ACOUSTIC EMISSION MONITORING OF THE TRUNNION SHAFTS ON OREGON DOT BRIDGE #1377A

I-5 (Interstate) Columbia River Bridge East Lift Span Portland, Oregon

By David W. Prine

Technical Report #6

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on

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Portland, Oregon

by

David W. Prine

Northwestern University
BIRL Industrial Research Laboratory
1801 Maple Avenue
Evanston, IL 60201

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Purpose

This report describes the results of applying acoustic emission (AE) testing to the trunnion shafts of the East Span of the I-5 Interstate Bridge. The tests were done at the request of Oregon DOT personnel to determine if active fatigue cracks are present in the subject shafts.

Background

The Interstate Bridge carries I-5 traffic over the Columbia River between Portland Oregon and Vancouver Washington. The bridge consists of two separate bridges each carrying three lanes of traffic. The east bridge was built in 1917 with rehabilitation work done in 1960. This bridge carries the northbound traffic. The west bridge was built in 1958 and carries the southbound traffic. Each bridge has a span drive vertical lift span to permit large vessels to pass through. The lift span trusses are 272 feet long between the live load supports. Vertical clearance at low water is 39.86 feet and the maximum vertical lift is 139 feet. Oregon DOT records indicate that the bridge openings average 400 to 500 per year and the average daily vehicular traffic volume is 87,000.

According to information furnished by Oregon DOT, the trunnion shafts on the east bridge were modified during the 1960 rehabilitation to allow application of tapered roller bearings in place of the plain sleeve bearings that were originally installed. The drawings indicate that prior to the taper machining operation on the shafts to accommodate the roller bearings, the longitudinal grease grooves were to be filled with weld metal. Laboratory testing performed on the shafts in 1987 under the supervision of Sverdrup Corp. determined that the forged steel had carbon content ranging from 0.50% to 0.87%. Carbon levels this high have a severe adverse effect on the weldability of the material. Charpy V-notch tests on samples taken from the bore area indicated low impact properties with a ductile to brittle transition temperature of 70° F or higher. Field Ultrasonic tests (UT) performed during the 1987 Sverdrup study and again in 1993 by Oregon DOT indicated the presence of a crack indication in the vicinity of the shoulder at the outboard end of the north east trunnion shaft. The presence of the roller bearings makes access to the shaft surface impossible without major costly disassembly thus precluding direct examination of the area containing the UT indication. The high cyclic loads and questionable material properties in conjunction with the UT indications led Oregon DOT to consider the use of AE to aid in their understanding of the trunnion shaft condition.

Summary

At the request of Oregon DOT, acoustic emission (AE) tests were performed by BIRL engineers on all four trunnion shafts of the east bridge. The testing was performed under the sponsorship of Northwestern University's Infrastructure Technology Institute (ITI). These tests detected acoustic emission signals indicative of crack related activity in the vicinity of the outboard shoulder on the north east shaft (same area as UT indication). No similar activity was detected on any of the other shafts in the shoulder areas. Considerable AE activity was detected on the N.E, S.E., and S.W. shafts in the area where the sheaves are attached. This AE data may be caused by slippage of the trunnion sheaves on their shafts.

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AE Testing
During the period of October 3 through 5, 1994, BIRL engineers performed AE tests on each of the four trunnion shafts of the East Interstate Bridge in Portland Oregon. The AE monitoring was done using a system that has 6 input channels and is computer based utilizing a Motorola MC68000 as the CPU. System operating software resides in EPROM's. This device is a hardened field portable unit that can be used in either of two operating modes. The system can operate as a stand alone monitor in which crack indications are displayed on a front panel LED display, or the system can be attached to a portable PC via a RS232 port and AE data can be stored on the PC's disk drive for post test analysis. Data recording and post test analysis was used for these tests.

A total of five AE sensors were used to acquire data during the opening and closing of the bridge. The AE sensors used for these tests were piezoelectric resonant devices with center frequencies of approximately 175 KHz. Line driving pre-amplifiers were used to eliminate any cable loading effects on the sensors and to reduce vulnerability to electrical interference. Over-all system gains of 80 db were used for these tests. Sensitivity was checked before and after each test with both a pulser and pencil lead breaks.

A sensor was coupled to each end of the shaft using silicone grease as an acoustic couplant and magnetic clamps to hold the sensors in place. This pair was used to perform linear AE source location on the shaft. On the N.E. shaft, these sensors were lined up with the UT crack indications probable position. The remaining three sensors were mounted on the outer portion of the sheave and spaced at 120° intervals to act as guards to intercept AE signals produced by cable slippage and other potential noise producing mechanisms. AE sources that are located off of the line joining the pair being used for linear location will not locate properly and so they must be rejected from the data set which is the function of the guard sensors. Figures 1 shows one end of the N.E. shaft with the AE sensor attached. Figure 2 shows a typical guard sensor placement.

Source location tests were run with simulated AE sources. Both pencil lead breaks and a sensor driven by an electronic pulser were used. These tests showed that the predominant acoustic propagation mode was the bulk longitudinal wave. This results from the shaft dimensions (19 inches in diameter and 67 inches long). This mode of acoustic propagation has a higher velocity than the normal plate or surface wave mode that is typically encountered in the thin plates (0.5 inches to 3 inches) that are common in bridge structural members. Plate or surface waves typically have velocities near the shear wave velocity which is the velocity that our AE monitor's internal software uses. The ratio between shear and longitudinal wave velocity for steel is .552. The measured length of the trunnion shaft was 67 inches. Our monitor which uses shear wave velocity (stored in firmware) should give a shaft length (measured by the internal calibration routine) of 37 inches. We actually measured 38 inches so our agreement with the theoretical shear to longitudinal velocity is within 2.7%. The presence of longitudinal wave propagation forced us to analyze all of the data off-line and thus not be able to make use of the powerful real-time noise rejection algorithm that the AE monitor has in its operating software. The

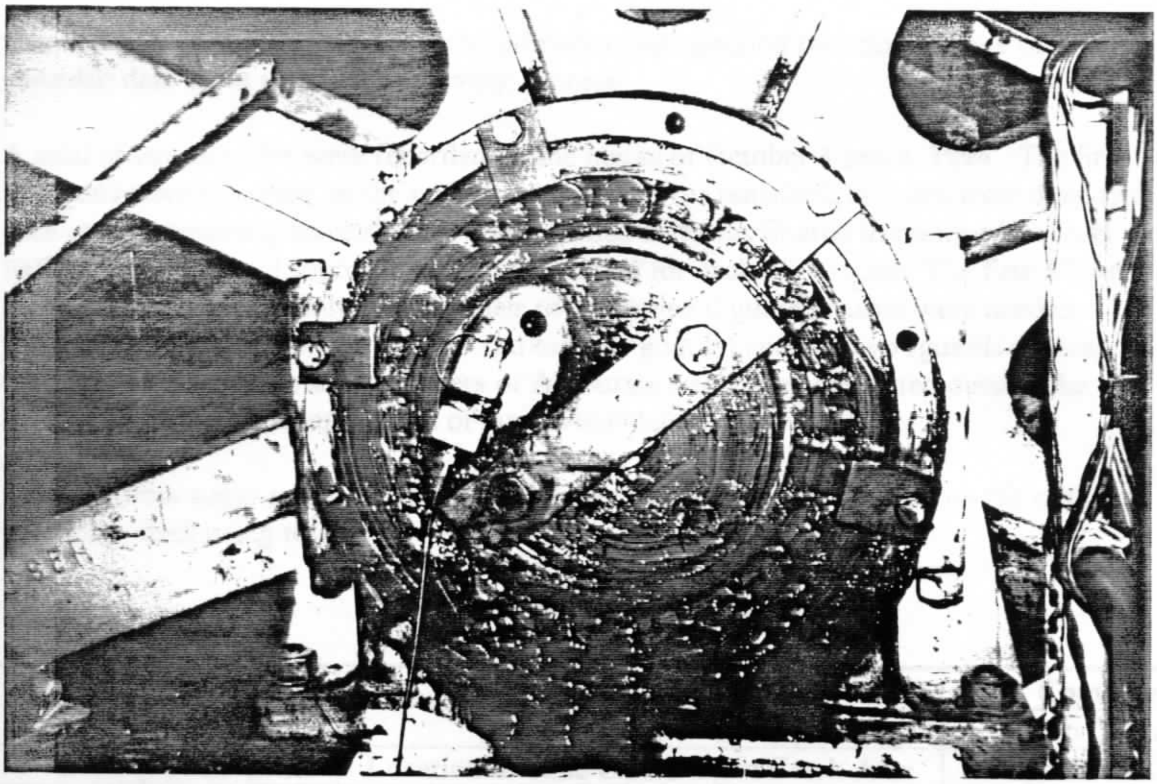

FIGURE 1. AE sensor mounted on end of NE shaft.

FIGURE 2. Typical guard sensor mount.

time and location clustering that is the primary noise rejection tool can be done off-line on recorded data but it is a time consuming process.

A total of ten data files were recorded on the nights of October 3 and 4, 1994. The first four tests were recorded on the north east shaft and the remaining six runs were done two each on the remaining three shafts. The recorded data was filtered to remove low level background noise and source location was plotted for each of the runs. The first AE test run was recorded with only two channels to determine if guard sensors were needed. Examination of the recorded data for run one (no guards) and run two (guards in place) in the field confirmed that large numbers of AE bursts were being generated outside the locating array thus making the use of guards mandatory.

Table 1 below summarizes the tests. In all cases, sensor #1 was mounted on the outboard end of the shaft being tested.

Table 1 AE Test Summary

Test Run	Location	Results	Comments
1	N.E. Shaft	NA	No Guards
2	N.E. Shaft	Location & Time Clustering in Crack Area	High Event Count
3	N.E. Shaft	Location & Time Clustering in Crack Area	High Event Count
4	N.E. Shaft	Location & Time Clustering in Crack Area	High Event Count
5	N.W. Shaft	No Clustering in Shoulder Areas	Low Event Count
6	N.W. Shaft	No Clustering in Shoulder Areas	Low Event Count
7	S.E. Shaft	No Clustering in Shoulder Areas	Moderate Event Count
8	S.E. Shaft	Location Clustering only in Shoulder Area	Moderate Event Count
9	S.W. Shaft	No Clustering in Shoulder Areas	Moderate Event Count
10	S.W. Shaft	No Clustering in Shoulder Areas	Moderate Event Count

The clustering analysis used on these data was developed to allow acoustic emission to reliably detect flaw growth in welds during the welding process. It is based on observations of acoustic emission signal characteristics that accompany known crack growth under controlled laboratory conditions. Crack growth typically produces AE event rates of the order of several per second (typically 3 to 5). Cracks are also localized sources of acoustic emission. In other words, the events produced by a crack have tightly clustered source locations. This algorithm has been successfully tested over the past 15 years in a wide variety of acoustic emission applications and has allowed AE to be utilized for applications that have large amounts of background noise. It is particularly useful in cases where noise sources are coincident with cracks such as cracks growing out of fastener holes. The data recorded during these tests had high background noise and the clustering algorithm allows us to see differences in the data for each of the shafts that probably would have been over looked in simpler analysis. To perform the analysis, we filtered the recorded data to remove low level noise and then computed source locations using the correct acoustic velocity as determined by our calibration process. These plots of event count versus source location are shown in Figures 3 through 11. Locational clustering was applied to these plots. Source locations with event counts equal to or greater than 3 are plotted. Superimposed on each figure is a sketch of the trunnion shaft drawn to scale so that AE sources can be associated with specific shaft features. The largest event count peaks in most of the runs coincide with the area of the shaft that is in contact with the sheave. This AE is probably being generated by slippage of the sheave on the trunnion shaft. This clustering can be clearly seen on runs 2, 3, 4 and 7, 8 and 9. Runs 2, 3, and 4 (Figures 3, 4, and 5) were recorded on the N.E. Shaft. Sensor # 1 was on the outboard end of this shaft so the maximum slippage is occurring at the outboard end. Runs 7 and 8 (Figures 9 and 10) were recorded on the S.E. shaft. Run 9 was recorded on the S.W. shaft. The application of clustering analysis to source location allows us to identify the areas of the shaft that produce significant AE signals. If we examine the source location clustering data for the shoulder region of the shaft (15 inches) with a window of plus or minus 2 inches, we see locational clustering only on the N.E. shaft outboard shoulder region (runs 2, 3, and 4) between 13 and 17 inches, and the outboard shoulder region of the S.E. shaft (run 8). Close examination of the recorded data for these clusters shows that only the N.E. shaft indications exhibit time clustering. Event rates in excess of three per second occur in runs 3 and 4 on the N.E. shaft at a source location of 13 inches. Event rates in excess of two in one second occur at 13 inches, 16 inches, and 17 inches on the N.E. shaft (runs 2, 3, and 4). The three event cluster on the S.E. shaft at 15 inches has a minimum time interval between events of over 3 seconds thus failing the time clustering test for both 3 in one second and two in one second. Extensive experimental observations using a time cluster criteria of three events in one second has shown very high correlation with the presence of crack growth. This analysis shows that only the N.E. shaft produces AE events in the shoulder area of the shaft that satisfy our location and time clustering criteria. This is the location that includes the ultrasonic crack indication so AE seems to add additional credibility to the UT findings with an indication of possible crack growth.

These tests point out the usefulness of applying multiple NDE methods to a difficult inspection problem. Either UT or AE by itself does not provide data that is positively conclusive. However, when we combine the two and the results correlate as they did in these tests, confidence in the test results is considerably improved. Positive confirmation of crack presence can only be obtained by performing a very expensive disassembly procedure to expose the shaft surface. These test results tend to indicate that such an effort is warranted on the N.E. shaft.

FIGURE 3. AE SOURCE LOCATION I-5 RUN 2 NE SHAFT (RDC>100)

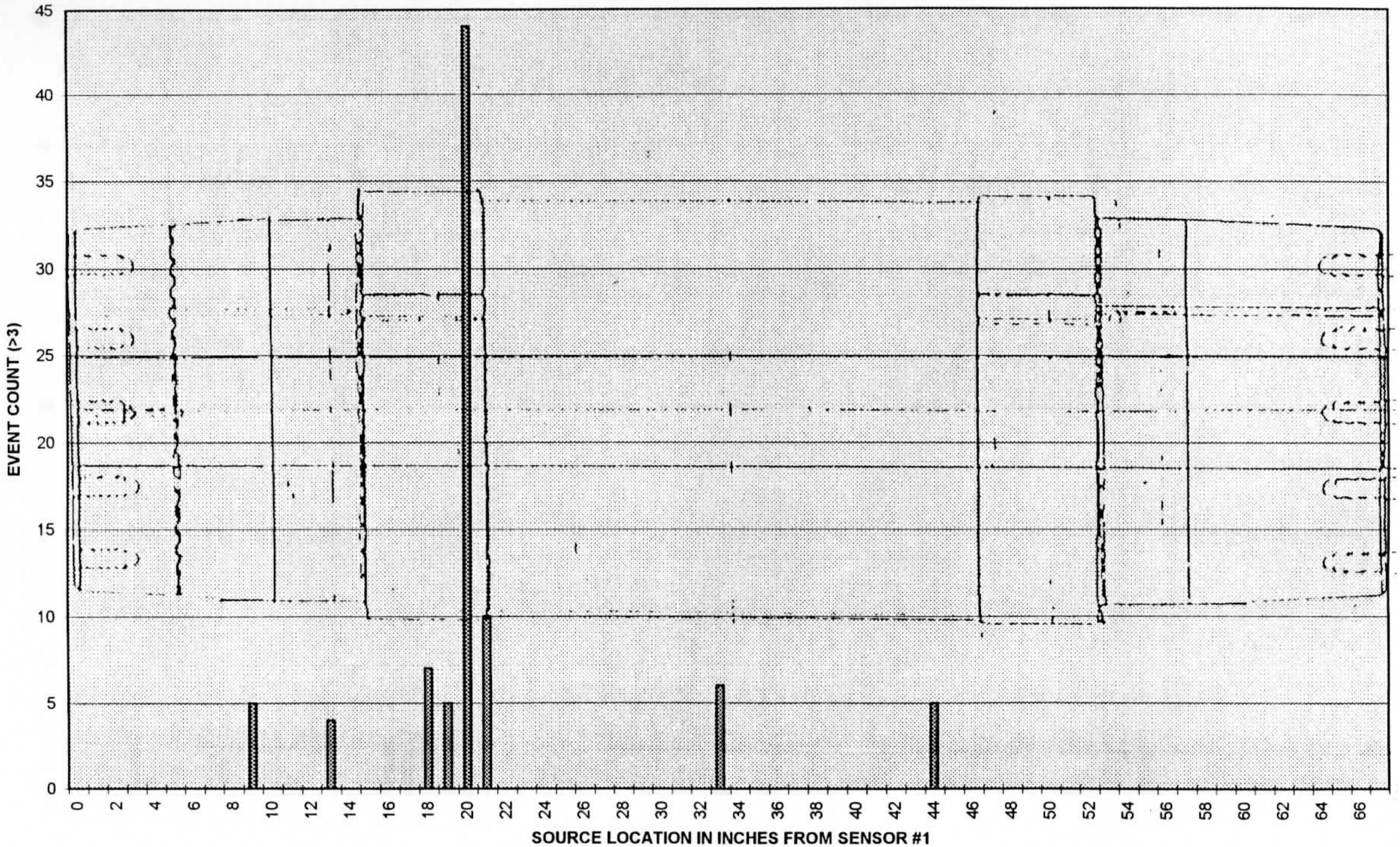

FIGURE 4. AE SOURCE LOCATION I-5 RUN 3 NE SHAFT (RDC>100)

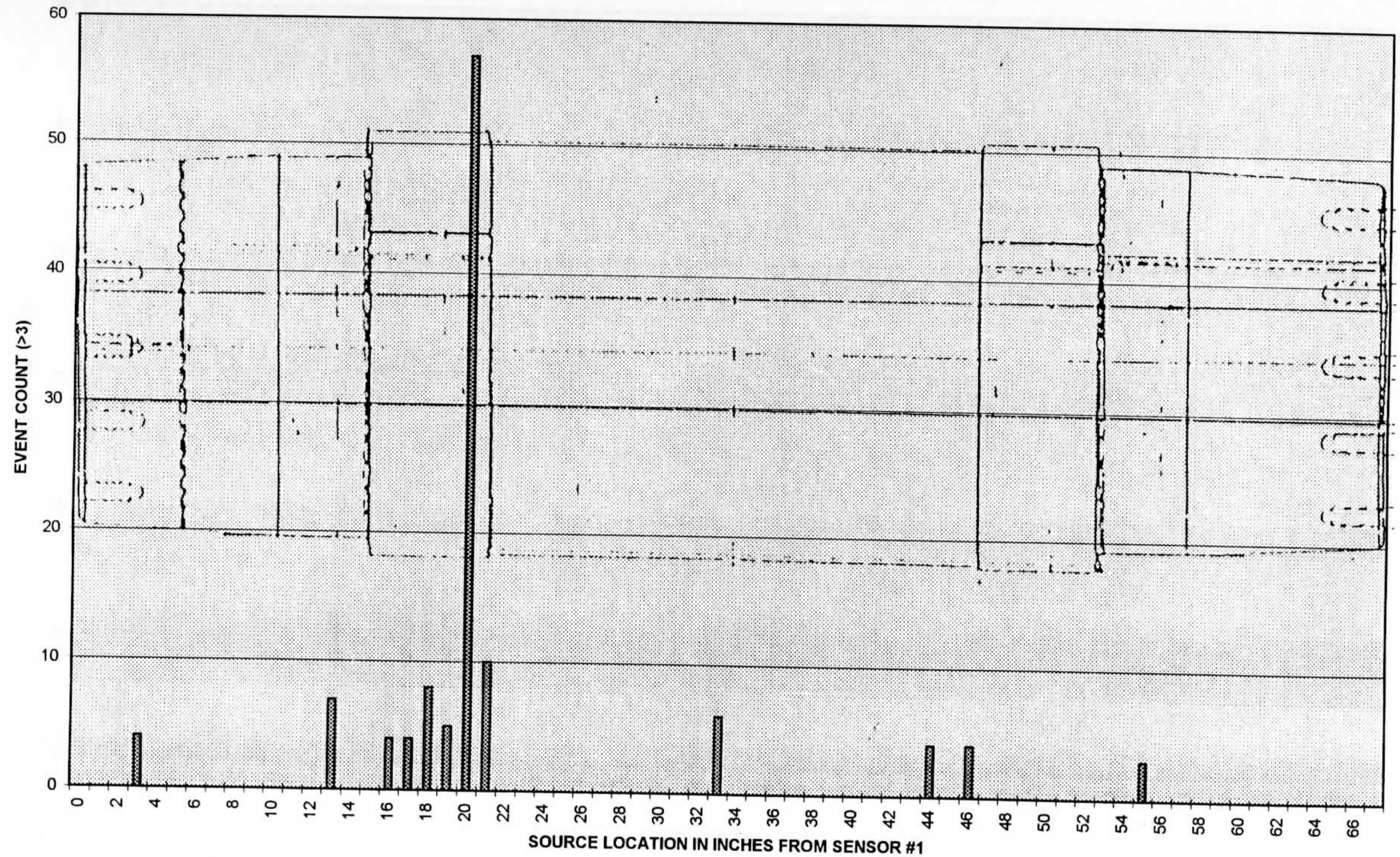

FIGURE 5. AE SOURCE LOCATION I-5 RUN 4 NE SHAFT (RDC>100)

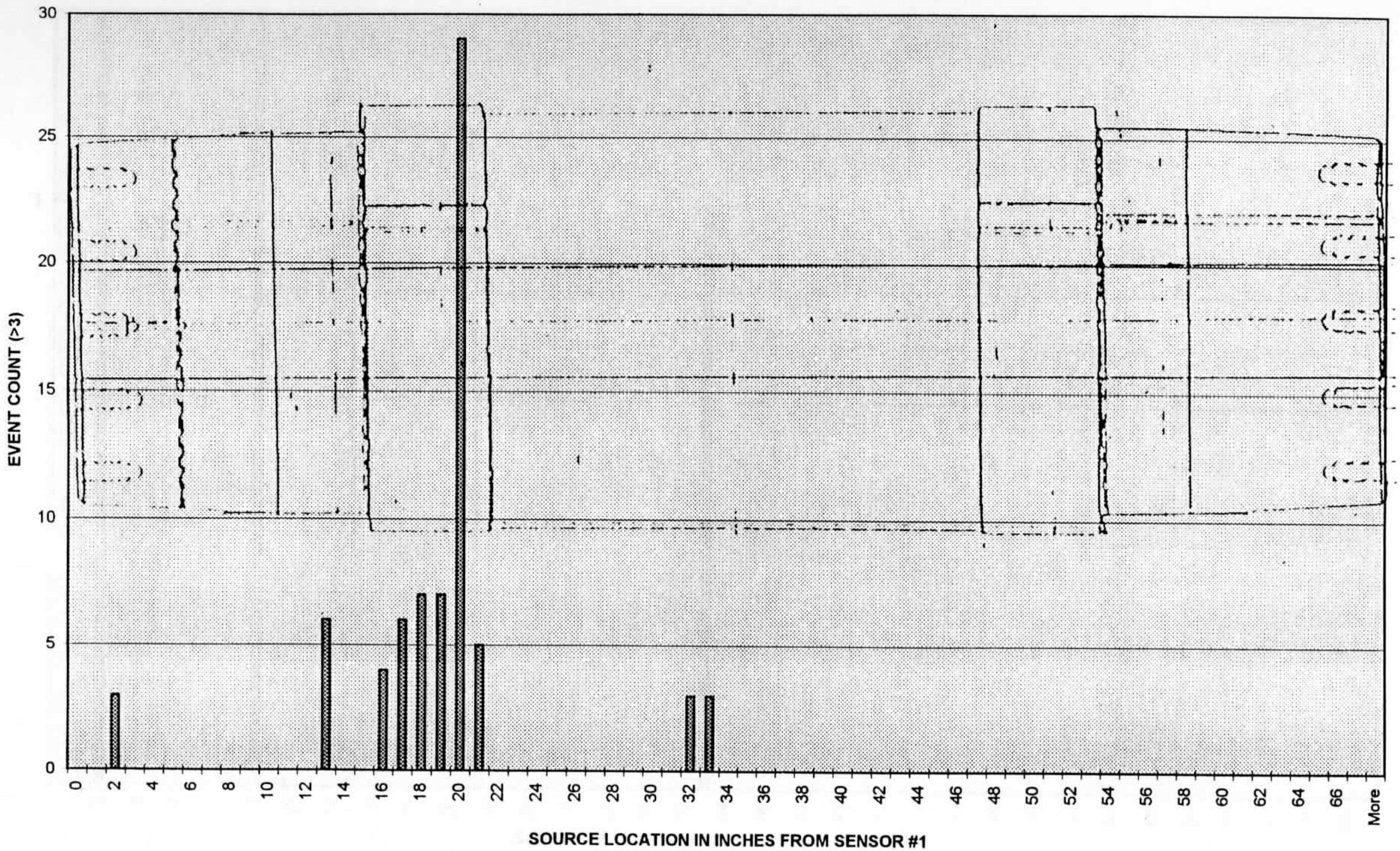

FIGURE 6. AE SOURCE LOCATION I-5 RUN 5 NW SHAFT (RDC>100)

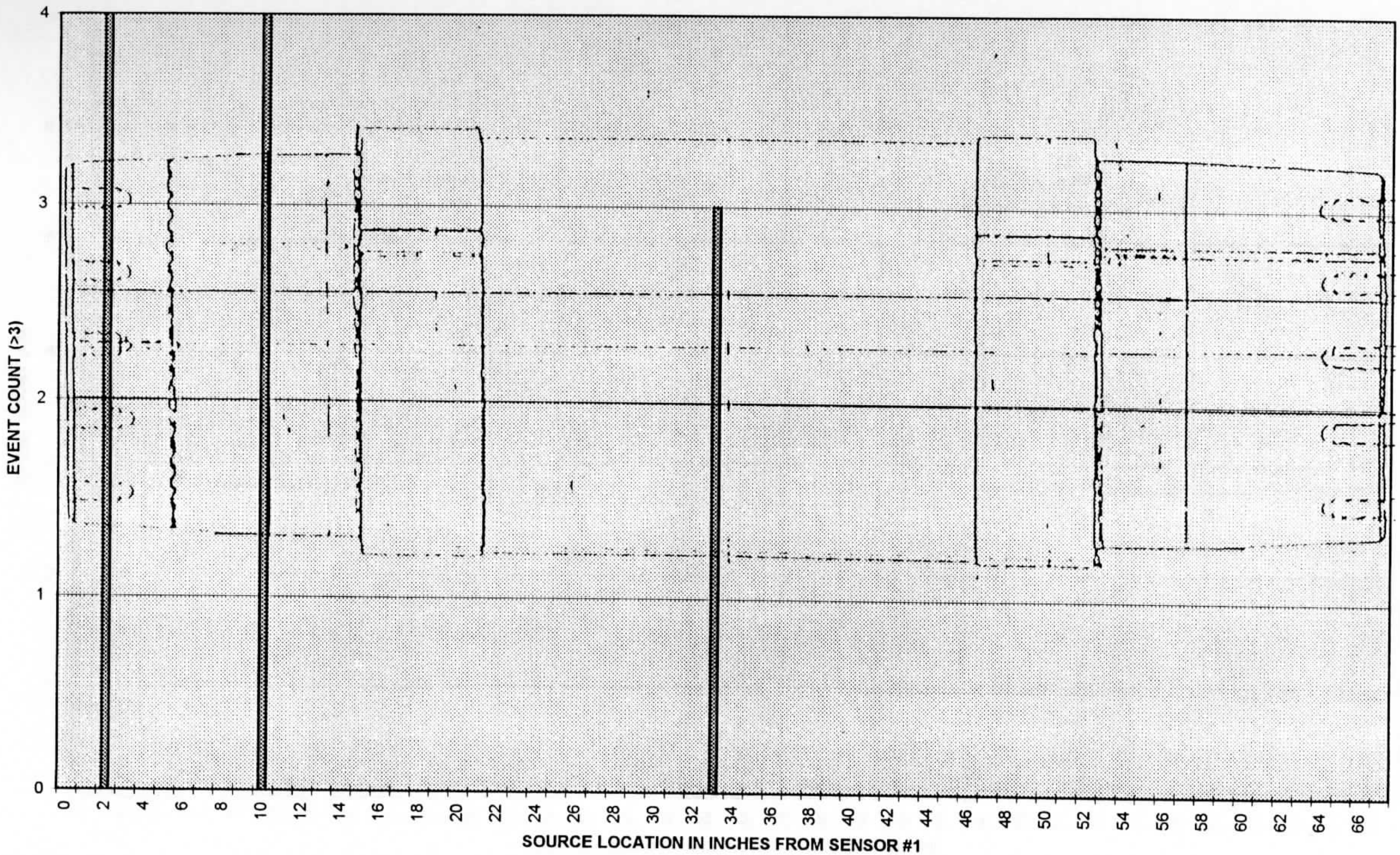

FIGURE 7. AE SOURCE LOCATION I-5 RUN 6 NW SHAFT (RDC>100)

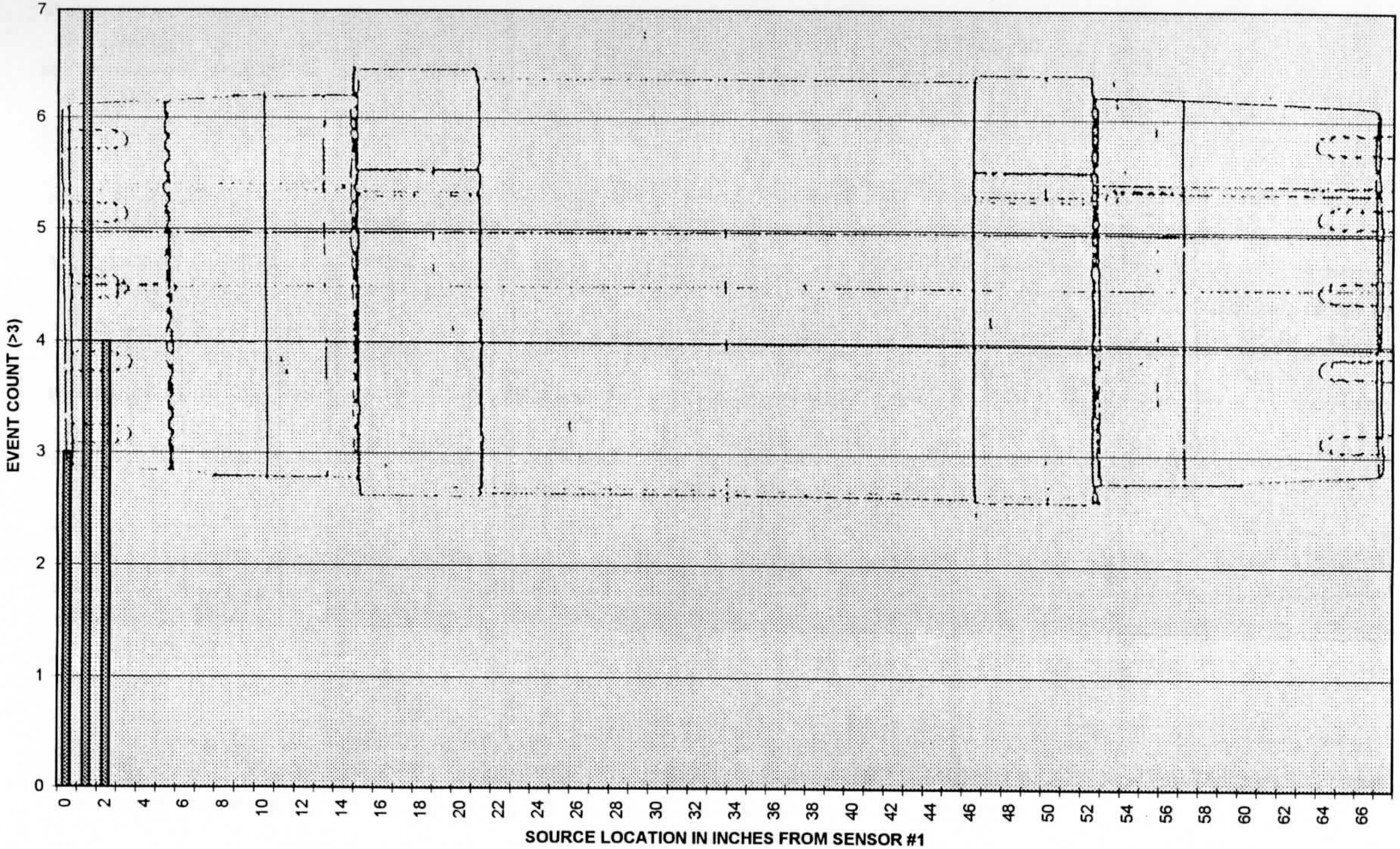

FIGURE 8. AE SOURCE LOCATION I-5 RUN 7 SE SHAFT (RDC>100)

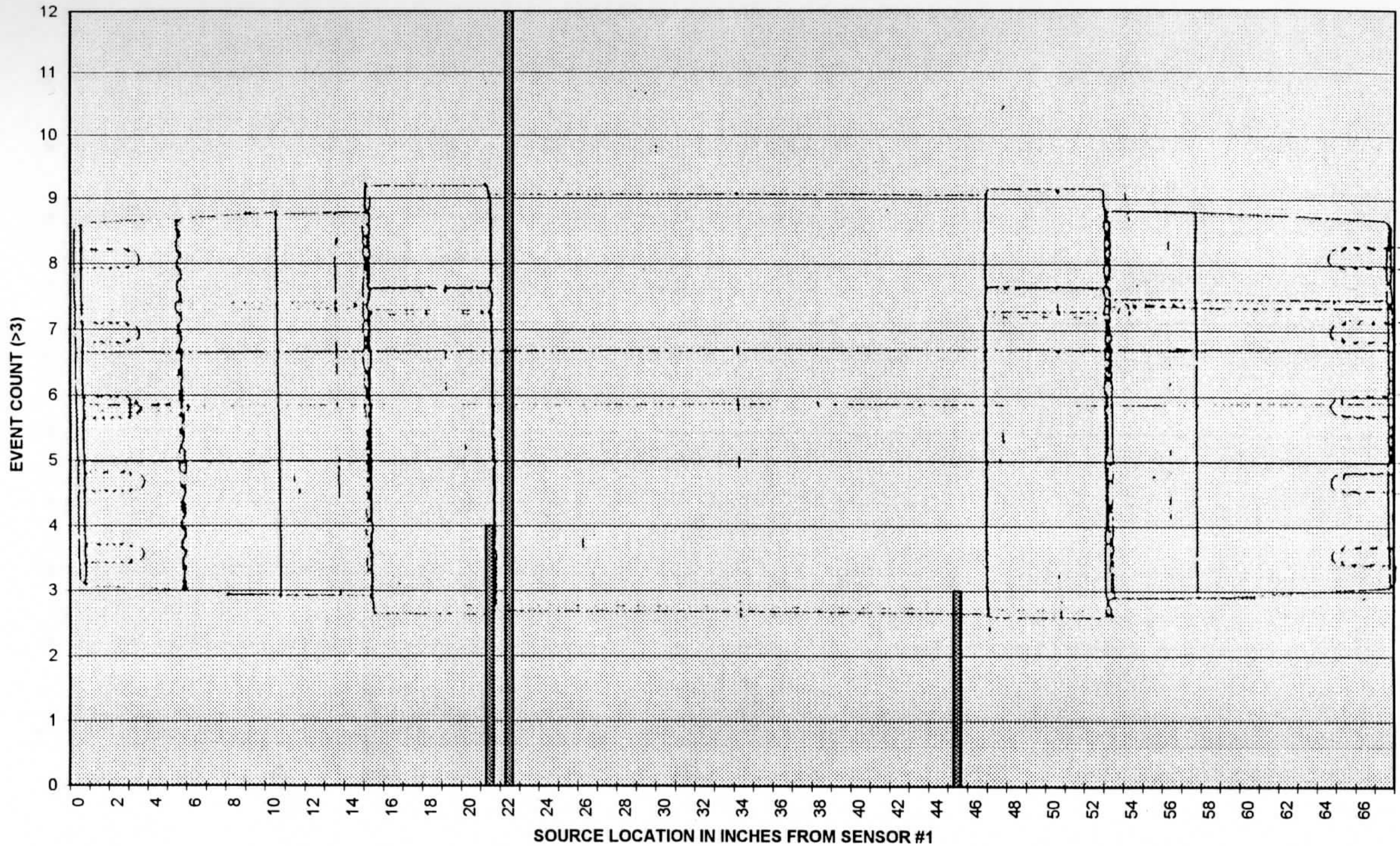

FIGURE 9. AE SOURCE LOCATION I-5 RUN 8 SE SHAFT (RDC>100)

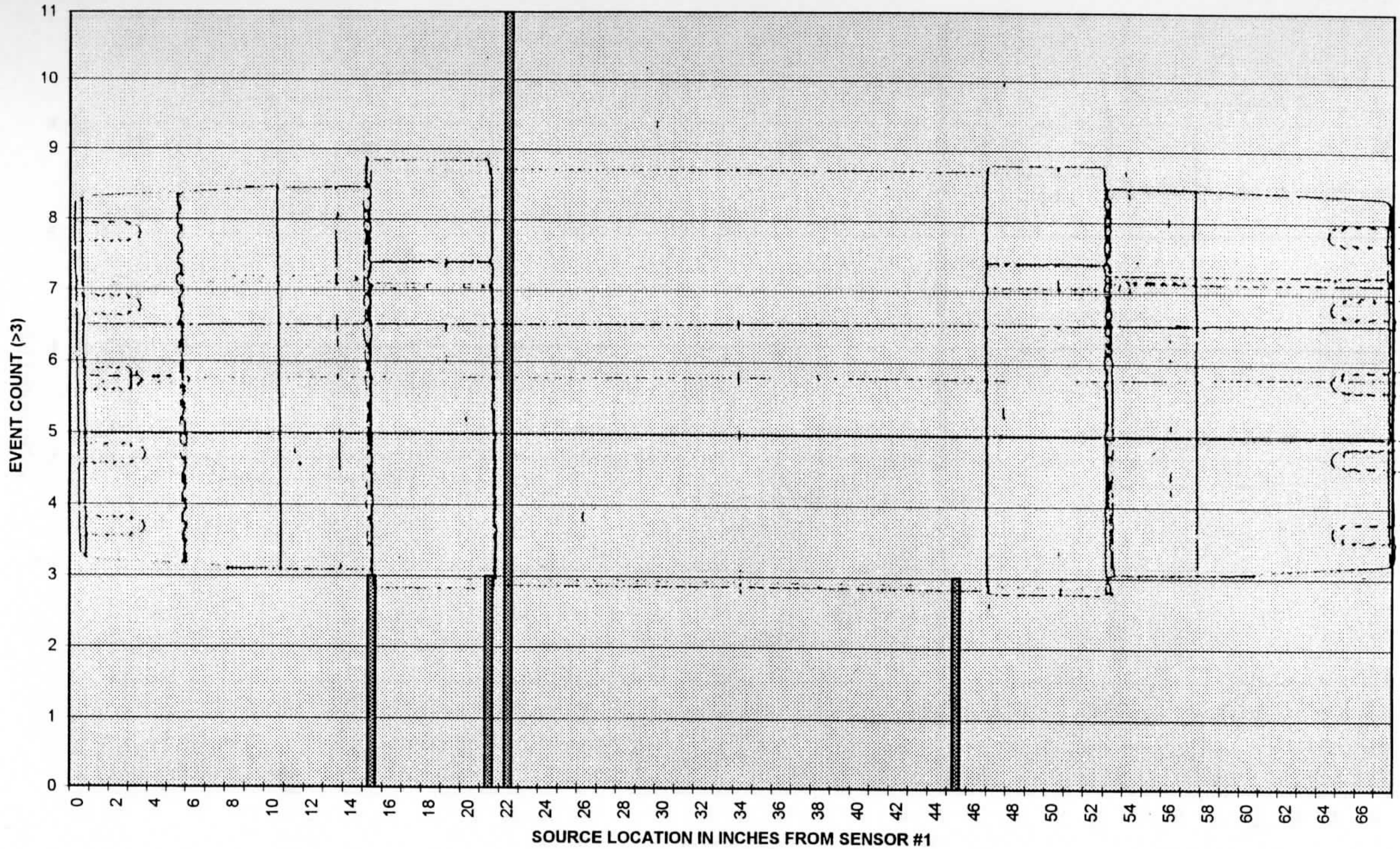

FIGURE 10. AE SOURCE LOCATION I-5 RUN 9 SW SHAFT (RDC>100)

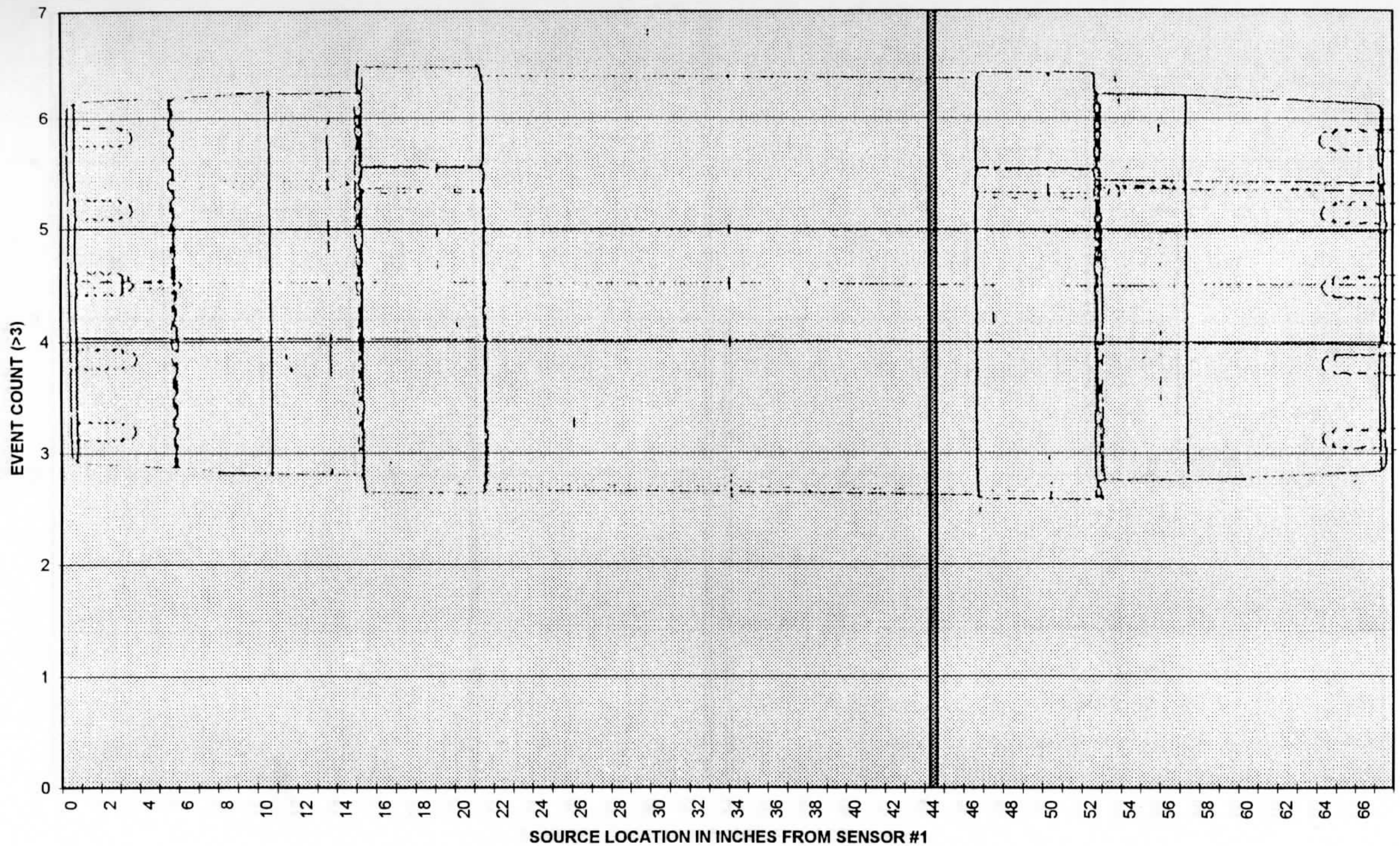

FIGURE 11. AE SOURCE LOCATION I-5 RUN 10 SW SHAFT (RDC>100)