lower flange of the girder. No defects were anticipated at the test site. A 44-inch transducer array spacing was employed. Truck traffic over the bridge produced multiple AE events per passage. However, the AEWM was able to reject those events as being noise-related.

The last structure tested to date was the I-64 bridge over the Ohio River at Louisville, Kentucky. Cracks were detected in stringers at coped locations in the flanges where they were affixed to deck beams. A transducer array of 30 inches was employed on a stringer which had the largest crack. That location was monitored for four hours and no AE flaws were detected by the AEWM. During that period 2,000 noise events were detected.

Those cracks had been visually monitored for several years with no sign of significant sub-critical crack growth. Either the crack was benign, crack-growth was too intermittent for the monitoring period, or the cyclic crack growth too small to presently be detected.

CONCLUSIONS

Field tests have shown that the AEWM is capable of detecting AE flaw activity from cracks in structures with high-noise backgrounds. AE noise to flaw activity ratios of 1,000 to 1 or greater have been typically encountered on bridges. The AE flaw activity was stimulated by normal service loadings. The tests indicate that the AEWM may provide economical survey-type inspections on large, complex structures such as airplanes, bridges, penstocks, off-shore oil platforms, pressure vessels, ships, submarines, and cranes. Presently, it is proving a useful tool for short-term evaluation of questionable flaw-indication sites, providing bridge engineers and inspectors with information for making more cost-effective repair decisions.

FIGURES

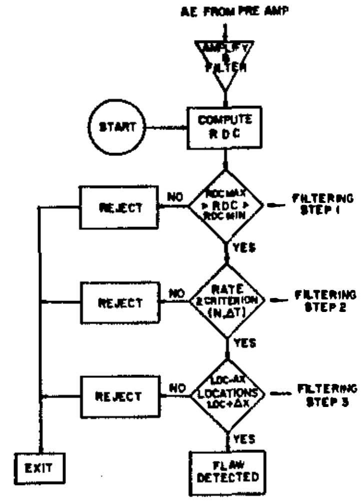

Figure 1. AEWM Processing Flow Chart for Flaw Detection.

Figure 2. AEWM in Rear of Station Wagon, I-24 Bridge over the Tennessee River.

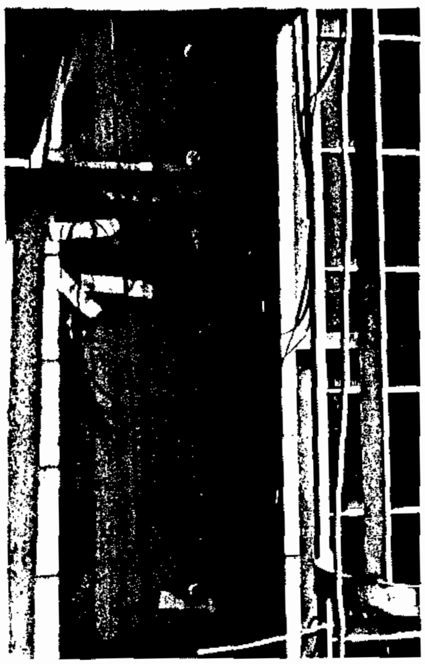

Figure 3. Linear Transducer Array on Floor Beam of I-24 Tennessee River Bridge.

Figure 4. Setting Up Transducer Array on a Tie-Chord Upper Flange on the I-24 Ohio River Bridge.

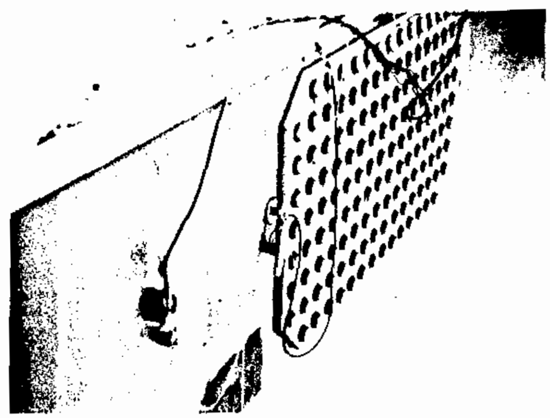

Figure 5. Transducer Array on the Tie-Chord Web of I-471 Ohio River Bridge.

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