Acoustic Emission Tests Fremont Bridge Portland, Oregon

During the week of March 24th, 1997 research engineers from the Infrastructure Technology Institute of Northwestern University conducted acoustic emission (AE) tests on the Fremont tied arch bridge in Portland Oregon. The purpose of the tests was to provide Wiss, Janney, Elstner and Associates (WJE) with additional information concerning the nature of the cracks found in various details on the end floor beams. WJE was conducting an in-depth inspection of the bridge under contract to Oregon DoT. The two types of details that were tested were the trapezoidal box attachments and the vertical bearing stiffeners on the webs of end floor beams 2E and 2W. The specific test sites were chosen by WJE. On beam 2W we tested both vertical bearing stiffeners and three trapezoidal box attachments. On beam 2E we tested four trapezoidal box attachments and one vertical bearing stiffener. Figure 1 below shows the test sites schematically.

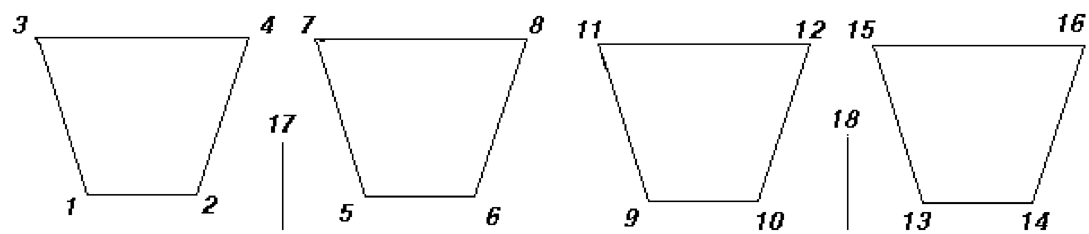

Figure 1 Schematic layout of test sites. Pier 2W view is looking east while 2E view is looking west.

Table 1 below shows the sites that were tested.

Table 1 AE Test Sites on Fremont Bridge

Pier	Test Sites
2W	2,5,14,17,18
2E	1,5,10,13,17

Summary

A total of 10 sites were evaluated which included 3 vertical bearing stiffeners and 7 trapezoidal box attachments. Of these 10, two produced significant crack activity, bearing stiffener 17 on pier 2E and trapezoidal box attachment site 10 also on pier 2E. The other sites all produced some crack activity (even one where no crack is thought to exist). The amount of AE activity observed at the other sites is small by comparison to the two 2E sites.

All of the AE sites tested on this bridge were very quiet compared to the results observed on a bridge that has confirmed growing fatigue cracks, the I-80 bridge near Sacramento, CA (Bryte Bend). On Bryte bend the crack hit rates ranged between 2 and 5 per second while on the Fremont bridge they ranged from .3 to 4 per min., a considerable reduction in activity. In the following sections we describe the tests in detail.

Bearing Stiffener Tests

A total of three bearing stiffeners were tested. These were sites 17 and 18 on pier 2W and site 17 on pier 2E. The same AE test setup and signal processing approach were used for all three tests. Figure 2 below shows the AE test setup for site 17 on Pier 2E.

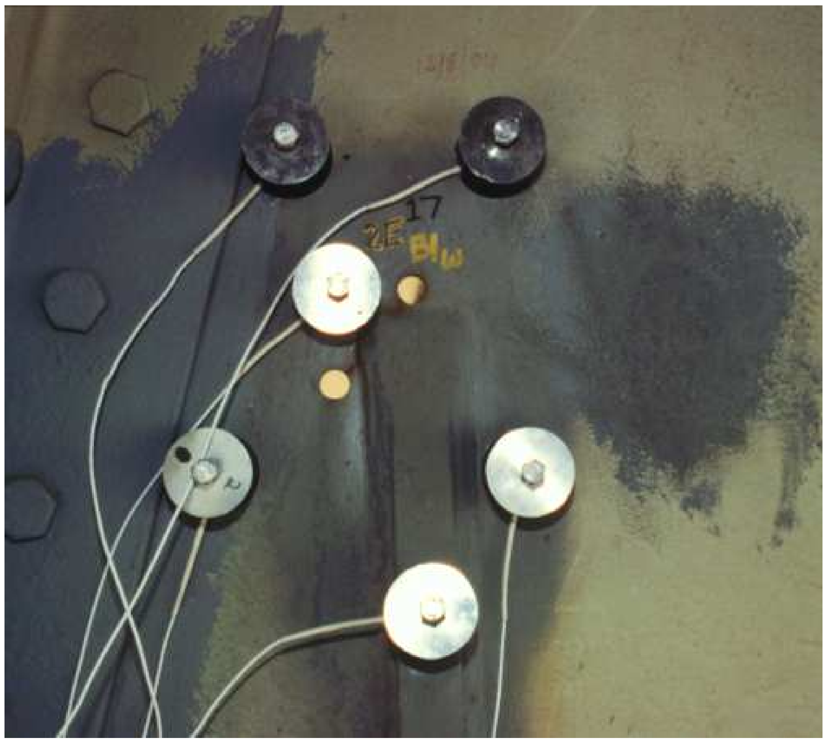

Figure 2 AE setup on test site 17 pier 2E

Six AE sensors are used in an array with one sensor mounted on the crack and the others arraigned in a planer location array with a guard sensor on the most likely source of out of array noise. The sensors were coupled to the floor beam web with silicone vacuum grease and held down by permanent magnet clamping devices. The sensors are connected to preamplifiers that drive a 160-foot cable that carries the amplified and filtered signals to the monitoring system on the bridge deck. The monitoring system is a digital AE monitoring and analysis system (model AMS3) manufactured by Vallen Systems GmbH, Icking, Germany. This system records the AE data on the hard drive of an associated PC and graphically analyzes the data, displaying the results on the PC's monitor. Two analysis techniques were used for these tests. They consisted of first hit channel (FHC) analysis and planar source location with both spatial and temporal clustering. FHC is a simple technique that determines the order of arrival of an AE event at the various members of an array of sensors.

Typically, one of the sensors is placed at or near the suspect crack and the remaining sensors are arrayed about it to intercept any signals arriving from sources other than the crack. In the analysis, any events that hit channel 1 (the crack sensor) first must be crack related. This technique is very sensitive and allows the amount of crack activity to be quantitatively evaluated. There are two important limitations to the effective application of this simple approach. The first is that no other noise sources must lie coincident or in the immediate vicinity of the crack. On a steel bridge these noise sources typically are the fasteners. Secondly, it is important to establish the minimum useful AE threshold for the portion of the structure under test. Bridges under live traffic loading conditions are acoustically noisy. Even at the high frequencies used for AE monitoring considerable noise is present at any given location on the structure. If we examine this noise at lower and lower amplitude thresholds we see an ever increasing rate of occurrence. Eventually the noise becomes continuous if we use a sufficiently low threshold. The processing threshold must be kept above this minimum value because the FHC analysis fails when

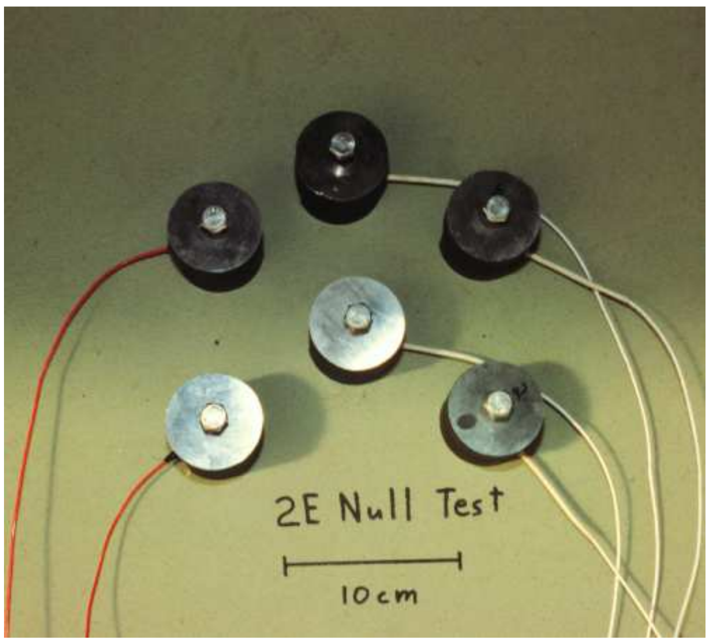

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Figure 3 Null Test Setup

signals become continuous. We determine this threshold value by performing a simple test on the structural detail being tested. The test array is placed on a region where no cracks
or fasteners are present and a sufficient data set is recorded. The threshold is then adjusted during playback until FHC activity is undetectable at sensor number one. A photograph of this test setup is shown in Figure 3. The number one sensor is located in the center of the array. This test was performed on both piers and the minimum useable threshold was determined to be 41dB. Prior laboratory tests have shown that this value is low enough to insure the detection of slow fatigue crack growth in the mild steels typically used for bridge construction.

In addition to the FHC analysis, planar source location with clustering was also applied to these test sites. The four sensors arranged around the crack sensor were used to form a planar location set. The AE monitor evaluates the order of receipt of the signals from an event and measures the time difference of arrival at each pair of sensors in the array to compute the source location for that event. The source locations are then further evaluated with a clustering algorithm that requires some preset number of events to fall within a preset location window. Each cluster is automatically identified in the location plot with a rectangle surrounding the event locations. The AMS3 can apply both spatial clustering as well as temporal clustering. Temporal clustering adds an additional requirement to the cluster, a time window. Clustering is a particularly useful technique for crack detection. Actively growing cracks tend to produce large numbers of AE events from tightly clustered locations (the cracks faces and tip) and these events tend to occur at higher event rates than the noises associated with stick-slip of the fasteners.

There were major differences in the pier 2W and pier 2E stiffeners. The cracks on the bearing stiffeners on 2W had been cored with a large core drill approximately 2 inches in diameter while the crack on site 17, pier 2E had relatively small holes drilled at the ends of the crack as seen in Figure 2. Test site 17 on pier 2W is shown in Figure 4

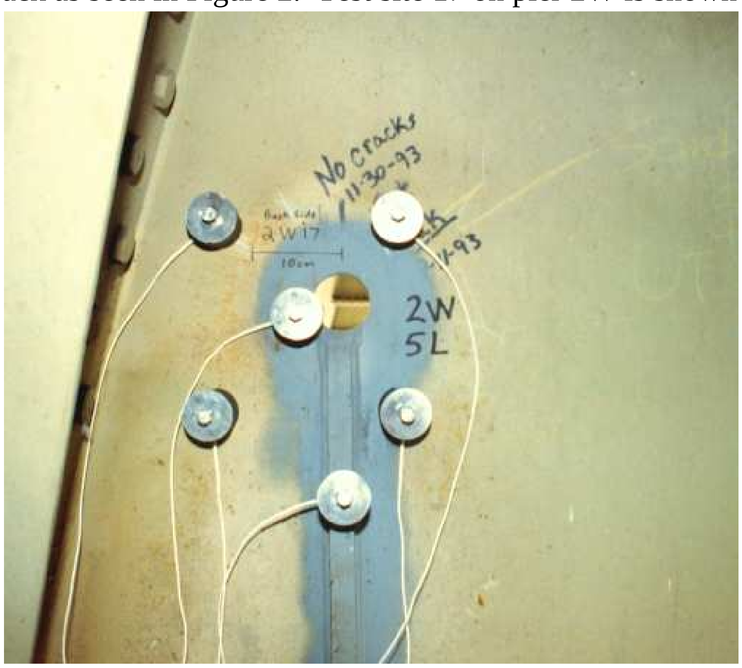

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Figure 4 AE test site 17 on pier 2W

comparison. There was little if any of the original cracks left on the pier 2W sites while on test site 17, pier 2E most of the original crack was still present and WJE had apparently detected an additional crack branching off of the original. Table 2 summarizes the FHC analysis for these three test sites.

Table 2 - Summary of FHC Analysis for Bearing Stiffeners

Pier	Site	Total Crack AE	% Total Crack	Crack Hit Rate	Total AE
2E	17	187	15.6%	3.72/min.	1196
2W	17	11	3%	.31/min.	341
2W	18	45	9%	1.39/min.	476

The FHC analysis shows that the crack in site 2E 17 was clearly more active than the two large diameter cored sites on pier 2W. The source location / clustering analysis shows the differences more clearly. Figure 5 below shows the location plot for site 2E 17. This plot

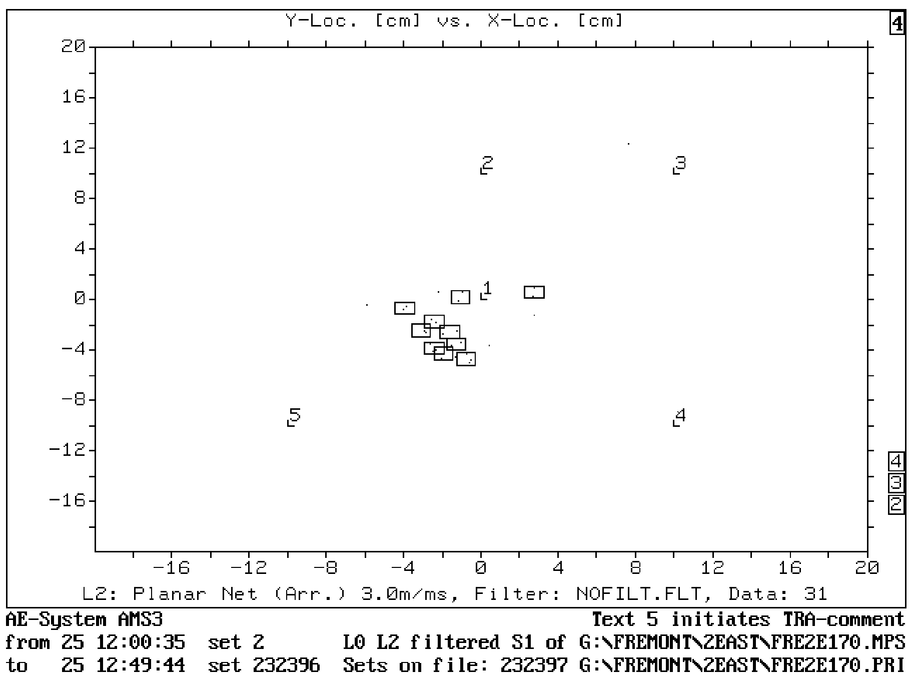


Figure 5 Source Location Plot for Site 2E 17

uses a cluster size of 1 square centimeter and a minimum number of elements of 2. No time clustering was used. The small angle marks with a number above and to the right are the sensor locations. If we add time clustering with a time window of two seconds we get the plot shown in Figure 6. In this plot one cluster is produced at a location 1.71 cm to the left of sensor 1 and 4.11 cm below. This location is coincident with the suspected branched crack. The pier 2W sites are shown in Figures 7 and 8 and have very few located sources and no clusters. These results are consistent with modifications made to the three sites by coring and end drilling. Little if any crack was left at the 2W sites while most of the crack with a possible addition is still present at 2E 17. In this case, time clustering was not necessary because no extraneous noise sources are located in the immediate crack vicinity. The time clustering does show the location of the most intense AE activity and minimizes the clutter of the additional clusters. The detected crack activity is a combination of both crack growth and crack face rubbing AE sources. At this time there is no reliable technique for separation of these mechanisms.

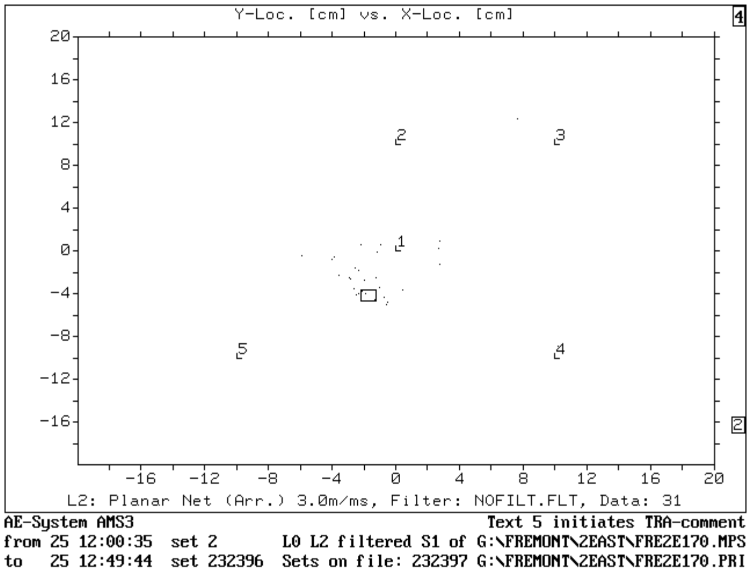


Figure 6 Source Location Plot for Site 2E 17 with Time Clustering

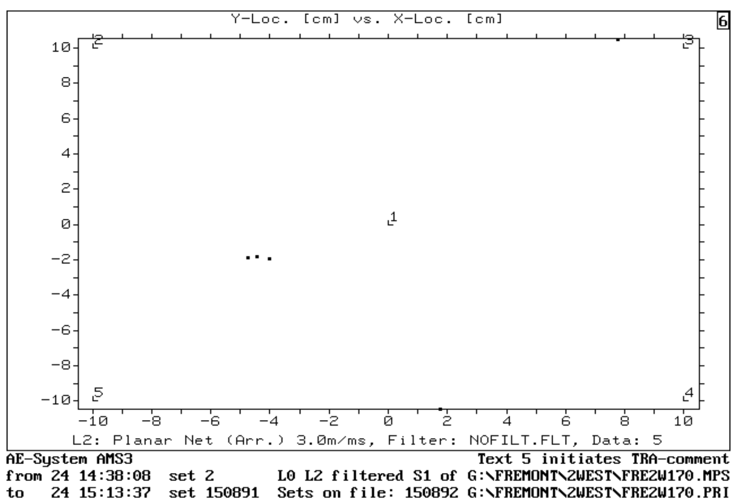


Figure 7 Source Location Plot for Site 2W 17

In Figures 7 and 8 the dots indicating AE source locations have been changed to small squares to improve visibility.

Trapezoidal Box Attachments

A total of seven test sites were monitored on the trapezoidal box attachments, three on pier 2W and 4 on pier 2E. These details are more complex to monitor than the bearing stiffeners. Following an examination of the sites we decided that the best AE procedure for these details was a FHC type setup. This procedure was followed on the first three sites tested which were located on pier 2 W. Unfortunately, when we moved to pier 2 E we discovered that undocumented modifications had been implemented consisting of bolted angle splices of various lengths that either partly or

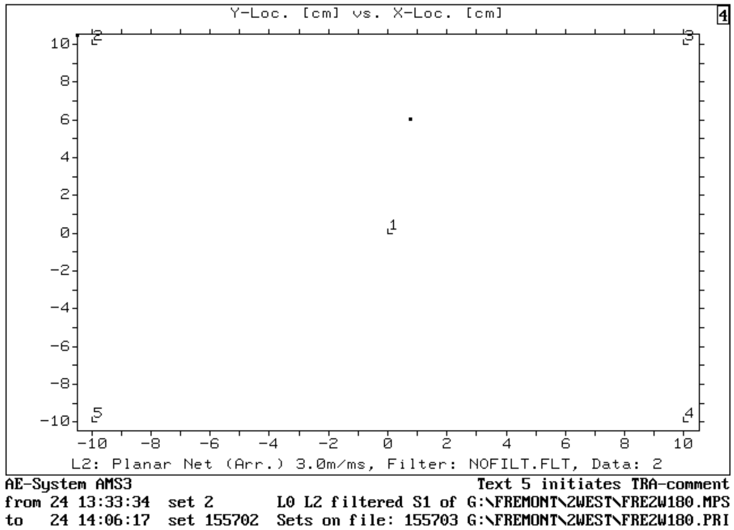


Figure 8 Source Location Plot for Site 2W 18

completely obscured the crack area at the bottom of the box to web weld. The angle splice modifications also placed bolts very close to the potential crack positions. The discovery of these modifications during our second day of testing forced us to modify our procedure for the pier 2E test sites from the FHC setup to linear source location with clustering. Figures 9 and 10 show the two AE setups employed on the 2W and 2 E Trapezoidal attachments.

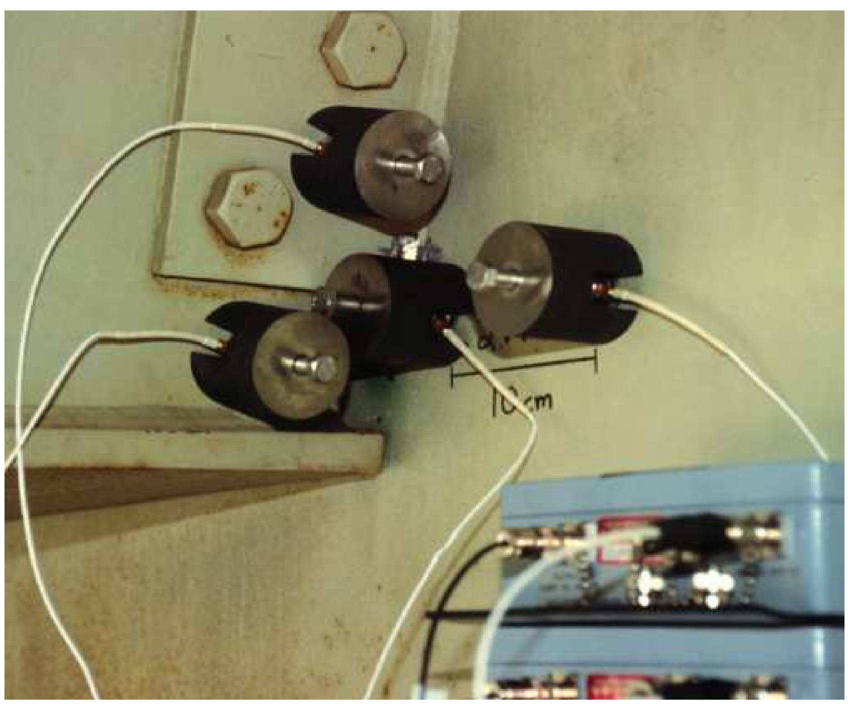


Figure 9 AE Setup on Pier 2W for Trapezoidal Attachments

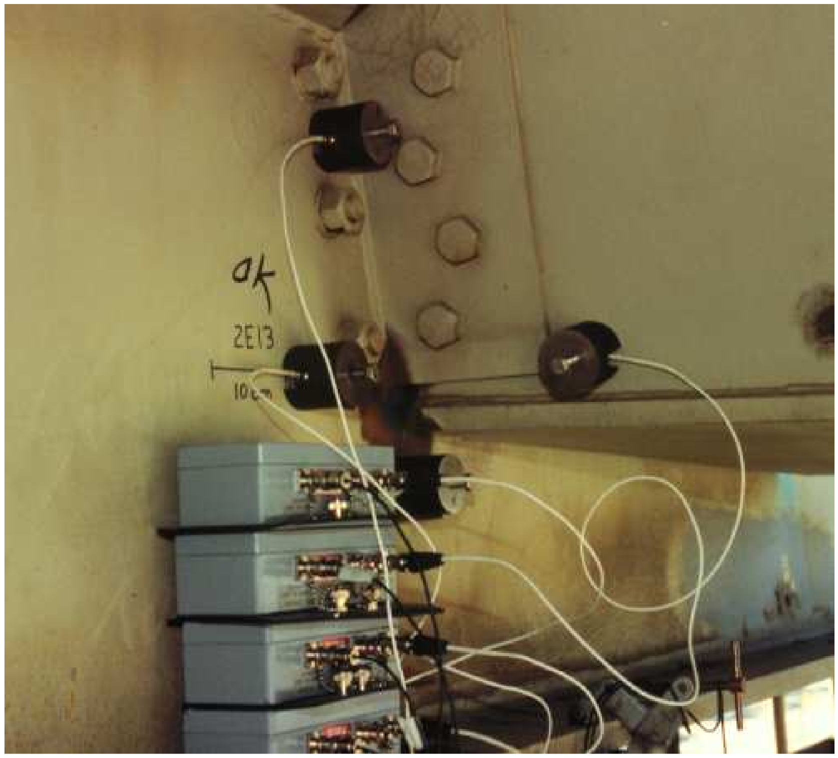


Figure 10 AE Setup on Pier 2E for Trapezoidal Attachments

Two additional sensors were mounted on the back side of the floor beam web to act as guards for both the 2W and 2E setups. The modification of the setups that was required for pier 2E precludes the direct comparison of the AE results for the 2E and 2W trapezoidal attachments. The linear source location setup has no sensor located at the crack because of the inaccessibility of the crack. Therefore we cannot determine the amount of AE activity associated with the crack. The clustering algorithm allows us to reliably detect crack activity in the presence of noise but does not allow any quantitative evaluation of the crack activity. Table 3 below summarizes the AE activity for the trapezoidal attachments.

Table 3 Summary of Activity for Trapezoidal Attachments

Pier	**Site**	**Total Crack AE**	**% Total Crack**	**Crack Hit Rate**	**Cluster(s)**	**Total AE**
2E	01	NA	NA	NA	no	182
2E	05	NA	NA	NA	no	1285
2E	10	NA	NA	NA	yes	2699
2E	13	NA	NA	NA	no	319
2W	02	26	12.5%	.78/min.	NA	207
2W	05	20	2.9%	.59/min.	NA	675
2W	14	52	14.6%	1.57/min.	NA	354

Of the four covered or partially covered sites tested on pier 2E only one produced a cluster. The indication centers at 6.93 inches. The potential crack site would run from 6.50 to 7.50 inches so this cluster is coincident with a potential crack site. None of the other three produced clusters. The source location plots for the 2E sites are shown in Figures 11 through 14. Source location and clustering was not used on the 2W sites. Two of these sites had visible cracks (2W-05 and 2W-14) while 2W-02 had a paint crack but no other indications. 2W-14 had slightly higher total crack related activity and crack hit rate however its statistics are comparable to the 2W bearing stiffeners which had virtually no cracks left after coring and showed no clustering. All of the 2W trapezoidal test sites show AE statistics that are comparable to the 2W bearing stiffeners and considerably lower than the 2E site that produced clustering. Therefore we conclude from

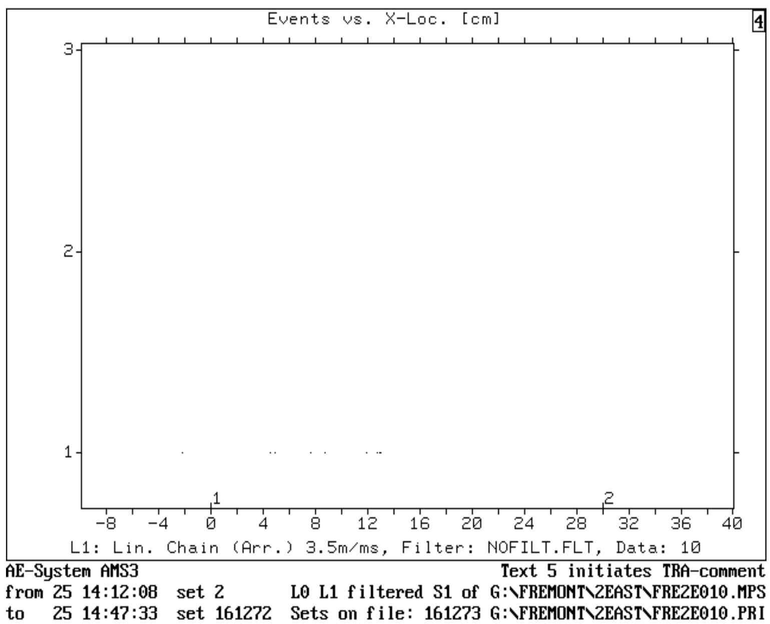


Figure 11 Source Location Data for Test Site 1, Pier 2E

this data that while some crack activity is detected at all of the sites, it is so low that it is probably insignificant with the exception of site 10 on pier 2E.

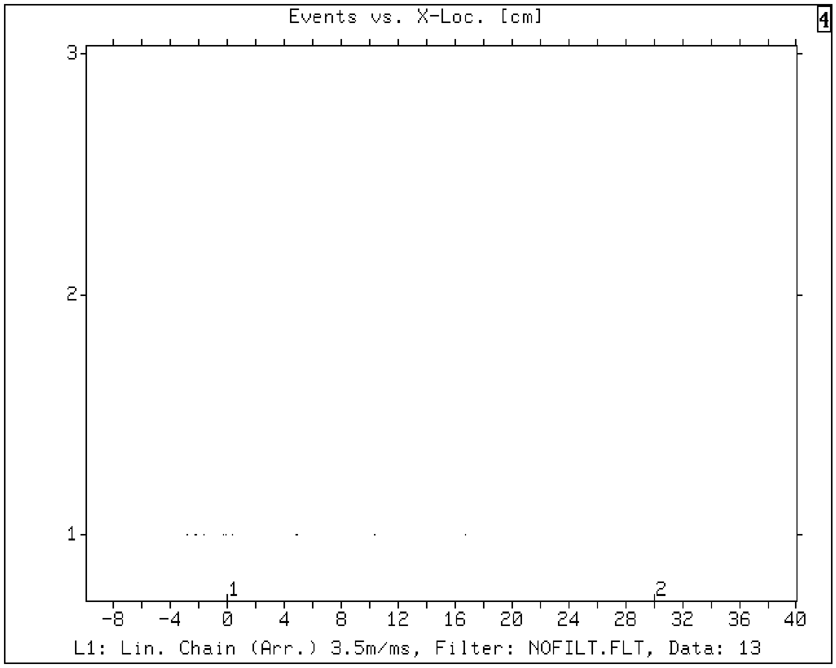
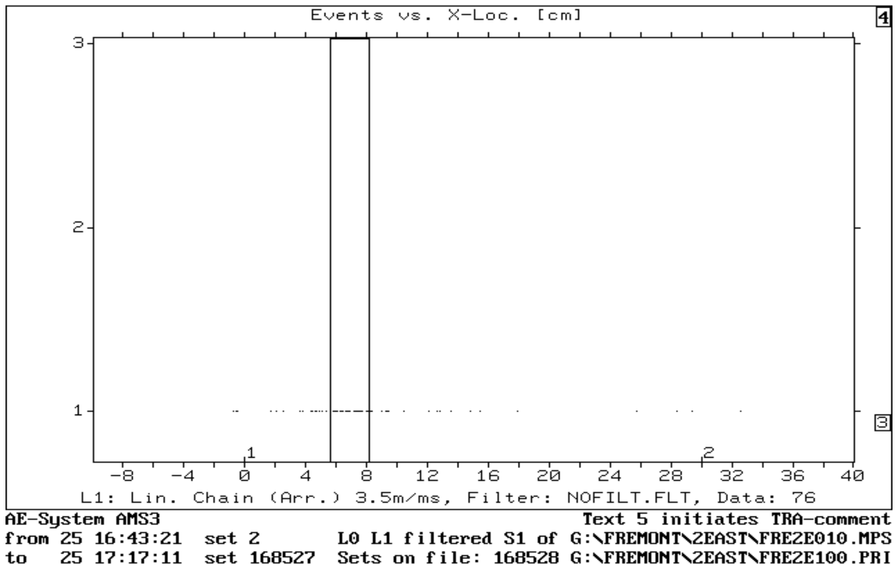


Figure 12 Source Location Data for Test Site 5, Pier 2E



. Figure 13 Source Location Data for Test Site 10, Pier 2E

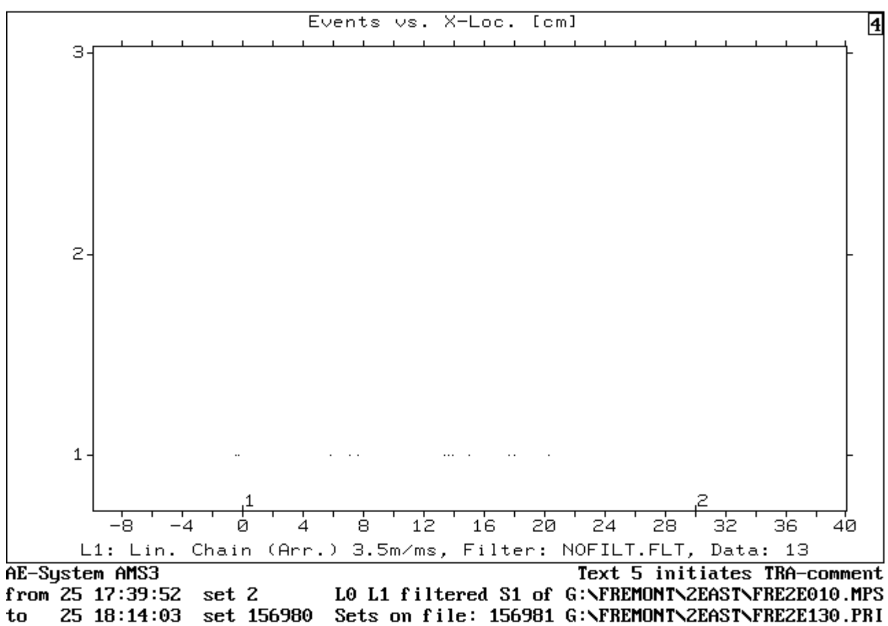


Figure 14 Source Location Data for Test Site 13, Pier 2E