Localization of Noise Sources in Large Structures Using AE

David W. Prine, Northwestern University ITI, Evanston, IL, USA

Abstract

This paper describes application of AE monitoring techniques to localize the sources of large noises in civil structures. These noises occur during operation of moveable portions of a structure in such things as lift bridges and moveable sports stadium roofs. The use of straightforward AE monitoring techniques can provide clear unambiguous location of these noise sources.

Introduction

Audible noises in large steel structures are extremely difficult to localize by means of audible sound. The reason for this is that the steel provides an excellent path for the sound and carries it great distances. Furthermore, the velocity of sound in steel is over 17 times faster than in air so that re-radiated sound from the steel can appear to the ear to come from multiple sources. The first step in correcting the structural problem responsible for the noises is to determine where they are coming from. ITI has successfully dealt with the sound localization problem in several steel bridges by applying AE to localize the sound. The AE technique uses high frequency contact sensors coupled to the steel structure. Processes such as stick-slip in bearings and bolt fretting typically produce acoustic energy in a very broad spectrum. The logic behind this application of AE to the noise localization problem is that the high frequencies (a few hundred kilohertz) are carried with little attenuation in steel but are quickly attenuated in air. Therefore, an array of high frequency sensors attached to the structure can accurately determine the location of the source by simple time of arrival measurement. This approach coupled with high pass filtering of the AE signals eliminates the confusing airborne low frequency sound and generally produces unambiguous source location. In this paper we will describe a case study performed on the moveable roof of a baseball stadium. The stadium roof is made up of seven segments shaped like the leaves of an oriental fan. The interior five segments are moveable. They pivot on ball and cup bearings located above home plate and are driven by electric powered “bogies” that run on a track structure above the outfield wall.

Set-up and Procedure

A Vallen AMS 3 digital acoustic emission monitoring system was used to record and analyze the signals from the sensors. This system makes a series of measurements (peak amplitude, arrival time, energy etc.) on the incoming signals and stores these readings in digital format. Additionally, the AMS3 digitizes and stores waveform data for one or more channels of information using a sampling rate of 10MHz at 12 bit resolution. The system is capable of real time plotting and analysis as well as post-test analysis. The system was set up in the Terrace Level seating area directly under the pivot points for the roof. A 250-foot 8- channel coaxial cable was used to connect the sensors and preamplifiers to the AMS3. The Vallen preamplifiers provide 34db or more of amplification and their low output impedance allows use of connecting cables up to 1000 feet in length. The sensors were 650 kHz resonant devices and were coupled to the structure using silicone grease. We used these high frequency sensors to reduce the sensitivity of the AE system. The high frequency portion of the noise signal has very high amplitude and will easily cause saturation of the monitoring system. We still experienced some amplitude saturation with the 650 kHz sensors but were able to accurately determine the source location. The sensors were held in place by magnetic clamps. A total of three AE sensors were used. Table 1 below summarizes the locations of the AE sensors.

Sensor & Plot Color	Location
Channel 1	Top surface of bearing
Channel 2	Bearing end of roof truss
Channel 3	Bearing support structure

Table 1 AE Sensor locations

In addition to the AE sensors two laser displacement sensors were used to monitor bearing movement. These devices have sensitivity in the micron range and a maximum frequency response of approximately 20Hz. Their range is limited to 6mm. This limited range forced us to use the displacement sensors on the first 6 mm of motion of each run. Our primary purpose in applying these sensors was to see if we could detect any transient motion accompanying the generation of a loud AE burst. If such could be detected it would provide additional evidence as to the origin of the noises (i.e. bearing stick slip). Table 2 below summarizes the displacement sensor placements.

Sensor & Plot Color	Location
PA0	Top of bearing and truss attachment
PA1	Bearing support and truss attachment

Table 2 Displacement sensor placements

Results

Each pivot bearing was separately tested. A minimum of one closing and one opening was run for each of the five bearings. All data were recorded on a hard disk and the data was backed up to a flash memory card post-test on-site. CDROM backup was generated in the ITI laboratory following our return. The AMS 3 has a self-calibration feature wherein each AE channel can be individually pulsed and the signals received at the other channels are tabulated. As a matter of routine a self-calibration was run before and after each test run to insure the integrity of the sensor-couplant-preamp-cable set for each channel. All calibrations indicated no detectable changes in the structure to monitor path. The self- calibrations also showed that system sensitivity remained constant throughout the tests.

The primary analysis of the AE data utilized the first hit channel (FHC) for each acoustic event. FHC=1 indicates the source for that event is in the bearing. FHC=2 indicates the source for that event is somewhere in the truss and FHC=3 indicates a source in the bearing support. The use of FHC analysis is dictated by the complex nature of the structure which makes conventional planer location impractical. This analysis shows

conclusively that the source of the loud noises is the pivot bearing. The overwhelming portion of first hits occur at channel 1 for all but one "quiet" bearing. Furthermore the channel 1 first hits are much higher in amplitude than the other first hits.
In the following section we will present the data from typical bearings.

The following figures show the data plots for one of the Roof Segments.

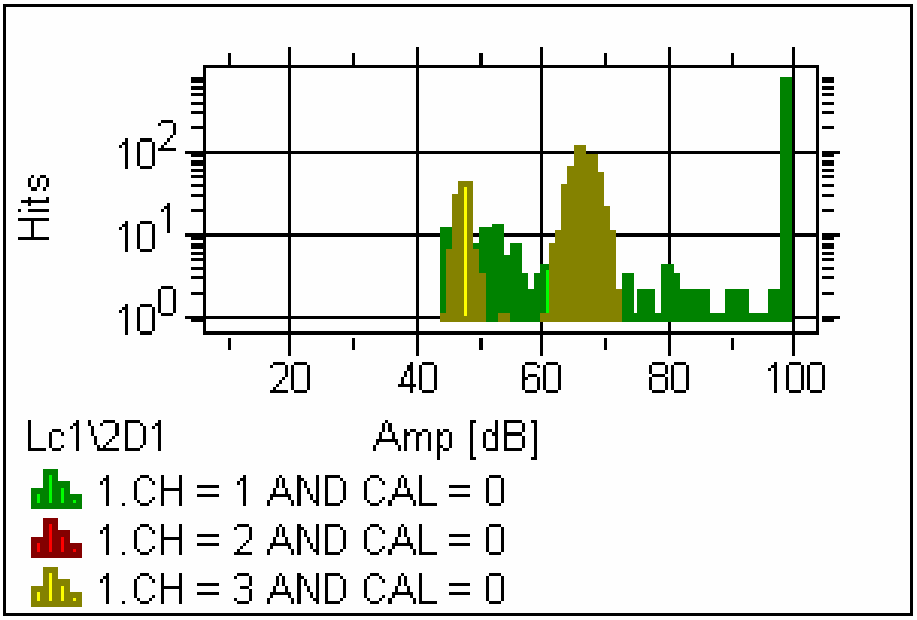

Figure 1 Amplitude Distribution for Closing of Left #2 Roof Segment

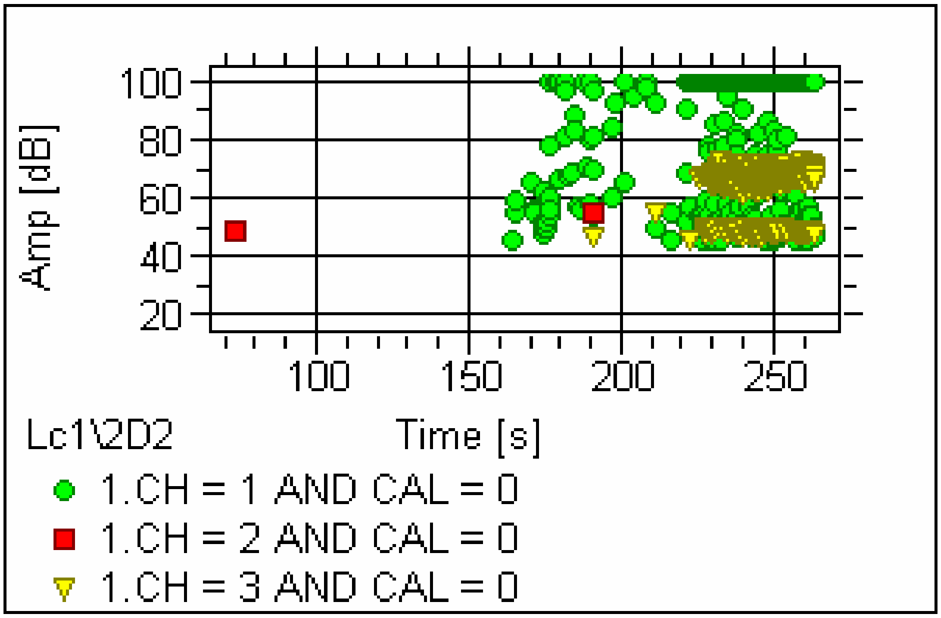

Figure 2 Peak Amplitude vs. Time for Closing of Left #2 Roof Segment

This bearing is typical of those tested. There is also structural noise which is consistent with high live loads caused by high bearing friction. Both figures 1 and 2 clearly show that the bearing is the noise source.

Figures 3 and 4 show the plots for an opening of the same bearing and an additional closure.

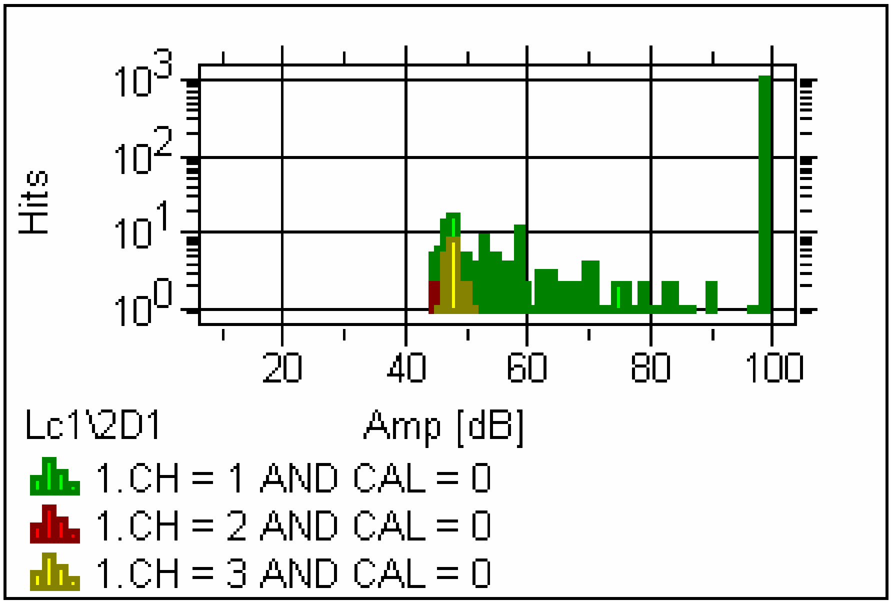

Figure 3 Amplitude Distribution for Opening and Additional Closing of Left #2 Roof Segment

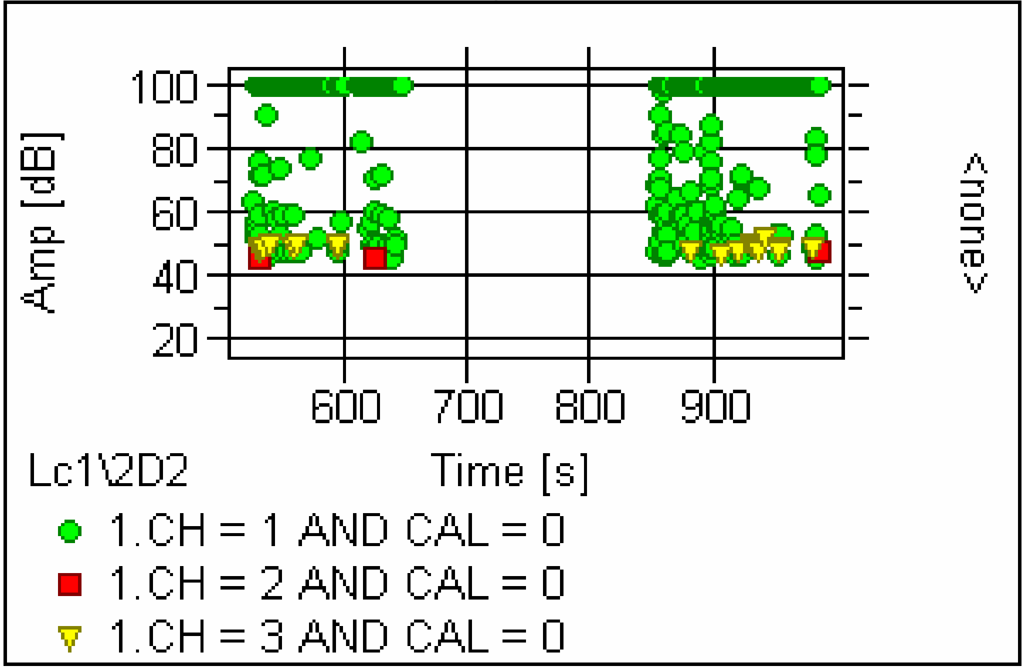

Figure 4 Peak Amplitude vs. Time for Opening and additional Closing of Left #2 Roof Segment

These runs provide further clear confirmation of the bearing noise source. Additionally, this bearing during the opening cycle showed a clear correlation of displacement anomalies with large AE events. Figure 5 below shows a 0.3 second portion of the displacement between the roof truss and the bearing base plotted on the same time scale as the AE.

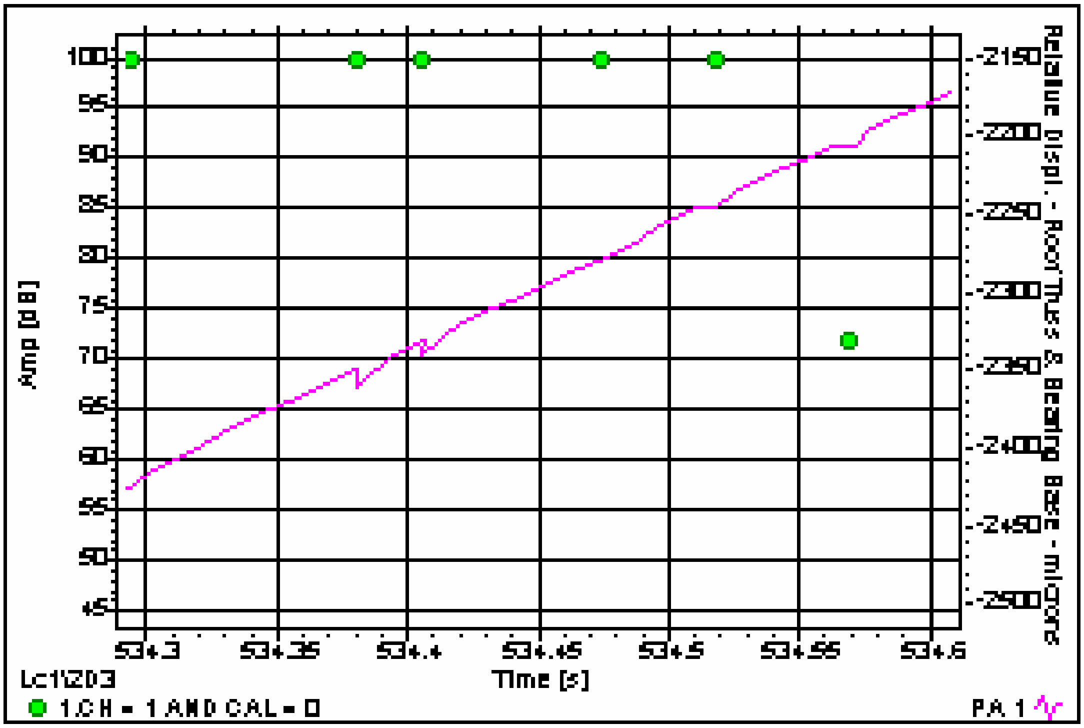

Figure 5 Showing AE Peak Amplitude and Displacement of Truss Relative to Bearing Base on Same Time Scale for L2 Bearing

Four out of five of the bearings produced significant noise but only two (L2 and R2) showed positive correlation between displacement and high amplitude AE events. Difficulties in aligning the sensors with their very limited range was the cause of this problem. Figure 6 shows the displacement data and AE peak amplitude for bearing R2 for a 0.30 second interval. Both sensors for the R2 bearing show transient movement that correlates with high amplitude AE. The frequency response of the displacement sensor is not sufficient to show an accurate representation of the transient movement. However, the sensors clearly show discontinuities in the time-displacement plot which correlate with high amplitude acoustic events.

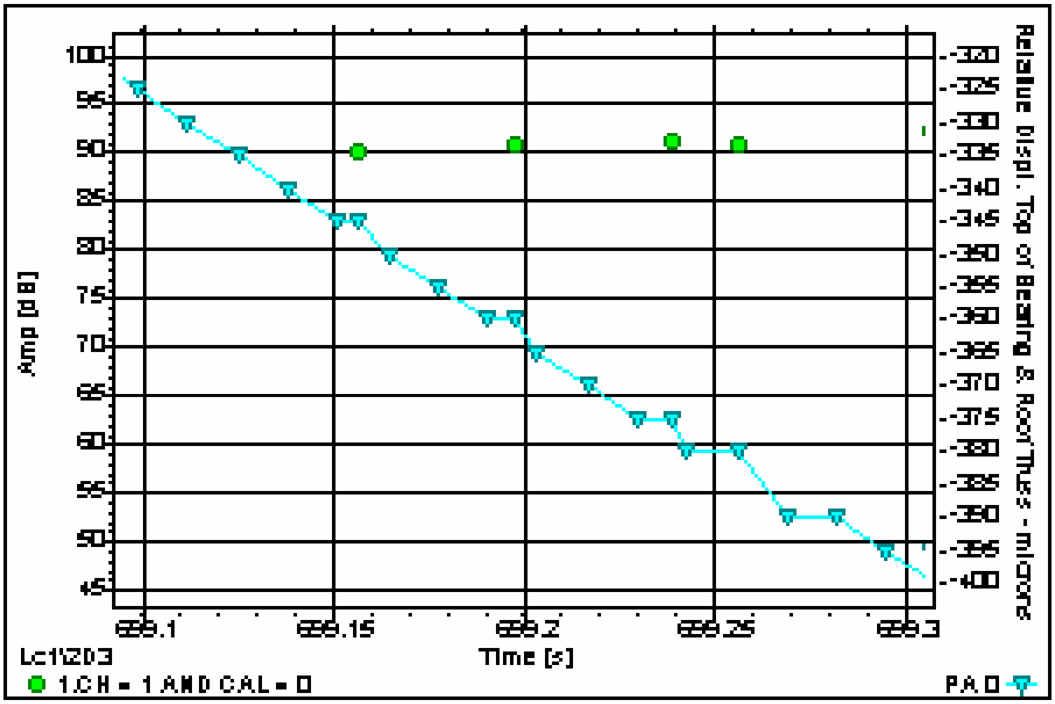

Figure 6 Showing AE Peak Amplitude and Displacement of Truss Relative to Bearing Top on Same Time Scale for R2 Bearing

Summery and Conclusions

Acoustic emission (AE) monitoring clearly showed that the loud noises generated during roof openings and closings are produced by the pivot bearings. The AE monitor used for these tests has an audio monitor that heterodynes the high frequency AE down to the audible range. Loud bangs from the roof opening were accompanied by audible pops from the AE system audio monitor and coincided with the real time detection of first hits on AE channel 1, the bearing sensor. A simple first hit analysis of the AE data showed that the AE associated with the loud audible impact like noises all came from the bearings. Furthermore, the bearing signals were overwhelmingly higher in amplitude than all other AE signals. The remainder of the AE came from the structure and is consistent with previous observations on steel structures undergoing live loading. These signals likely are produced by bolted connections in the roof trusses. The driving live load is the action of the bearing friction and the roof driving force flexing the structure. Additional confirmation of the source of the noise was provided by laser displacement sensors. These devices consist of a measuring head and a target. We used two sensors. One was attached to the top of the bearing with the target attached to the roof truss end and the other sensor was attached to the bearing base with the target attached to the roof truss end. Two bearings showed clear correlation between high amplitude AE events and transient movement detected by the displacement sensors. This data is consistent with stick slip operation of the bearing. These tests confirm that the pivot bearings are not operating properly.