# PROJECT NO. B371
# ACOUSTIC EMISSION AND STRAIN GAGE MONITORING OF WIDOT STRUCTURE B-5-158, TOWER DRIVE TIED ARCH - GREEN BAY, WISCONSIN

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**Technical Report #1**

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# Acoustic Emission and Strain Gage Monitoring of WIDOT Structure B-5-158, Tower Drive Tied Arch Green Bay Wisconsin

by

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## BACKGROUND

Wisconsin Department of Transportation Bridge B-5-158 is located in the city of Green Bay in Brown County, Wisconsin. The structure carries eastbound and westbound I-43 traffic over the Fox River at the southern end of Green Bay. Total length of the structure is 7982 feet including a 450-foot-long tied arch. The bridge was constructed in 1980.

In-depth inspection of the bridge by WIDOT personnel detected visual cracks inside the tie girders in the tied arch. The cracks were located in welds at the ends of 1-by 6-inch bars that join the bars to the hanger diaphragms. The bars, which serve as horizontal stiffeners, are welded to the inside of the tie girder at the point of attachment of the floor beams. The welds that join the 1-by 6-inch bars to the tie girder web and the hanger diaphragm were fabricated using shielded-metal-arc welding (SMAW) and have rough unfinished reinforcements, which makes ultrasonic inspection very difficult to perform. The welds were supposed to have been full penetration and both visual as well as ultrasonic inspection indicate that this is not true. WIDOT expressed an interest in gaining a better understanding of the nature of the visible cracks as well as additional information on the condition of the stiffener-to-web welds. Following discussions between BIRL and WIDOT, this project was initiated. The test program utilized a combination of acoustic emission and strain gage monitoring to provide the needed information on live load and crack activity. The tests were performed by BIRL with assistance from The Kentucky Transportation Center (KTC).

## EXECUTIVE SUMMARY

The in-depth inspection by WIDOT detected two sites that had visible cracks in the stiffener-to-hanger diaphragm welds, the east side of Hanger 6 in the north tie girder, and the east side of Hanger 4 in the south tie girder. Additionally, many ultrasonic indications were detected by WIDOT in the web-to-stiffener welds. On May 3, 1993, BIRL commenced testing. Test sites included Hangers 4 and 6 on both the north and south tie girders. A total of six sites were monitored (the west side of Hanger 4 on the north girder, the east side of Hanger 6 on the south girder, and the east and west sides of Hanger 6 on the north and Hanger 4 on the south girder). These sites included all of the known cracks, sites that were adjacent to known cracks but with no known cracks, and sites that had no known cracks present either in or adjacent to the test site. The acoustic emission setup monitored both the stiffener-to-diaphragm and stiffener-to-web welds at each test site. Two strain gages were monitored at each of the test sites. Testing continued through May 13, 1993. Traffic loading during the tests included many large obviously heavy loads. A wide range of environmental conditions were encountered, including high gusty winds and temperatures ranging from 37 degrees F to 80 degrees F. Test results showed no detectable crack-related activity from any of the six test sites and very small live loads (30 to 50 $\mu$in./in. strain) from the strain gage tests. These test results imply that some mechanism other than fatigue is responsible for the visible cracks.

## TEST PROCEDURE

The acoustic emission (AE) monitoring was done using a system developed by David Prine of BIRL. The AE monitor has six input channels and is a computer-based system that uses a Motorola MC68000 as the CPU. This device is a hardened, field-portable unit that can be used in two operating modes. The system can operate as a stand-alone monitor in which crack indication information is displayed on a front panel LED display, or the system can be attached to a portable PC via an RS232 port and AE data can be stored on the PC's disk drive for post-test analysis. Both modes were used for these tests. The key feature of this AE monitoring system is the powerful pattern-recognition system that is applied in real time to the AE signals.

This pattern-recognition algorithm was originally developed for in-process weld monitoring. It is based on empirical results that key on signal characteristics which allow crack-related information to be separated from a noisy background. The algorithm tests the rate of occurrence of the AE bursts, and, when a group of bursts is received that exceeds the pre-programmed rate limit (typically 3 Hz), the algorithm evaluates the locational spread of the group of signals. If the high-rate group all came from a tightly clustered location (typically less than 1-inch spread), the algorithm counts this group as one indication. The technique is based on experimental results that have consistently shown that crack-related AE activity has high burst rates and that the crack-related activity emanates from a small localized area. The algorithm has been successfully applied to in-process weld monitoring on virtually every type of weld process and material that is commonly encountered in heavy fabrication. Since 1982, the same approach has been successfully applied to the in-service monitoring of steel highway bridges.

This approach is the only known way that AE can be successfully applied to details that are adjacent to or part of bolted splices. The fundamental problem with AE monitoring these details is the noise produced by the bolts. The bolt fretting imitates AE very well, and, if the area to be monitored is not locationally isolatable from the bolts, the noise rejection algorithm must be used to eliminate the irrelevant bolt noise. Figure 1 shows an overall view of a typical location inside the tie girder that was monitored during these tests. The end of the stiffener is adjacent to bolts in the hanger diaphragm, and the bolts

from the floor beam attachment run parallel to the stiffener. Clearly, there would be no way to locationally isolate these bolts from the areas being monitored.

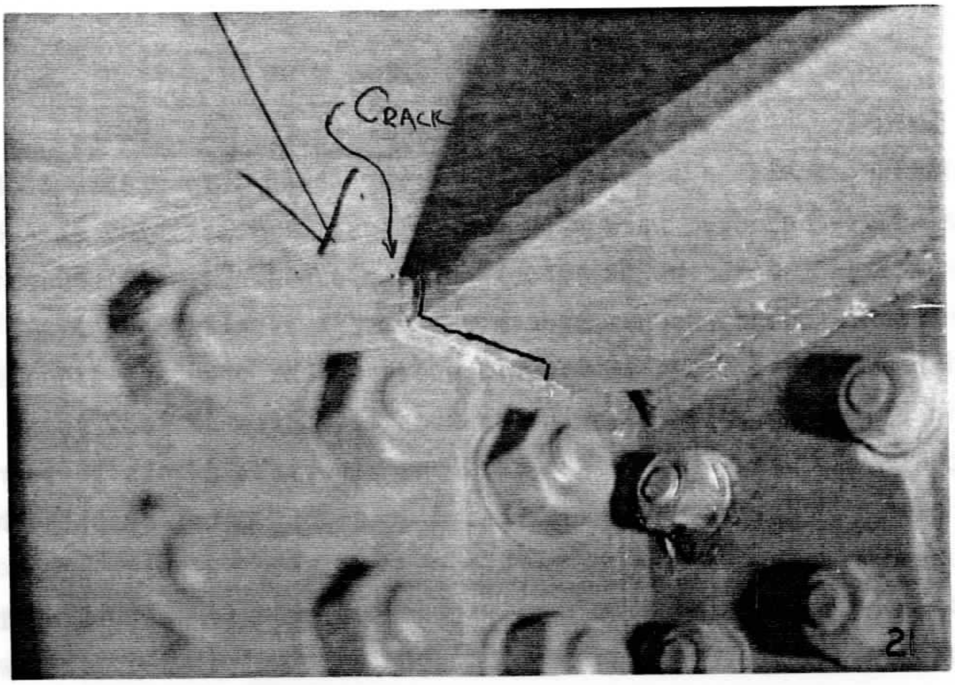

FIGURE 1. Typical test site inside tie girder

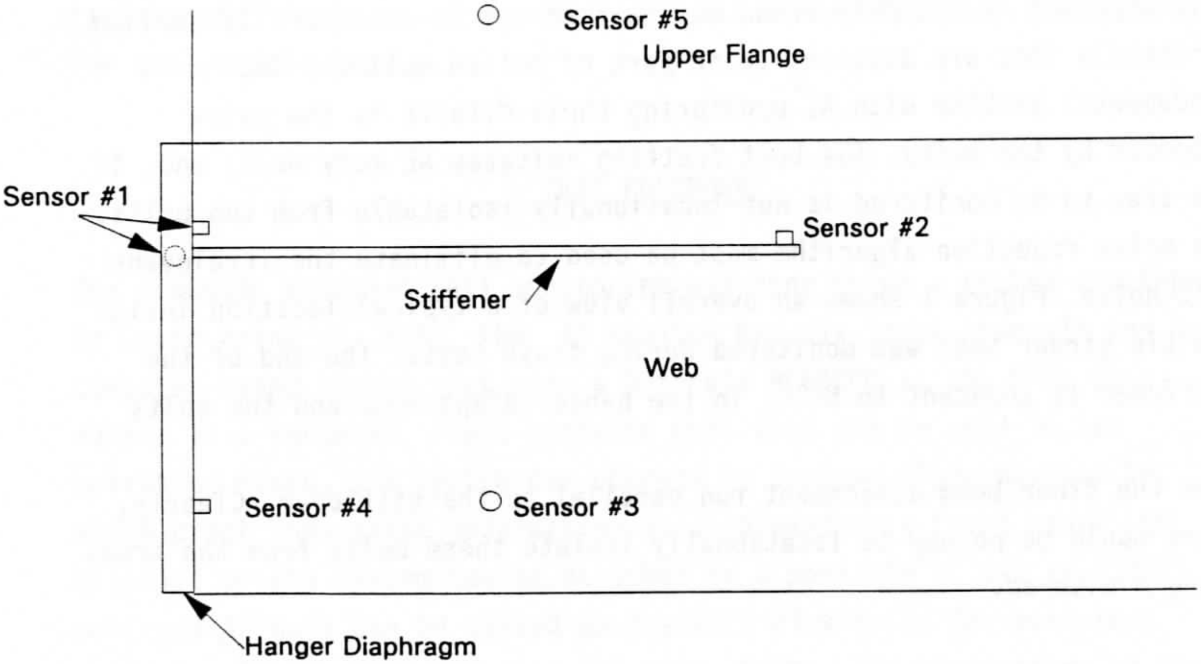

FIGURE 2. AE sensor layout

The AE sensors used for these tests were resonant devices with a pass band from 100 Khz to 300 KHz. A total of five sensors were used in an array as shown in Figure 2. Sensors 1 and 2 were the active monitoring sensors and were located so as to listen along a line that included the entire length of the stiffener. Sensor 1 was mounted in either of two positions depending on local conditions at the monitoring site. The first setup had Sensor 1 mounted on the outside surface of the tie girder on line with the stiffener in the gap between the splice plates that attached the floor beam to the tie girder. A second variation with Sensor 1 mounted on the hanger diaphragm approximately 1 inch above the stiffener top surface had to be used when the gap on the outside surface was too small to allow insertion of the sensor and its magnetic hold-down clamp. Calibration tests with a pulsed AE simulator showed that both setups worked in a satisfactory manner.

The remaining three sensors were used as guard sensors. These sensors were necessary to eliminate AE signals that originate from sources outside our linear location array. Proper source location is a critical element of the noise-rejection algorithm. Location is accurate to less than 1 inch along a line drawn between the Number 1 and 2 sensors. Any sources located outside of this linear array will be improperly located and cause errors in the noise-rejection process. The flaw model evaluates the order of receipt of the AE signal at the various array members. If the burst arrives at any of the guard sensors first, it is rejected. The array layout used for this set of tests was designed to eliminate bolt signals and other noise sources that originate far enough outside the listening array to cause locational errors.

The sensors were acoustically coupled to the bridge using silicone grease. Magnetic clamps held the sensors in place. Line-driving pre-amplifiers are used between the sensors and the cable that connects them to the AE monitor. The system calibration and sensitivity was verified by using a pulsed transducer to simulate an AE source. The pulser/transducer delivers a uniform calibrated acoustic pulse to the bridge. It is placed at each end point of the active array (Sensors 1 and 2), and at the mid and quarter points. Multilevel LED indicators on the front panel of the monitor indicate signal level at each of the sensors. The pulse repetition rate of the pulser can be adjusted to exceed the rate minimum for flaw indication, and its location can be observed on the AE monitor display. This procedure was followed at each of the test sites to verify system integrity and locational accuracy. AE was monitored at each of the test sites for periods of at least 1 hour at system gains of 78 to 79 db. Experience has shown that this sensitivity is sufficient to reliably detect crack-related activity on highway bridges.

Strain gages were attached to the web and diaphragm on both sides of Hangers 4 and 6 on both the north and south tie girders. On the north girder, the strain gages were located approximately 1 inch above the stiffener. The web-mounted gages were located as close as possible to the diaphragm (approximately 3-1/2 inches) and the diaphragm-mounted gages were centered over the stiffener. On the south girder, a slightly different mounting position was used for the diaphragm-mounted gages. These gages were mounted approximately 1 inch from the edge of the stiffener and even with its centerline. Position of the gages varied slightly due to surface condition of the steel and our ability to adequately prepare the steel substrate about the welds. Typical strain gage layouts are shown in Figures 3 and 4 respectively.

Measurements Group Model CEA-06-W250A-350 welded foil strain gages were employed in all of the tests. The strain gages were attached to a SoMat Series 2000 field computer. The Somat 2000 is a two-channel device having signal conditioners and data processing modules that allowed the unit to operate in conjunction with a PC. In addition to allowing real time observation of the strain gage data, the Somat can record the data in any of several modes, storing the data in its internal memory. The recorded data can be uploaded to a PC for post-test analysis. The strain gages were attached to the field computer using 3-wire 26-gage twisted and shielded wire in a quarter-bridge configuration.

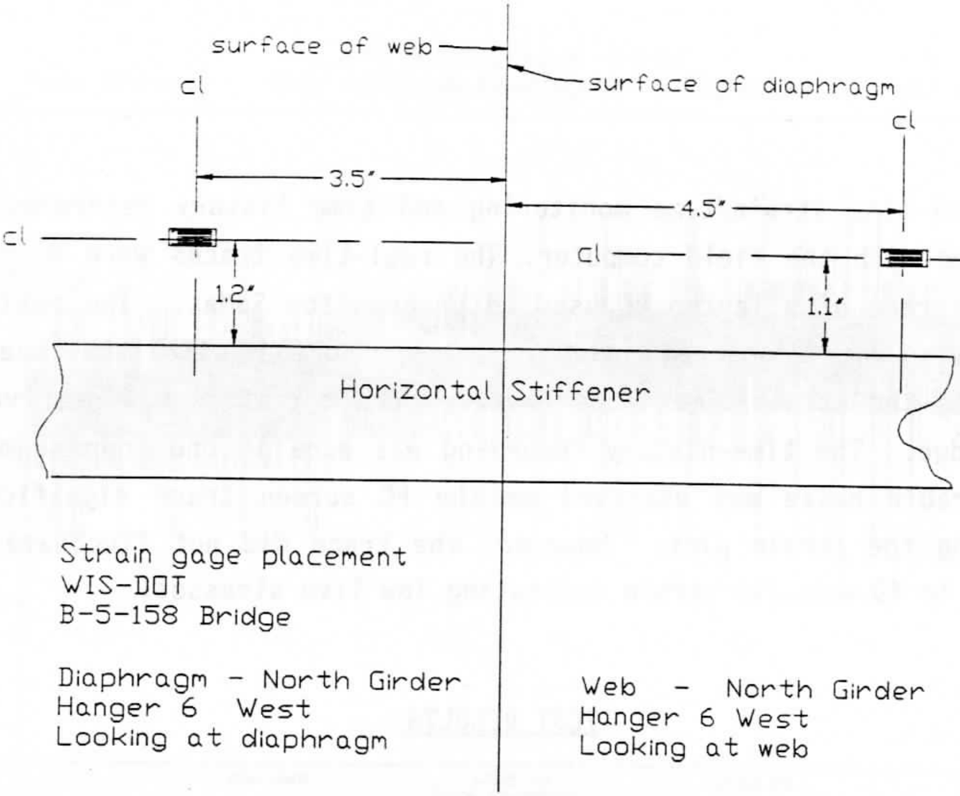

**FIGURE 3. Typical strain gage layout for north tie girder**

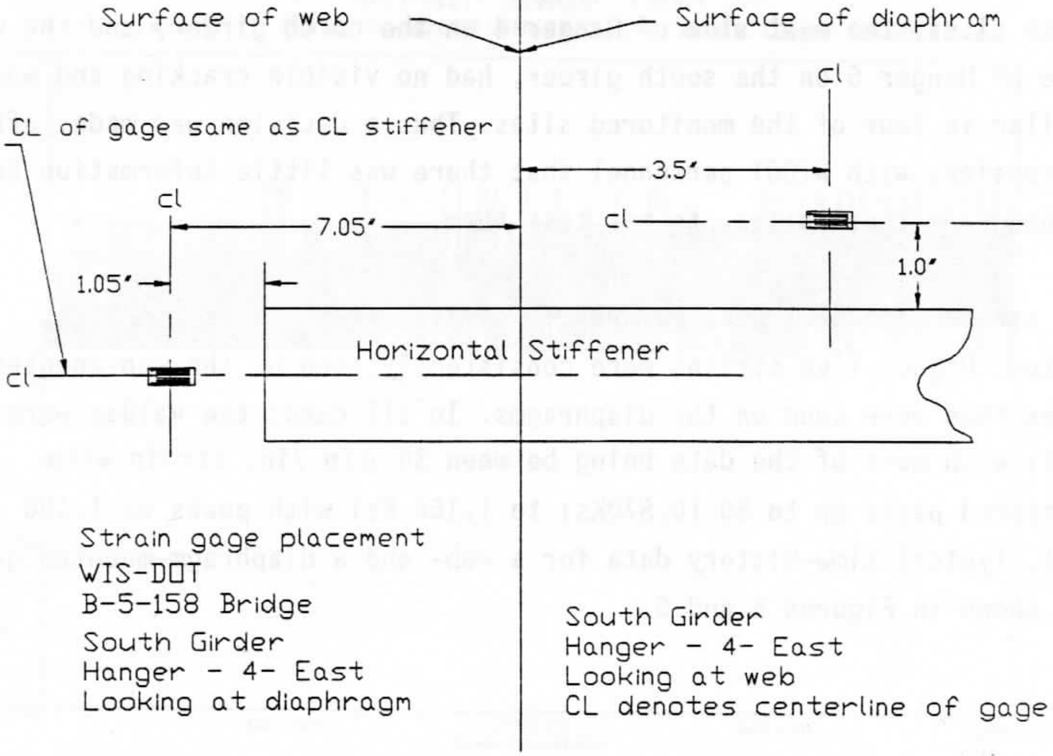

**FIGURE 4. Typical strain gage layout for south tie girder**

Both real-time strain/time monitoring and time history recording were performed with the field computer. The real-time traces were displayed on the screen of a laptop PC used to program the SoMat. The real-time monitoring was conducted over a 2-hour period with the operator observing the strain/time trace whenever truck traffic was observed on the bridge. The time-history recording was done in one hour segments. Considerable noise was observed on the PC screen trace significantly obscuring the strain plot. However, the trace did not fluctuate more than 30 to 40 $\mu$in./in strain indicating low live stresses.

## TEST RESULTS

The strain gage and acoustic emission data were obtained using procedures described in Section 3.0. Two of the sites originally planned to be tested were dropped from consideration due to time limitations. These sites, the east side of Hanger 4 on the north girder, and the west side of Hanger 6 on the south girder, had no visible cracking and were similar to four of the monitored sites. Thus a decision was made, after discussions with WIDOT personnel that there was little information to be gained from these sites, to not test them.

The strain gage data were remarkably similar from all of the sites tested. Higher live strains were consistently seen on the web-mounted gages than were seen on the diaphragms. In all cases the values were small with most of the data being between 30 $\mu$in./in. strain with scattered peaks up to 50 (0.870Ksi to 1.160 Ksi with peaks to 1.450 Ksi). Typical time-history data for a web- and a diaphragm-mounted gage are shown in Figures 5 and 6.

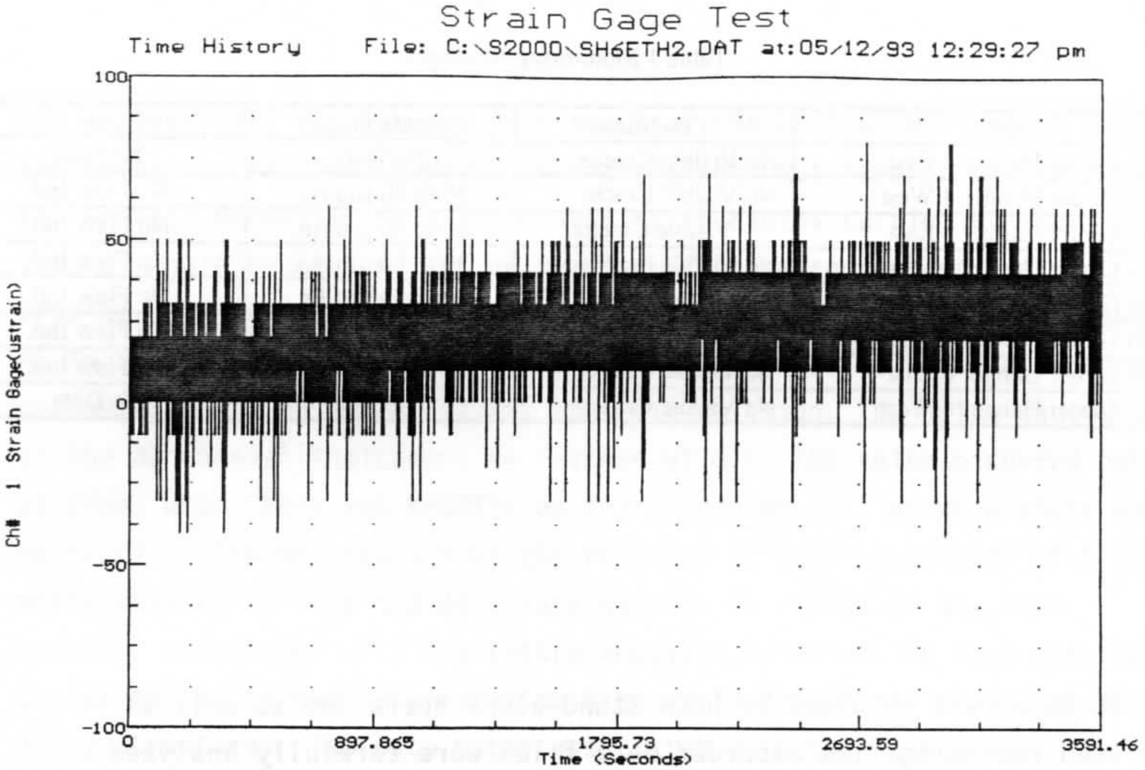

**FIGURE 5. Time-history strain gage data for a web-mounted gage**

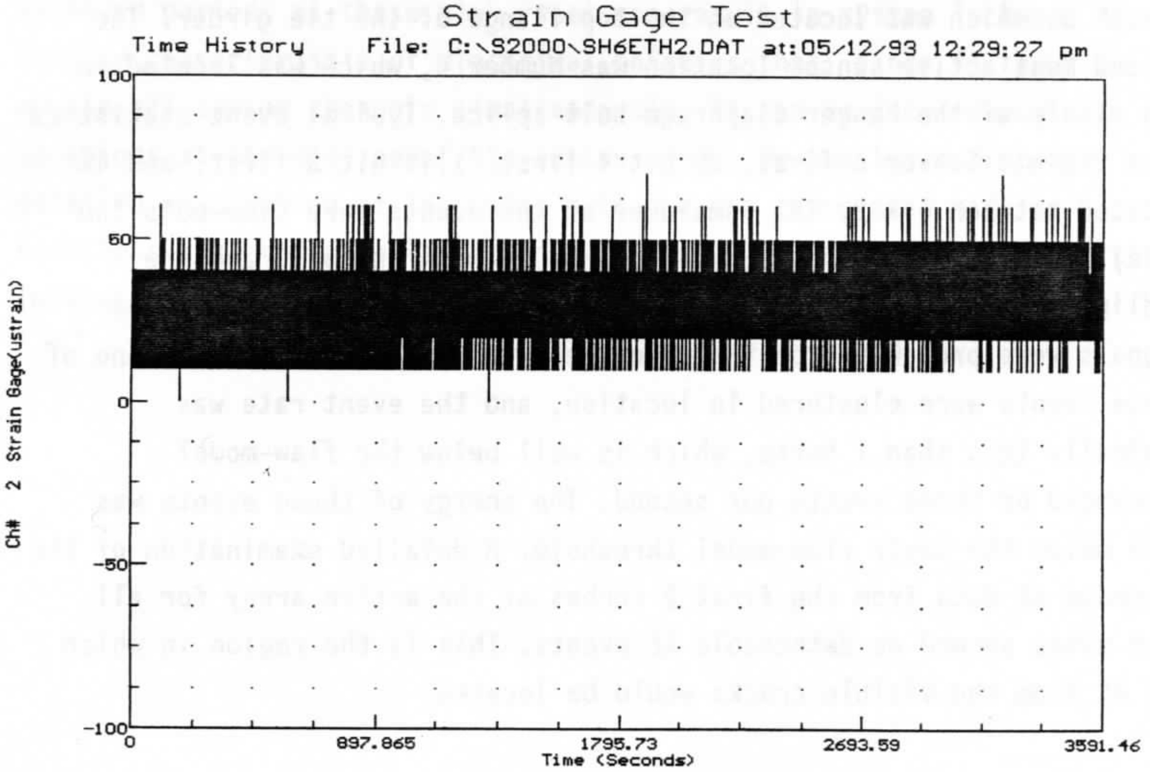

**Figure 6. Time-history strain gage data for a diaphragm-mounted gage**

Table 1 Monitoring Summary

| Site | Condition | Strain Gage | AE |
|---|---|---|---|
| North Girder Hanger 4 East | No Visible Cracks | No Data | No Data |
| North Girder Hanger 4 West | No Visible Cracks | 30 to 50 µin./in. | No Flaw Ind. |
| North Girder Hanger 6 East | Visible Cracks | 30 to 50 µin./in. | No Flaw Ind. |
| North Girder Hanger 6 West | No Visible Cracks | 30 to 50 µin./in. | No Flaw Ind. |
| South Girder Hanger 4 East | Visible Cracks | 30 to 50 µin./in. | No Flaw Ind. |
| South Girder Hanger 4 West | No Visible Cracks | 30 to 50 µin./in. | No Flaw Ind. |
| South Girder Hanger 6 East | No Visible Cracks | 30 to 50 µin./in. | No Flaw Ind. |
| South Girder Hanger 6 West | No Visible Cracks | No Data | No Data |

The AE data were obtained by both stand-alone operation as well as PC-assisted recording. The recorded data files were carefully analyzed post-test to determine the nature of the received AE signals. This analysis showed that most of the acoustic emission was received first by Sensor 5, which was located on the top flange of the tie girder. The second most active sensor location was Number 4, which was located in the middle of the hanger diaphragm bolt splice. Typical event statistics were 26% hit Sensor 5 first, 8% hit 4 first, 1.4% hit 3 first, and 4% located between 1 & 2. The remainder of the events were time-outs (no data). The located events were scattered between Sensor 1 and the midline of the active array and were of generally low energy. These signals were probably from the floor beam to web bolted splice. None of these events were clustered in location, and the event rate was typically less than 1 hertz, which is well below the flaw-model threshold of three events per second. The energy of these events was well below the lower flaw-model threshold. A detailed examination of the recorded AE data from the first 2 inches of the active array for all test sites showed no detectable AE events. This is the region in which any AE from the visible cracks would be located.

In general, the AE system operated reliably except for the occasional problems experienced with electrical noise. The source of the noise is unknown; however, the bridge ran parallel to high-tension electrical power lines. A power plant was located just to the north of the bridge, and a paper mill was located just south of the bridge. We suspect that the noise was related to power line transients but have no way to prove it. Another potential noise candidate is CB radios carried by the trucks. Again we have no way of knowing if these sources caused the problem. What we were able to determine is that the occasional midline AE indications that were experienced during periods of high noise were definitely not due to legitimate acoustic emission. The noise caused all of the AE channel indicators to flicker wildly. The noise occurred both at times when there was traffic on the bridge as well as when there was no traffic. The key feature of the recorded AE data associated with the noise problem is that the data rate was far in excess of any rate normally associated with legitimate acoustic emission. We have observed occasional sustained data rates as high as 10 events per second on very noisy structures. The data rates associated with the suspected electrical noise were consistently 50 events per second or higher. Event rates beyond 50 cannot be processed properly by the monitor, and extended periods at these high rates can result in system lockups. A further characteristic of electrical noise is that, since it tends to excite all sensor channels simultaneously, it can produce source locations at the midline of the active array. We concluded from a detailed examination of the noise data and the associated midline locations that the signals were not acoustic in origin and therefor the indications were not valid.

## SUMMARY AND CONCLUSIONS

The combination of acoustic emission and strain gage monitoring on the four areas tested on Structure B-5-158 has shown two things to be true. First, the sites monitored showed very low live loads of typically less than 1.5 Ksi. Secondly, no crack-related acoustic emission indications were detected either from the areas that had visible cracks or from the stiffener-to-web welds. These results show that the visible cracks are probably not due to fatigue but more likely are examples of early weld failure resulting from a combination of poor weld quality, high residual stress, and/or loading beyond the weld's load-carrying capacity.

Stress concentrations and local residual stress fields can combine to produce short-term crack growth. The crack will arrest outside the local stress field. The same process also can allow movement of the component to better accommodate the stress concentration. Welds can have very low fracture-toughness values that will allow a crack to start growing, but the crack will arrest in the higher-fracture-toughness base metal.