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Technical Report Documentation Page

1. Report No. MN/RC- 1999-18	2.	3. Recipients Accession No.
4. Title and Subtitle ACOUSTIC EMISSION EQUIPMENT FOR INFRASTRUCTURE MONITORING		5. Report Date April 1999
		6. 24-16c.1
7. Author(s) Carol K. Shield		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Minnesota Department of Civil Engineering 122 Civil Engineering Bldg. 500 Pillsbury Drive, S.E. Minneapolis, Minnesota 55455		10. Project/Task/Work Unit No.
		11. Contract (C) or Grant (G) No. (c) 74359 TOC # 198
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard Mail Stop 330 St. Paul, Minnesota 55155		13. Type of Report and Period Covered Final Summary Report - 1999
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This project details the development and evaluation of an acoustic emission (AE) system for monitoring large scale structures, both in the lab and in the field.

The system consists of acoustic emission sensors, preamplifiers, filers, an AE monitor, and a digital oscilloscope. The system has been applied successfully to both steel and concrete structures and used to detect brittle fracture and low-cycle fatigue failures in welded steel joints and crack propagation in cover-plated rolled bridge girders, in the field and in the laboratory. The AE system detected initial cracking during the flexural crack testing of two high-strength concrete prestressed bridge girders. The acoustic emission monitoring of bond tests also provided insight into the behavior of the bond between glass fiber reinforced polymer rebar and concrete.

17. Document Analysis/Descriptors Acoustic emission Bridge girders	AE monitor Digital oscilloscope	18. Availability Statement No restrictions. This document is available through the National Technical Information Services, Springfield, VA 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 10	22. Price

ACOUSTIC EMISSION EQUIPMENT FOR INFRASTRUCTURE MONITORING

Final Summary Report

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April 1999

Published by:

Minnesota Department of Transportation
Office of Research Services
Mail Stop 330
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EXECUTIVE SUMMARY

An acoustic emission (AE) system has been developed which can be used for monitoring large scale structures, both in the lab and in the field. The system is consists of acoustic emission sensors, preamplifiers, filters, an AE monitor, and a digital oscilloscope. As of the writing of this report, the system has been successfully applied to both steel and concrete structures. The system was used to detect brittle fracture and low cycle fatigue failures in welded steel joints, and crack propagation in cover-plated rolled bridge girders, in the field and in the laboratory. Initial cracking was detected using the AE system during the flexural crack testing of two high strength concrete prestressed bridge girders. Insight into the behavior of the bond between glass fiber reinforced polymer (GFRP) rebar and concrete was gained through acoustic emission monitoring of bond tests.

INTRODUCTION

Nondestructive evaluation of the infrastructure is an increasingly important subject as the state's infrastructure begins to age. There is a demand for developing new techniques for assessing damage in steel and concrete structures. One such technique is acoustic emission (AE) monitoring. The funds for this project were used to develop an acoustic emission monitoring system for use on medium, large, and full-scale structures.

Acoustic emissions (AE) are defined as the transient stress waves generated by the rapid release of energy from localized sources within a structure. In concrete, these sources may consist of tension cracking, shear cracking, bond failure, etc. In steel, these sources usual consist of fracture or crack propagation. After originating, these stress waves propagate through the structure to the surfaces, where they become surface waves. These surface waves can be detected using piezoelectric sensors. Using an AE system (sensors, data acquisition equipment and a computer), characteristics of these AE events can be captured and recorded for later analysis.

One of the major benefits of AE monitoring is the ability of AE to monitor large portions of a structure by using very few sensors. Because of this, the development of the AE system makes it possible to gain much more information from experiments performed in the Structural Engineering Laboratory at the University of Minnesota. With other types of sensors, information is gathered only at discrete locations (strain gages, LVDTs, load cells). If per chance the structure does not behave as expected when the instrumentation was designed, then it is a very real possibility that important structural behavior will be missed. With AE instrumentation, the entire structure is monitored with the use of relatively few externally placed sensors. Although it is very difficult, if not impossible, to get out quantitative measurements (such as strain, load, or displacement), Much qualitative information is gathered (amount of AE activity, where the AE activity is located and when the AE activity occurred).

The AE system developed under this project has already been used on a number of projects at the University of Minnesota, many of which were funded by the Minnesota Department of Transportation (Mn/DOT). This report gives a brief description of the AE system, and an overview of some of the projects for which this system has been used.

AE SYSTEM

The AE system at the University of Minnesota consists of a Physical Acoustics Mistras Acoustic Emission Monitor, Mistras 2001 software, eight Physical Acoustic 50 Hz High Pass filter/Preamplifiers, a Hi-Techniques 20 MHz 2 channel high resolution digital oscilloscope, and a Pentium 90 personal computer. Figure 1 shows a schematic of how the system elements interact. This Mistras system is capable of monitoring up to eight channels of AE simultaneously; including real-time signal feature extraction of peak amplitude, duration, rise-time, and energy for each AE event. The scope is used to digitize individual signals to ensure that the parameters of the AE data acquisition system are set properly.

Software Development

Software has been developed using the visual basic language within Microsoft Excel to filter unwanted AE events and to perform source location after filtering. Most of the data manipulation can be done directly in Excel Spreadsheets, and the Mistras system writes data files that are directly importable into Excel.

Calibration

Before use, all eight channels of the Mistras system were calibrated using known inputs from a function generator. The gain and filters of all eight preamplifiers were also verified using known inputs. All system components conform to the ordered system specifications.

RESULTS FROM THE AE SYSTEM

This system has been used on one National Science Foundation Project (NSF) and three different Mn/DOT projects since its purchase in 1996. The NSF funded project was an investigation of failures of steel beam-to-column connections. The Mn/DOT sponsored projects include: The High Strength Prestressed Bridge Girder Project, "Development Length of GFRP Reinforcement in Concrete Bridge Decks," and "Acoustic Emission Monitoring of Fatigue Cracks in Steel Bridge Girders."

Connection failures of Welded Steel Beam-Column Connections

Quasistatic cyclic tests on three welded steel two-sided beam-column connections were monitored. These connections were full scale models of pre-Northridge moment connections. Two of the three specimens had a composite deck attached to the beam. A schematic of the specimen and experimental test setup is shown in Figure 2. AE transducers were located on both sides of the top and bottom welds on both beams. It was anticipated that the bottom welds would fracture during testing, causing the failure of the specimen. This was the type of failure most often seen in the field after the earthquake. The transducers placed along the bottom welds were used for monitoring these welds, providing information about when in the test AE occurred, and from where along the weld line the AE emanated. The transducers along the top weld were used to screen out AE events caused by cracking of the concrete floor slab and slip between the floor slab and steel girder.

Figures 3 and 4 illustrate some of the results from AE monitoring of the first of these three tests. Figure 3 contains a plot of cumulative AE events versus Load Increment for AE detected by both the East and West bottom welds AE transducers. In addition, this plot shows the loading history (peak tip displacement vs. load increment) for the test. The large increase in cumulative AE Events over a small number of load increments clearly indicate the failure of both welds: the West weld failed at approximately Load Increment 40, and the East weld failed at approximately Load Increment 65. As was expected, both sets of transducers were able to detect the impending failure of either weld. Figure 4 illustrates the location of the AE event versus test time for the same specimen. The y-axis indicates from where along the 14 inch weld the AE event emanated, and the x-axis indicates the test time. Approximately 580 minutes into the test, a large number of AE events were recorded coming from across the entire West weld. This type of source location pattern indicates a very quick brittle fracture of the weld. On the other hand, approximately 850 minutes into the test, a group of AE events localized to the middle of the East weld were recorded, these events were spread out over a larger time period than the events for the brittle fracture of the West weld, and were indicative of a low cycle fatigue failure of the East weld.

Results from the monitoring of the other two test specimens were similar. The results of the AE monitoring of these tests showed that AE could be used to detect steel welded beam-column connection failures, and could differentiate between brittle fracture and low cycle fatigue.

Behavior of High Strength Concrete Prestressed Girders

During the High Strength Concrete project, the equipment was used to monitor the girders during flexural cycling, flexural crack testing, and shear testing. Figure 5 shows the location of the AE transducers on the girder during flexural testing. These four transducers were monitored throughout flexural cycling and crack testing. This application of Acoustic Emission encompasses one of the largest concrete structures every monitored. The equipment successfully identified cracking in the deck of Girder I during cyclic testing that likely would have been missed without the equipment. During crack testing, the equipment detected cracking prior to the cracks becoming visible. The loads at which the AE equipment detected cracking were used to determine the cracking moments, and hence the prestress loss at the time of flexural crack testing. The AE system identified the initial cracking 4 to 7 kips prior to the cracks becoming visible. Details of the crack testing can be found in "Behavior of Two High Strength Concrete Prestressed Bridge Girders" [1].

In addition, the system was used during shear testing of the four girder ends. Figure 6 shows a plot of cumulative AE events versus time for the shear test of Girder End IA. The increasing rate of acoustic emission activity clearly indicates the increased damage occurring to the girder end during the testing. AE successfully detected initial cracking in the webs of the girders. Figure 7 shows a source location vs. time plot for the same shear test. The y-axis indicates the location of the AE source in inches, where 0 inches is at the reaction of the shear end of the girder end being loaded. Figure 8 shows the applied load versus time for the same portion of the test. These figures clearly show that almost all the AE was produced during the loading portions of the testing, with very little AE being produced during the loading holds. The source location plot indicates that the initial cracks developed near the middle of the shear span, and as the test progressed, cracking progressed in toward the reaction.

Bond of Glass Fiber Reinforced Polymer Rebar

In the project entitled "Development Length of GFRP Reinforcement in Concrete Bridge Decks," 72 half-beam bond specimens were instrumented with AE equipment [2]. The information gathered from this monitoring was successfully used to better understand the behavior of bond between GFRP rebar and concrete. Distinctly different AE signatures were found for the two type of GFRP rebar tested. These two types of rebar had significantly different deformation systems on their surface. Coupled with visual observations of cracking, and measured slips, the AE helped to explain the differences in bond behavior for these two types of bars. A complete report of the AE results from this project can be found in the final report of the above mentioned project.

Fatigue Cracking of Cover-plated Steel Bridges

In the project entitled "Acoustic Emission Monitoring of Fatigue Cracks in Steel Bridge Girders," the system was used to monitor a test specimen in the lab, as well as three bridges in the metro area (West 7th over a railroad track in St. Paul, TH36 over Cleveland Avenue, and I94 over Hiawatha) [3]. The lab study clearly indicated that growing fatigue cracks in steel girders emanate detectable acoustic emission, and that the rate of emissions grows as the crack size grows. The system also determined differences in the rate of acoustic emissions in the field bridge girders due to a known truck load. In this project, it was determined that two of the three bridges had growing fatigue cracks. A complete report of the AE results from this project can be found in the final report of the above mentioned project.

CONCLUSIONS

An acoustic emission system was developed for use in monitoring of structural tests and in situ monitoring of field structures. Acoustic Emission monitoring has been successfully applied to three projects funded by the Minnesota Department of Transportation and one project funded by the National Science Foundation. These projects encompass both steel and concrete structures, as well as laboratory applications and field applications. It is anticipated that this system will continue to yield valuable information about the behavior of a variety of different structures both in the laboratory and in the field.

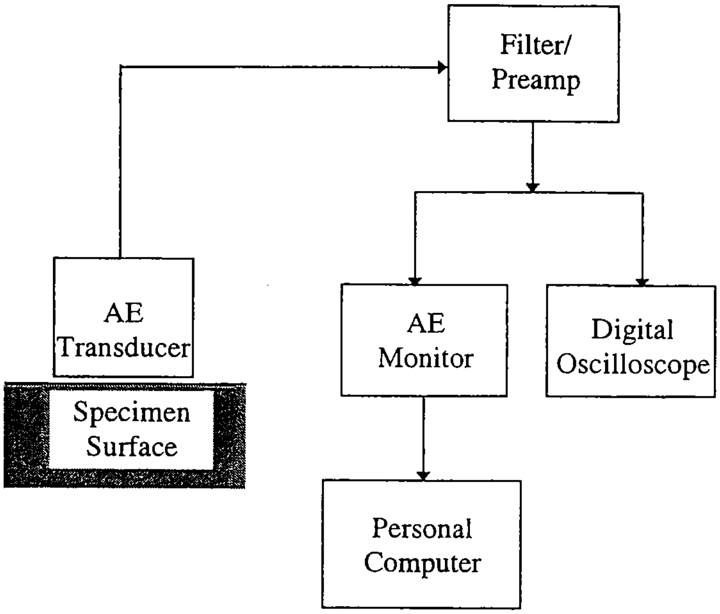

Figure 1 AE System Block Diagram

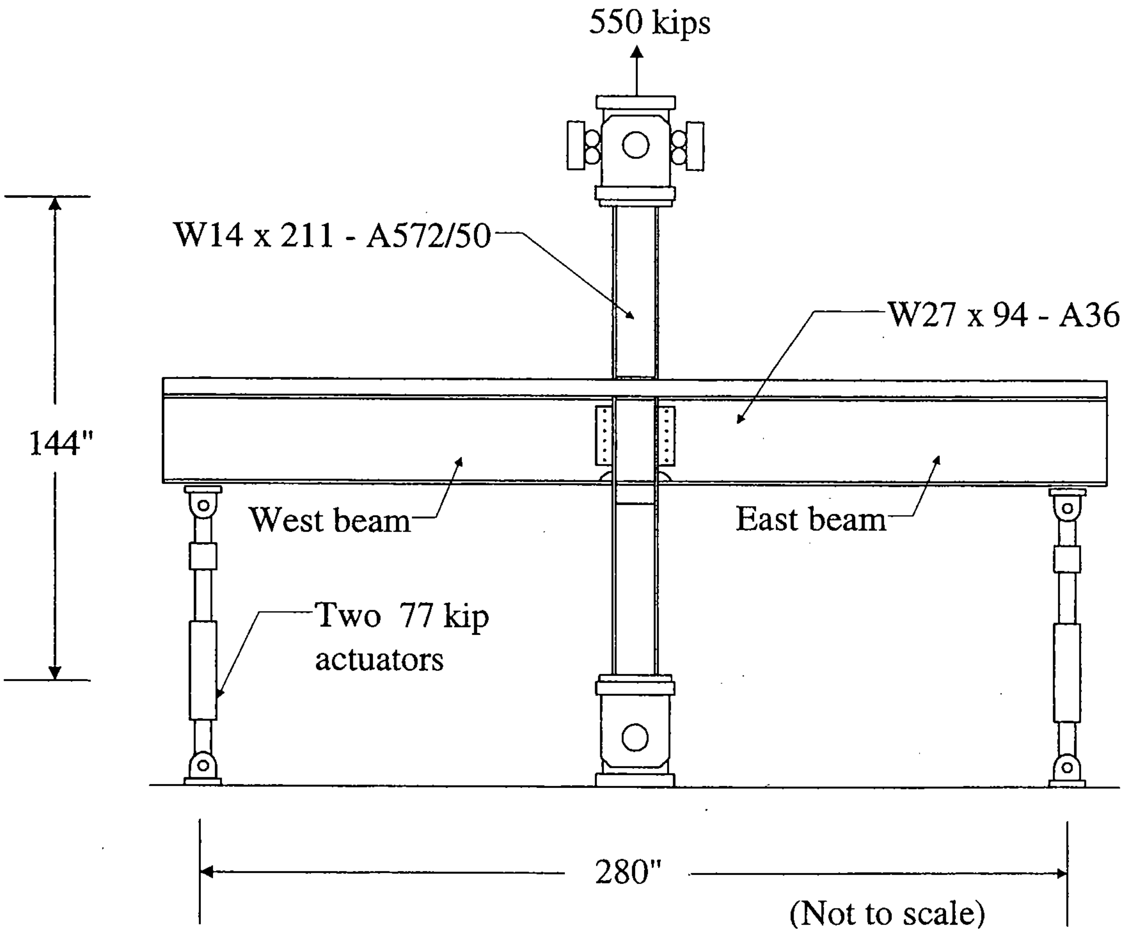

Figure 2 Schematic of beam-column test setup

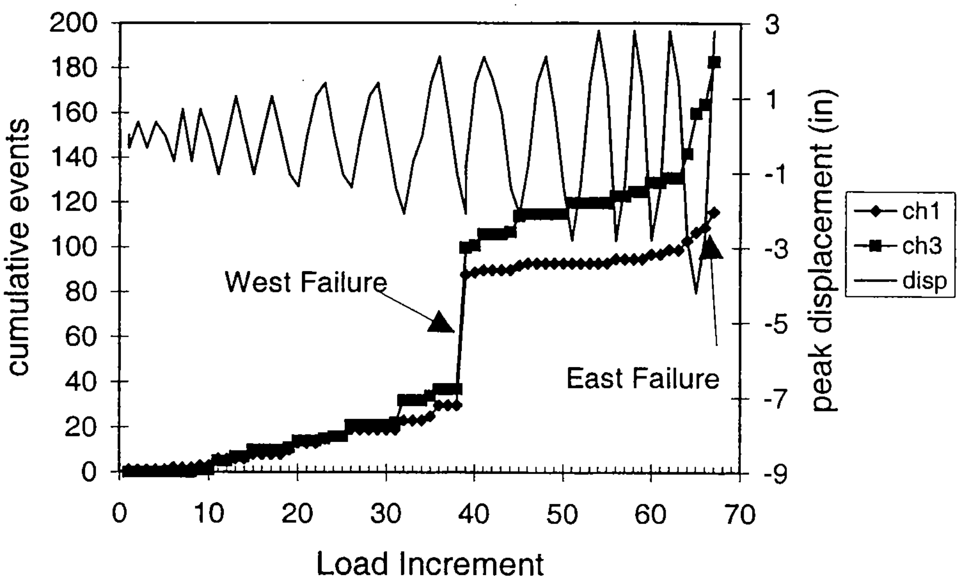

Figure3 Cumulative Events vs. Load Increments

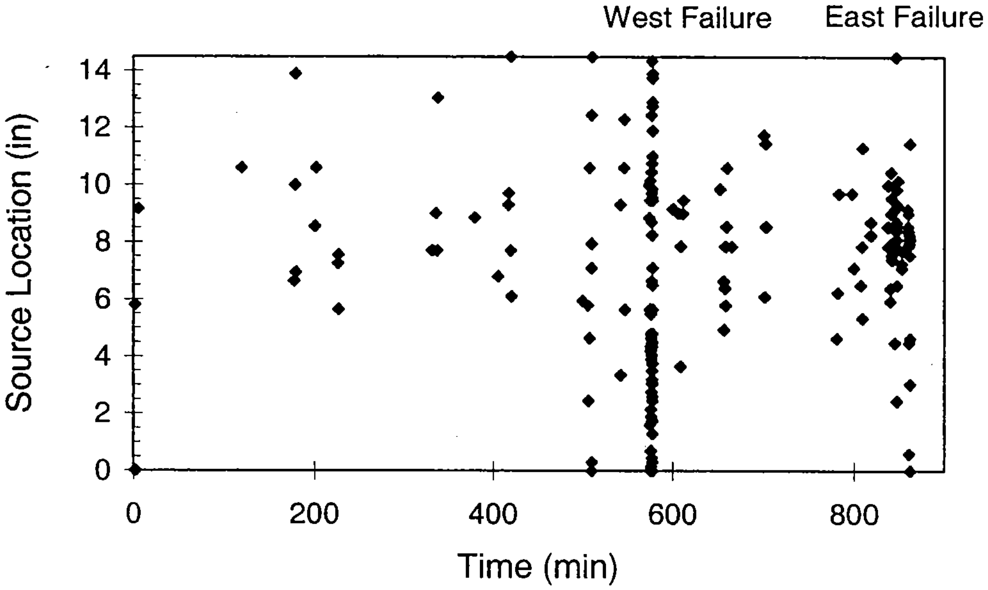

Figure 4 Location of AE events along the welds vs. test time

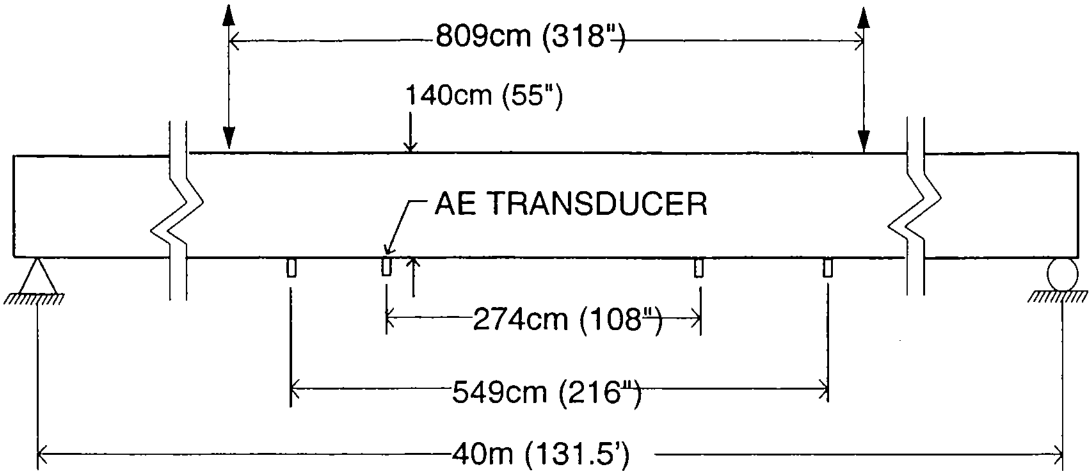

Figure 5 Location of AE transducers on Prestressed Bridge Girder

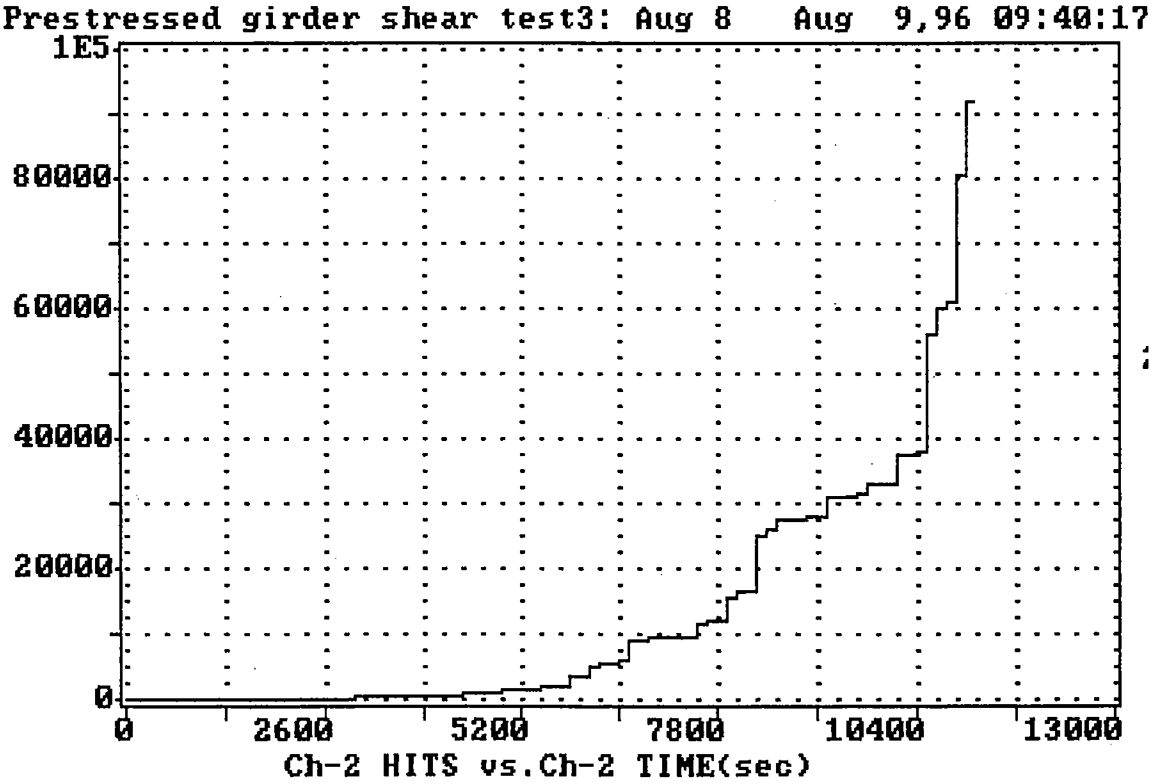

Figure 6. Cumulative AE hits versus time

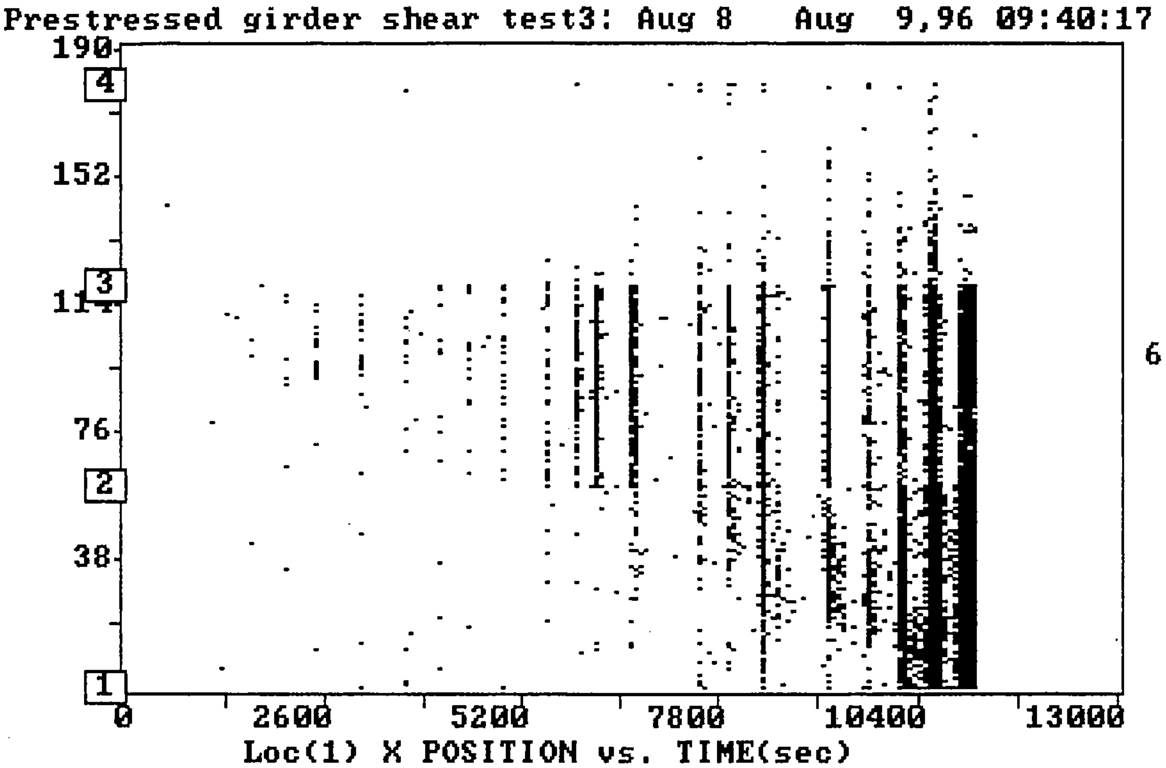

Figure 7. Source Location vs. Time for Shear Test of Girder End IA

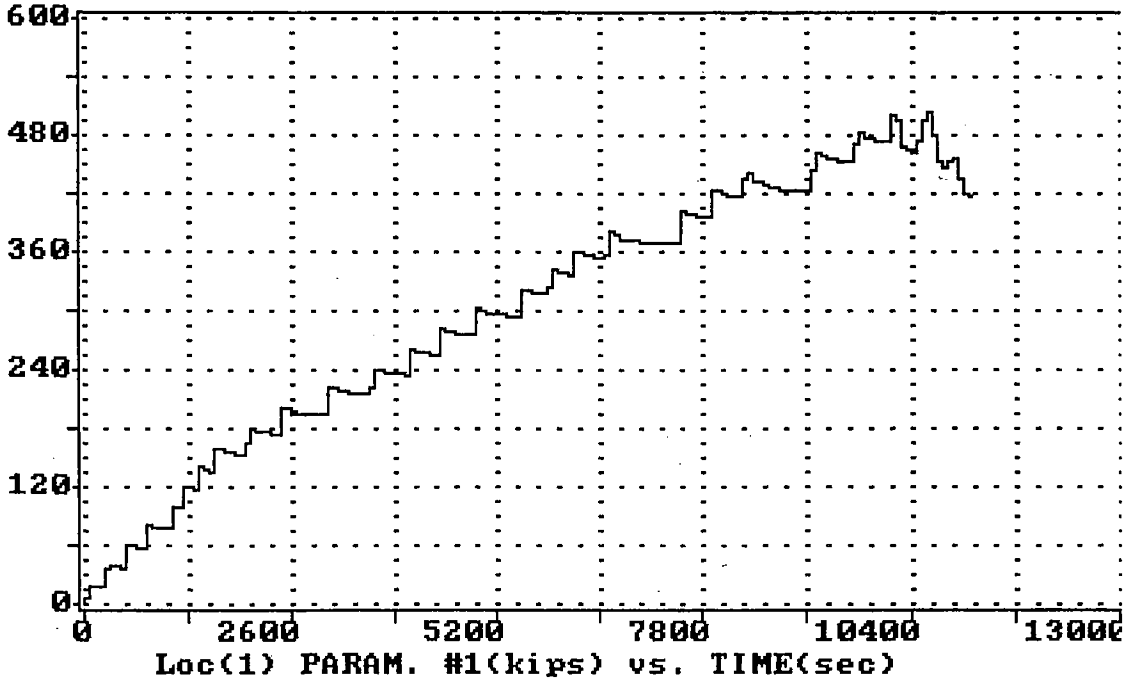

Figure 8 Load versus Time for Shear Test of Girder End IA