DETERMINING VIBRATIONAL FORCES EXPERIENCED BY HIGH PRESSURE SODIUM VAPOR LAMPS IN ROADWAY LUMINAIRES

SUPPLEMENT
TO
FINAL REPORT

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By

H. Dexter Jones
District Traffic Design Engineer
District 12

Joseph G. Raska
Materials and Test Chemical Engineer

Thad Bynum
Supervising Designing Engineer
Safety and Maintenances Operations Division

THE STATE OF TEXAS

Conducted By

District 12, Materials and Test Division and
Safety Maintenance Operations Division
in Cooperation with the Texas Transportation Institute,
the Mechanical Engineering Department and The
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A & M University

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Reports

I. PURPOSE

This volume is intended as a supplement to the Final Report, Research Report Number 273-1F. Included are three reports prepared by project personnel from the State Department of Highways and Public Transportation and from Texas A & M University. The reports explain the preliminary tests performed, test parameters, and test procedures. Also, included are test data, data analysis, explanations and recommendations. The reports contain many details not included in the basic report.

This volume also includes a report by the General Electric Company entitled "Ballast Failures Caused by Defective High Pressure Sodium (H.P.S.) Lamps".

REPORT A

ROADWAY LUMINAIRE VIBRATION ENVIRONMENTS

ROADWAY LUMINAIRE VIBRATION ENVIRONMENTS

by

W. E. Red, Department of Mechanical Engineering,
Brigham Young University
H. D. Jones, Texas State Department of Highways
and Public Transportation
B. Don Russell, Electric Power Institute,
Texas A & M University

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ROADWAY LUMINAIRE VIBRATION ENVIRONMENTS

ABSTRACT

Early failures of high-pressure sodium (HPS) lamps at a number of roadway lighting installation across the nation can not be attributed to poor installation or maintenance procedures, but rather to an environment in which luminaire vibration precipitates lamp failure. This paper summarizes the vibration environment found at five sites in the Houston, Texas area.

Because the vibration environment proved unexpectedly severe, designers of HPS lamps are challenged by a dynamic environment where g levels commonly exceed 1 g, often approaching 4 g, sometimes approaching 10 g. The severity of this environment is a strong function of luminaire location and local traffic patterns.

INTRODUCTION

Three Texas lighting projects have experienced difficulty in maintaining highway lighting integrity. As described in (1), HPS lamp outages and problems with starter boards and ballast systems occurred on a regular basis. Many of these lighting failures could not be traced to poor installation/maintenance procedures or to lamp manufacturing defects.

By laboratory testing (2), those HPS lamps used in the lighting projects (General Electric, Sylvania, North American Phillips Lighting Corporation) were demonstrated to be sensitive to vibration. In addition, lamp "blink-out" was related to vibration levels. Blink-out, an HPS lamp ballast control instability, is postulated to result from the vibrationally induced dislodging of amalgam which then vaporizes. Subsequently, the tube pressure increases to the point where the voltage required to sustain the arc is too high. The lamp then extinguishes itself and cools until the tube pressure falls to levels where the voltage pulse from the ignitor will again strike the arc.

To assess the nature and severity of the field vibration environments encountered by actual luminaire structures, the Texas State Department of Highways and Public Transportation (SDHPT) contracted the Texas Transportation Institute (TTI) to monitor and record vibrational environments at six Houston area sites. Piezoelectric accelerometers were placed at ten positions on the luminaire mast, arm and lamp chassis to monitor vibrational histories over specific testing periods. Because the recorded correlation of the ballast control reaction to vibrational levels and frequencies during blink-out was an important test objective, the primary voltage/current to the ballast and the secondary voltage/current to the lamp were instrumented also.

TESTS

Table 1 lists the five test sites and the test durations/dates. Although six sites were originally scheduled, the final test was cancelled because of recorder failure.

At site 1 data were recorded for seven continuous days using an AMPEX PR 2200 16 channel tape recorder. A tape speed of 15/16 ips and Ampex 766 intermediate band tapes, 5600 feet long, enabled continuous monitoring for twelve hour periods before tape change. Whereas the HPS lamp was on continuously at Sites 2-5, even during daylight hours, the HPS lamp was permitted to function normally Site 1 (photocell on/off).

Table 1 - Field Test Sites

Site No.	Site Description	Test Duration (days)	Test Dates
1	Bridge mounted, single arm pole, south approach to Ship Channel Bridge, site on prestressed unit approximately 30' from a bent	7	3-11-82 to 3-19-82
2	Ground mounted, twin arm pole north of Ship Channel Bridge at Clinton Drive exit	2	3-28-83 to 3-30-83
3	Side mounted, ground mounted, single arm pole on off-ramp from I-10 EB to I-610 EB	3	4-25-83 to 4-28-83
4	Side mounted, bridge mounted, single arm pole on ramp from I-10 EB to I-610 SB, pole located at midspan	3	5-31-83 to 6-03-83
5	Median mounted twin arm pole on I-610 North Loop at T.C. Jester exit	2.5	7-05-83 to 7-07-83

INSTRUMENTATION

Figure 1 identifies the accelerometer locations and the instrumentation used to acquire the accelerometer time histories. Figure 2, a photo of Site 4, depicts the typical challenges which accompanied the instrumentation of each site. The instrumentation van, fondly named the "yellow-elephant," was air-conditioned to protect the temperature sensitive instrumentation.

Though not shown in Figure 1, wires carrying the ballast and lamp voltage and currents were segregated from the accelerometer wires on opposite sides of the mast/arm to minimize cross-field electrical excitation. Figure 3 shows the Pearson Model 411 wideband (35 MHz) precision current transformers used to obtain the pre and post ballast currents. Tektronix P6007 x 100 voltage probes were used to monitor the voltage.

Of the ten accelerometers, channels 1-8 used PCB 308B10 accelerometers having a sensitivity of 100 mV/g and a frequency range of 1-3000 Hz. Two PCB 312A high-temperature accelerometers,channels 9 and 10, were used to monitor the vertical (Z) accelerations on the tube surface and at the lamp base. Because the PCB 321A accelerometers lack internal amplifiers, in-line charge amplifiers mounted on the lamp chassis were used to amplify the PCB 321A signals to 100 mV/g sensitivity.

Comparing the PCB 312A mass, including mounting components (approximately 50 grams), to the mass of the HPS tube (approximately 165 grams), it was considered permissable to mount one accelerometer on the lamp surface, Figure 4. The accelerometer was mounted on the tube surface near the lamp socket. The tube surface temperature here falls within the PCB 312 limitation of 400°F. Also, this location enabled the researchers to discern the vibration transmissibility across the lamp socket. Since the lamp tube is protected from direct wind loading by a glass shield, the socket provides the only means of tube excitation.

HPS tube modal frequencies, both the rigid-body rotational modes relative to the socket and the cantilevered bending modes, are altered least by mass added to the tube surface near the socket. Treating the socket/tube interface as a rotational spring having spring constant k, the rigid-body rotational modes are inversely proportional to the square root of the mass times the distance squared. The bending modes modes for a uniform cantilevered bar are inversely proportional to the square root of the total mass, m, times the distance (length of the tube) cubed (see page 163 of [3]).

Base rigid-body frequency:

$$\omega_r = \sqrt{k/I_r} \tag{1}$$

Cantilevered bending frequencies:

$$\omega_1 = 1.875^2 \sqrt{EI/mL^3} \tag{2a}$$

$$\omega_2 = 4.694^2 \sqrt{EI/mL^3} \tag{2b}$$

$$\vdots$$

$$\omega_i = \text{"determined from frequency equation"}$$

$$(i = 1, 2, \ldots, \infty)$$

I_r, the rotational mass moment of inertia having dimensions $M \cdot L^2$, is distinguished from the I in (2), the area moment of inertia having dimensions L^4. The frequency equation for ω_i is

$$\cos \beta_i L \cosh \beta_i L = -1 \qquad (i = 1, 2, \ldots, \infty) \qquad (3)$$

where $\beta_i^4 = m\omega_i/EIL$.

Approximating the tube shape by a cylinder, it can shown that the PCB 312A mass attached near the tube base reduces the tube's lower natural frequencies by 3% or less, an acceptable amount.

Instrumentation Pre-Test

Luminaire inaccessiblity at most test sites made close proximity of the instrumentation van to the luminaire base impossible. For example, at Site 1 the instrumentation van was located at ground level, fifty feet below the bridge structure upon which the fifty foot high luminaire was mounted, Figure 5.

Concerns relative to signal loss in wiring runs approaching 250 ft. the proper amplifier settings, and the interactions that may occur during blink-out all necessitated an instrumented pre-test. In this pre-test the tip of a partially instrumented luminaire arm was forcefully excited by test personnel elevated from a bucket truck. Periodic impulses were applied in all directions to excite the dominant modes of vibration and to raise vibration levels through resonant amplification. The test results were used to set the instrumentation parameters for Site 1.

Both unimproved and improved* GE LU 400 HPS lamps were used and left on

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*Restricted flow amalgam reservoirs

in the pre-test. Interestingly enough, the unimproved lamp experienced blink-out during a particular excitation mode whereas the improved lamp did not. Blink-out with the unimproved lamp occurred when vertical acceleration levels exceeded 2 peak-to-peak (p-p) and, simultaneously, horizontal impulses were applied down the arm. It is postulated that tube aligned impulses caused the "weightless" amalgam to flow more freely, thereby precipitating the blink-out phenomenon.

After blink-out and during a restart condition, an electrically traumatic period was found to occur, one not documented in GE's electrical data sheets. The primary voltage acquired four spikes per cycles, very short in duration and approaching 1500 V amplitude. The lamp secondary voltage became a sharp-edged, ragged waveform 900 V p-p, far above the 140 V_{rms} (392 V p-p) value specified as the maximum lamp voltage.

Current transients were found similar to the GE lamp specification. The restart phenomenon continued for one or two minutes before the lamp lighted again and all parameters returned to normal.

Amplification and Acceleration Factors

Table 2 lists the amplification factors (A_f)used at the five field sites. Given a 100 mV/g accelerometer sensitivity, the acceleration level factor G_f, in g's per volt, is determined for each site and also listed in Table 2. Modification of the Site 1 A_f values was necessary after examining the Site 1 accelerations. Notably, vertical accelerometers 9 and 10 experienced unexpectedly high g levels. These levels are postulated to result from the shock interaction of the luminaire lamp surface area with upwardly mobile wind vortices that trail rapidly moving semi-trucks. Figure 6 digitally represents one such Site 1 shock recorded by accelerometers 9 and

10. Multiplying the ordinate acceleration magnitude in volts by the Site 1 G_f factor of 2, we determine a maximum pulse magnitude of about 2.2 g for accelerometer 9 and 1.7 g for accelerometer 10.

Table 2 - Amplification Factors (A_f), Acceleration Level Factors (G_f)

	A_f, G_f(g/V) at Sites 1-5			
	Site 1		Sites 2-5	
Accelerometers	A_f	G_f	A_f	G_f
Channels 1-8 (PCB 308B10)	5	2	10	1
Channel 9 (PCB 312A; PCB 421A)	5	2	5	2
Channel 10 (PCB 312A; PCB 421A)	5	2	2	2

TEST RESULTS

Tables 3-7 compile the pulse frequencies of occurrence as distributed over specific g bands at the five test sites. As would be expected, Sites 1, 3 and 5 proved most active for pulse loading whereas Sites 2 and 4 were at locations where vehicle speeds would generally be reduced. Although the luminaire at Site 3 was located on an off-ramp, significant pulses still occurred - see Table 5. This resulted from the entrance location of the luminaire where vehicle speeds are still high.

Comparing these five tables, a direct correlation between pulse severity, measured in terms of g level, and site location (vehicle speed) is evident. Dynamically active sites, like Sites 1 and 5, may be subject to over 100 pulses per week which exceed 1 g in magnitude. Site 1 experienced 14

Table 3 - Site 1 Pulse History

		Pulse Frequency in g Bands			
Period	Time	0.1-1.0	1.0-2.0	2.0-4.0	>4.0
	(Begin: 3-11-82)				
1	Th/F 6:30 pm-6:00 am	19	0	1	0
2	F 6:10 pm-6:00 pm	15	11	4	2
3	F/Sa 6:08 pm-6:00 am	8	3	1	1
4	Sa 6:09 am-6:00 pm	10	7	1	1
5	Sa/Su 6:09 pm-6:00 am	12	6	2	0
6	Su 6:10 am-6:00 pm	15	11	0	1
7	Su/M 6:15 pm-6:00 am	9	5	0	0
8	M 6:10 am-6:00 pm	18	13	5	1
9	M/Tu 6:09 am-6:00 am	8	4	1	0
10	Tu 6:09 am-6:00 pm	10	6	3	0
11	Tu/W 6:08 pm-6:00 am	2	0	0	1
12	W 6:08 am-6:00 pm	13	9	3	2
13	W/Th 6:08 pm-6:00 am	8	5	1	1
14	Th/F 6:09 am-1:46 am	15	7	5	3
15	F 11:30 am-11:27 pm	9	6	5	1
	(End: 3-19-82)				

Table 4 - Site 2 Pulse History

Period	Time	Pulse Frequency in g Bands			
		0.1-1.0	1.0-2.0	2.0-4.0	>4.0
	(Begin: 3-28-83)				
1	M-Tu 2:06 pm-1:44 am	25	0	0	0
2	Tu 1:55 am-1:49 pm	29	0	0	0
3	Tu/W 1:57 pm-1:46 am	31	0	0	0
4	W 1:55 am-1:50 pm	18	0	0	0
	(End: 3-30-83)				

Table 5 - Site 3 Pulse History

Period	Time	Pulse Frequency in g Bands			
		0.1-1.0	1.0-2.0	2.0-4.0	>4.0
	(Begin: 4-25-83)				
1	M-Tu 6:00 pm-6:00 am	23	0	0	0
2	Tu 6:10 am-6:00 pm	40	10	3	0
3	Tu/W 6:10 pm-6:00 am	20	0	0	0
4	W 6:10 am-6:00 pm	42	11	5	0
5	W/Th 6:10 pm-6:00 am	27	0	0	0
	(End: 4-28-83)				

Table 6 - Site 3 Pulse History

		Pulse Frequency in g Bands			
Period	Time	0.1-1.0	1.0-2.0	2.0-4.0	> 4.0
	(Begin: 5-31-83)				
1	Tu/W 6:00 pm-6:03 am	30	0	0	0
2	W 6:25 am-5:55 pm	43	0	0	0
3	W/Th 6:01 pm-6:23 am	40	0	0	0
4	Th 6:31 am-5:55 pm	53	0	0	0
5	Th/F 6:03 pm-6:41 am	45	0	0	0
	(End: 6-3-83)				

Table 7 - Site 5 Pulse History

		Pulse Frequency in g Bands			
Period	Time	0.1-1.0	1.0-2.0	2.0-4.0	> 4.0
	(Begin: 7-5-83)				
2	W 6:21 am-6:00 pm	8	3	2	2
3	W/Th 6:19 pm-6:05 am	4	1	0	1
4	Th 6:25 am-6:00 pm	7	3	2	1
5	Th/F 6:21 pm-6:21 am	5	0	0	1
	(End: 7-7-83)				

pulses over 4 g and one which may have exceeded 10 g had not instrument saturation occurred. In contrast, Sites 2 and 4 were not subject to pulses having magnitudes which exceed 1 g, obviously because the site configuration reduced the nominal vehicle speeds.

These results seem to indicate that vortex-induced pulses are insignificant until vehicle speeds exceed 50 mph. We also postulate that severe pulse levels don't occur until vehicle speeds approach or exceed 60 mph, although the direct correlation of "measured" speed to acceleration level was not made.

Pulse Histograms

Figures 7a)-7d) display 24 h pulse distributions for pulses 0.5 g at Sites 1, 3, and 5. As expected, most activity occurred between 8:00 am and 8:00 pm, with the greatest frequency occurring midday.

Digital Signal Analysis

Digital analysis was performed using a Hewlett-Packard 5423A Structural Dynamics Analyzer. To understand the figures shown, note the following:

1. TI AVG = time history of selected accelerometer signals where:
    - o ABSCISSA = time in seconds
    - o ORDINATE = acceleration level in volts (V)
    - o m = 10^{-3}
2. L SPEC = linear Fast Fourier Transform (FFT) where:
    - o ABSCISSA = frequency in Hz (cps)
    - o ORDINATE = absolute value of signal in volts rms (V_{rms})
    - o MAG = represents ordinate as the FFT amplitude

3. A SPEC = auto spectrum which for random signals is the same as the Power Spectral Density (PSD) where:

o ABSCISSA = frequency in Hz (cps)

o ORDINATE = V_{rms}/Hz (in V_{rms}/Hz if ordinate MAG)

The ordinate level in g, g/Hz, or g^2/Hz can be determined by appropriately multiplying the ordinate values by the G_f conversion values in Table 2.

Site 1

Comparing the accelerometers 9 and 10 time histories in Figure 6, we observe a signal attenuation of about 30% across the HPS lamp socket structure. This attenuation typically ranges from 20-50% for pulses at other times and sites, but may occasionally be greater.

The spectral analyses of this pulse, Figures 8a and 8b, indicate that the trailing vortex interacts with the luminaire arm at lower frequencies and may* excite two primary luminaire modes (12 Hz, 14 Hz). Also apparent in the PSD of Figure 8b is the spike at 7 Hz, a fundamental mode of vibration for the Ship Channel Bridge. A number of frequencies below 5 Hz are excited by the wind vortex as it impacts the HPS lamp chassis, causing a gross, low frequency, vertical displacement of the arm end.

The waveform shapes in FIgure 9 indicate instrument saturation. Nevertheless, the vibration severity demonstrates that vortex-induced pulses can generate g-levels approaching or exceeding 10 g and may last for several seconds.

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*Bridge vibration at 7 Hz may have played the major role in exciting these

Although not shown, accelerometers 1-8 reacted little to the pulse of Figure 9. This indicates that the pulse loading may be unidirectional, often exciting only the vertical motion of the luminaire arm tip.

Figure 10 shows another significant pulse of approximately 8 g, but one much shorter in duration. Note the significant attenuation between accelerometers 9 and 10.

In contrast to the vortex-induced, high g, short-duration pulses of the luminaire arm, the luminaire structure often vibrates or "rings" for extended periods in one or more vibrational modes. Usually at levels less than 1 g p-p, this vibration is precipitated by ambient wind conditions. Two such examples are shown by the 14 Hz mode of vibration in Figure 11 and the dual-mode vibration in Figure 12 (12 Hz, 14 Hz). The rather slow transient in the mean voltage signal from accelerometer 10, Figure 11b, results from HPS bulb temperature variation.

Comparing FFT's of the Figure 12 signal as recorded by accelerometers 1, 6, 9, and 10, see Figures 13 and 14, it appears that the ringing mode represents a 14 Hz cantilevered bending mode of the luminaire mast and arm superimposed on a 12 Hz arm bending mode, but localized to the outer arm region.

Site 2

Because Site 2 was located near the top of an incline, truck speeds were insufficient to generate significant luminaire pulses. Structural ringing like that shown in Figure 11 and 12 occurred frequently, causing lamps vibration levels to approach 1 g p-p.

Site 3

Although located on an off-ramp, the luminaire at Site 3 still experienced significant pulses because of its near entrance location. Here trucks have not yet moderated their freeway speed to ramp speeds. Figure 15 shows that ringing levels can occasionally exceed 1 g p-p.

Site 4

At Site 4 the instrumented luminaire was mounted near midspan on an elevated on-ramp. As at Site 2, vortex induced pulses at the arm end were insignificant. More characteristic of this site was highly random, low-level vibration of the luminaire structure precipitated by passing vehicles exciting the ramp foundation supporting the luminaire, see Figure 16. Spectral analyses show the frequency content of the vibration to be distributed, Figure 17.

Site 5

Site 5 proved as dynamically active as Site 1 - compare Tables 3 and 7. Figure 18 shows a 3 g pulse response similar to that found at Sites 1 and 3. The PSD in Figure 19 again depicts the localized, low frequency nature of the luminaire response. Note the absence of the luminaire modal spikes between 10 and 15 Hz.

DISCUSSION OF THE RESULTS

The vibration environment experienced by luminaire structures results from:

1. Short duration pulses which are caused by the impact of HPS lamps and moving vortices that trail rapidly moving semi-trucks.
2. Periodic, "modal" vibration of the luminaire structure at g levels less than those caused by pulses. Modal vibration can be excited by pulse loading, by a fluctuating ambient wind environment, or by foundation excitation when the luminaire is mounted on a flexible structure such as a bridge.
3. Vibration of the luminaire structure at or near the frequency of a vibrating foundation, such as the bridge vibration of Site 1.

Much of the pulse energy appears to be distributed over frequencies below 5 Hz. This distribution makes shock isolation of the HPS bulb difficult because of its low mass. A more viable approach would incorporate damping into the lamp support structure at the bulb/socket interface. Stiffening the luminaire arm in the vertical direction offers another alternative approach but at great expense.

No lamp failure, breakage, or blink-out occurred at the five sites. But since these tests were of relatively short duration, one must postulate that the lamp failure rate on Texas freeways correlates with vibration levels. We note that half of the lamps tested in [2] structurally failed at levels below 2 g.

In an earlier paper [6], Van Dusen predicted that 5% of luminaires will see g levels that exceed 1 g. This paper failed to recognize the severe pulse excitation of HPS by freeway traffic moving at 55 mpg or greater in close proximity to luminaire structures. Acceleration levels at these locations often exceed 1 g and can approach, possibly exceed, 10 g.

Acknowledgements

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Figure Captions

Figure 1 - Instrumentation

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Figure 3 - Acquiring Pre and Post Ballast Currents

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Figure 19 - Pulse PSD's: Site 5, 7-8-83, Friday, 6:20 am
  a) Accelerometer 9
  b) Accelerometer 10

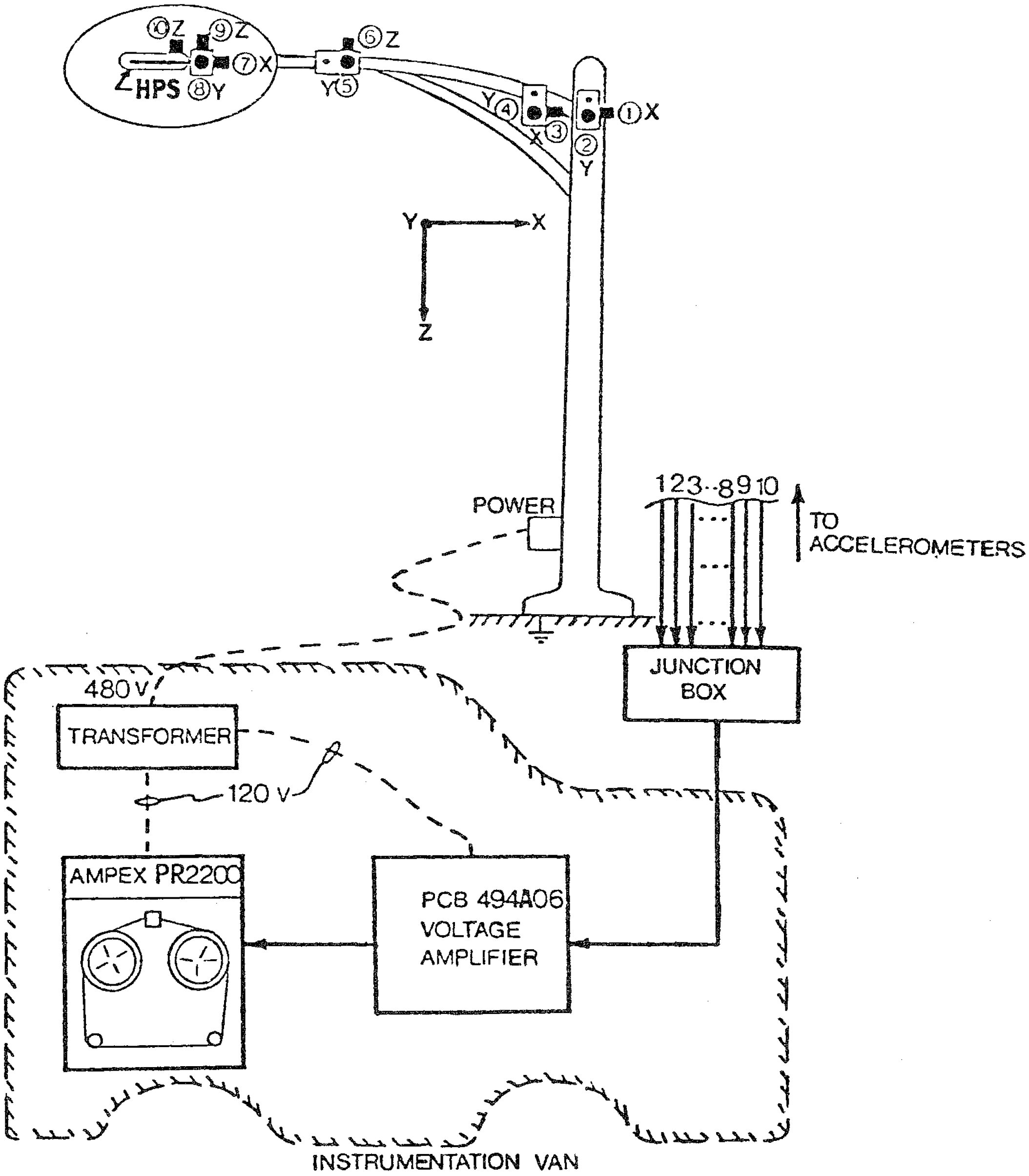


Figure 1 - Instrumentation

Figure 2

Instrumenting Site 4

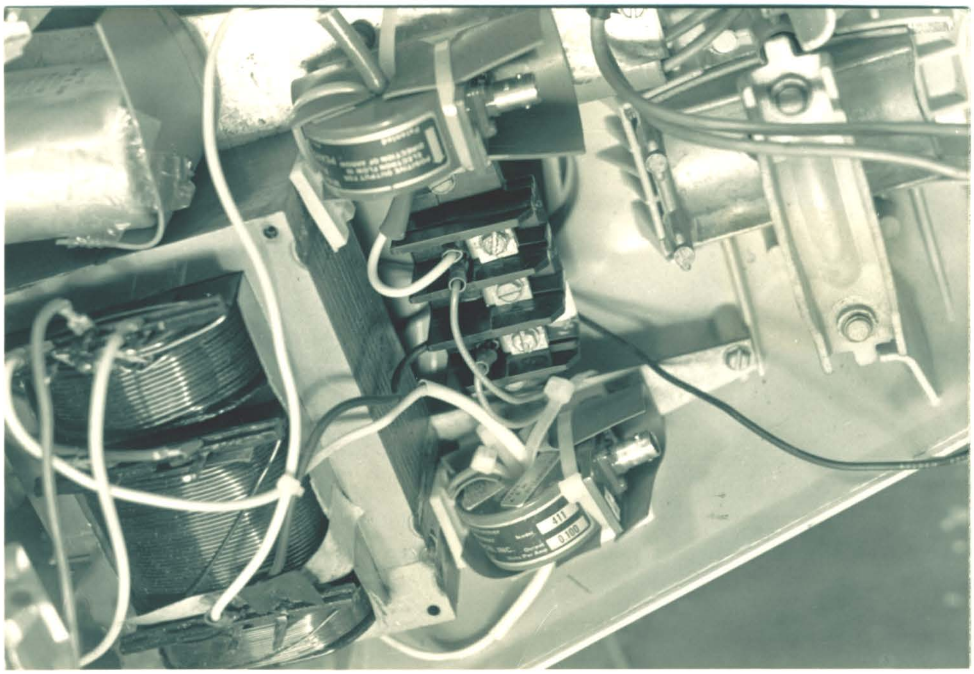


Figure 3

Acquiring Pre and Post Ballast Currents

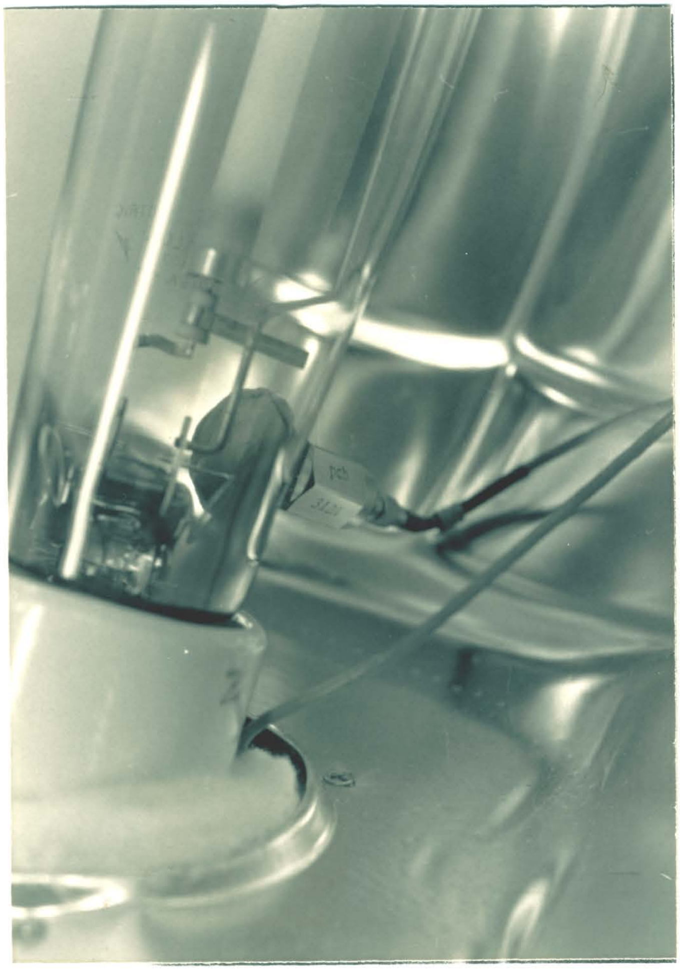


Figure 4

Tube Mounted Accelerometer

Figure 5

Below Bridge Location

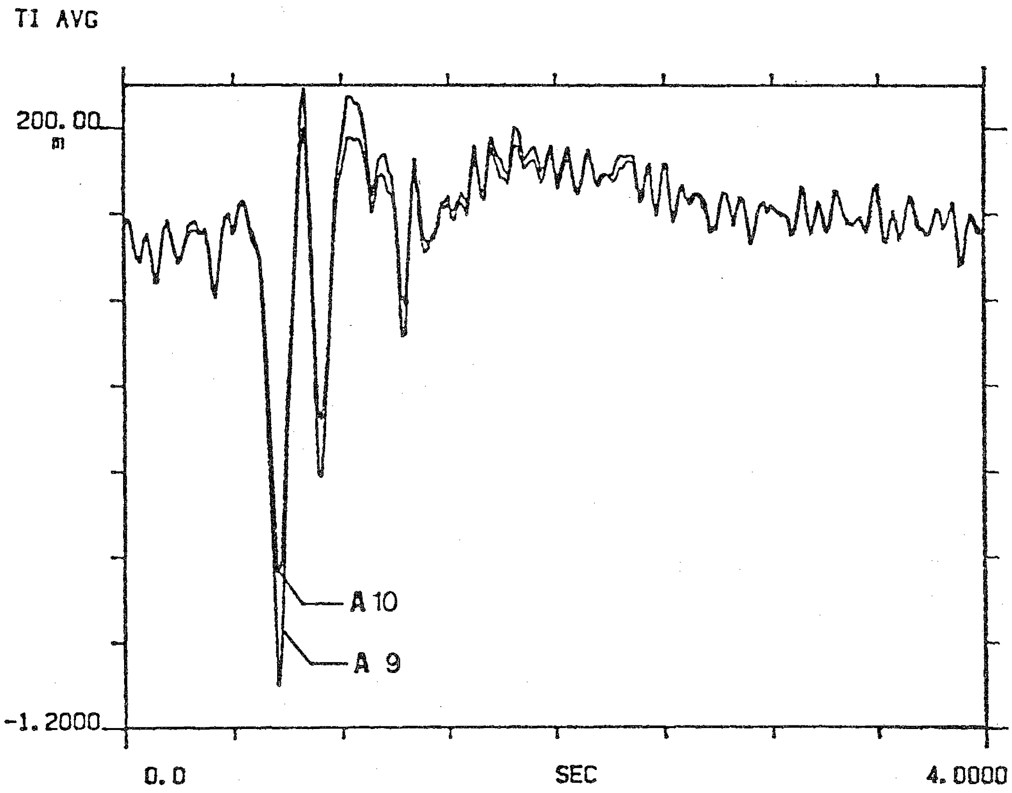
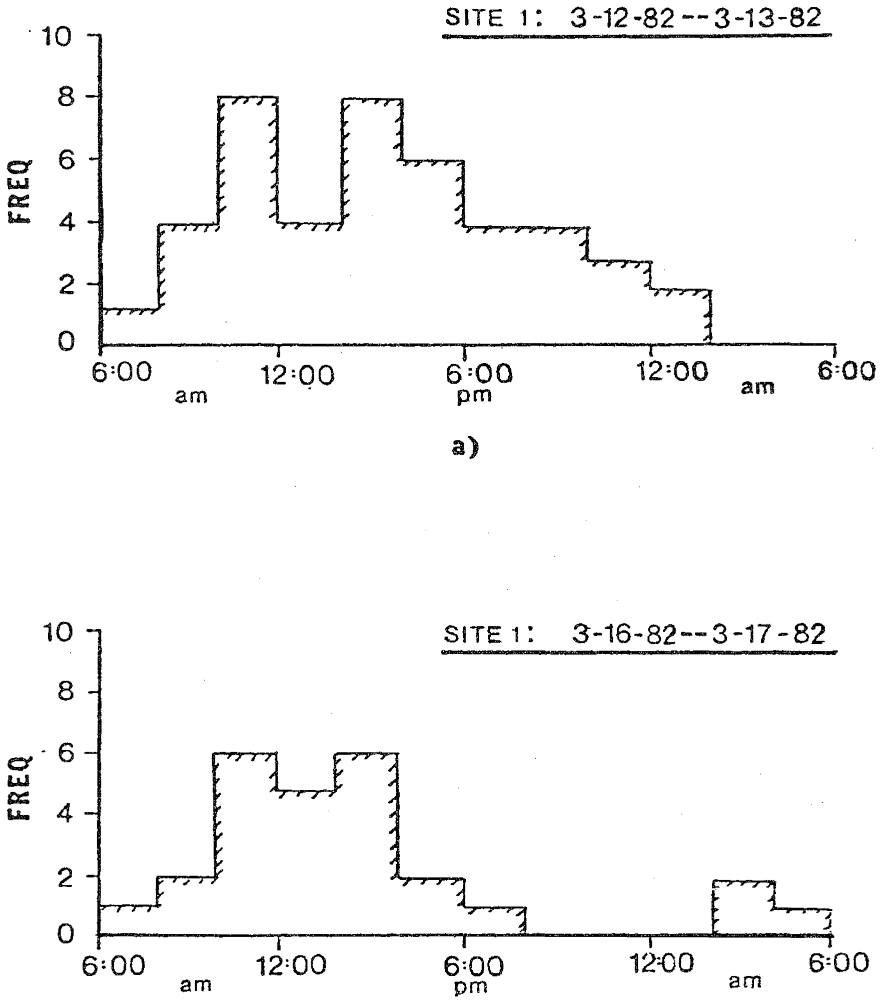


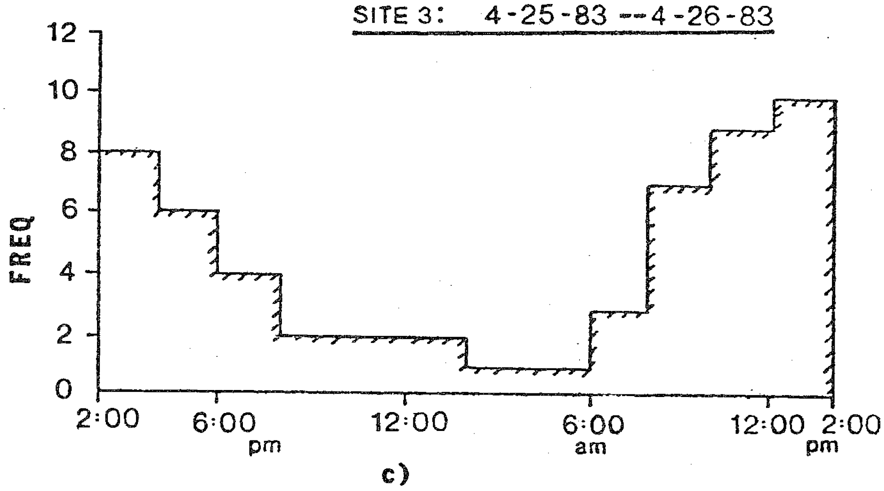
Figure 6 - Accelerometer 9 and 10 Pulses: Site 1, 3-11-82, Thursday, 8:53 pm



a)

b)

Figure 7 - 24 h Pulse Distribution
a) Site 1: Friday/Saturday
b) Site 1: Tuesday/Wednesday



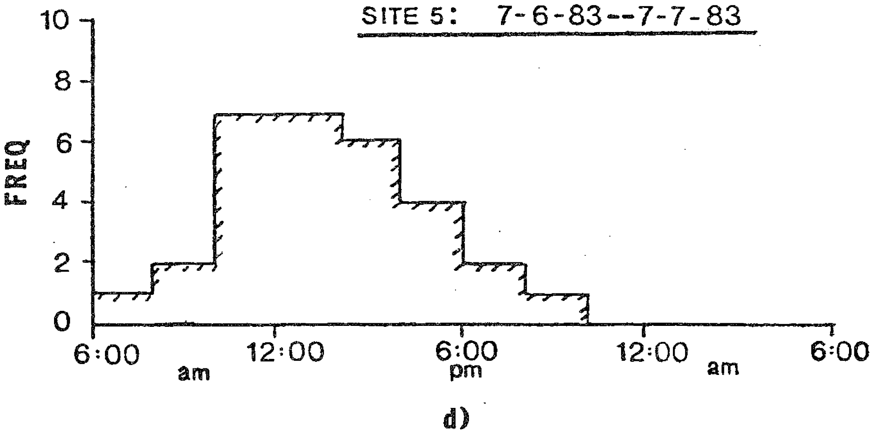


Figure 7 - 24 h Pulse Distribution
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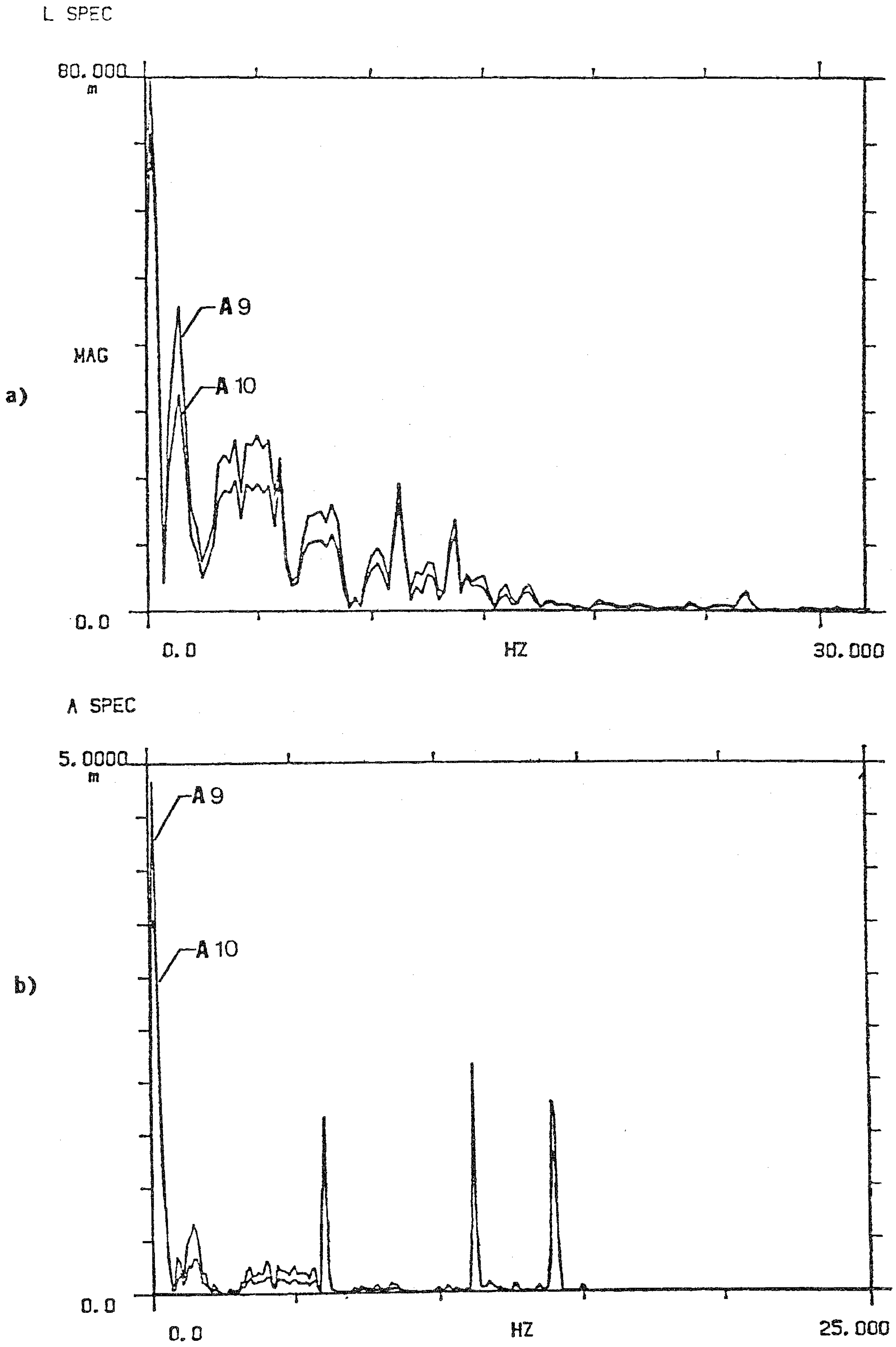

Figure 8 - Pulse Spectra: Site 1, 3-11-82, Thursday, 8:53 pm
a)FFT
b)Auto Spectra (PSD)

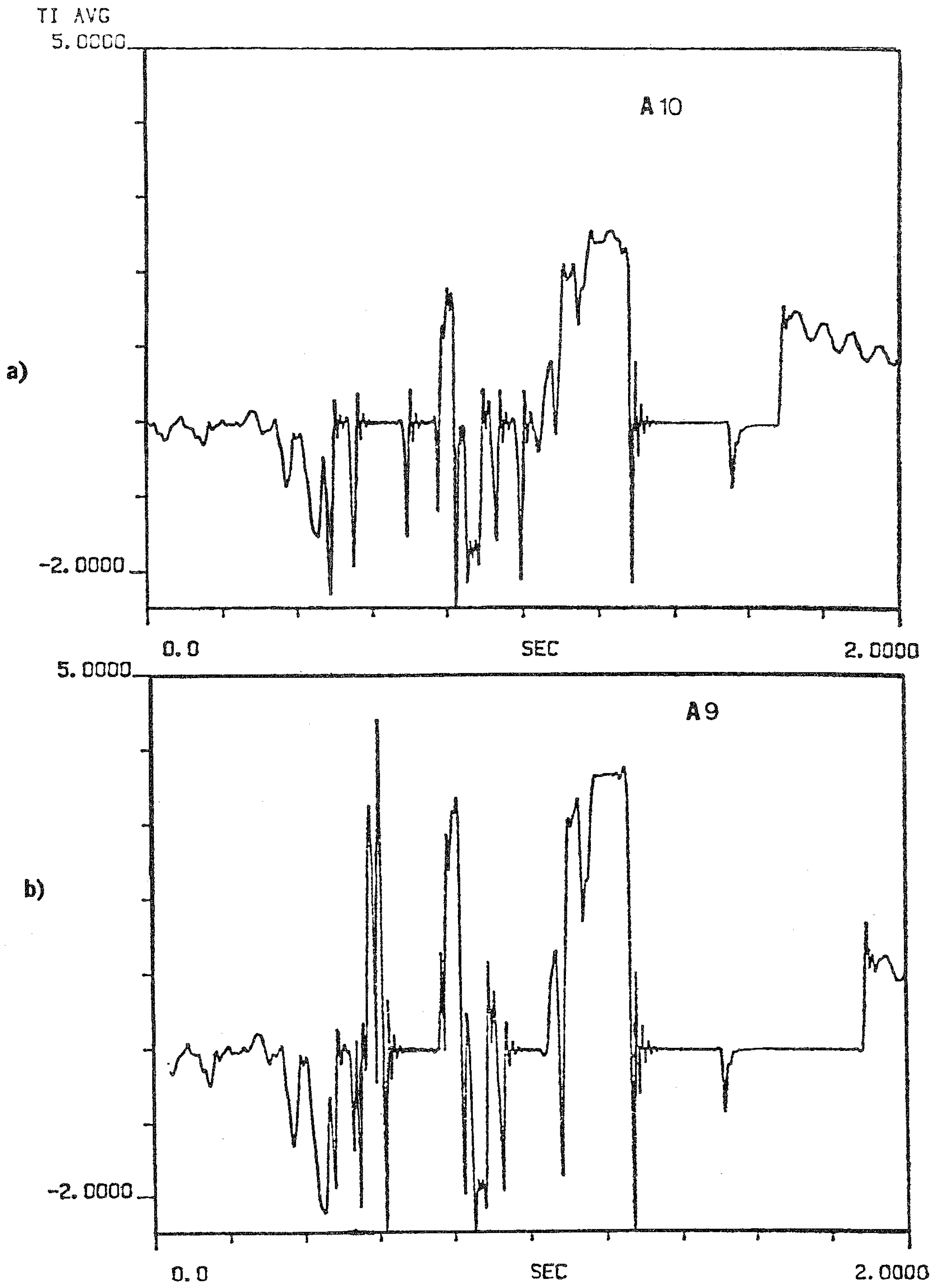

Figure 9 - Pulses: Site 1, 3-12-82, Friday, 11:53 am
a) Accelerometer 10
b) Accelerometer 9

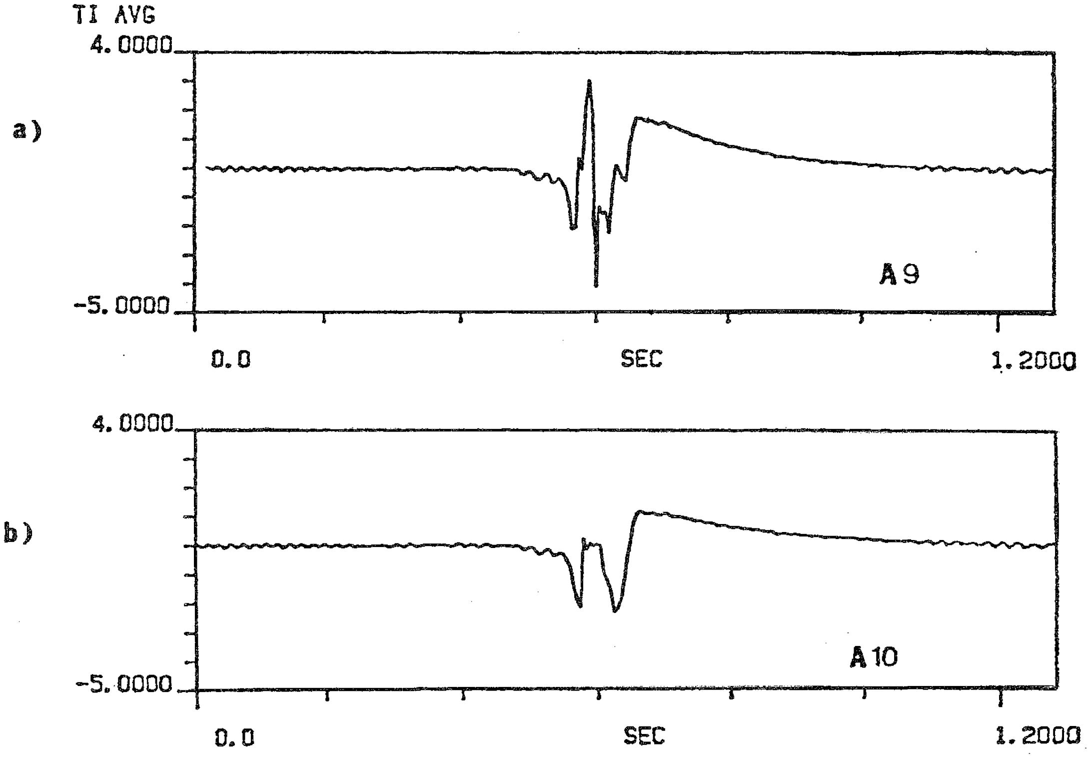

Figure 10 - Pulses: Site 1, 3-12-82, Friday, 4:10 pm
a) Accelerometer 9
b) Accelerometer 10

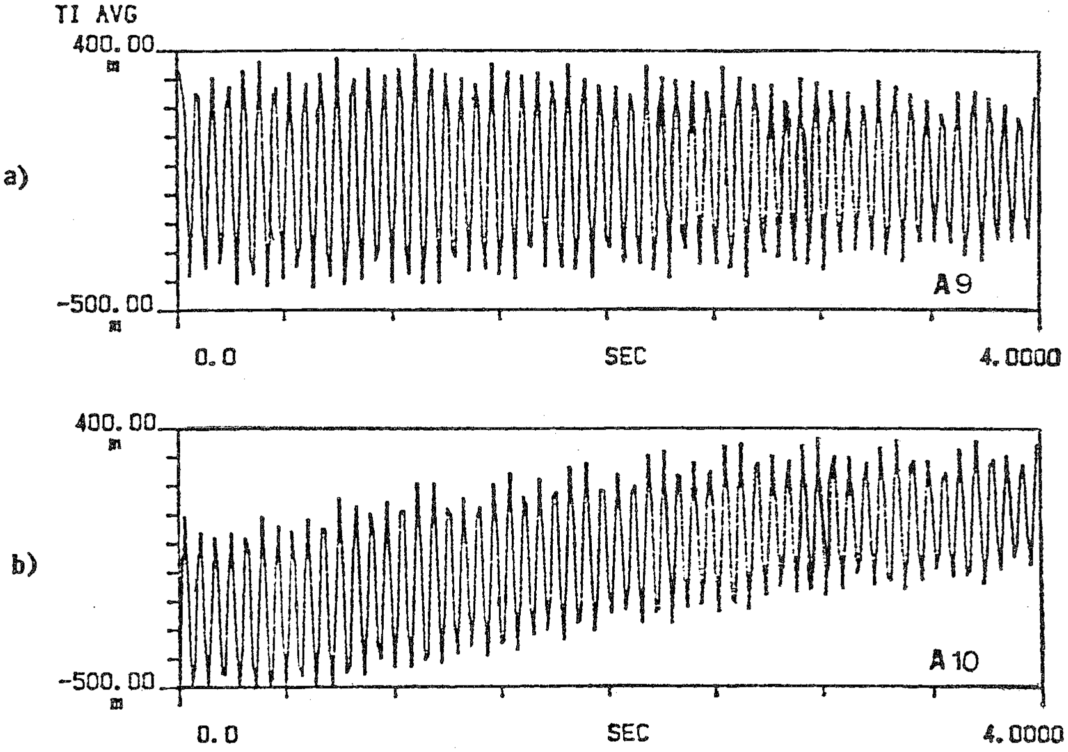

Figure 11 - Ringing: Site 1, 3-14-82, Sunday, 3:29 am
a) Accelerometer 9
b) Accelerometer 10

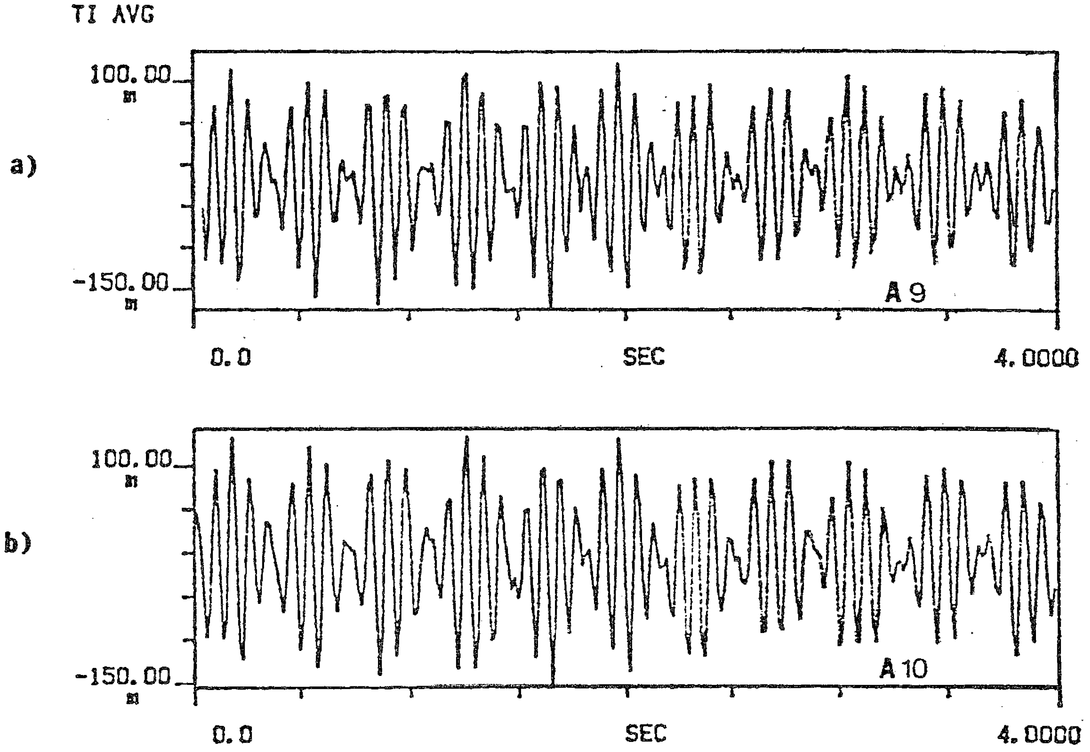

Figure 12 - Dual-Mode Ringing: Site 1, 3-15-82, Monday, 1:52 pm
a) Accelerometer 9
b) Accelerometer 10

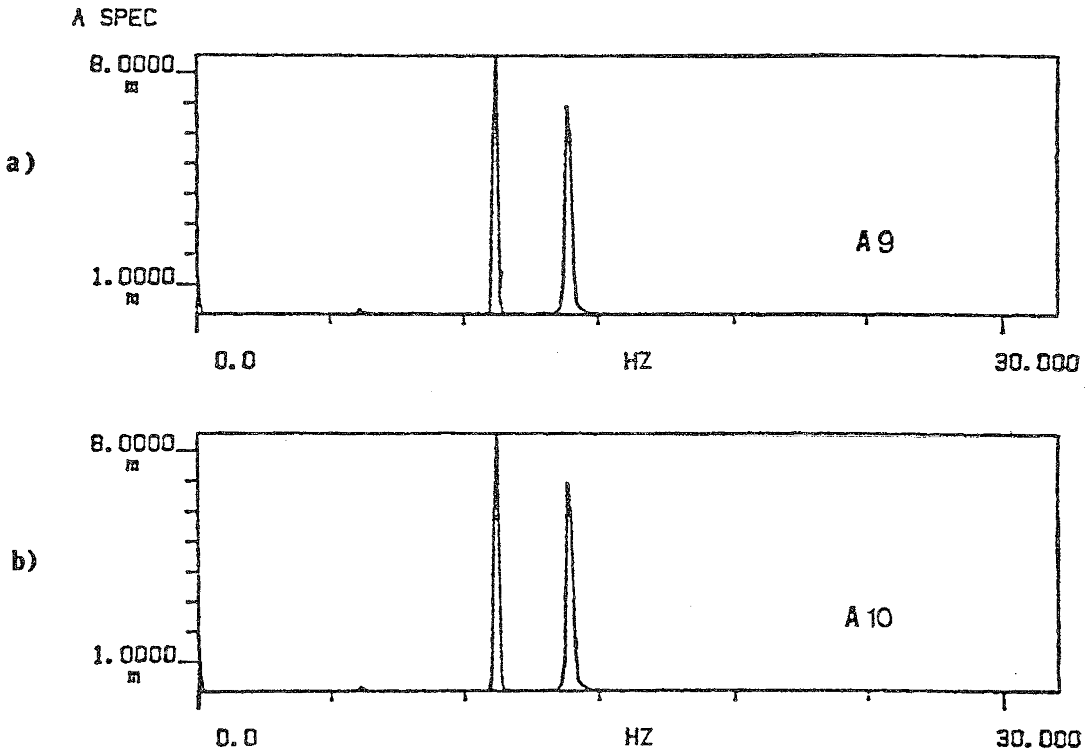

Figure 13 - Dual-Mode PSD's: Site 1, 3-15-82, Monday, 1:52 pm
a) Accelerometer 9
b) Accelerometer 10

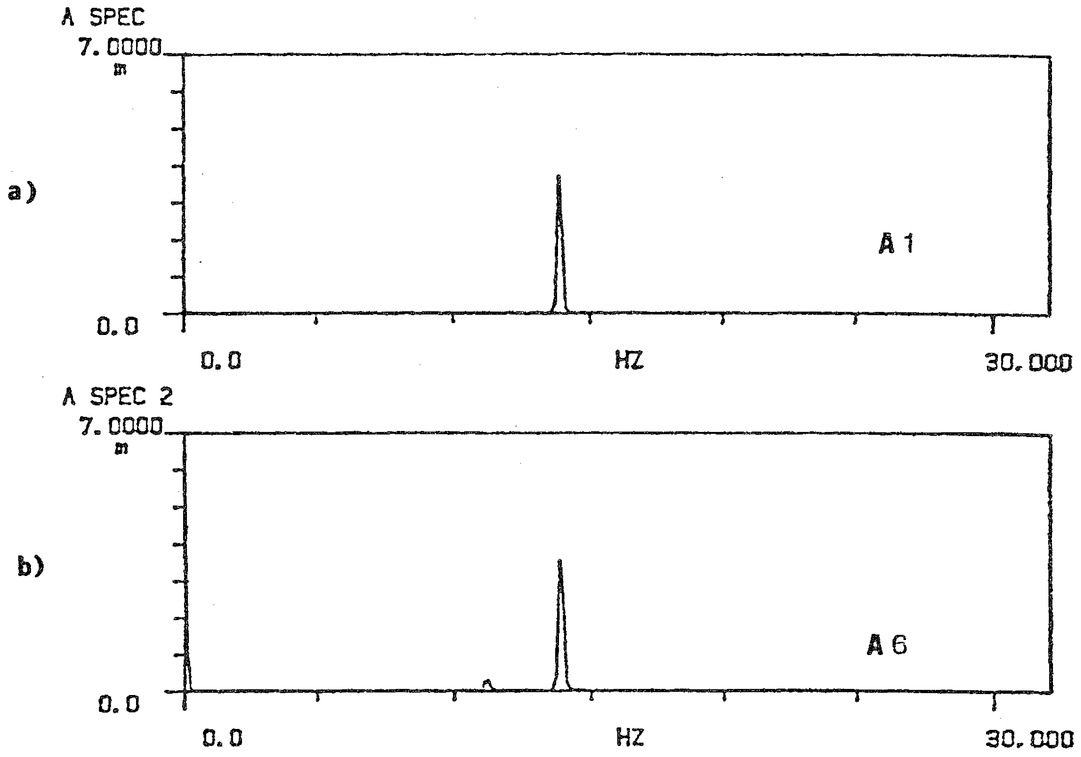

Figure 14 - Dual-Mode PSD's: Site 1, 3-15-82, Monday, 1:52 pm
a) Accelerometer 1
b) Accelerometer 6

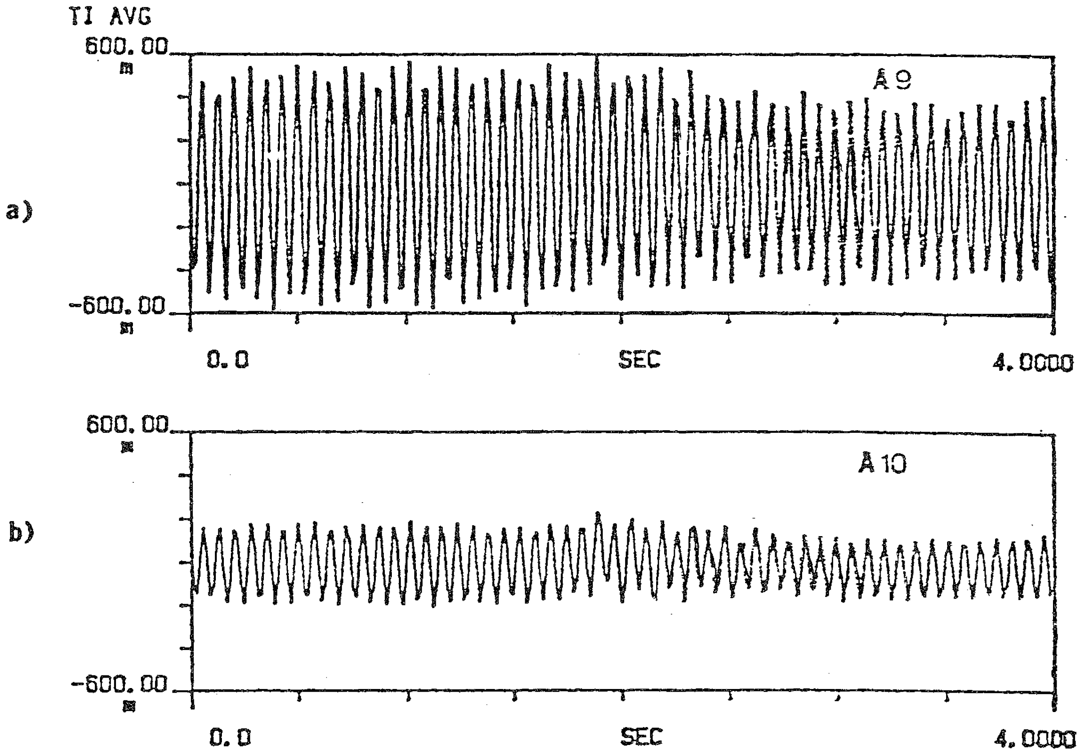

Figure 15 - Ringing: Site 3, 4-26-83, Tuesday, 4:14 am
a) Accelerometer 9
b) Accelerometer 10

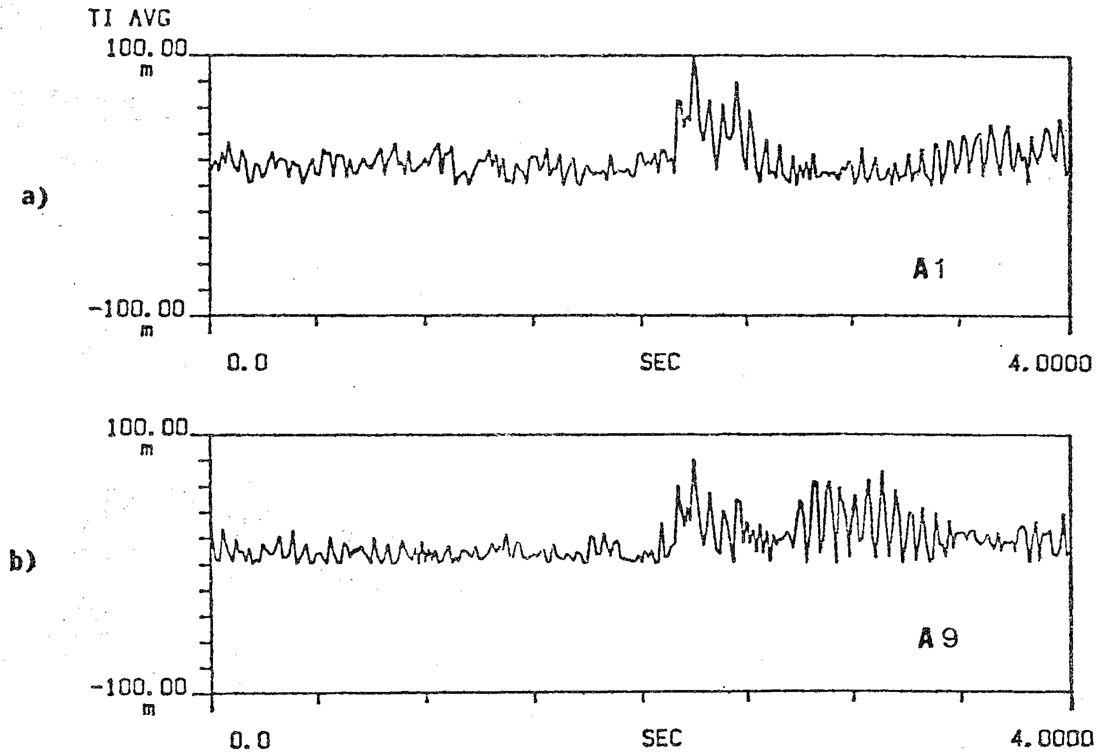

Figure 16 - Typical Time Histories: Site 4, 6-1-83, Wednesday, 6:49 am
a) Accelerometer 1
b) Accelerometer 9

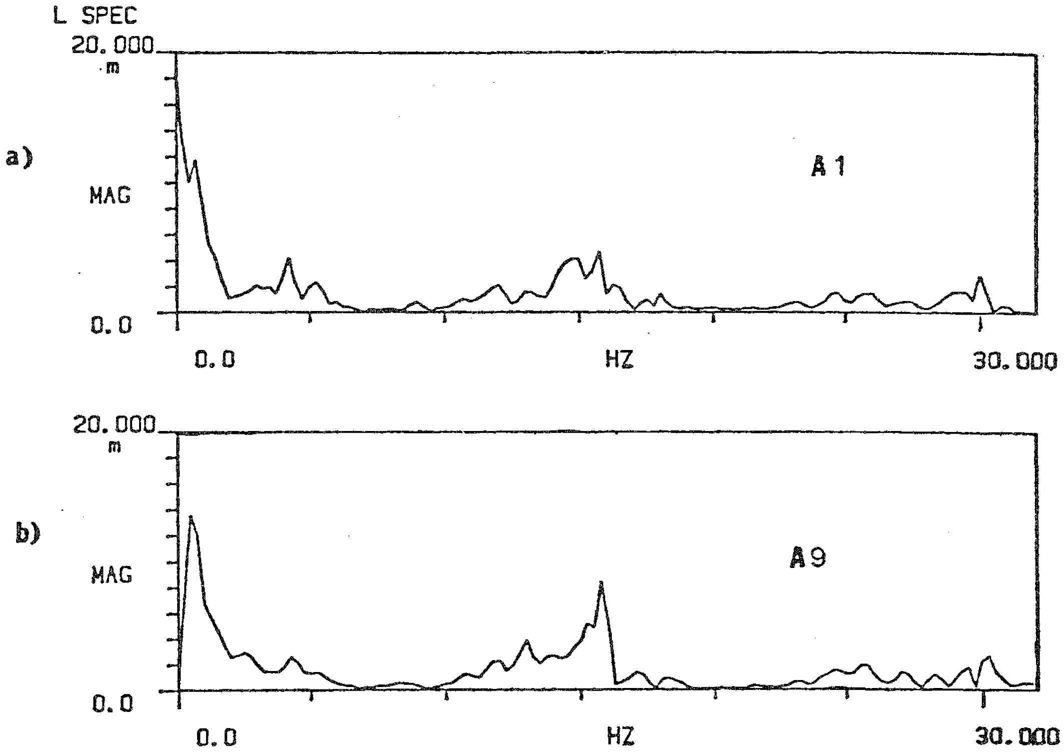

Figure 17 - FFT's: Site 4, 6-1-83, Wednesday, 6:49 am
a) Accelerometer 1
b) Accelerometer 9

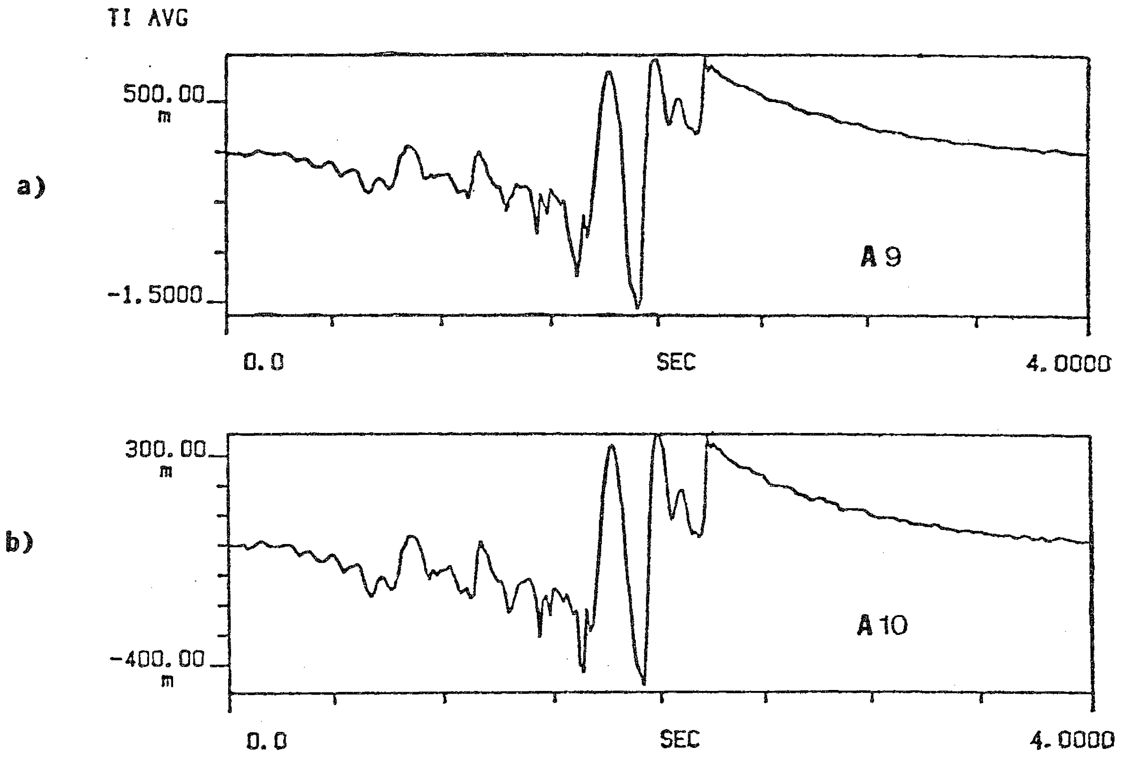

Figure 18 - Pulses: Site 5, 7-8-83, Friday, 6:20 am
a) Accelerometer 9
b) Accelerometer 10

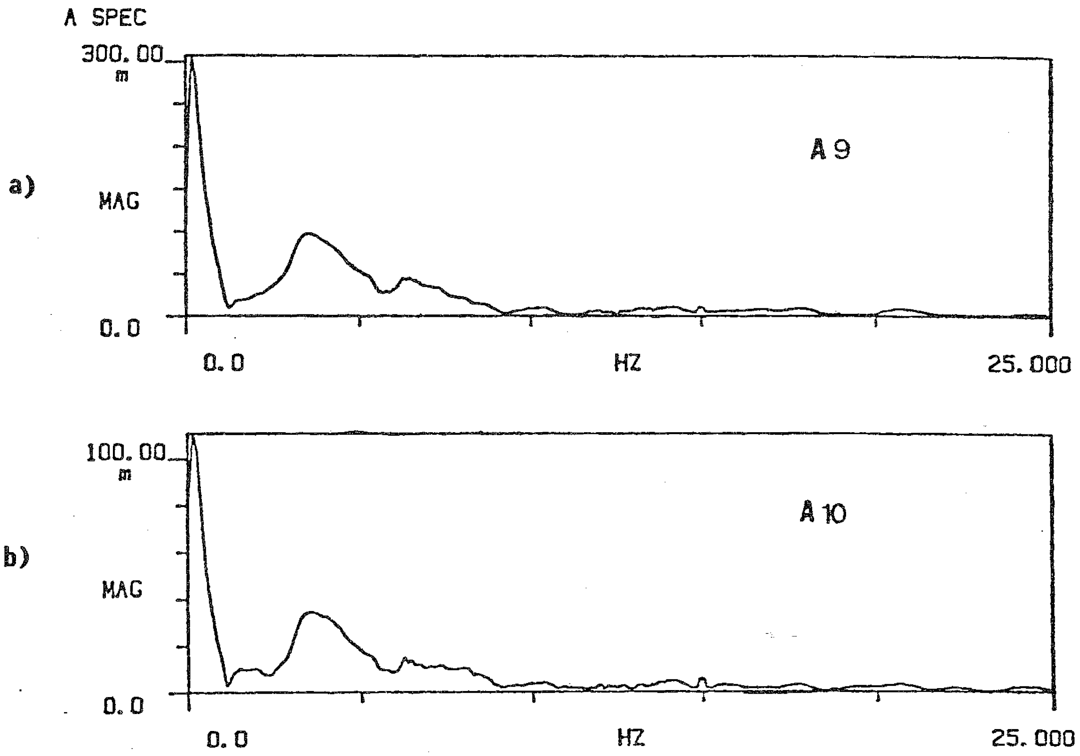

Figure 19 - Pulse PSD's: Site 5, 7-8-83, Friday, 6:20 am
a) Accelerometer 9
b) Accelerometer 10

REPORT B

THE EFFECTS OF VIBRATION ON HIGH PRESSURE SODIUM LAMPS IN ROADWAY LUMINAIRES:

PART I:

OVERVIEW OF THE RESULTS FROM SITES 1-5

The Effects of Vibration on High Pressure Sodium Lamps in Roadway Luminaires:

Part 1:

Overview of the Results from Sites 1-5

Prepared by: W. Edward Red, Mechanical Engineering Dept.
and
Don Russell, Electrical Engineering Dept.
Representing
Texas Transportation Institute
Texas A & M University

Prepared for: Texas State Dept. of Highways
and Public Transportation
Houston Urban Office
Project #22730

Preface

PART I of the liminaire vibration investigation contains primarily an overview of the vibration tests conducted in 1983 at four luminaire field sites in the Houston, Texas area. The site types are correlated with the vibration environment experienced by the luminaire lamps and by the luminaire structure itself. For comparison purposes, reference is often made to the test results from the site 1 tests conducted in 1982.

In general, two dominant modes characterize the vibration environment: 1) a shock environment which causes high, momentary, acceleration levels in the luminaire HPS (high-pressure sodium) lamp structure, including the lamp itself, 2) a structural "ringing" of the luminaire structure as-a-whole. Mode 1 environments may realize vibration levels which significantly exceed 1g whereas the ringing mode amplitudes rarely exceed 1g.

PART II reports shock-spectra analyses conducted on the vibration data. Specific data were selected from among the many pulses recorded on magnetic tape at the four sites identified in the PART I report, and also include data from test 1 conducted in 1982.

Table of Contents

1.0 Introduction

Reference [1], attached to this report in the Appendix, details the problem that precipitated this research project. To summarize, many HPS lamp failures are not traceable to poor installation/maintenance procedures or lack of quality assurance when being manufactured. Rather, some lamp failures were suspected to result from field vibration environments [2].

Tests conducted by HPS lamp manufacturers have demonstrated a functional sensitivity to vibration not previously suspected. In some cases manufacturers redesigned their lamps by modifying the shape of their amalgam reservoir to discourage vibrationally induced flow or by adding internal springs to "shock isolate" the lamp.

This report, PART I of a two-part final report, summarizes the field vibration investigation undertaken in 1983 at four sites in the Houston area. Relevant data from the Site 1 tests are reconsidered for comparison purposes. Although a fifth site was scheduled for testing in 1983, it was cancelled due to tape recorder failure at the site.

1.1 Test Locations

Table 1 identifies the field sites, test durations, and the dates when conducted. Figures 2-5 depict the luminaire configurations and freeway locations at sites 2-5. Note that the durations for tests 2-5, originally scheduled for one day, were extended from one to two days, depending on the site.

Table 1 - Field Test Sites

Site No.	Site Description	Test Duration (days)	Notes
1	South approach to Ship Channel Bridge, site on prestressed unit, approximately 30' from a bent	7	Conducted from 3-11-82 to 3-19-82
2	Ground mounted twin arm pole north of Ship Channel Bridge at Clinton Dr. exit	2	Conducted from 3-28-83 to 3-30-83 Originally scheduled for one day at a luminaire located nearer bridge.
3	Side mounted, ground mounted, single arm pole on ramp from I-10 EB to I-610 EB	3	Conducted from 4-25-83 to 4-28-83. Originally scheduled for one day
4	Side mounted, bridge mounted, single arm pole on ramp from I-10 EB to I-610 SB, pole located at midspan	3	Conducted from 5-31-83 to 6-03-83. Originally scheduled for one day
5	Median mounted pole on I-610 North Loop at T.C. Jester Exit	2.5	Conducted from 7-05-83 to 7-07-83. Originally scheduled for one day
6	Test cancelled due to recorder failure		

2.0 Site Descriptions

The following sections describe the site locations, the vibration environment as recorded on tape, and enumerate other minor problems which occurred at each test site.

2.1 Site 1 - Ship Channel Bridge

Site 1 was discussed in detail in [1]. Figure 1 depicts the luminaire structure and the accelerometer locations. These accelerometer locations were used at each site.

2.1.1 Site 1 Vibration Environment

The vibration environment was more severe than expected and characterized primarily by

1) low g vibration (0.5 g's) of the luminaire structure as a whole caused by bridge base excitation,
2) short duration, high g, vibration due to wind gust loading from the trailing vortices of moving vehicles, probably large semi-trucks (primarily 0.25g's-4 g's),
3) quiescent periods of low g loading interrupted by occasional high frequency vibrational waves pulsing through the luminaire structure at low g amplitudes.

By sampling the tapes it was estimated that, during the daytime period, 25-40 gust load "shocks" occurred in the range from 0.25-1 g's, from 2-5 shocks in the range 1-2 g's, and anywhere from 0-4 vibration shocks greater than 2 g's. Nighttime periods were quieter with the frequency of incidence 25%-75% of that experienced during the daytime periods.

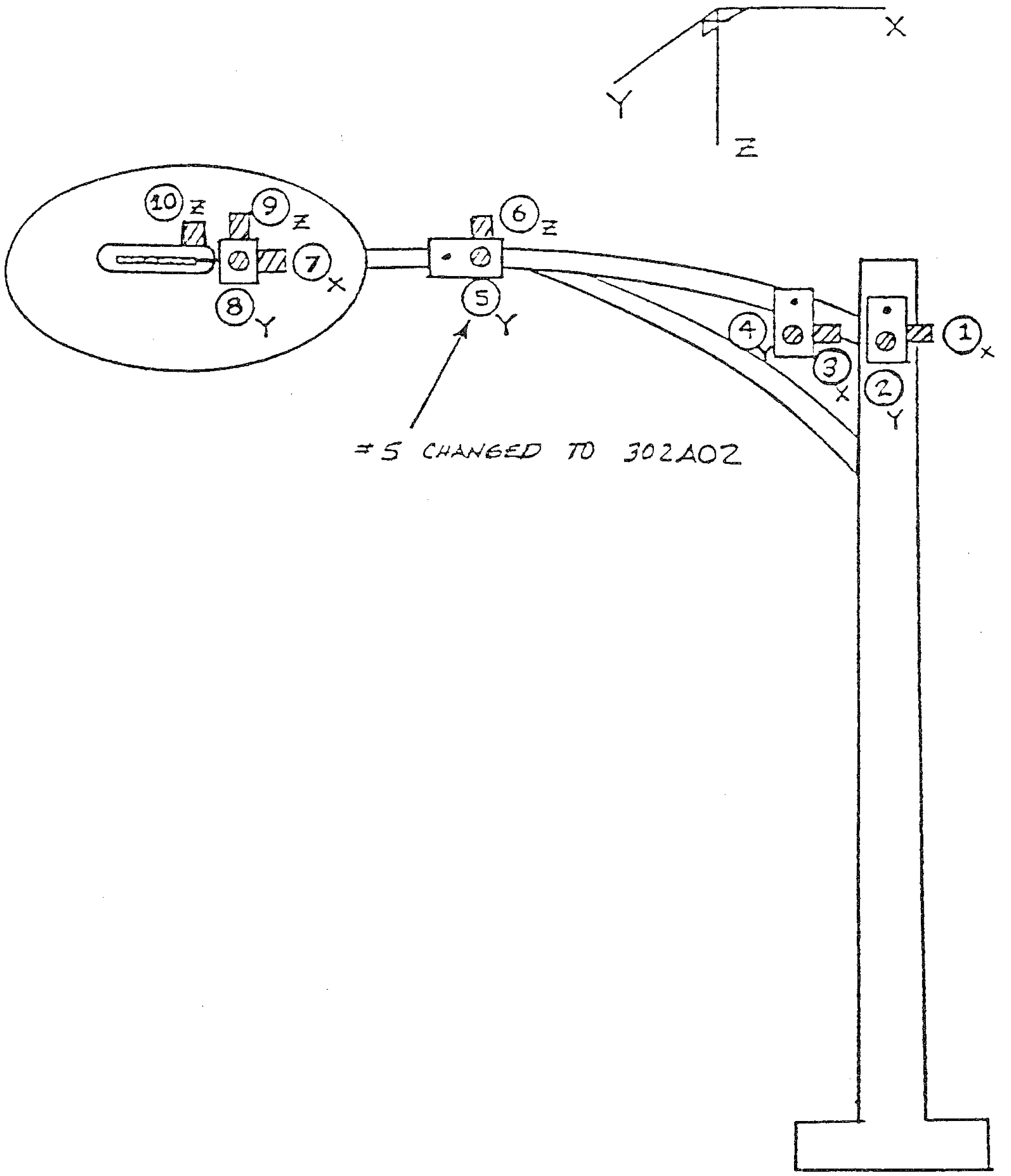

Figure 1 - Luminaire Accelerometer Placements at Site 1

Lamp blink-out was not experienced at Site 1 and thus no relationship of blink-out to vibration severity could be identified.

2.2 Site 2

Figure 2 identifies test Site 2 and the twin arm luminaire, one of which was instrumented according to the accelerometer placements of Figure 1. The Clinton Exit site was used rather than a prefered, more active, site nearer the entrance to the Ship Channel Bridge because the required signal wire length exceeded 300 feet. To get the accelerometer and other monitoring wires to the median, it was necessary to string them across the overhead sign structure, Figure 2.1.

One significant problem developed. The charge amplifier for accelerometer 10, mounted to the lamp surface and used to amplify the vertical accelerations, failed. Consequently, the vertical vibration levels on the lamp surface were not recorded. Because accelerometer #9 mounted on the lamp socket measures quite similar vibration, it was felt that the test should be continued.

The original lamp had to be replaced after test start since it proved defective. Because of the shorter testing period scheduled for sites 2-5, it was decided to keep the HPS lamp on continuously during the testing period. It was hoped that this would increase the chance of recording HPS lamp blink-out and subsequent identification of the coupling of ballast instability to severe or unusual vibration environments. Unfortunately, blink-out did not occur in any of the tests.

Figure 2 - Site 2 Clinton Dr. Exit

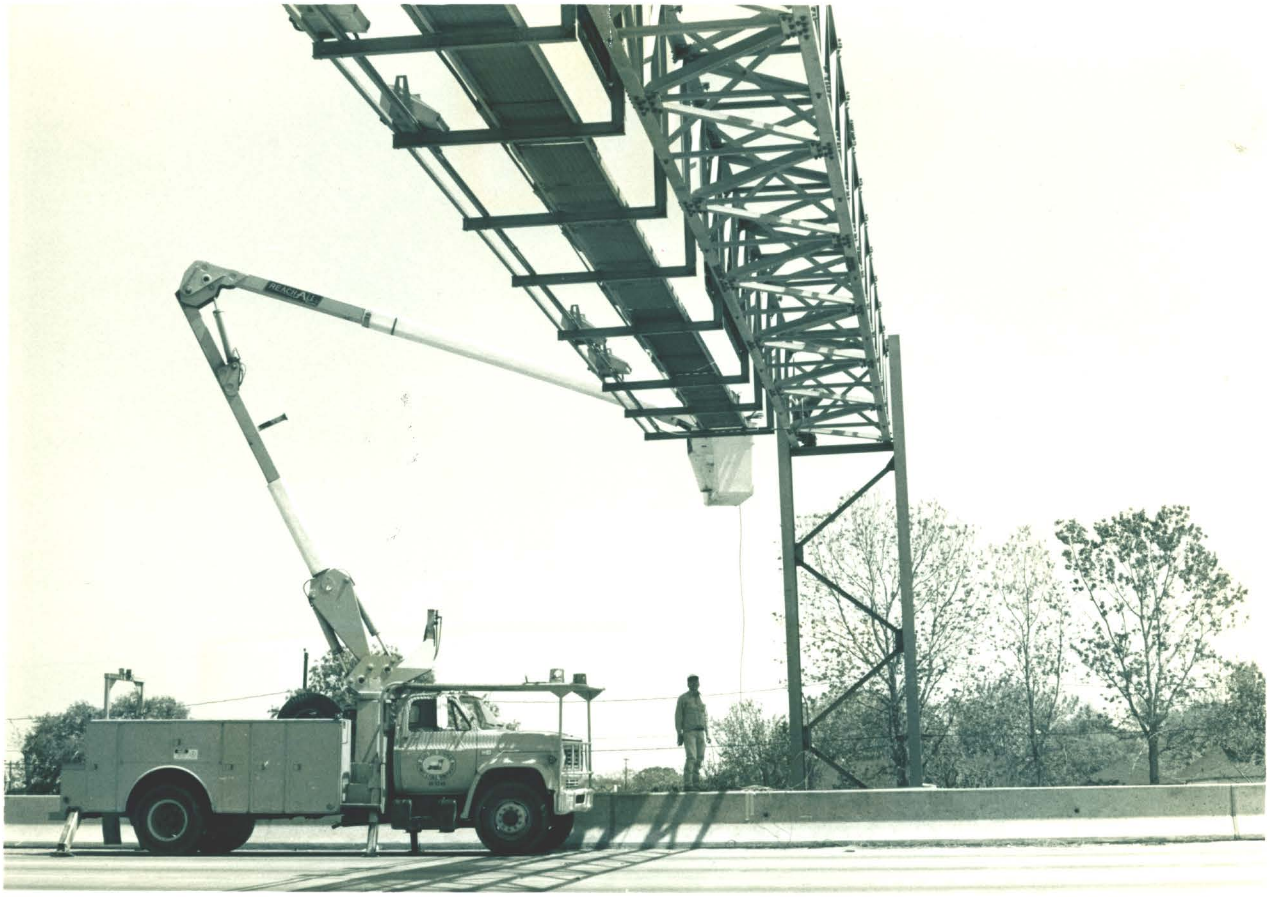

Figure 2.1 - Stringing Cables on the Overhead Sign Structure

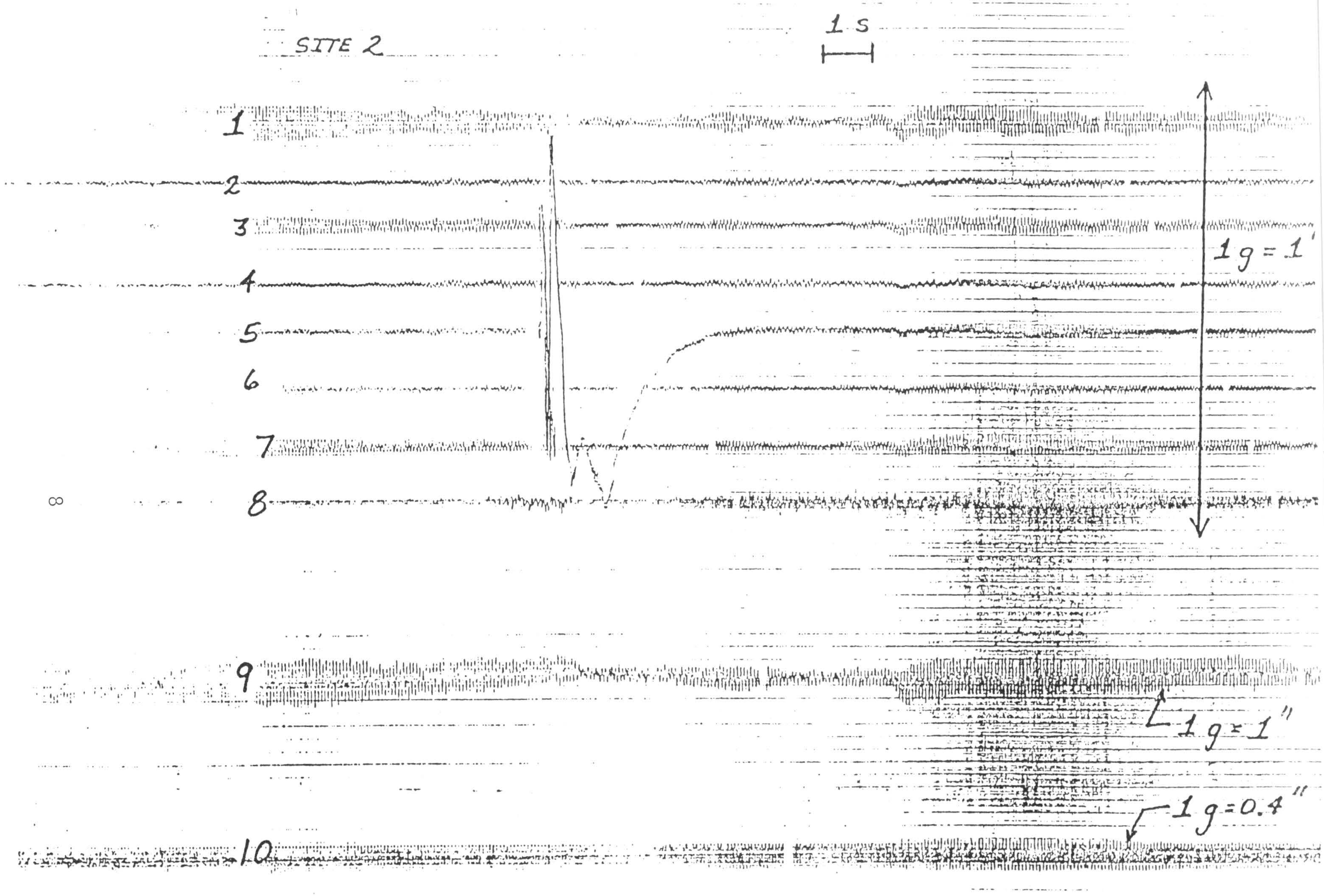

Figure 2.2 - Low-Level Ringing of Luminaire Structure

Figure 3 - Site 3 Ramp Luminaire Pole

Figure 3.1 - Power Connection

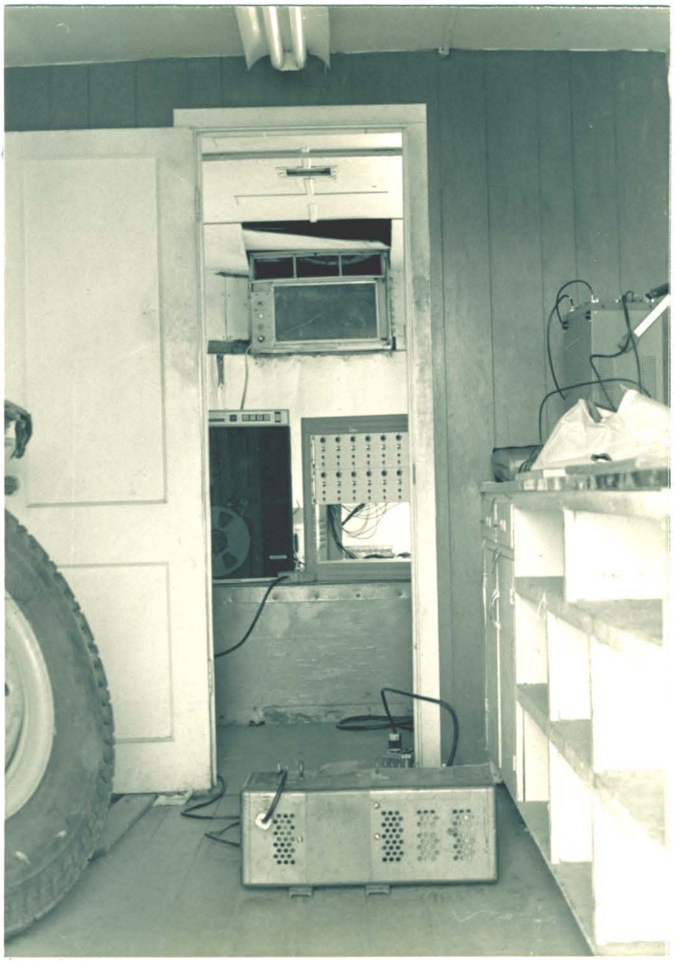

Figure 3.2 - Power Transformer

2.2.1 Site 2 Vibration Environment

A review of the vibration data recorded on tape revealed a quiescent environment having insignificant vibration levels other than low-level "ringing" of the luminaire structure as shown in Figure 2.2 (a ringing frequency of about 14 Hz). This is attributed to the last minute site relocation to a less active site nearer the top of an incline where traffic speeds were reduced.

Also note the significant channel 5 perturbation shown in Figure 2.2. It is felt that this represents an unknown electrical anomaly since other similarly oriented accelerometers did not respond similarly.

2.3 Site 3

Figure 3 shows the ramp located, side mounted, luminaire at Site 3. In this test accelerometer 3 was placed in the accelerometer 9 location and accelerometer 9, a temperature insensitive accelerometer, placed on the lamp surface.

Accessibility to Site 3 proved to be more convenient than previous sites because of its side location. Unfortunately, the test start was delayed considerably due to insufficient voltage levels. Power was taken from the base feed junction for the overhead sign structure, Figure 3.1, located near the luminaire structure. It was necessary to abandon the use of the power transformer, shown in Figure 3.2, and directly connect the amplifiers and Ampex tape recorder to the power source. The voltage levels hovered around 100 V, a marginal level.

2.3.1 Site 3 Vibration Environment

Site 3 experienced few wind shocks, but often experienced substanial ringing at frequencies of about 14 Hz, see Figure 3.3. Similar to the ringing at previous sites, this vibrational mode characterizes the gross vibration of the luminaire as it sways about the mounting base. It is the fundamental mode of vibration caused by gross bending of the column. Amplitudes occasionally reached levels of 1 g peak-to-peak or about 1/2 g in either the positive or negative vertical direction. More specific results are tabulated in the PART II report.

2.4 Site 4

Test 4, the site shown in Figure 4, instrumented a single arm luminaire mounted to the side of a bridge ramp. The instrumentation van was located under the bridge and power delivered by a take-off at the luminaire base, Figure 4.1. As in each of the lastfour shorter duration tests, the lamp was turned on for the entire testing period.

2.4.1 Site 4 Vibration Environment

The vibration environment at Site 4 was characterized by low-level vibration of the bridge structure at about 7 Hz. This background environment was often interrupted by 1/2 g peak-to-peak short duration vibration due to the "impulse" loading of trucks that traversed the bridge, see Figure 4.2. Little excitation of the luminaire fundamental mode of vibration occurred.

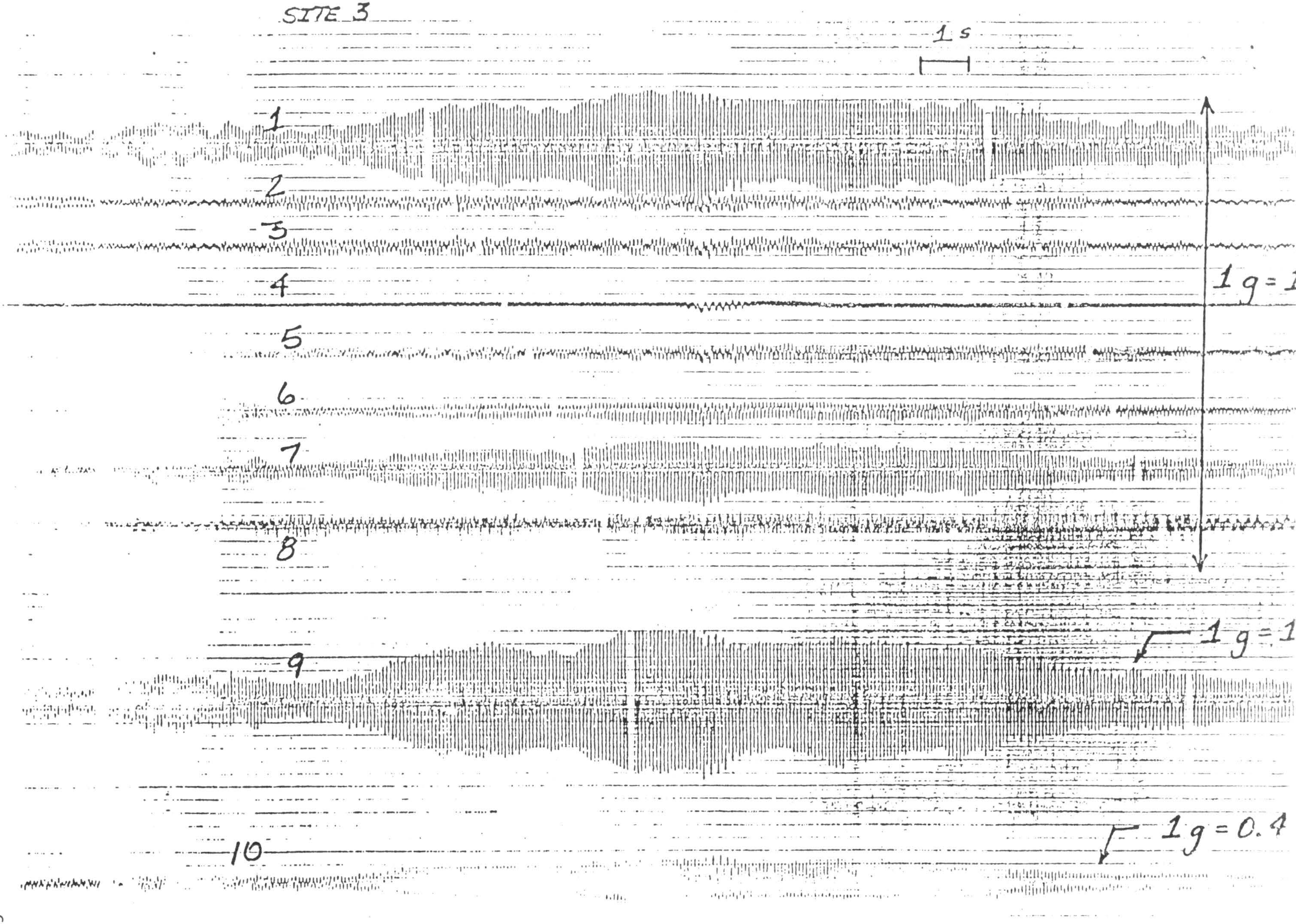

Figure 3.3 - Luminaire Ringing at 1 g Peak-to-Peak

Figure 4 - Site 4 Bridge Ramp

Figure 4.1 Suspended Power and Instrumentation Cables

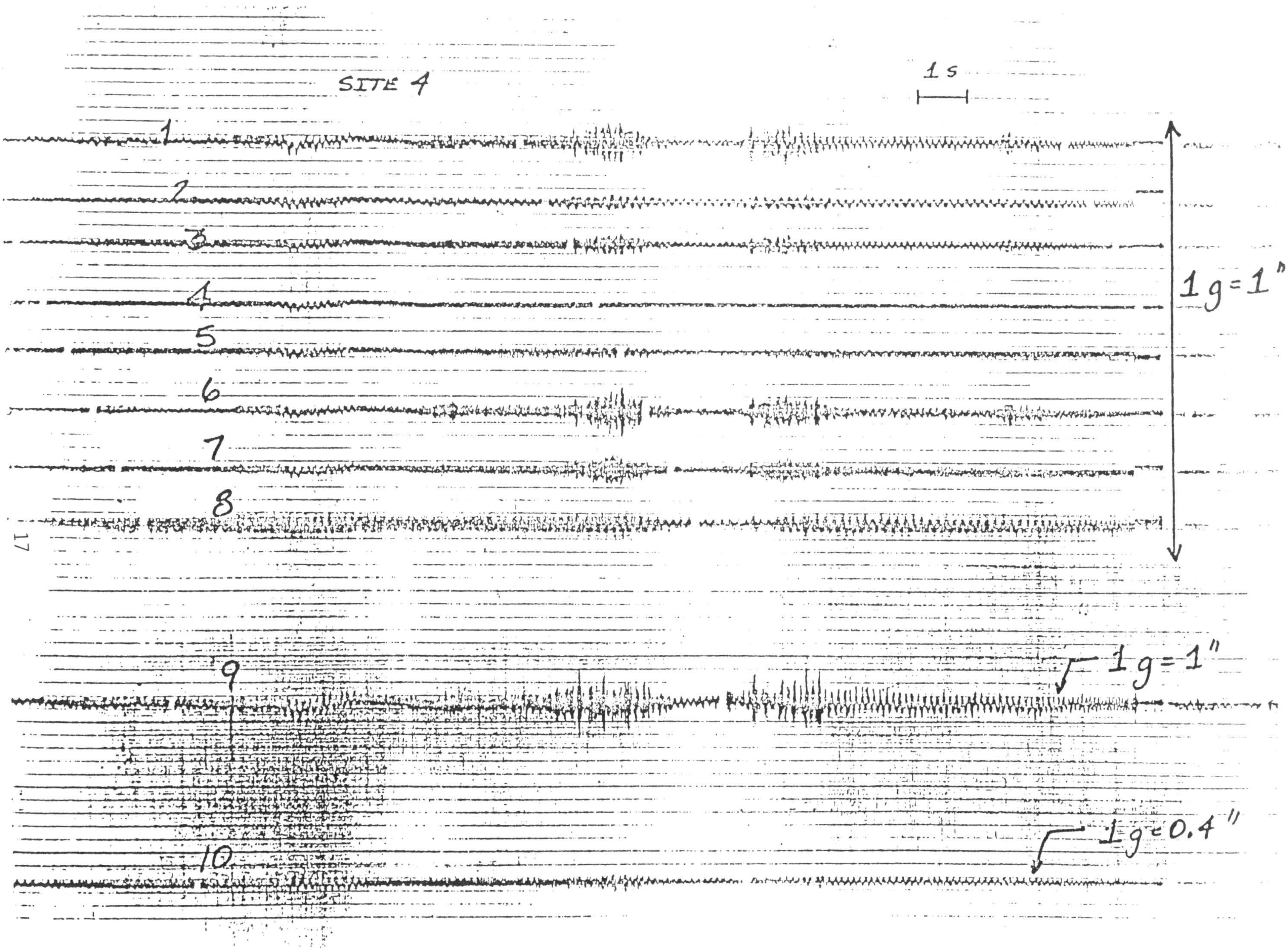

Figure 4.2 - Luminaire Vibration on the Bridge Ramp

2.5 Site 5

Site 5 was a median located, twin arm luminaire structure, Figure 5. In contrast to the traffic patterns at previous sites, the traffic moves at typical freeway speeds, moderated somewhat by traffic congestion. Sites 1-4 were located either at off/on ramps, at the end of a long, moderate incline or after a moderate decline preceeding the ship channel bridge entrance. At Sites 2-4 we postulate that speeds were most often less than 50 mph while at Sites 1 and 5 speeds exceeding 55 mph were not unusual.

2.5.1 Site 5 Vibration Environment

Site 5 proved to be a more active site for wind gust induced vibration of the luminaire arm. Vibrational responses appeared quite similar to those found at Site 1 but at reduced levels. Gust loads up to 3 g's peak-to-peak were not unusual, see Figure 5.1 for one example. More specific results can be found in PART II of this report.

Figure 5 - Site 5 Twin Arm Luminaire

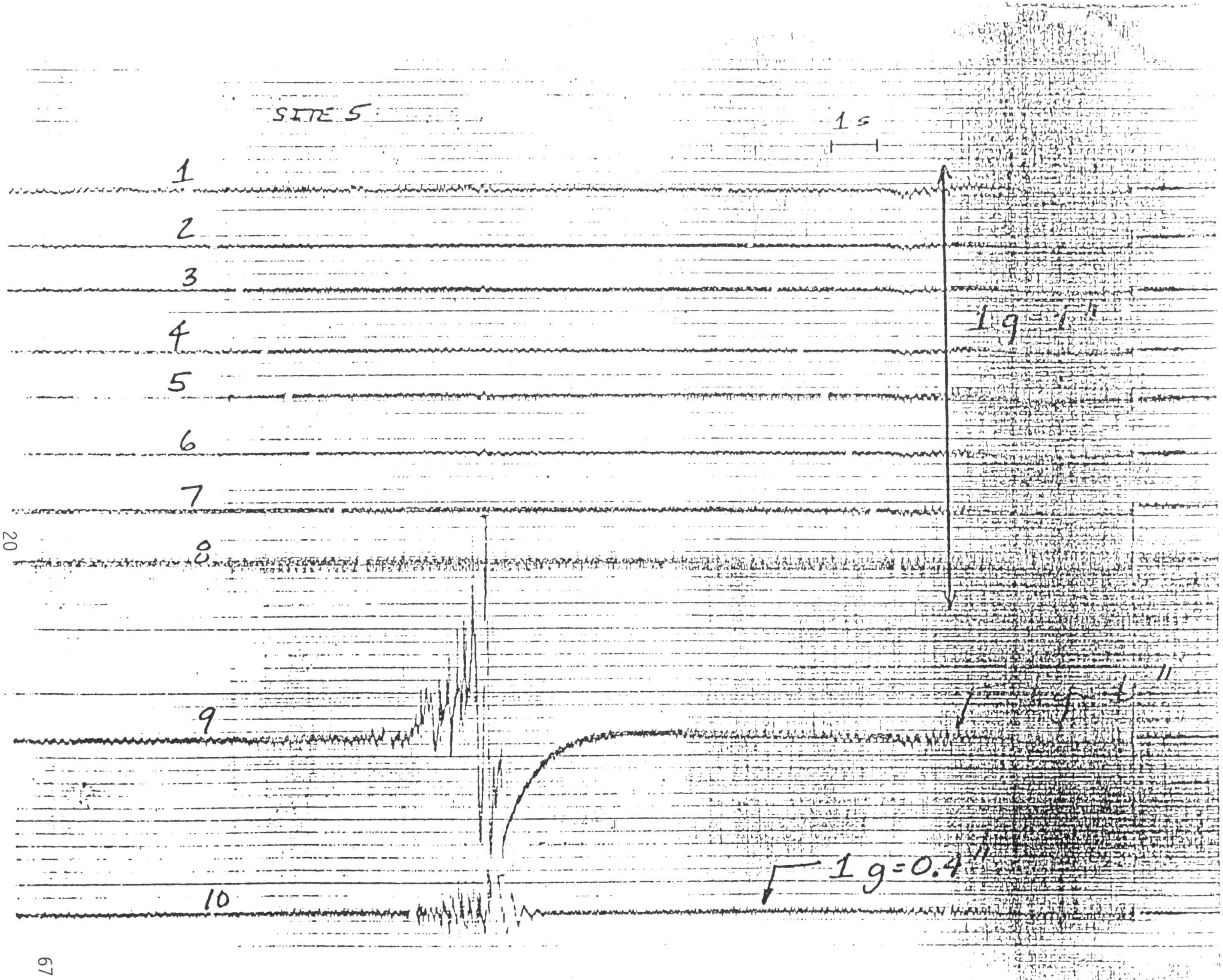

Figure 5.1 - Gust Induced Vibration (approx. 3 g's p-p)

3.0 Conclusions

Specific results pertaining to frequency of occurrence, vibration levels, and frequency content of the vibration environment are found in PART II of this report. More general conclusions are listed and discussed as follows:

1. HPS lamps experience a vibration environment more severe than expected. Wind gust loads are attributed to wind vortices which trail semi-trucks. These can cause accelerations which often exceed 1 g peak-to-peak, occasionally increasing to 10 g's, perhaps even more.

2. Luminaire structures vibrate in their fundamental bending mode but at levels which do not exceed 1 g peak-to-peak in both the horizontal and vertical directions. The typical modal frequency for the luminaires investigated was about 14 Hz.

3. Luminaires located on off/on ramps and other locations which moderate traffic speeds do not experience large, gust-induced vibrations. They may experience luminaire "ringing" of the entire structure or vibrate with characteristic frequencies of the ramp or bridge. Note that the vibration frequencies of both the Ship Channel Bridge and the bridge ramp of site 4 were between 6 and 7 Hz. Luminaires located on bridge ramps may be subjected to higher frequency pulses due to the impulse loading of moving trucks, but acceleration levels are less than 1/2 g peak-to-peak.

4. Wind gust loads are a strong function of site location and the associated traffic speeds. We postulate that semi-trucks traveling at speeds below 50 mph can't generate trailing vortices having sufficient kinetic energy to shock, significantly, the 40' high luminaire lamp. We suspect that it takes truck speeds of greater than 55 mph to induce the significant vibration levels found at sites 1 and 5.

5. No correlation was found between lamp blink-out and the vibration environment at the five sites investigated. Although we choose not to discount any synergistic effects of vibration on ballast instability, it appears that lamp failure may also be attributable to the unexpected severity of the vibration environment.

References

1. Red, W. E., and Russell, Don, The Effects of Vibration on High Pressure Sodium Lamps in Roadway Luminaires: Results of the Field Test Conducted at the I-610 East Loop Ship Channel Bridge Site from 3-11-82 to 3-19-82, Texas Transportation Institute, Texas A & M University, August, 1982.

2. Jones, H. Dexter, Problems Encountered in Three High-Pressure Sodium Lighting Projects in Texas, Report No. 5522.3, Texas State Department of Highways and Public Transportation, Nov., 1980.

Appendix

Site 1 Test Report

THE EFFECTS OF VIBRATION ON HIGH PRESSURE SODIUM LAMPS IN ROADWAY LUMINAIRES

RESULTS OF THE FIELD TEST CONDUCTED AT THE I-610 EAST LOOP SHIP CHANNEL BRIDGE SITE FROM 3-11-82 TO 3-19-82

August, 1982

Prepared by: Edward Red, Associate Professor
Mechanical Engineering Dept. TAMU
and
Don Russell, Associate Professor
Electrical Engineering Dept., TAMU
representing the
Texas Transportation Institute

Prepared for: Texas State Dept. of Highways
and Public Transportation
Houston Urban Office
Project # 22730

PREFACE

This report summarizes the results of the field site test conducted to gather luminaire vibration and ballast circuit data at the I-610 east loop ship Channel Bridge site from 6:00 pm Thursday, 3-11-82 to 11:30 pm, Friday, 3-19-82. In addition results and observations from the test procedures evaluation test conducted on October 2, 1981 are discussed in light of the field site test results. These tests were conducted in the hope that the test data might reveal the sources of early failure in the luminaire high pressure sodium lamps at many highway locations and lead researchers and manufacturers to a better understanding of the environment experienced by highway luminaires.

TABLE OF CONTENTS

1.0 INTRODUCTION

Early failures of high pressure sodium (HPS) lamps are occurring at a number of roadway lighting installations, both in the state of Texas and elsewhere. In response to a request made by representatives of the Texas State Department of Highways and Public Transportation (SDHPT) for technical assistance with this problem, the Texas Transportation Institute (TTI) and SDHPT entered into an agreement by which field site vibration tests would be conducted at specific sites to acquire data which will describe the operational environment of highway luminaires, see [1]*

This report contains the results of the first field site test conducted at the I-610 ship channel Bridge during a scheduled 7-day testing period. In addition, the results from the instrumentation evaluation test conducted on October 2, 1981 are presented and compared, where appropriate, to the 7-day site test results. This evaluation test was conducted to verify instrumentation capabilities, identify unexpected problems and select measurement ranges for the March test.

1.1 Historical Background

An interesting historical background of the problems encountered in three Texas HPS lighting projects is contained in [2]. Basically this report details the events which precipitated this project. All three lighting projects experienced difficulty in maintaining the highway lighting integrity.

Since the inception of these projects, lamp outages and problems with starter boards and ballast have occurred on a regular basis. Some problems were traced to poor installation/maintenance procedures while others related to poor quality assurance in the manufacture of the HPS lamps used. Nevertheless many lamp failures occurred which could not be blamed on these deficiencies but rather to an environment in which luminaire vibration precipated lamp failure.

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* Brackets denote references

General Electric (GE), Sylvania, and ITT, manufacturers of the HPS lamps used in these three lighting projects, admitted that significant vibration could cause their lamps to "blink-out" (blink-out is a HPS ballast control instability detrimental to the life of HPS lamps). GE, in the interim period, redesigned their lamp by modifying the shape of their amalgam reservoir, and conducting laboratory vibration tests to demonstrate improved vibration insensitivity. Redesign did not appear to eliminate GE's lamp sensitivity to vibration. In addition, some of the vibration tests used to simulate the field environment had suspect relevance to what was actually being experienced by luminaires in the field.

1.2 Project Objectives

In the original proposal, the project objectives were established to minimize the overall costs associated with the testing and evaluation program and to maximize understanding of the lamp failure problem. The objectives which follow place the field tests into the role of providing representative environmental data.

Project Objectives

1. Install vibration-measuring instruments on selected existing roadway lighting to measure amplitude and frequency of lamp vibration over selected measurement periods. Monitor the ballast control system, including primary and secondary sides.
2. Analyze data to determine the acceleration levels and the frequency content of the luminaire vibration time histories. Correlate this with the response of the ballast control system (if there appears to be some coupling present).
3. Precipitate the lamp failure mode, if necessary, by impacting the base of the luminaire and by investigating the resulting time history relationships between the vibration and electrical control circuit.

1.3 Scheduled Tests

This report describes the data acquired from the first of the six field sites identified as follows. At site 1, data was recorded for 7 nearly continuous twenty-four hour days. The remaining five tests to be conducted at sites 2-6 will acquire data for a continuous 24 hour period at each site.

Table 1 - Field Test Sites

Site No.	Site Description	Test Duration
1	South approach to Ship Channel Bridge. Site is on prestressed unit, approximately 30 feet from a bent.	7 days
2	Ground mounted twin arm pole on north end of ship channel bridge	1 day
3	Side mounted, ground mounted, single arm pole on ramp from I-10 EB to I-610 EB	1 day
4	Side mounted, bridge mounted, single arm pole on ramp from I-10 EB to I-610 SB, pole located approximately at midspan.	1 day
5	Median mounted pole on I-610 North Loop at M.K.T.R.R.	1 day
6	First pole west of I-610 North Loop and I-45 North Freeway Interchange. This is a gull-wing pole that is to be refitted with new HPS Westinghouse fixtures (existing fixtures are ITT mercury).	1 day

* - As specified by SDHPT in [3].

2.0 INSTRUMENTATION EVALUATION TEST

On Friday, October 2, 1981, we conducted a series of tests to evaluate the test procedures and equipment that were planned for the first field site test. The tests were conducted on a luminaire erected at the TAMU Research Annex so that the vibrational environment could be simulated and monitored. Results of this evaluation test are briefly summarized in [4].

2.1 Objectives

The primary objectives of the evaluation tests were to:

1) check the instrumentation arrangement and data acquisition procedures.
2) insure that the instrumentation would pick up the vibration and ballast signals with cable lengths of 250-350 feet.
3) determine lamp directional sensitivities to vibration and project the expected vibration ranges.
4) determine whether an accelerometer mounted to a vibrating and high temperature sodium lamp would remain bonded.
5) identify any unexpected problems.

2.2 Instrumentation

The proposal [1] calls for 10 accelerometers, Figure 1, to be distributed on the luminaire structure: two on the mast, four on the arm, two on the lamp base and two on the lamp itself. In addition, primary voltage and current to the ballast are to be monitored along with the lamp (secondary) voltage and current. The 14 channels of data are to be recorded on a 14-channel Ampex PR 2200 tape recorder capable of tape speeds from 15/16 ips to 60 ips, Figure 2. Operating instructions and calibration procedures for this tape recorder are included as Appendix A.

For the evaluation test, only 12 channels of information were monitored since one accelerometer was mounted to the lamp instead of two as originally planned and the primary voltage across the ballast was not monitored, see Table 1 - in Appendix B.

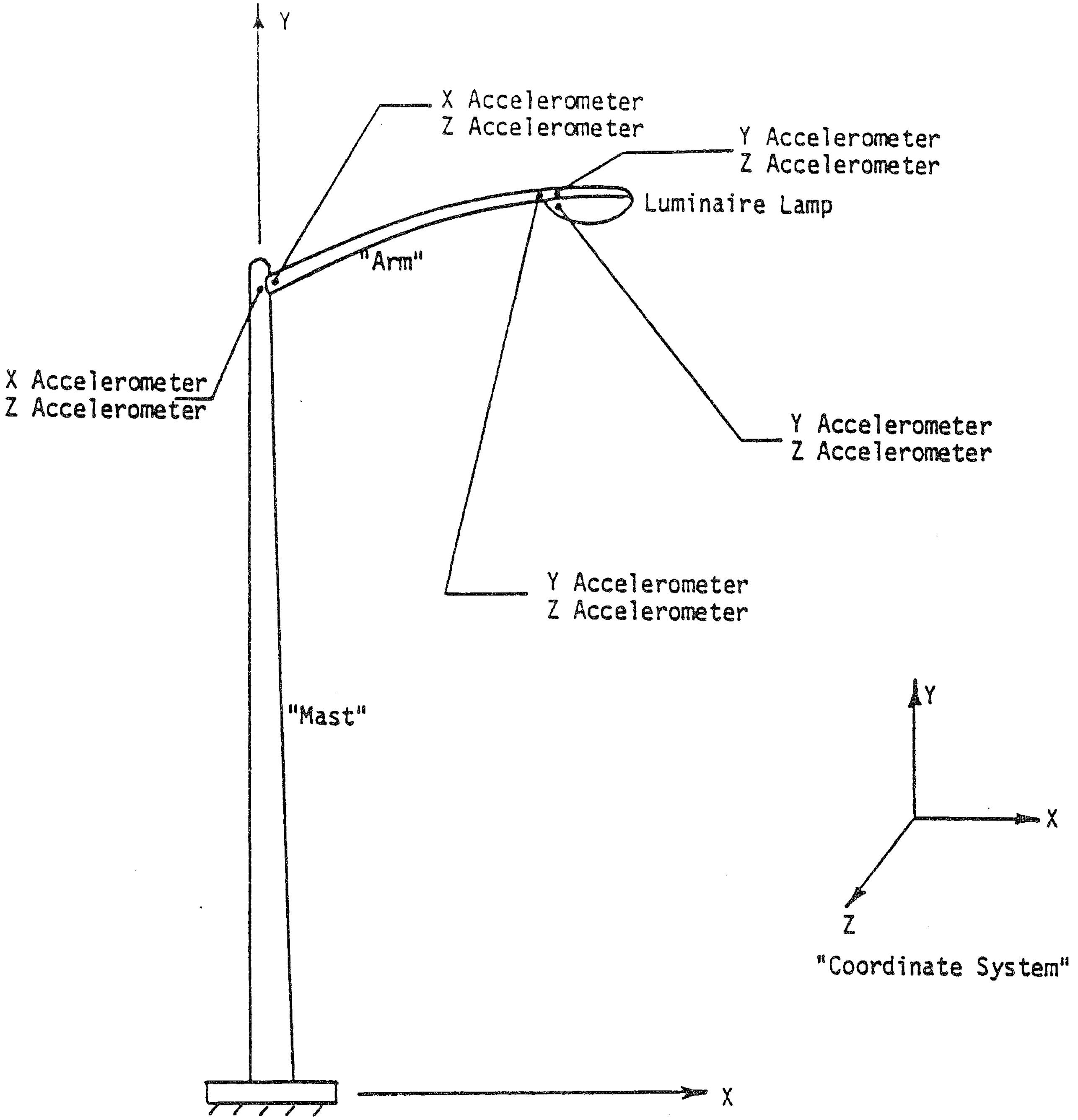


Figure 1 - Placement of Accelerometers

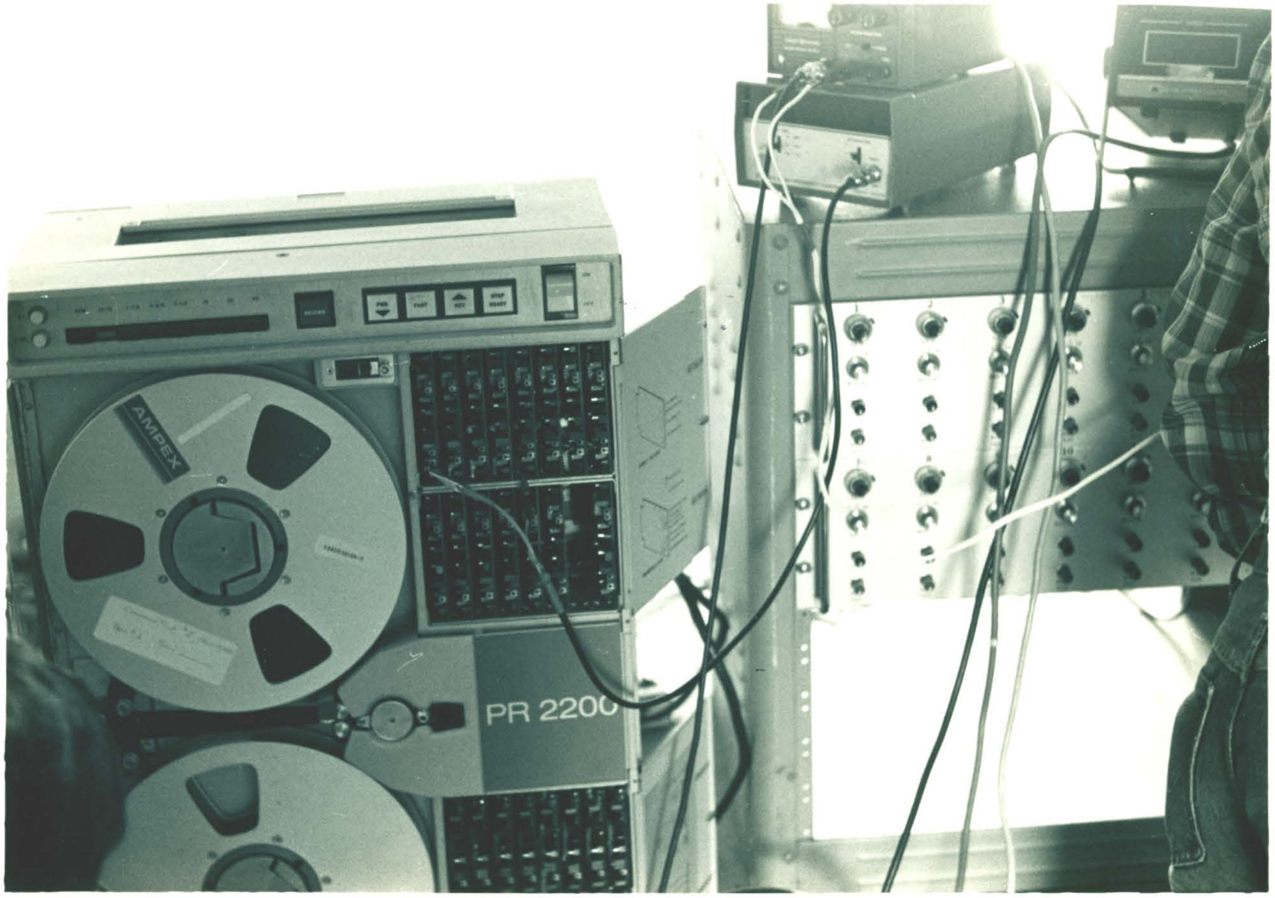


Figure 2 - Ampex Tape Recorder

After comparing the mass of the lamp accelerometers (≈ 80 grams) to the mass of the lamp (≈ 160 grams), it was decided to mount only one accelerometer on the lamp surface. In the opinion of the investigators the vibrational characteristics of the lamp within the socket would be unrealistic if an accelerometer were mounted on the top of the lamp (natural vibration frequencies are inversely proportional to the square root of the mass). The mounting position of the single-accelerometer was chosen to be the base of the lamp for several reasons:

1) the lamp's surface temperature is minimum here (≈ 200°C) and low mass accelerometers can be selected to withstand the predicted temperature extremes and temperature transiencies.
2) the cantilevered vibrational frequencies are affected less by adding the accelerometer mass to the lamp at its base
3) this location would enable us to discern the vibration transmissibility through the lamp substructure/socket since the vibration must ultimately be transmitted through the socket to the lamp itself (the lamp is protected from any direct wind loading by glass shield).

The accelerometers were distributed on the luminaire in directions which correspond to the lowest natural frequencies of the luminaire structure. Thus, we monitored the mast and arm base horizontal vibrations in two orthogonal directions (X and Z), the end of the arm in the vertical and lateral directions (X and Z), the base of the lamp socket in the vertical and lateral directions (Y and Z), and the lamp in the vertical direction. A more detailed description of the instrumentation and test results is found in Appendix B (an attachment of reference [5] and copies of some of the accelerometer and amplifier specifications).

2.3 Test Personnel

The test personnel involved were Page Heller and Don Russell of the Electrical Engineering Dept. at TAMU, Edward Red of the Mechanical Engineering

Dept. at TAMU, and Dick Zimmer and John Curik of TTI. Dexter Jones, Thad Bynum, and Dave Edwards of SDHPT were also present.

2.4 Test Procedures and Results

Tests were first conducted with an improved GE Lucalox sodium lamp (LU 400, improved). One accelerometer was mounted on the base of the lamp with a temperature resistant epoxy. The other accelerometers were mounted to the luminaire structure as previously planned for in the project proposal. After turning on the lamp the tip of the luminaire arm was then forcefully and periodically excited from a lift bucket raised to the level of the luminaire arm. During this period, the accelerometer and ballast data were recorded on magnetic tape and two channels of data were plotted on strip chart. The vibration did not cause the lamp to go out and the ballast system showed none of the expected instability. The primary current to the ballast and secondary current and voltage from the ballast were recorded but the primary voltage to the ballast was not.

The excitation to the luminaire arm was first applied to excite torsional vibration of the arm about the luminaire column, and then vertical vibration of the arm. Shock impacts were then applied to the base of the luminaire column and subsequently to the arm itself. The shocks to the arm caused the lamp accelerometer to fall off the lamp. Examination of the lamp showed that the epoxy bond held but the lamp surface fragmented around the accelerometer base.

Tests were then conducted with an unimproved Lucalox sodium lamp (LU 400, old type). The tests demonstrated that the vertical excitation would quickly cause the lamp to go off and excite the ballast instability problem, see the attached data recorded on strip chart.

Interestingly enough, we see the problem occurs when the vertical acceleration of the lamp exceeds - 1g; in other words, the amalgam reservoir experiences a zero g environment and can flow more freely. To note the phenomenon, examine the response in Figures 3,4, and 5, and observe that the X and Y accelerometers lie in the plane of the luminaire arm and column. In particular, note the g levels in the Y accelerometers . At the aforementioned instances the secondary current to the lamp goes off; note the short straight lines at the bottom of the strip. Further excitation caused the lamp itself to go off and precipitated the ballast on-off instability. Once the vibration excitation was stopped, the lamp came back on.

2.5 Conclusions

It was concluded from these evaluation tests that the operational procedures were acceptable with only a few modifications necessitated:

1) A more elastic epoxy was needed for the accelerometer base as mounted to the lamp glass surface.
2) The ballast lines and accelerometer lines need to be better segregated from each other because of some cross field effects.
3) Since only one accelerometer should be mounted to the lamp itself, it was decided to mount the accelerometer now available to the base of the lamp socket, providing a third axes reading (X direction).

Other conclusions which can tentatively be drawn are:

1) On the basis of one sample, the improved GE LU 400 HPS lamp appears less sensitive to vibration blink-out than the unimproved lamp.
2) Blink-out with the unimproved GE LU 400 lamp occurred in a vibration environment where vertical accelerations exceeded 1 g at the lamp. The frequency of the vertical vibration is about 3.5 HZ.

The implication of these conclusions is that, although the GE LU 400 lamps might be identical electrically (see Appendix C which summarizes electrical characterization tests performed on both the improved and unimproved tests), they do not perform similarly in a vibration environment.

A notable element missing from these early evaluation tests was the effect of wind gust loads due to vortex shedding from moving vehicles.

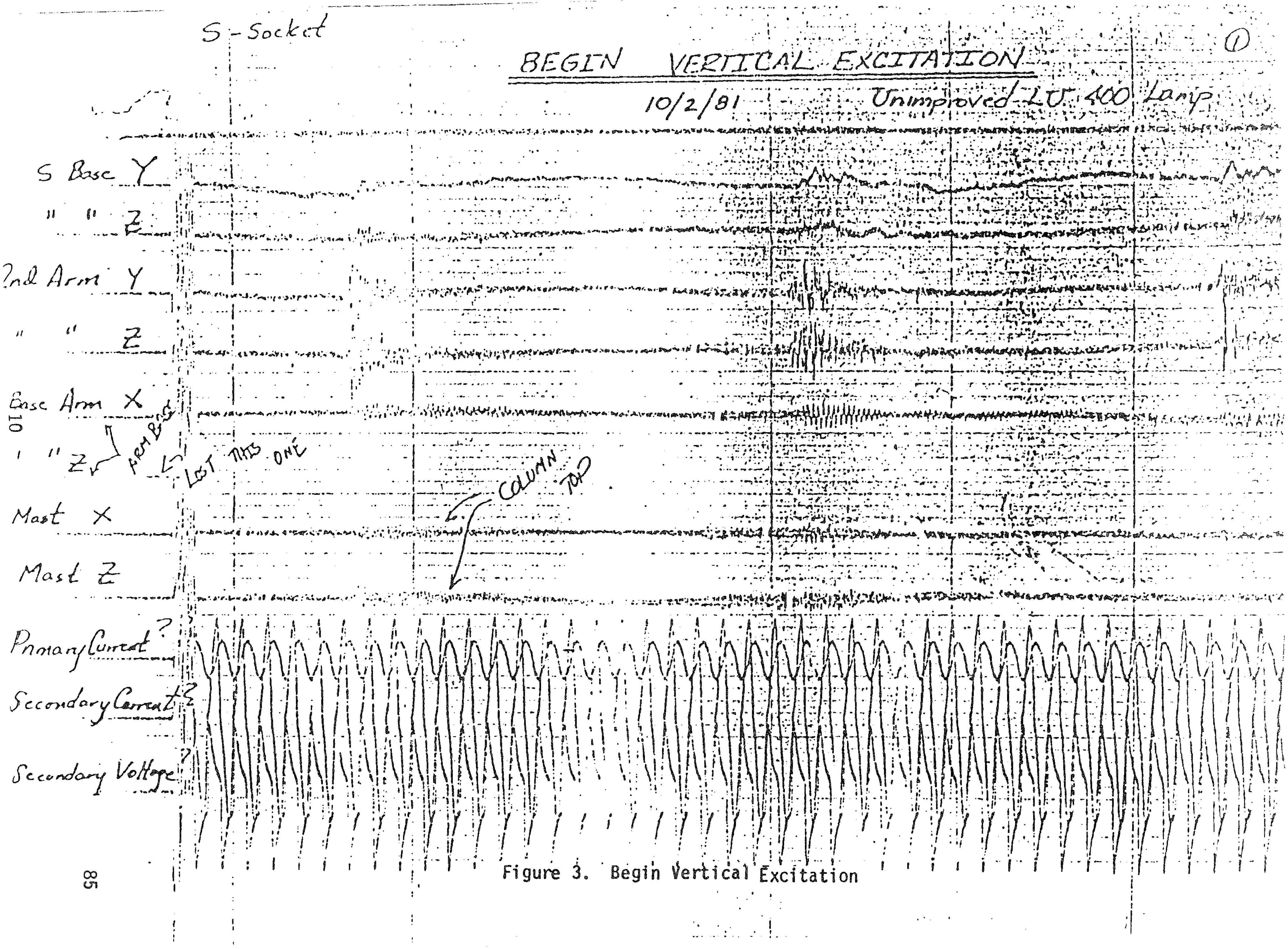


Figure 3. Begin Vertical Excitation

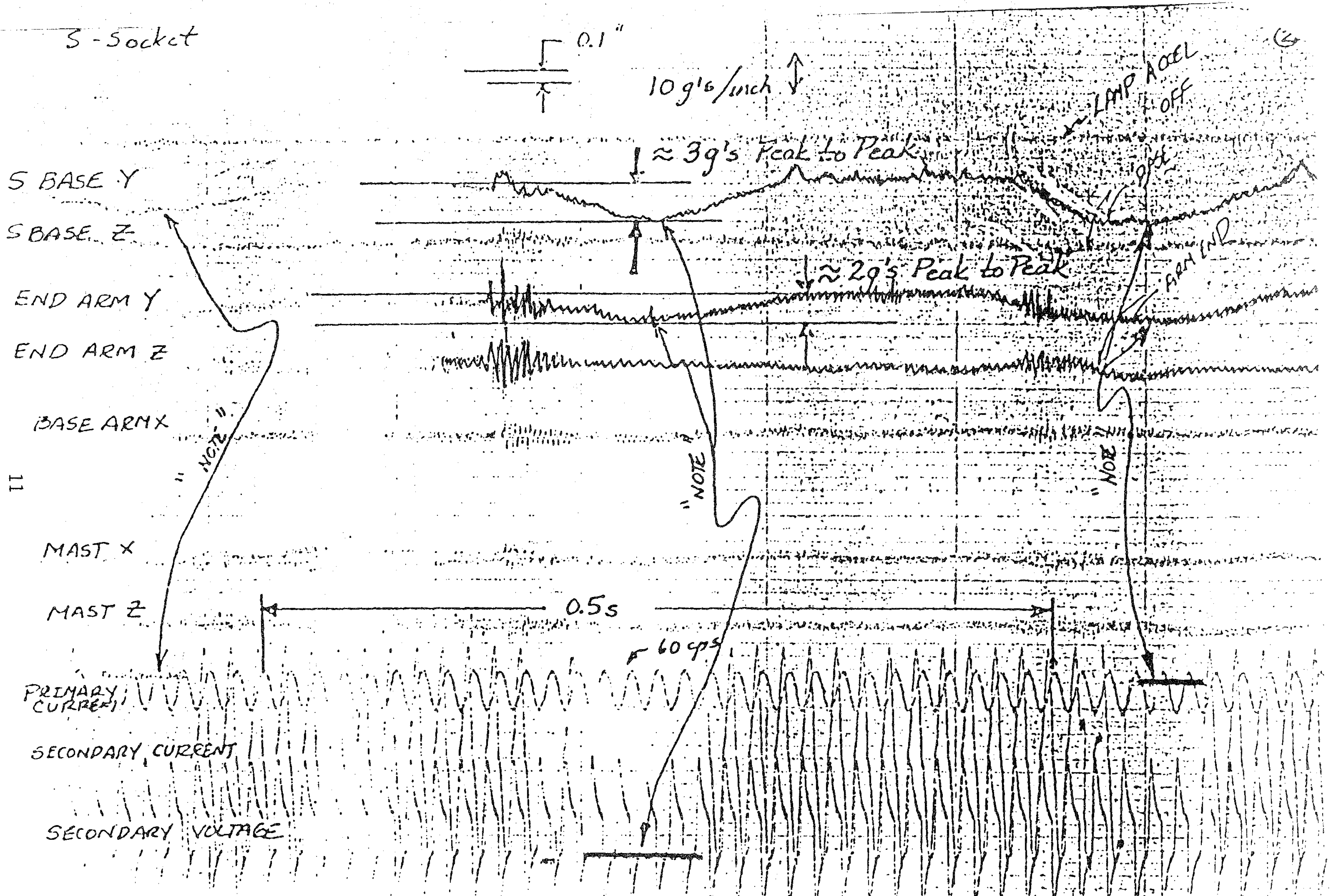


Figure 4. Secondary current flickers

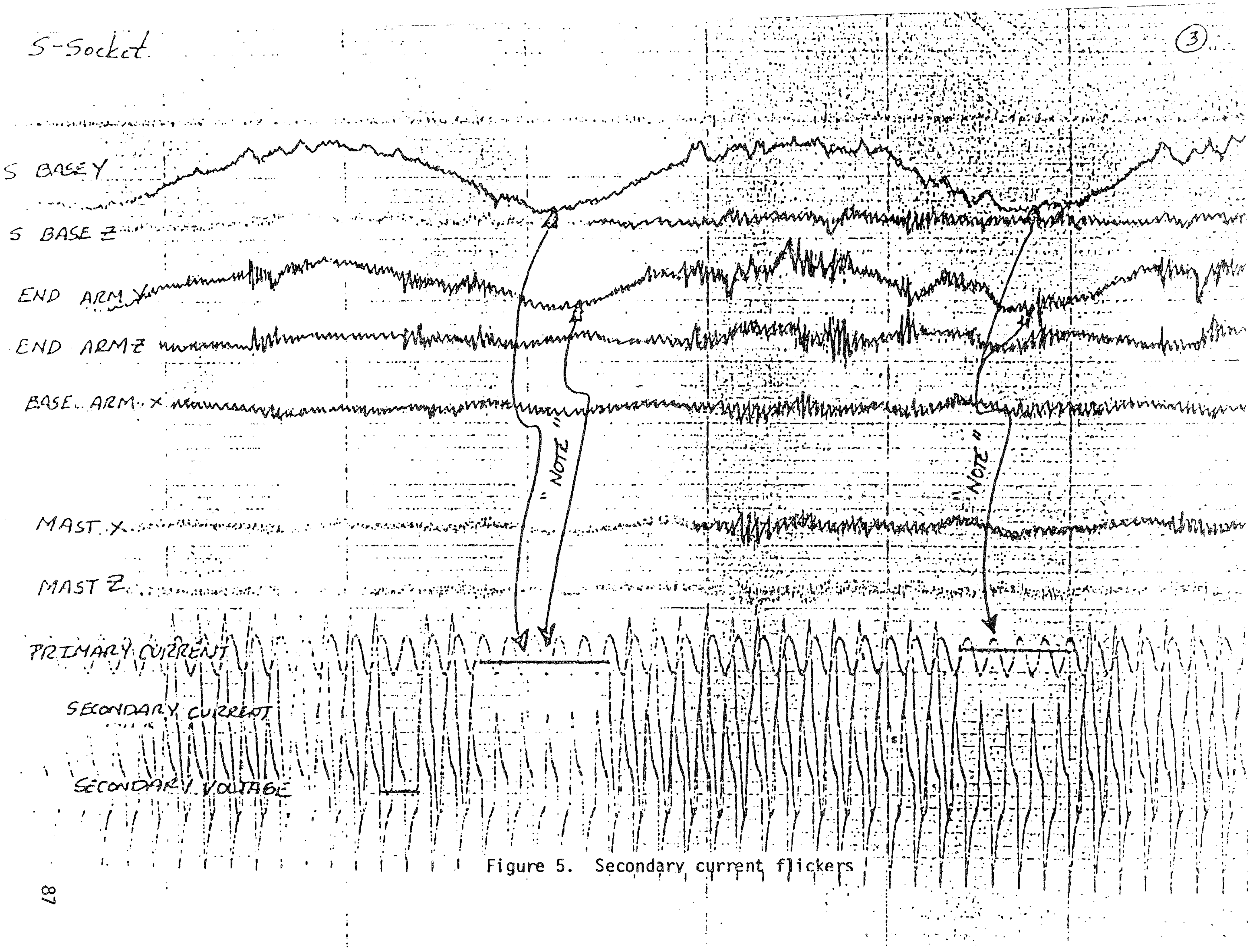


Figure 5. Secondary current flickers

3.0 SHIP CHANNEL BRIDGE TEST

After several schedule changes (see [6] and [7] included as Appendix D), the first field test was conducted from Thursday, March 11, 1982 through Friday March 19, 1982. Fourteen channels of data were recorded during this test period almost continuously - 10 channels dedicated to vibration data and four channels dedicated to ballast circuit data as previously planned.

3.1 Objectives

The objectives of this test are those stated for the project as a whole, see Section 1.2, with the exception that we did not impact the luminaires to precipitate blink-out. The amount of data gathered made it impossible to ascertain by reviewing the data at the site whether blink-out occurred. In the future one-day tests it will be possible to review the tape data at the site and attempt to precipitate blink-out by impacting the base of the luminaire mast, if blink-out has not occurred. We note that, although we successfully precipitated blink-out in our evaluation tests, there was no freeway wind/gust coupling interaction to perpetuate the ballast instability; thus, this data does not represent the interaction we are seeking.

Of course, the primary objective of this project is to characterize the environment that luminaires must operate within. As noted in [2], manufacturers of HPS lamps are unsure as to what vibration environment they should subject their designs to when doing qualification testing. The data gathered in this project should erase some of this uncertainity.

3.2 Instrumentation

Figure 6 is an accelerometer placement schematic for the test. A change of coordinate directions has the Z axis vertical and the X-Y plane parallel to the plane of the luminaire structure.

It was necessary to substitute a PCB 302A accelerometer (location 5 in Figure 6) because of the failure of one of the PCB 308B accelerometers.

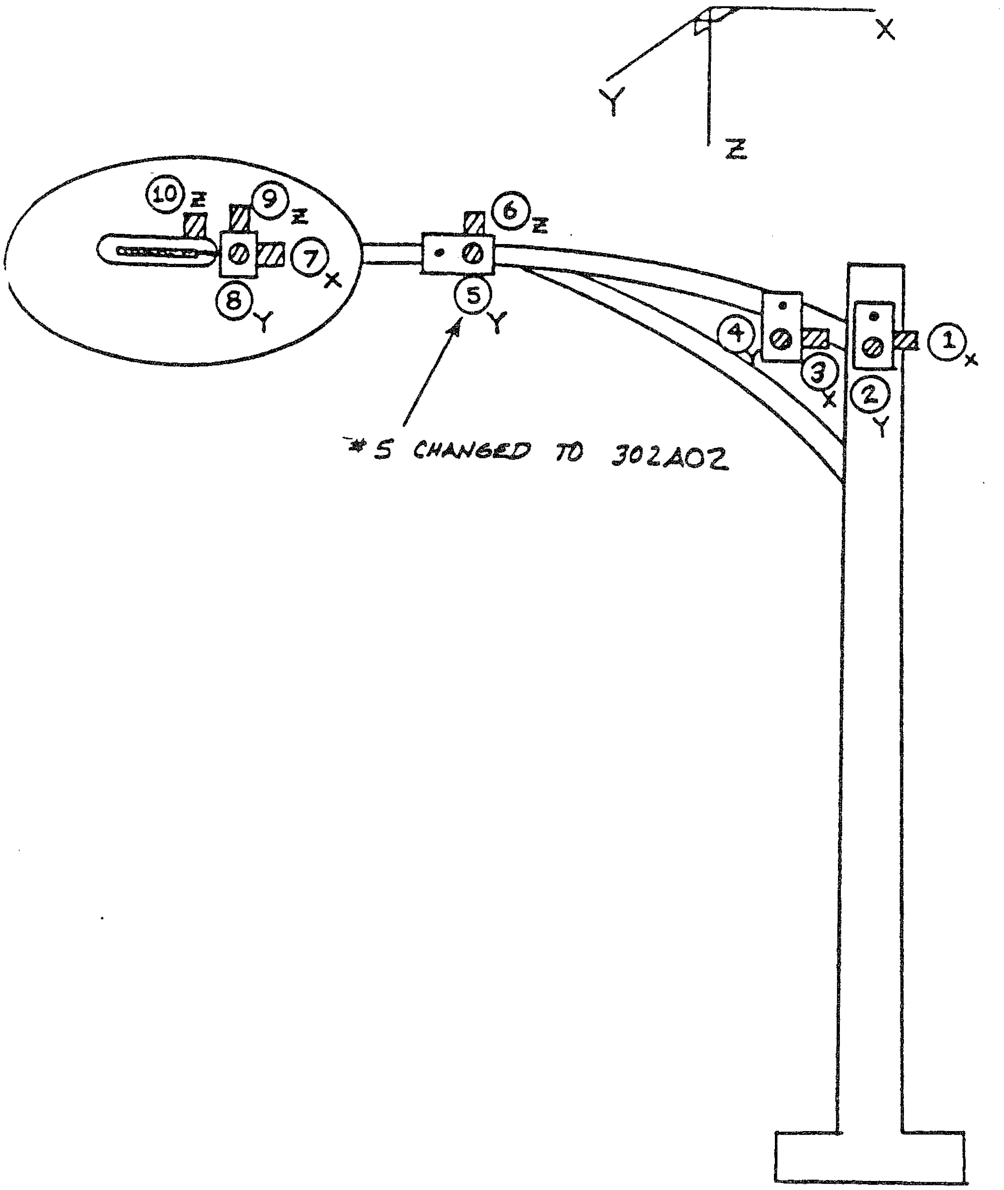


Figure 6. Accelerometer Location - Test #1.

More sensitive to temperature changes, the PCB 302A accelerometer data recorded on tape tended to move with the temperature changes experienced by the luminaire at location 5, making the assessment of the vibration environment experienced at location 5 in the Y direction more difficult.

Leads from the accelerometers and ballast circuit instrumentation were fed through the bridge opening, Figure 7, down the truss substructure, Figure 8, and into the instrumentation van, Figure 9. In Figure 10 the tape recorder is being readied for the test. More detailed information on the instrumentation arrangement can be found in Appendix E along with a listing of some of the minor problems that arose during the testing period.

One concern that might affect future tests should be noted. The power available from the overhead lighting structure was insufficient to run the van air-conditioner; this was ascertained by the size of the wire available for power tie in and the power instabilities during the period when the luminaire lamps were lit. Fortunately, the test personnel integrated a voltage regulator into the instrumentation and the weather was cool during the test period. Unless the power availability can be improved at future sites the next tests may be relegated to the winter season.

3.3 Test Personnel

The TTI representatives were Ed Red (ME), Page Heller (EE), John Curik (TTI), and one other individual from TTI. Dexter Jones, Dave Edwards, Thad Bynum, Sonny Wong and one other technical assistant represented SDHPT, see Figure 11. Sonny Wong was SDHPT's test assistant designated to interface with the test equipment during the test period, changing the tapes every 12 hours, and solving any minor problems. He made a noteworthy contribution to the success of the first test.

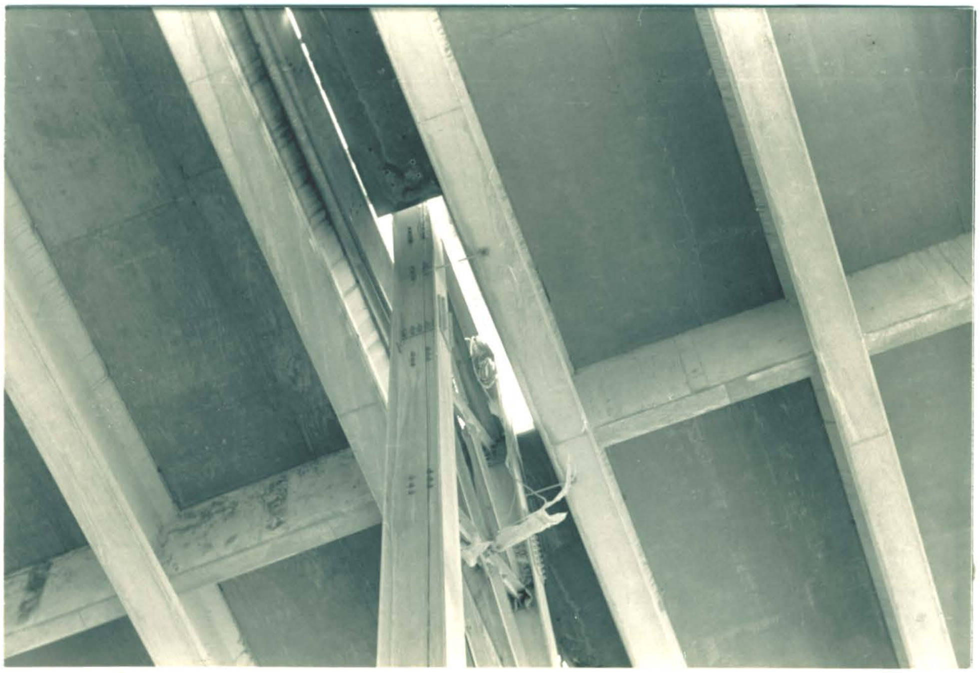


Figure 7. Bridge Opening For Truss Structure

Figure 8 - Feeding The Wires Down The Truss

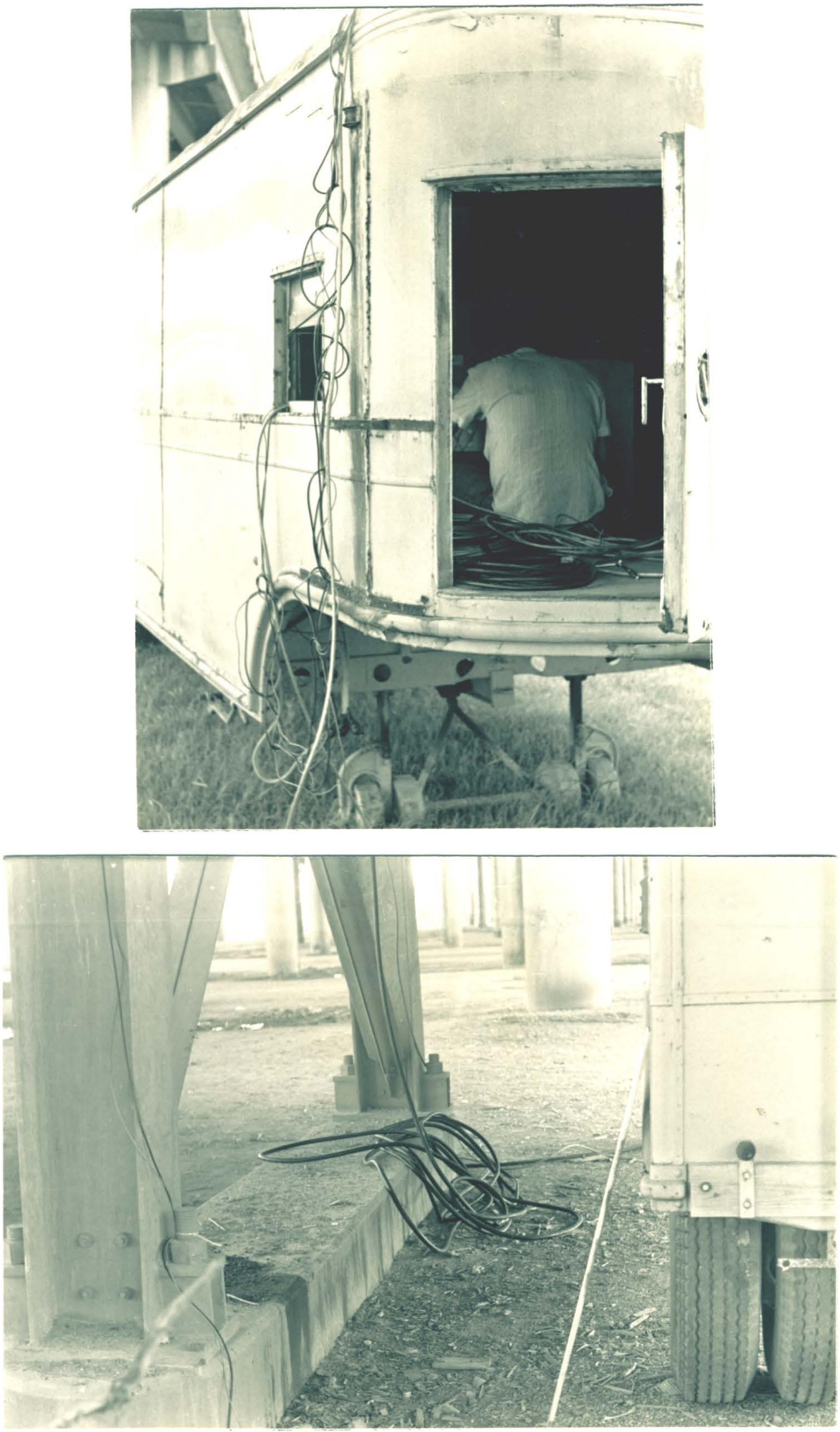


Figure 9 - Wires Leading Into The Data Acquisition Van

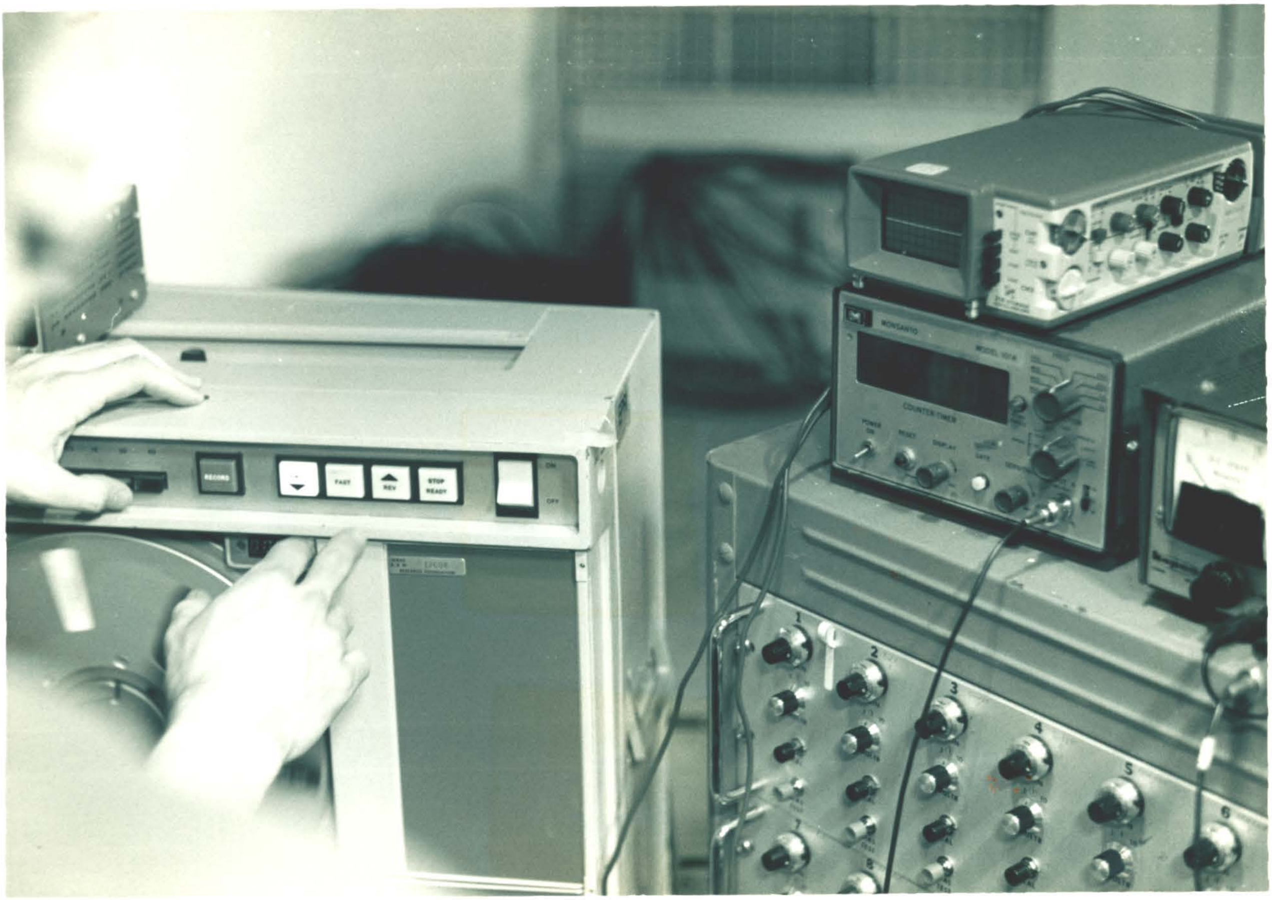


Figure 10 - Preparing The Tape Recorder

Figure 11 - Test Personnel in the Instrumentation Van

L. To R. SDHPT Representatives Louis Petry,

Sonny Wong, Page Heller (EE Dept. of TAMU).

3.4 Test Procedures

Ed Red (ME), Page Heller (EE), John Curik (TTI) and another representative from TTI left the Zachry Engineering Building at 7:30 a.m. on Thursday, March 11, 1982, arriving at SDHPT in Houston at 9:25 a.m. After meeting Dexter Jones, Thad Bynum and other representatives of SDHPT, we proceeded to the field site, arriving at approximately 10:15 a.m. The lift bucket scheduled by Dexter Jones arrived several hours late (approximately 1:00 p.m.) delaying the test set-up.

From 1:00 p.m. to about 5:00 p.m. the instrumented luminaire was installed along with those accelerometers mounted to the luminaire support structure. Wires were run to the instrumentation van (yellow elephant) and the 220 volt power connection was made to the overhead freeway light.

Data acquisition began at 6:30 p.m. on Thursday, 3-11-82 after making some last minute scale changes for the accelerometer data based onthe magnitude of the vibration monitored up to the test start.

Data acquisition ended at 11:27 p.m. on Friday, 3-19-82 after experiencing a power loss on Thursday, 3-18-82, see Appendix E for more detail.

3.5 Test Results

The test results contained in this section reflect only a preliminary sample of the test data and not an in-depth study. To conduct an in-depth study of 14 channels of approximately 168 hours of data would require a committment of time and personnel not planned for in this project. Nevertheless the study conducted does reveal some rather interesting results.

First, the vibration environment is more severe than expected and characterized by three distinct vibration environments:

1) low g vibration of the luminaire structure as a whole (we call this the structural "ringing") caused by base excitation of the luminaires due to the vibration of the bridge as a whole,
2) short duration, high, g vibration due to what we presume to be wind gust loading from the trailing vortices of moving vehicles, probably large semi-trucks,
3) quiescent periods of low g loading interrupted by occasional high frequency vibration waves pulsing through the luminaire structure.

Figures 12-31 at the end of this section are strip chart graphs chosen to display representative accelerometer accleration time histories and ballast voltage and current readings (on most of the figures, the scale is 0.5 g's per inch). We should note at this time that we did not locate any incidence of blink-out in the test data. It appears that either this particular HPS lamp was not particularly sensitive to the vibration levels present or the "directional" qualities of this vibration environment did not correlate with the directional sensitivities of the HPS lamp. We note that HPS lamp manufacturers indicate a sensitivity to g levels parallel to the amalgam reservoir. This corresponds to the X direction in Figure 6. From the data review conducted thus far, it appears that the g levels experienced by the arm and lamp in this direction were low.

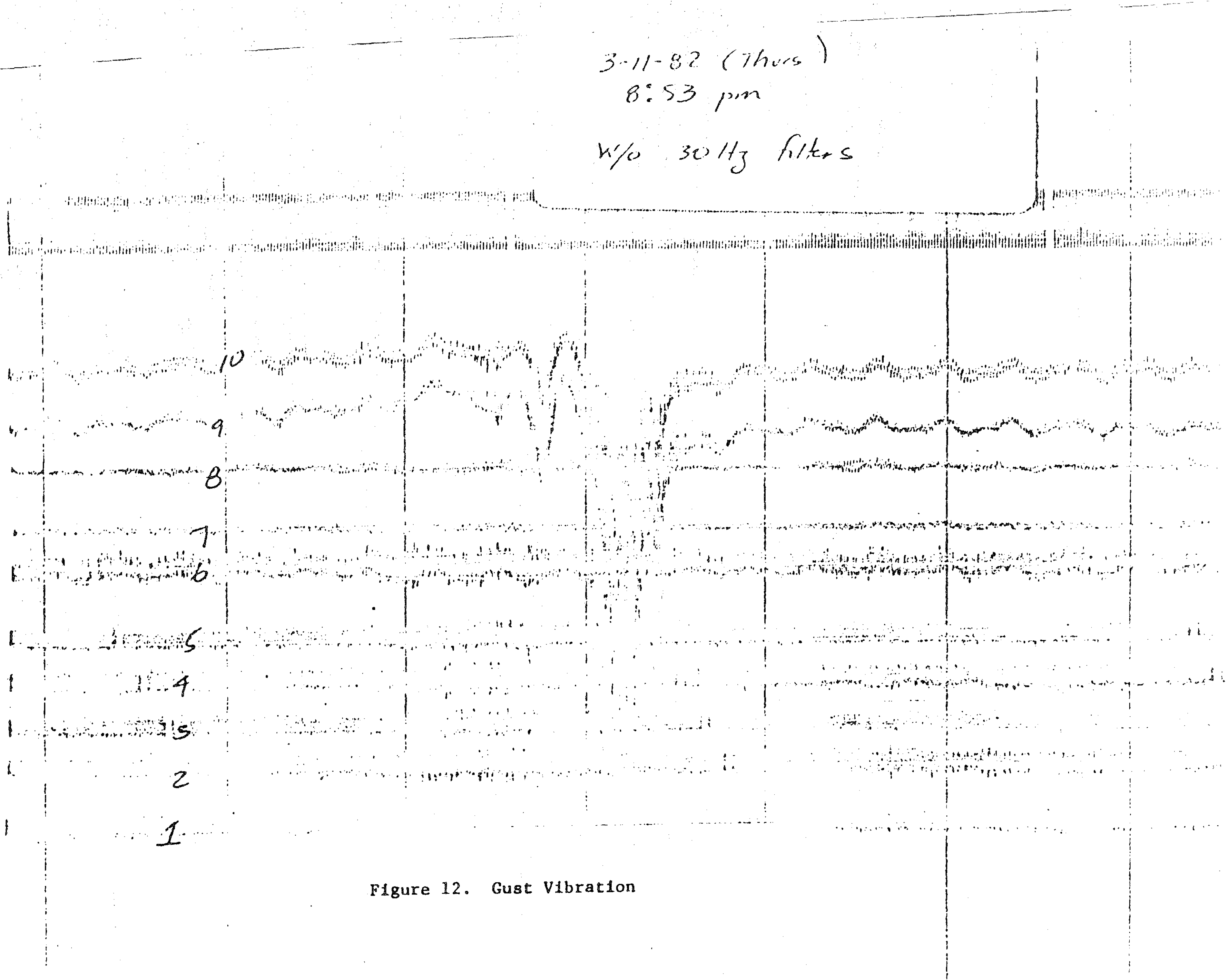
Table 2 summarizes the acceleration data for Figures 12-31 as appropriate. The reader may wish to inspect these figures more closely. Not contained in this table is an estimate of the frequency of occurrence of various g levels. From our preliminary review of the data we "roughly" estimate that during the daytime period you may expect 25-40 gust load vibration "shocks" in the range of 0.25 - 1 g's, from two to five vibration shocks in the range 1 - 2 g's and anywhere from 0 - 4 vibration shocks greater than 2 g's. Nightime periods were generally quieter with the frequency of incidence anywhere from 25% - 75% of that experienced during the daytime periods.

Most of the vibration severity occurred near the tip of the luminaire arm in the vertical direction. Accelerometers 9 and 10 monitored this environment although the vibration levels on the lamp surface were less severe than at the lamp socket base due to vibration attenuation across the lamp socket. Vibration levels in the other directions/placements appear to be rather low and at various frequencies ranging up to 200-300 Hz, although all the data was filtered at 1000 Hz to eliminate tape recorder noise superimposed on the the tape.

3.6 Conclusions

For this particular test site, wind gusts can cause short duration vibration more severe than expected. Acceleration levels up to 2 g's are not unusual and levels which exceed 2g's may occur occasionally. Vibration levels associated with the other luminaire directions and placements are reduced considerably, generally below one-tenth g.

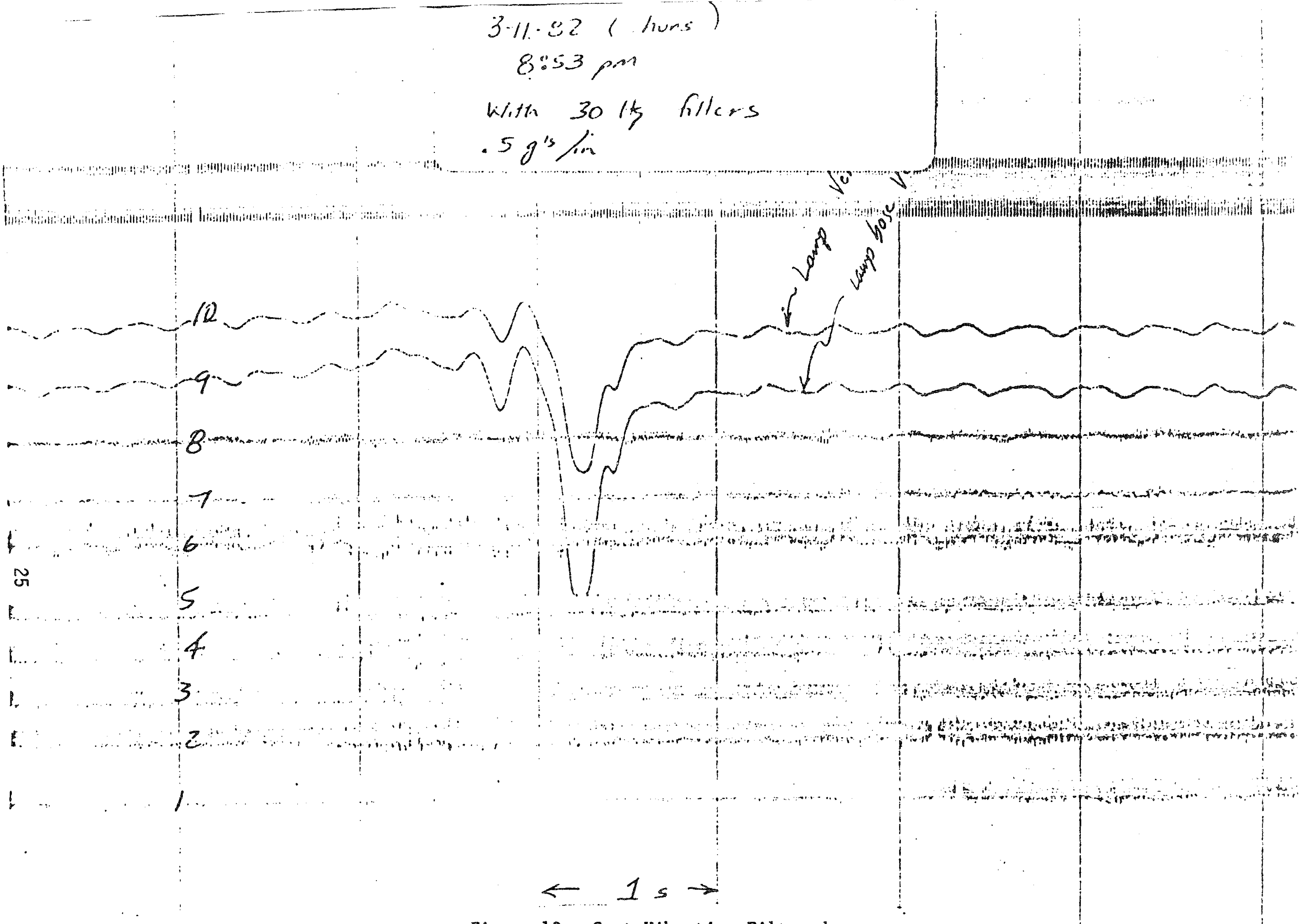
Lamp blink-out was not experienced at site #1 and thus we were unable to identify any relationships between the vibration environment and the ballast instability. Obviously, the HPS lamp remained intact and the epoxy mount proved to be satisfactory.



3-11-82 (Thurs)
8:53 pm

W/o 30 Hz filters

Figure 12. Gust Vibration



3-11-82 (Thurs)
8:53 pm
With 30 Hz filters
.5 g's/in

Figure 13. Gust Vibration Filtered

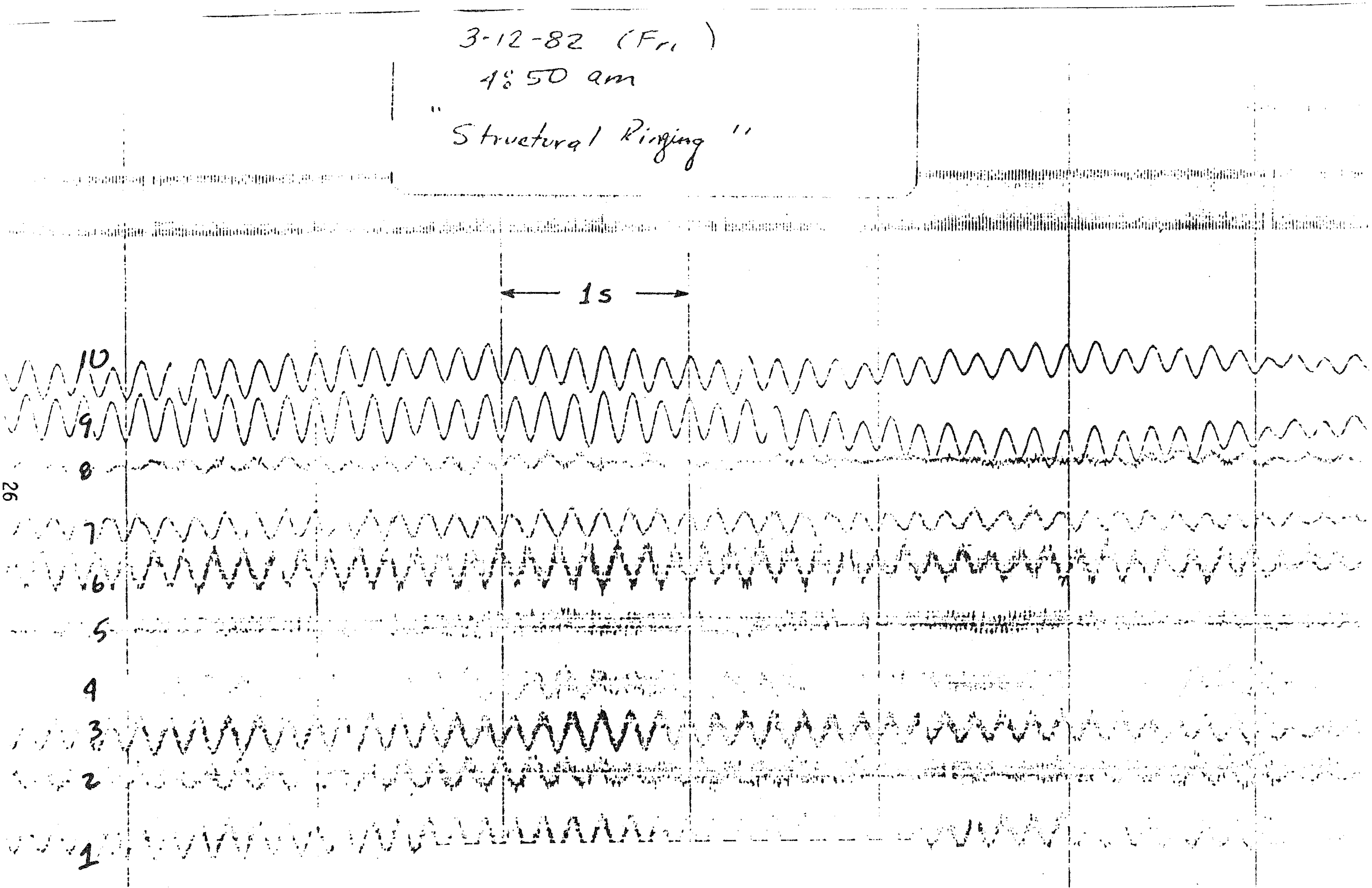
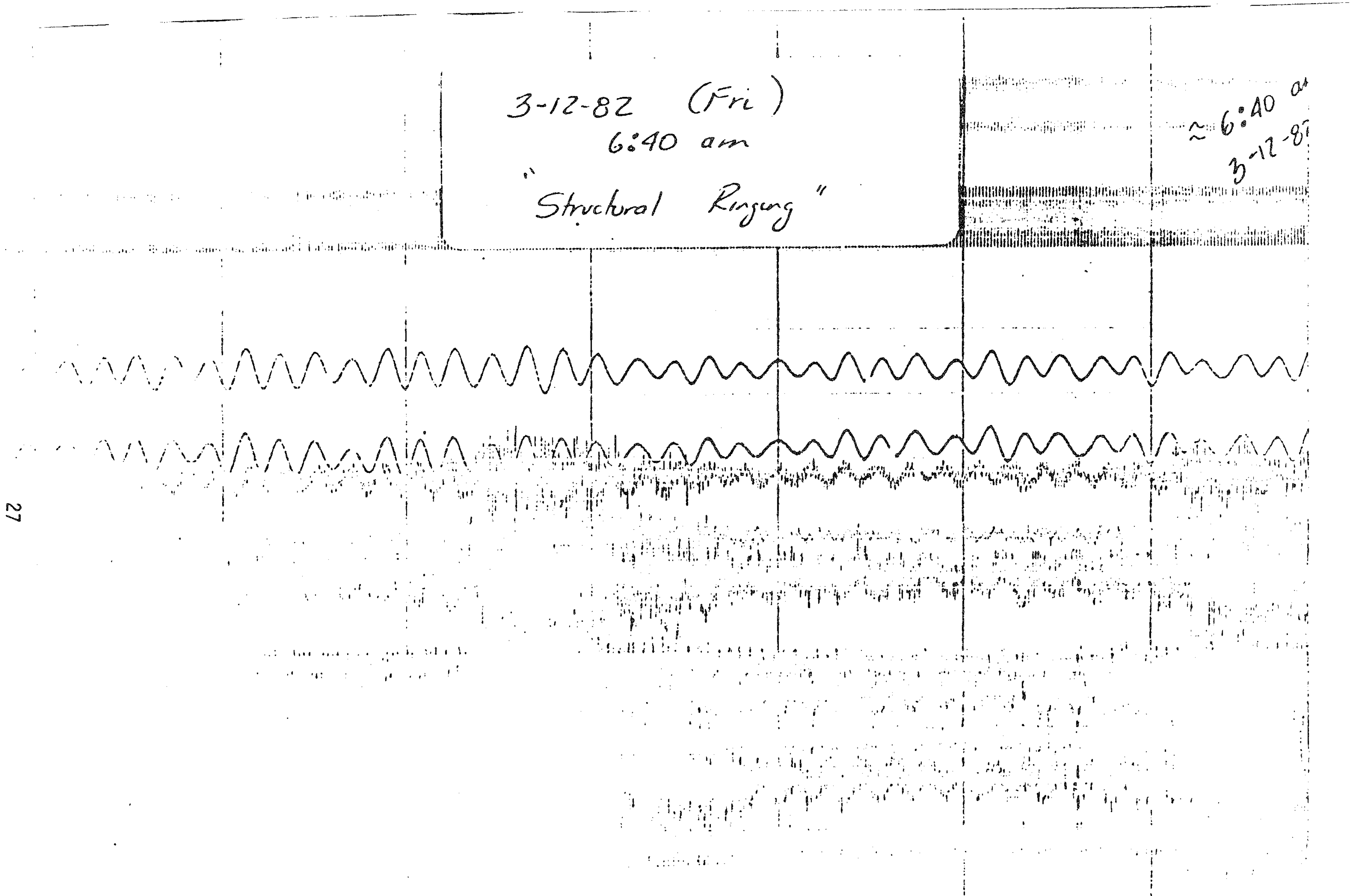


Figure 14. Structural Ringing



3-12-82 (Fri)
6:40 am
"Structural Ringing"

≈ 6:40 a
3-12-8

Figure 15. Structural Ringing

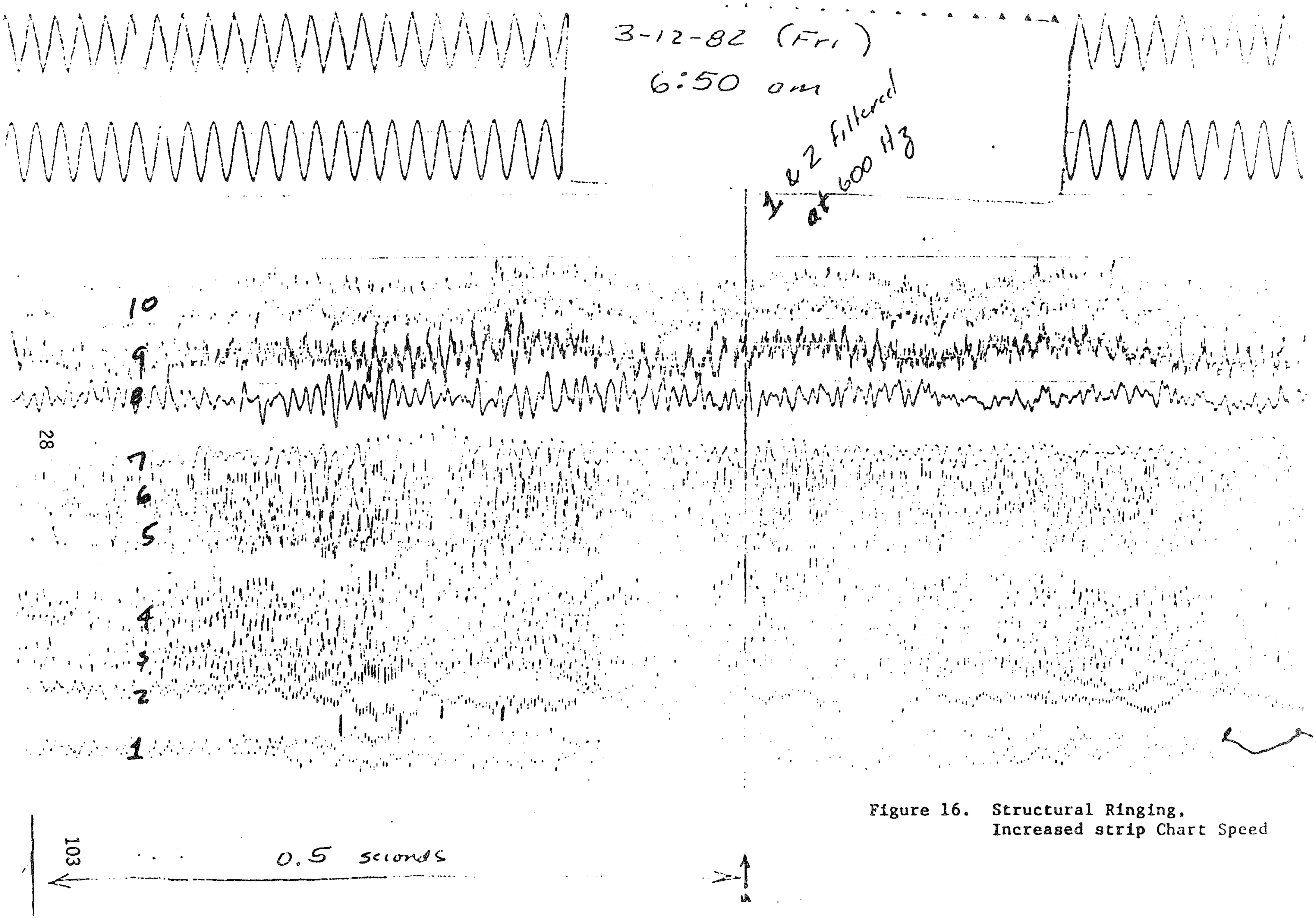
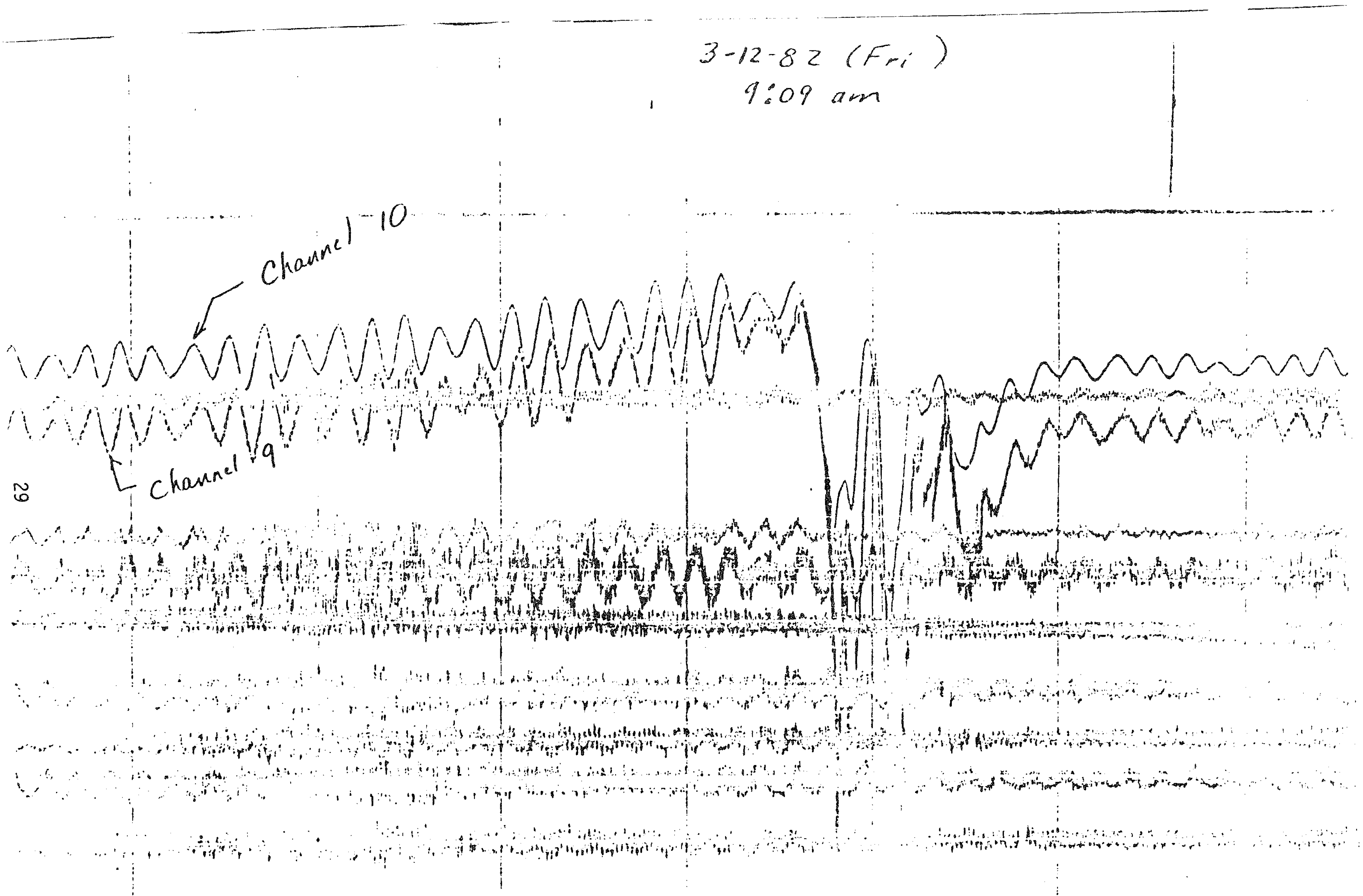
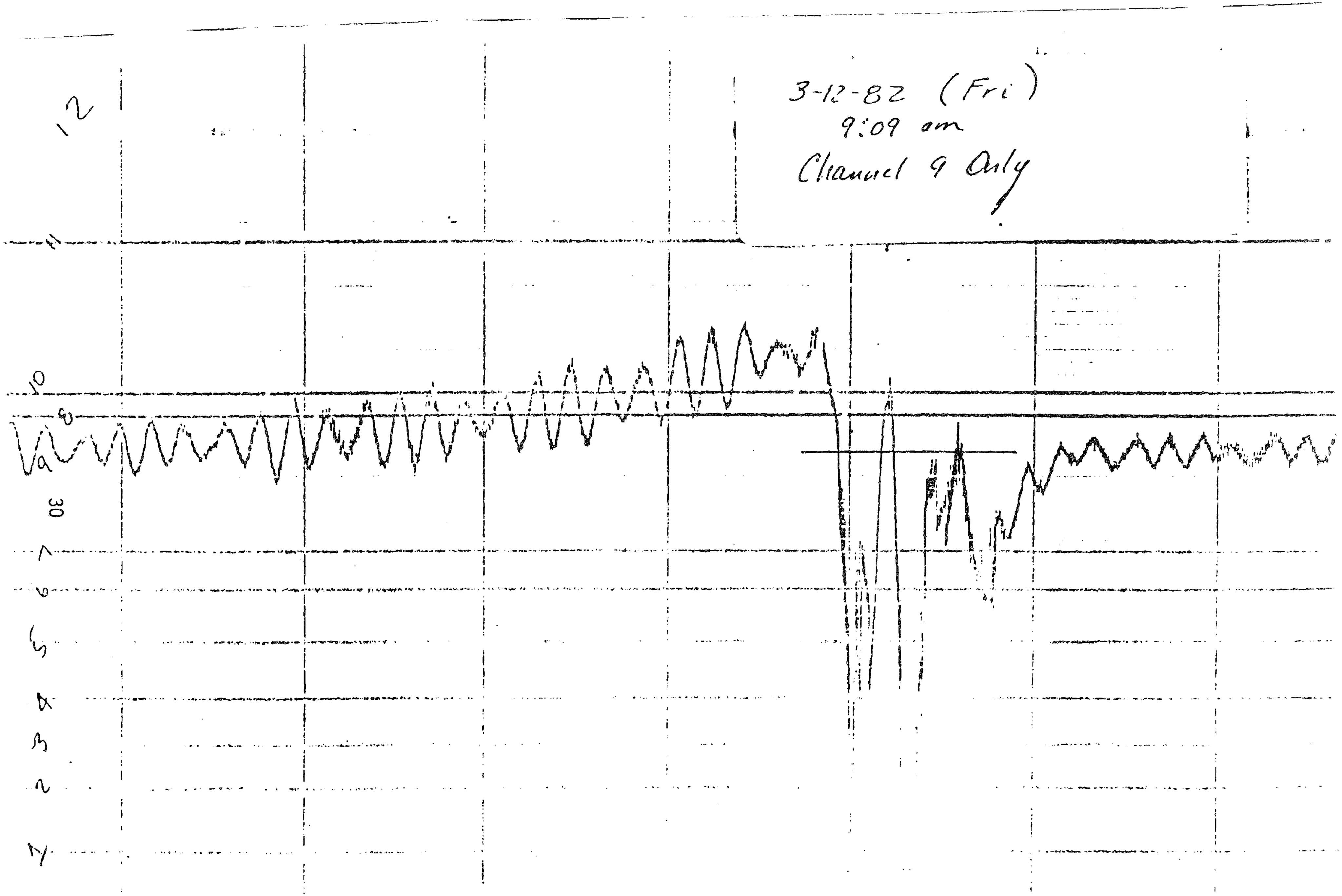


Figure 16. Structural Ringing, Increased strip Chart Speed



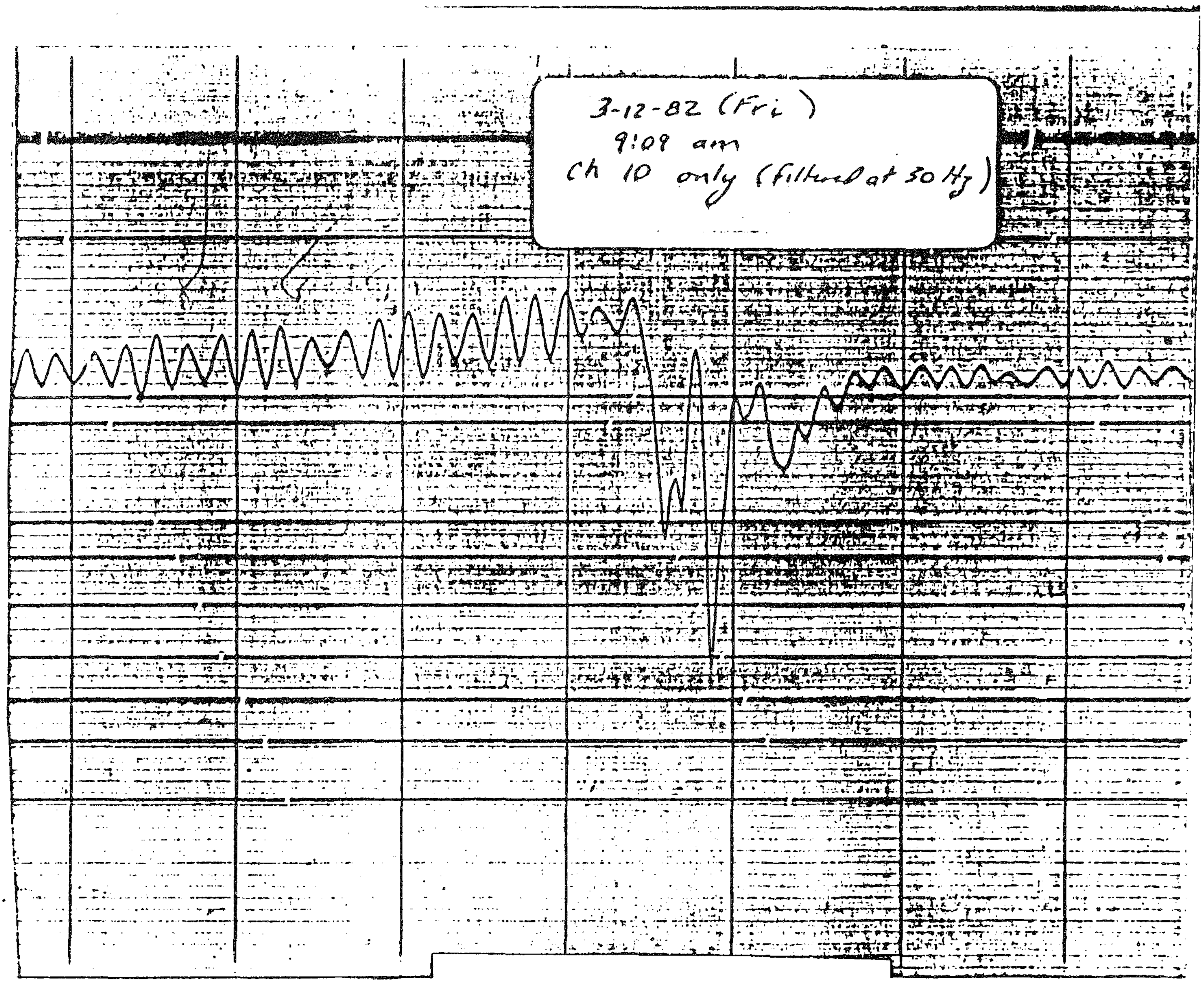
3-12-82 (Fri)
9:09 am

Figure 17. Gust Vibration



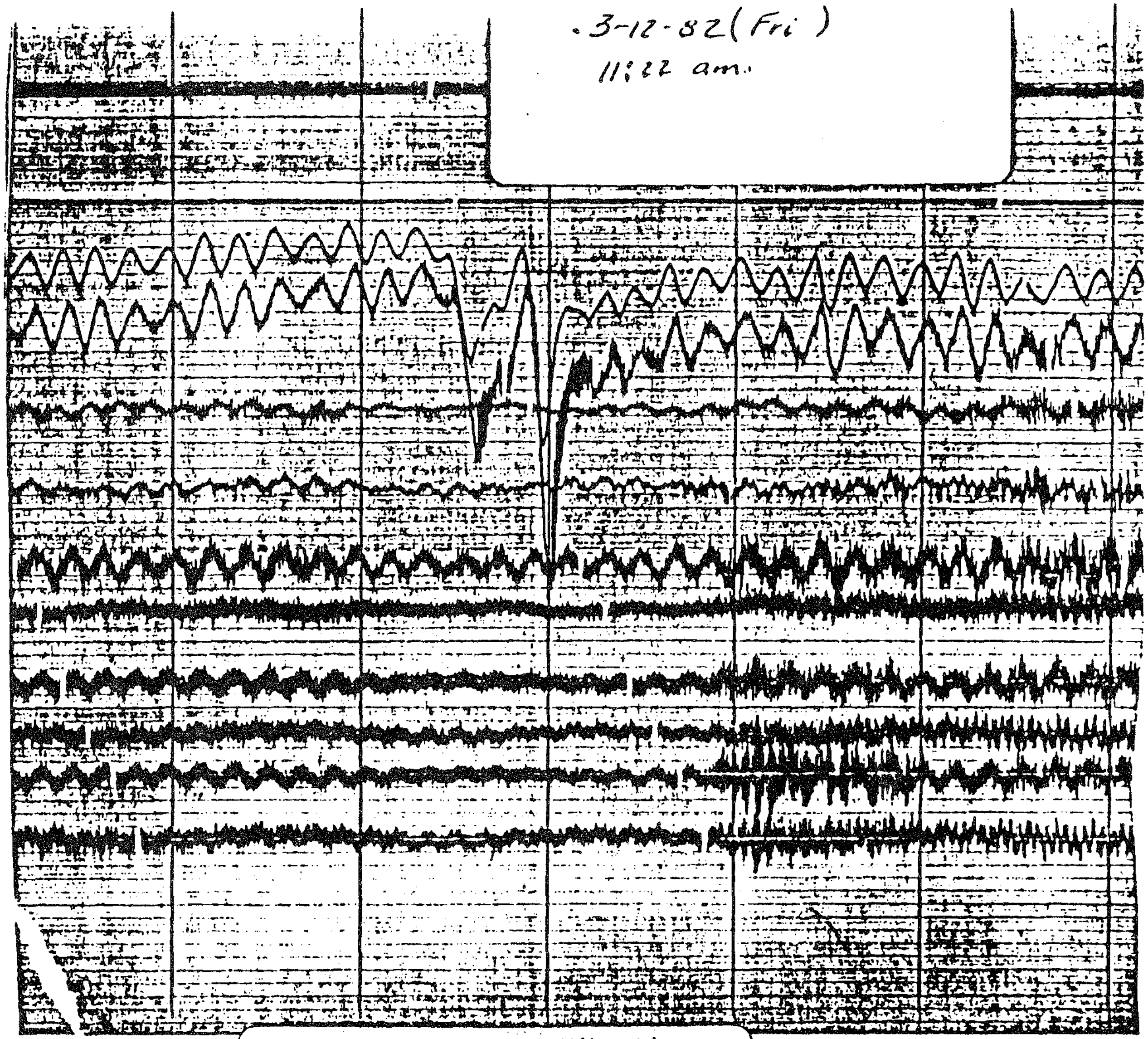
3-12-82 (Fri)
9:09 am
Channel 9 Only

Figure 18. Gust Vibration, Channel 9 Only



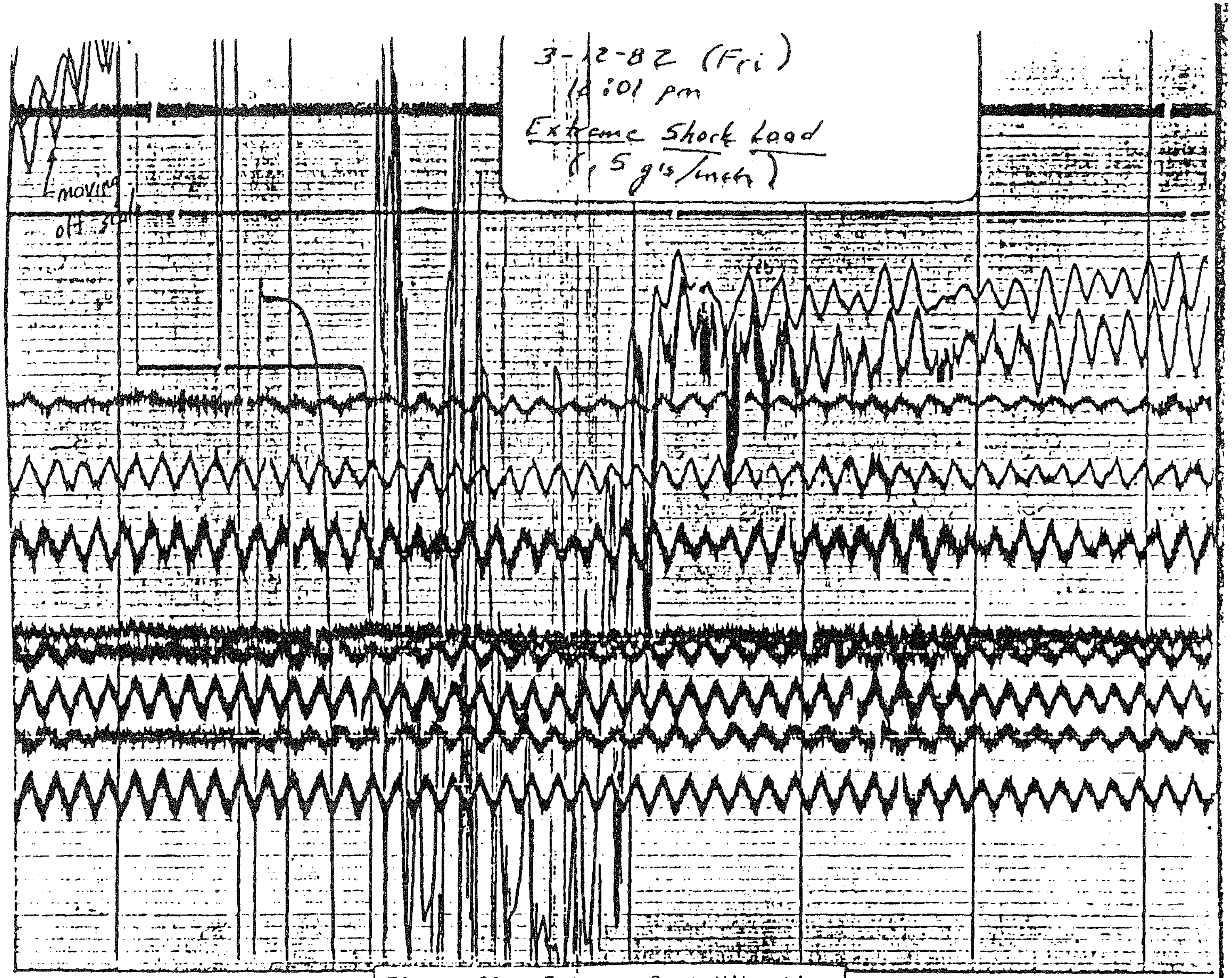
3-12-82 (Fri)
9:09 am
Ch 10 only (filtered at 30 Hz)

Figure 19. Gust Vibration, Channel 10 only



3-12-82 (Fri)
11:22 am.

Figure 20. Gust Vibration



moving off scale

3-12-82 (Fri)
12:01 pm
Extreme Shock Load
(.5 g's/inch)

Figure 21. Extreme Gust Vibration

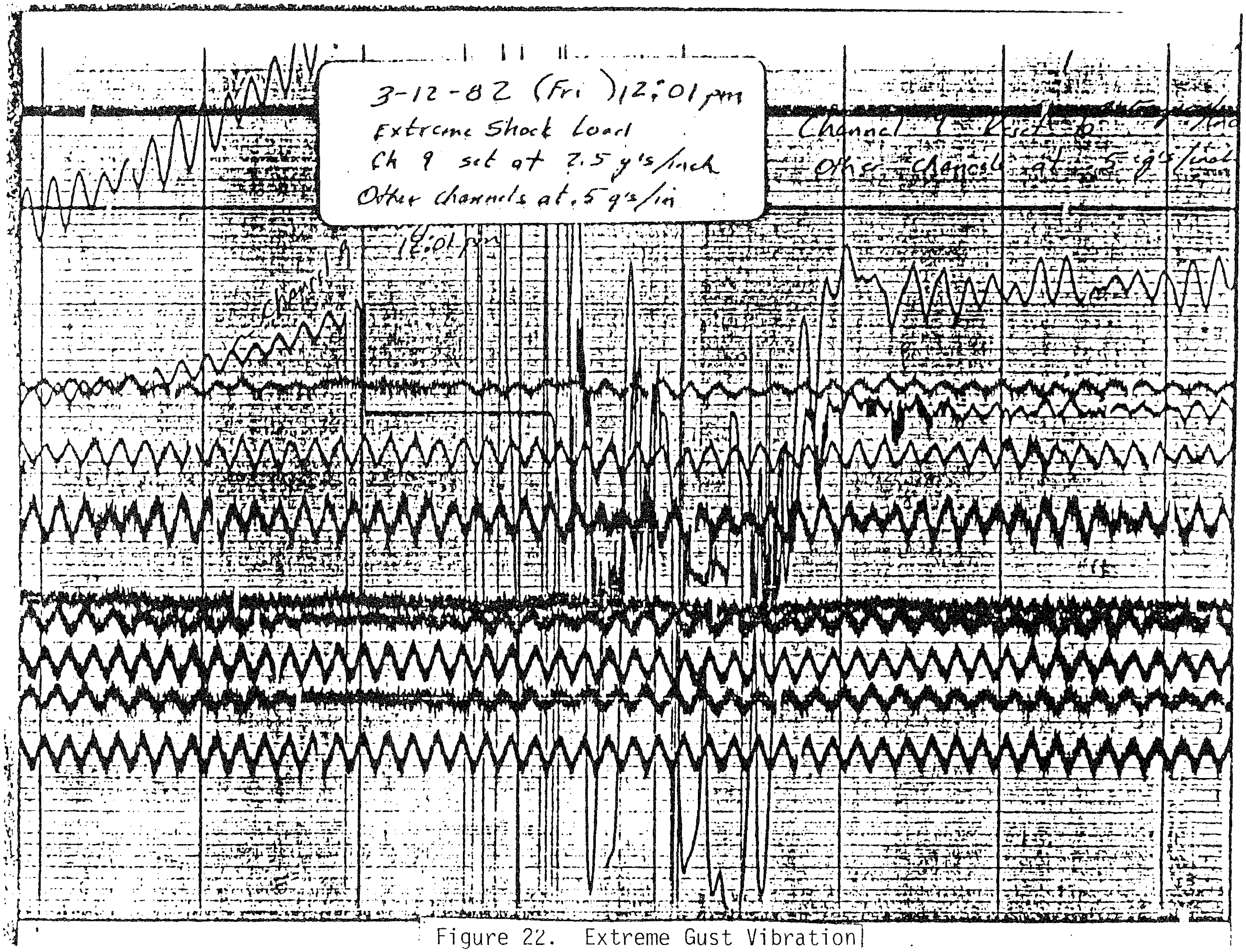
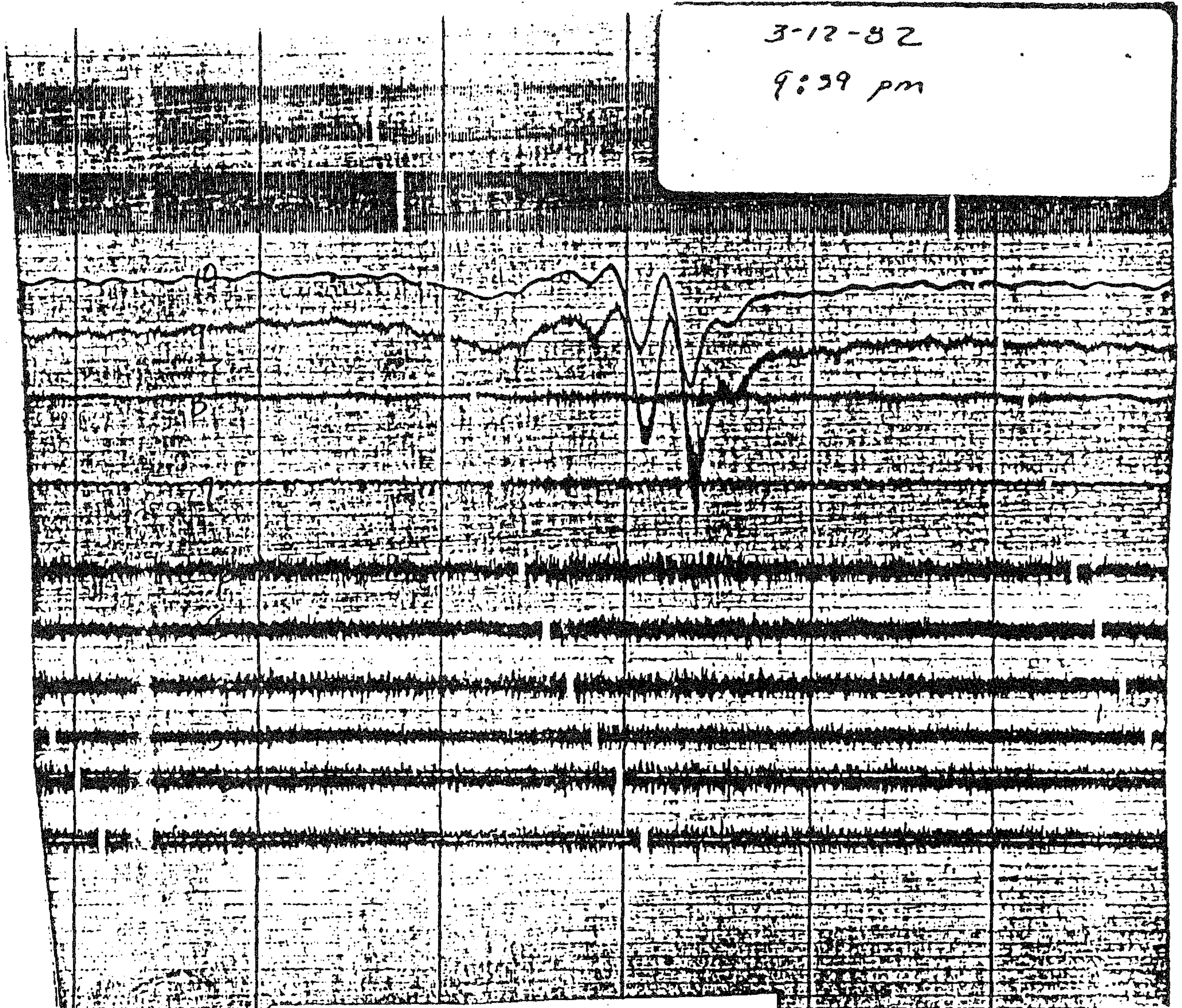


Figure 22. Extreme Gust Vibration



3-12-82
9:39 pm

Figure 23. Gust Vibration

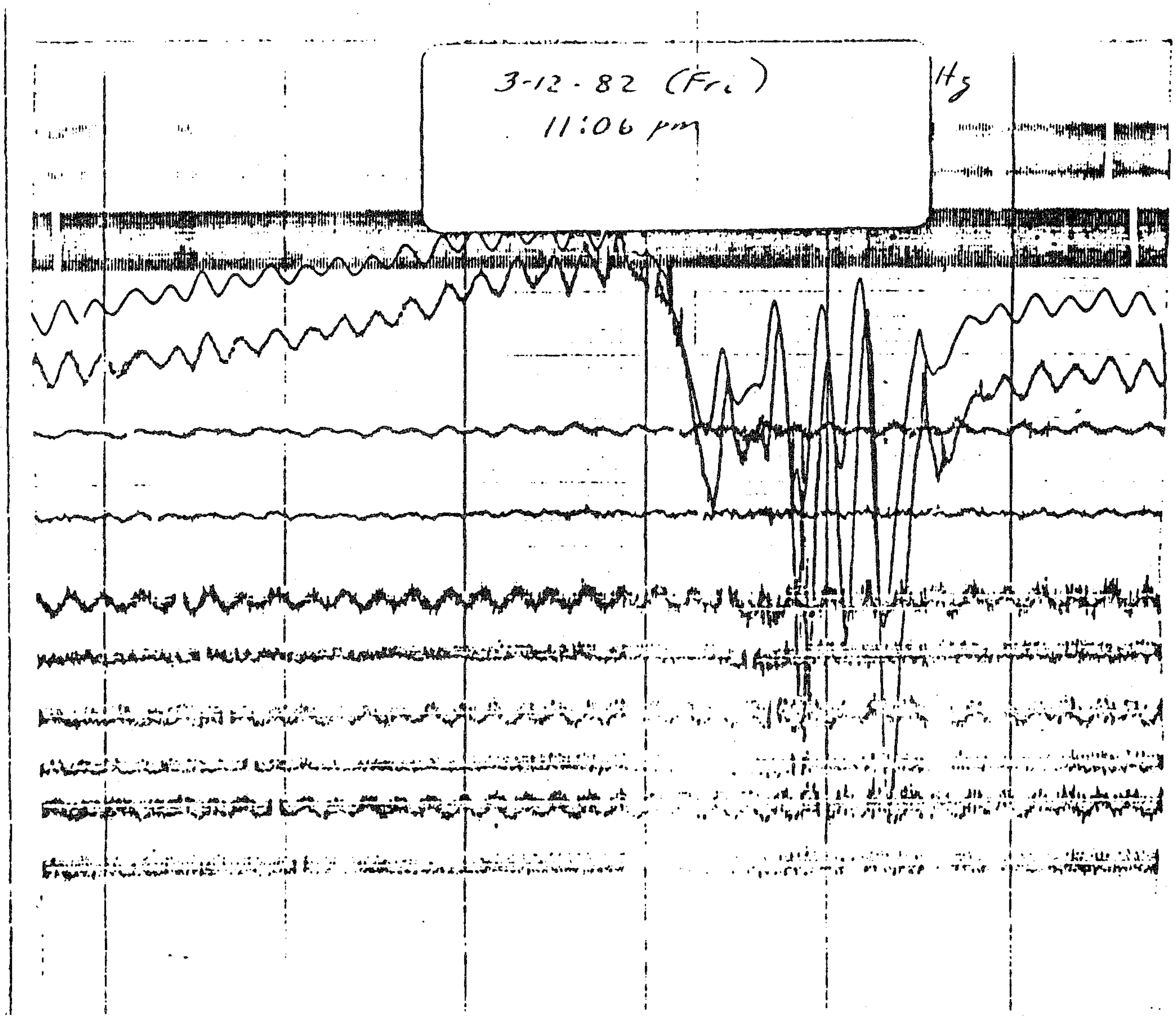
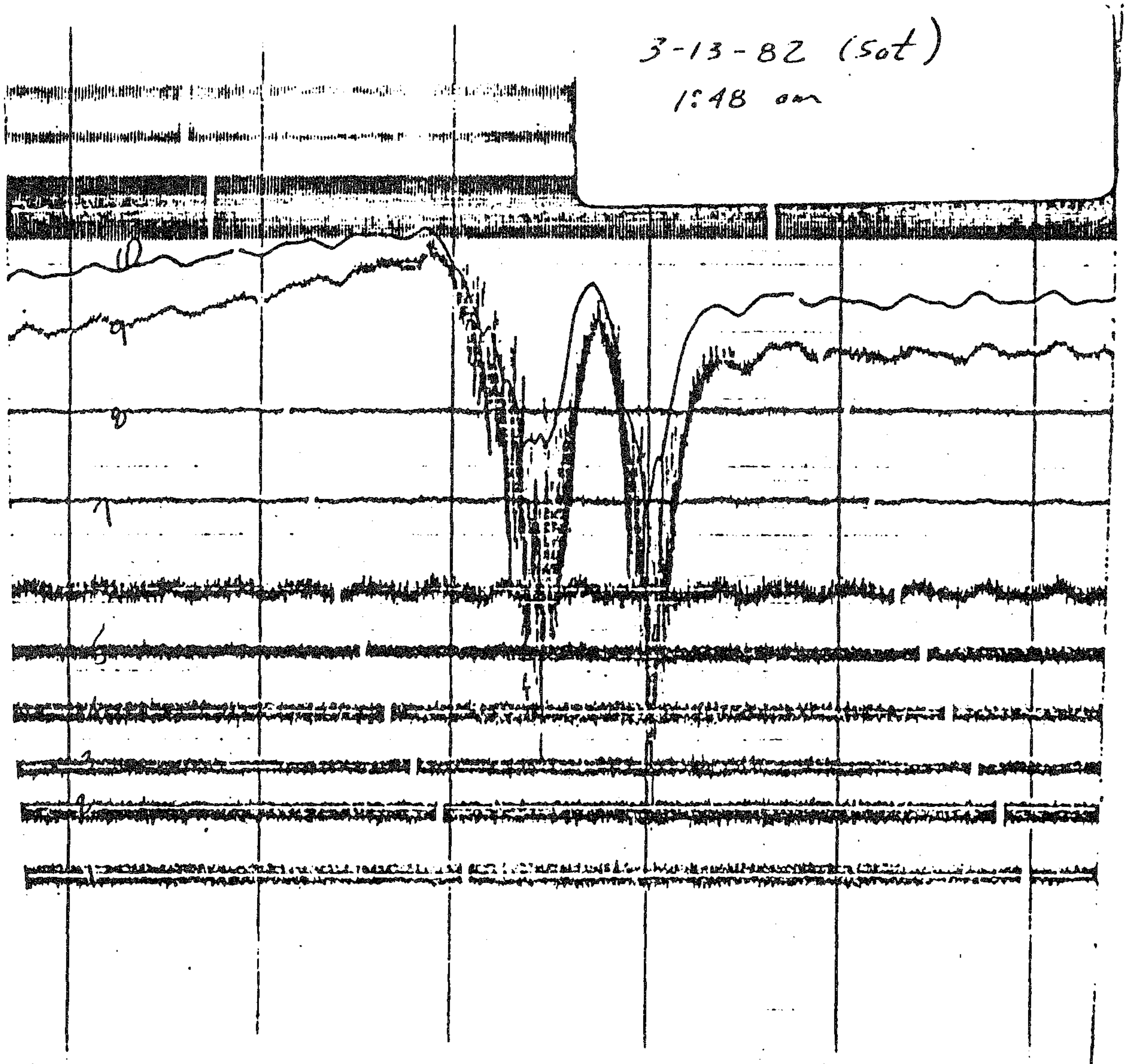


Figure 24. Gust Vibration



3-13-82 (Sat)
1:48 am

Figure 25. Gust Vibration

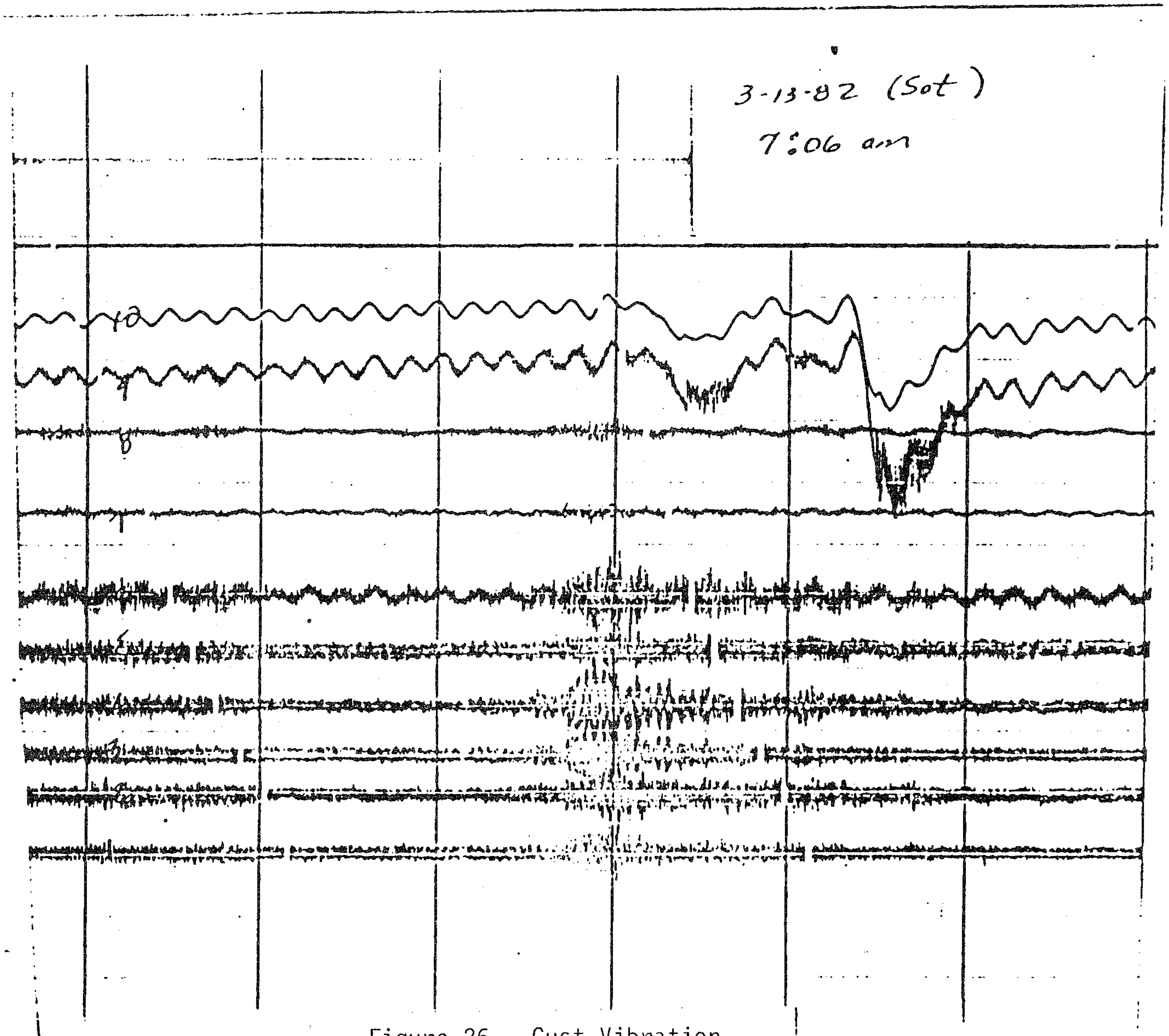
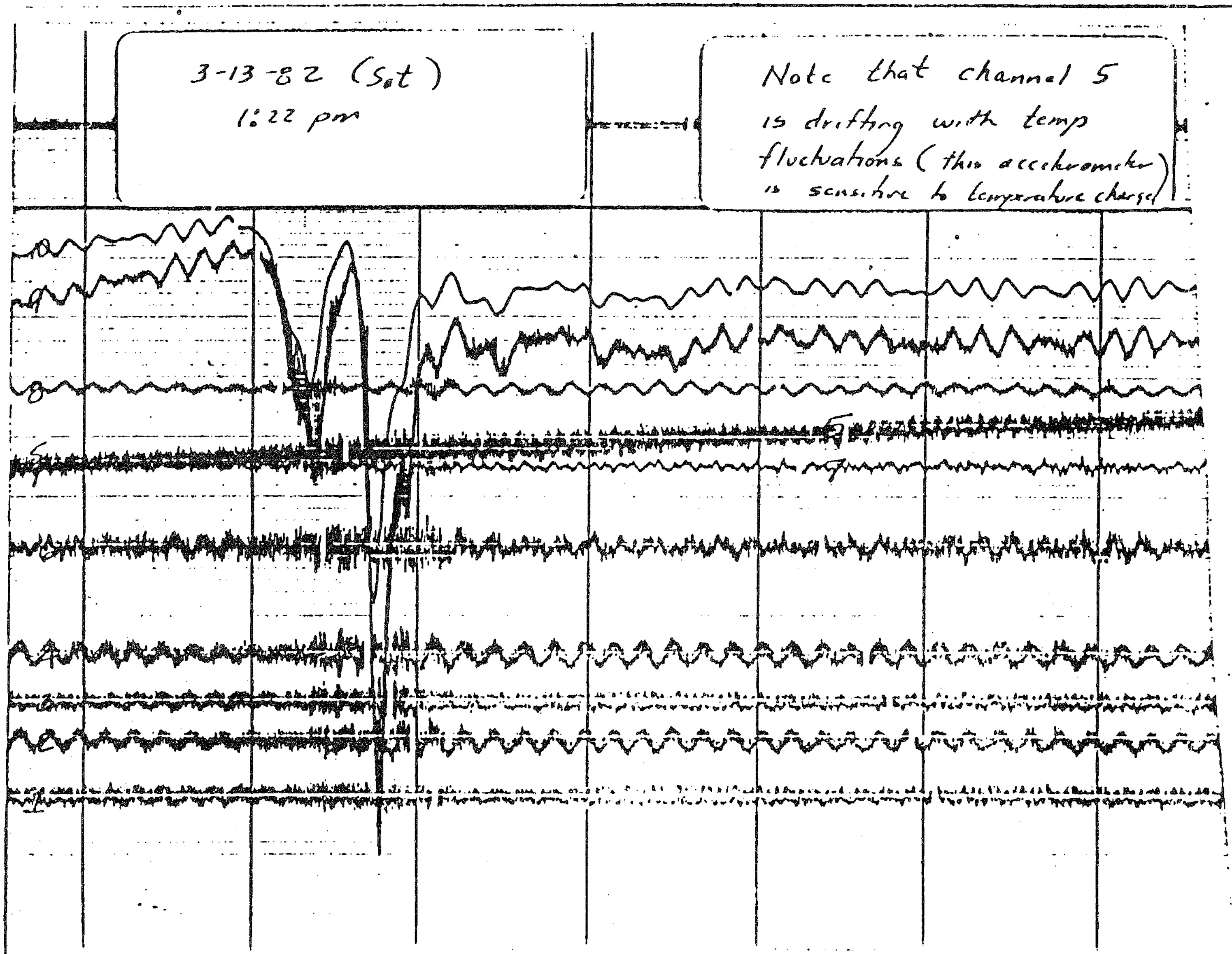


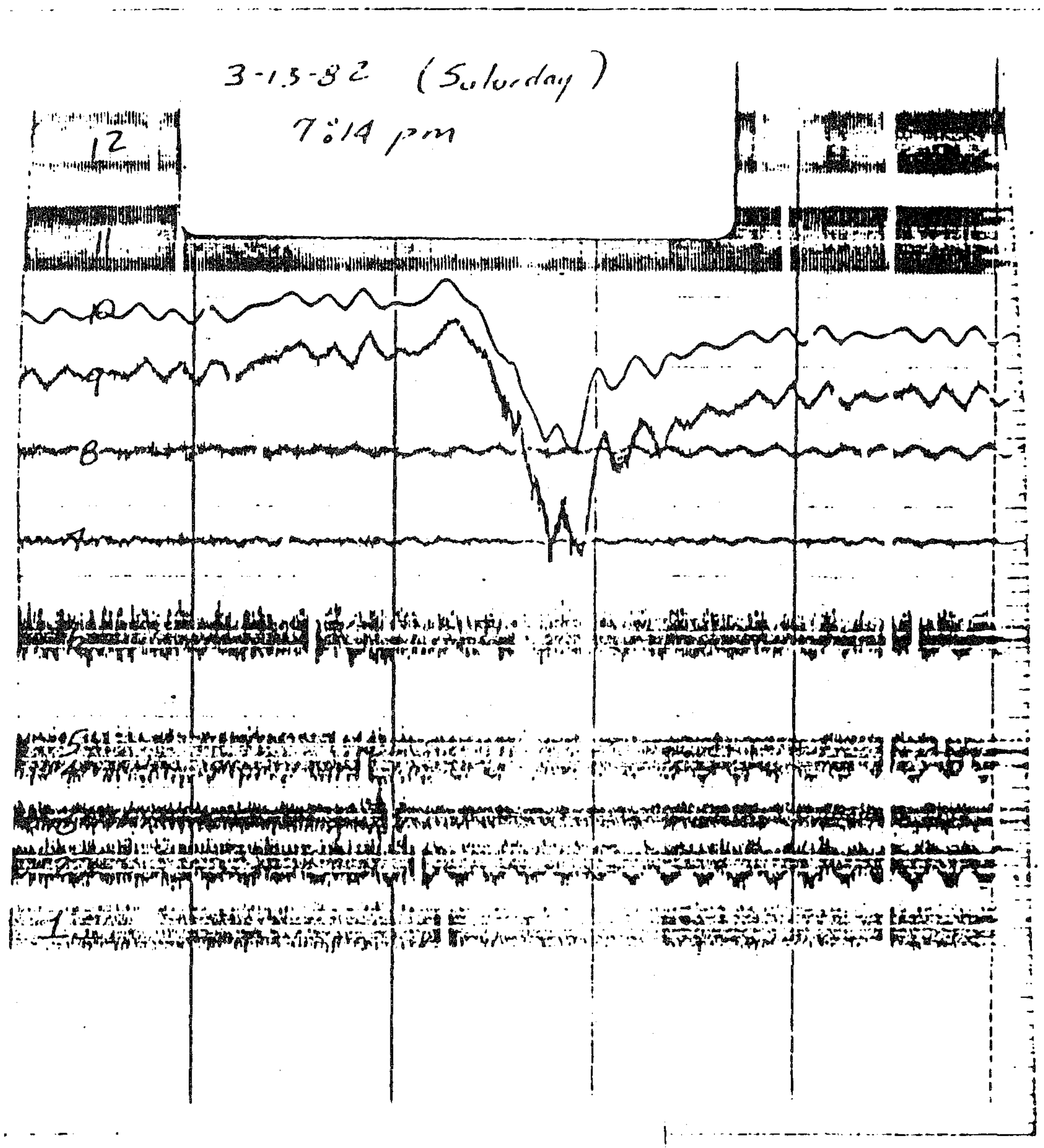
Figure 26. Gust Vibration



3-13-82 (Sat)
1:22 pm

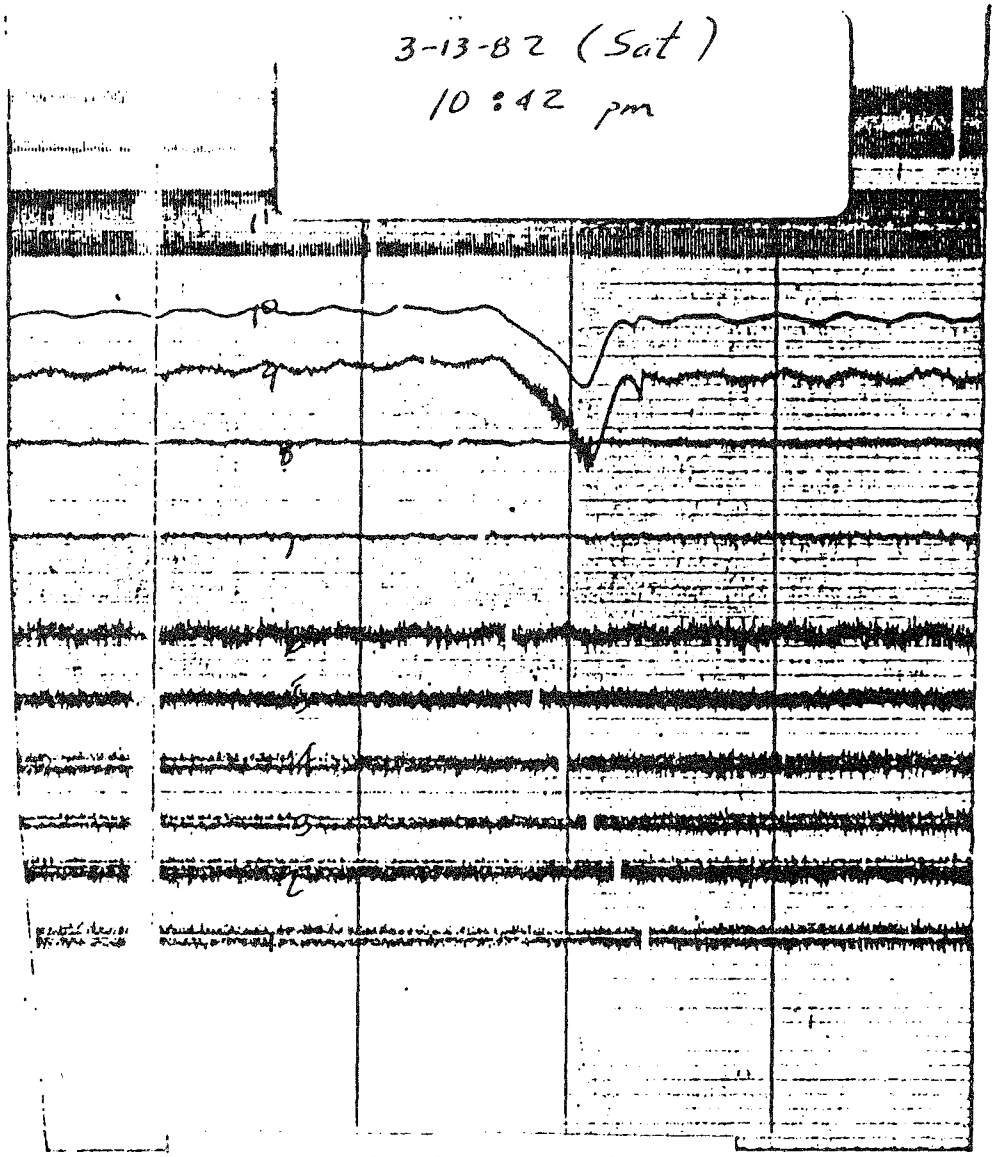
Note that channel 5 is drifting with temp fluctuations (this accelerometer is sensitive to temperature change)

Figure 27. Gust Vibration



3-13-82 (Saturday)
7:14 pm

Figure 28. Gust Vibration



3-13-82 (Sat)
10:42 pm

Figure 29. Gust Vibration

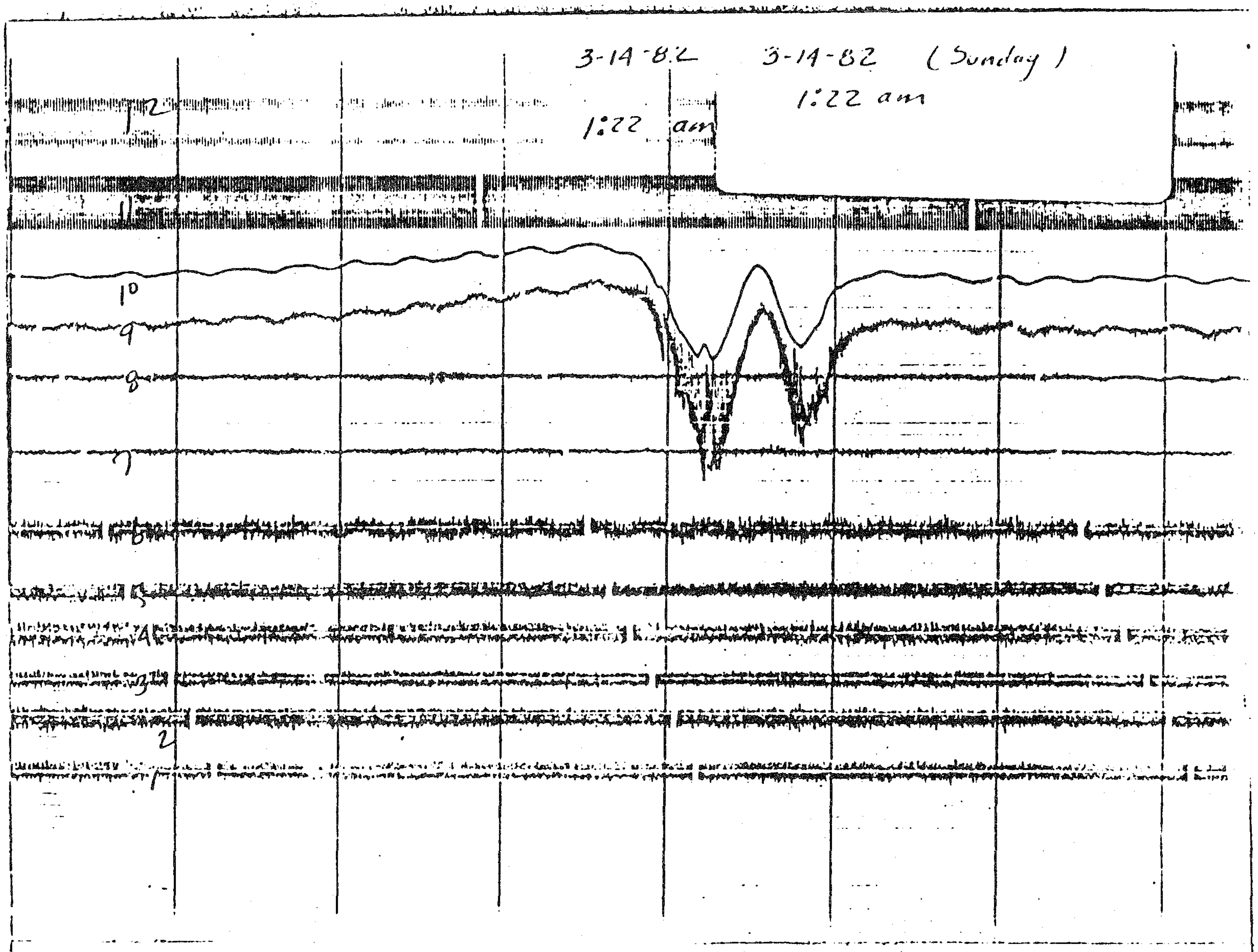
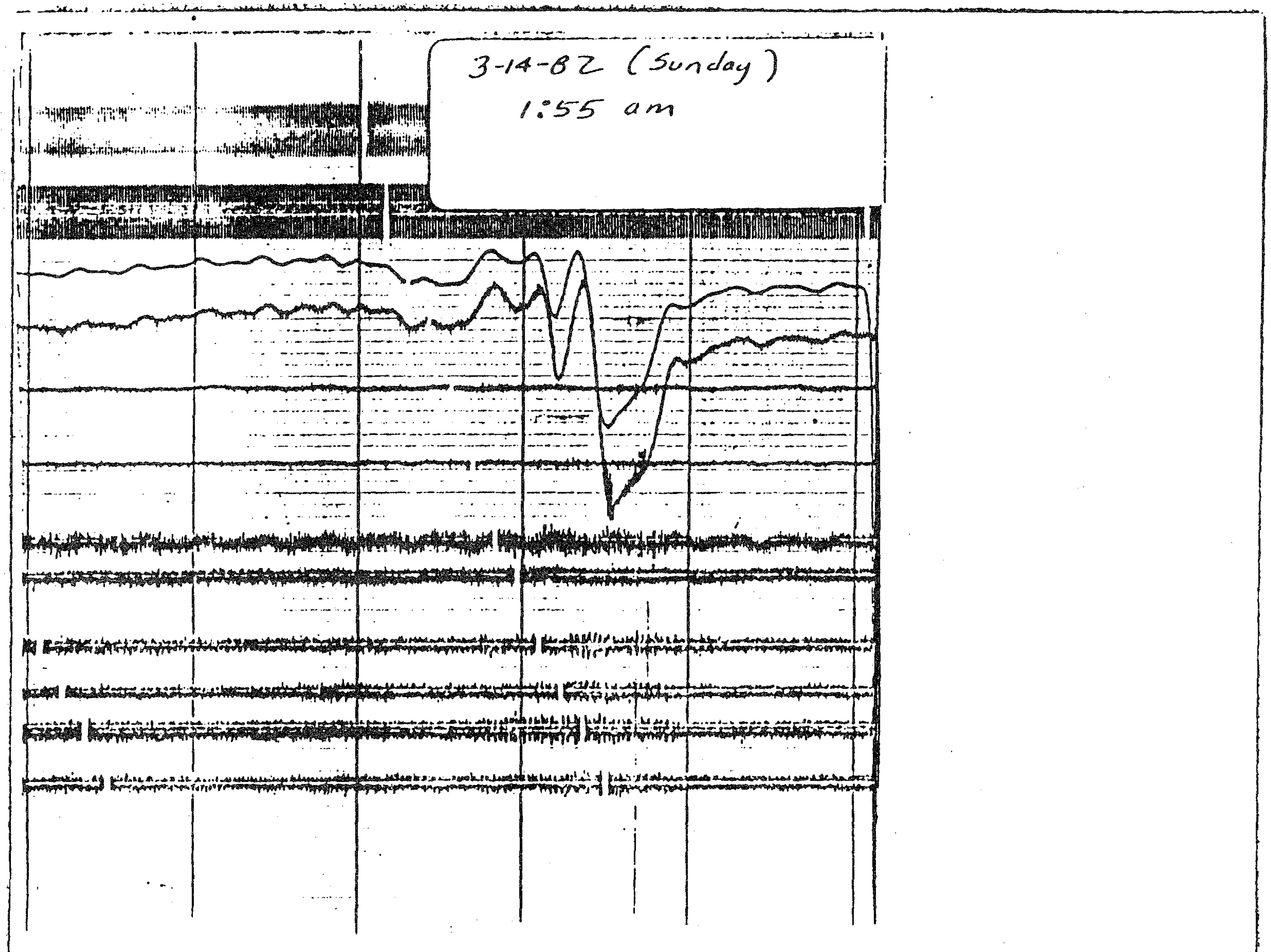


Figure 30. Gust Vibration



3-14-82 (Sunday)
1:55 am

Figure 31. Gust Vibration

Table 2 - Vibration Characteristics of Representative Data for Test #1

Figure(s)	Type of Vibration	Max Amplitude (g's)	Frequency (Hz)	Comments
12,13	Gust	≈ 1	-	Vertical acceleration, accelerometer 9, damps out within 1 s.
14,15	Ringing	≈ 0.1	6.5	Lower frequency bridge vibration
16	Ringing	≈ 0.1	Variable (6.5 - 200)	Vibration frequencies up to 200 Hz and 0.1 g magnitude present in the data. Channels 1 and 2 filtered at 600 Hz.
17,18,19	Gust	> 2	-	Note vibration attenuation between socket (channel 9) and lamp (channel 10)
20	Gust	≈ 1	-	Channel 9
21,22	Gust	>> 2	-	Extreme shock load in tip of arm in vertical direction. Mostly local effect. Other vibration levels low.
23	Gust	0.7	-	Channel 9
24	Gust	≈ 1.7	-	Channel 9
25	Gust	≈ 1.7	-	Channel 9
26	Gust	≈ 0.5	-	Channel 9
27	Gust	≈ 2.2	-	Channel 9. Note temperature drift of channel 5.
28	Gust	≈ 0.6	-	Channel 9
29	Gust	≈ 0.3	-	Channel 9
30	Gust	≈ 0.6	-	Channel 9
31	Gust	≈ 0.7	-	Channel 9

4.0 SUMMARY & RECOMMENDATIONS

The test procedures proved successful and the data acquired for site # 1 should prove useful to both the SDHPT and HPS lamp manufacturers. Unfortunately lamp blink-out was not experienced, even though an unimproved GE LU 400 lamp was used. In future tests, we recommend that preliminary testing be conducted to identify and select a lamp sensitive to vibration and that, at least in one of the 24 hour tests, this lamp be used.

Concerns were raised about the available power. If sufficient power is unavailable to run the instrumentation van air-conditioner, then we recommend that future tests be conducted in the cooler part of the year. (November - February?). We also recommend that the lamps remain on during the entire 24 hour period for each of the remaining tests so that we may gain the maximum information from these tests.

In general, the "shock" vibration due to wind vortex loading is more severe than expected and can cause acceleration levels occasionally to exceed, even far exceed, 2 g's. This is a local excitation phenomenon which exists at the arm tip and does not have sufficient energy to excite the entire luminaire structure.

REFERENCES

1. "Investigation of the Effects of Vibration on High Pressure Sodium Lamps", Proposal submitted by W.E. Red and Don Russell, representing TTI, to the SDHPT, March 11, 1981.

2. Jones, H.Dexter, "Problems Encountered in Three High-Pressure Sodium Lighting Projects in Texas", Report No. 5522.3, Texas State Department of Highways and Public Transportation, Nov., 1980.

3. Jones, H. Dexter, "Second Meeting with T.T.I. - Proposed Lighting Vibration Study", Technical Memorandum of 2-11-81, State Department of Highways and Public Transportation.

4. Red, E., "Luminaire Vibration Study - Test Procedures Evaluation Test October 2, 1981 ", Technical Memorandum of October 19, 1981 to Dexter Jones.

5. Heller, Page, "Luminaire Tests Performed on 10/2/81", File report prepared by Page Heller of the Electrical Engineering Dept. for Dr. Don Russell.

6. Red, Ed, "Rescheduling of Luminaire Field Site Test, Thursday, March 4, 10:00 a.m., "Project memorandum of Feb. 23, 1982 to Page Heller (EE), Dexter Jones (SDHPT), Don Russell (EE), and Dick Zimmer (TTI).

7. Red, Ed, "Seven Day Luminaire Field Test", Project memorandum of Dec. 18, 1981 to Dexter Jones (SDHPT), Don Russell and Page Heller (EE), and Dick Zimmer (TTI).

APPENDIX A

Ampex Recorder

AMPEX RECORDER

Operating Instructions

I. To remove tape -

A. Fill in "Tape Removal Log" Sheet.

B. Read Footage Counter.

C. Tape Speed REM 15/16.

D. Press "FAST" and "REV" buttons at the same time. (Pressing "STOP READY" when footage counter is around 0040 will slow tape down as it exits head assembly.)

E. When tape is fully rewound and is completely out of the head assembly, unlatch retention ring in center of tape spool and remove tape.

F. Record date, time, tape ID, last footage, and your initials on log.

II. To load tape -

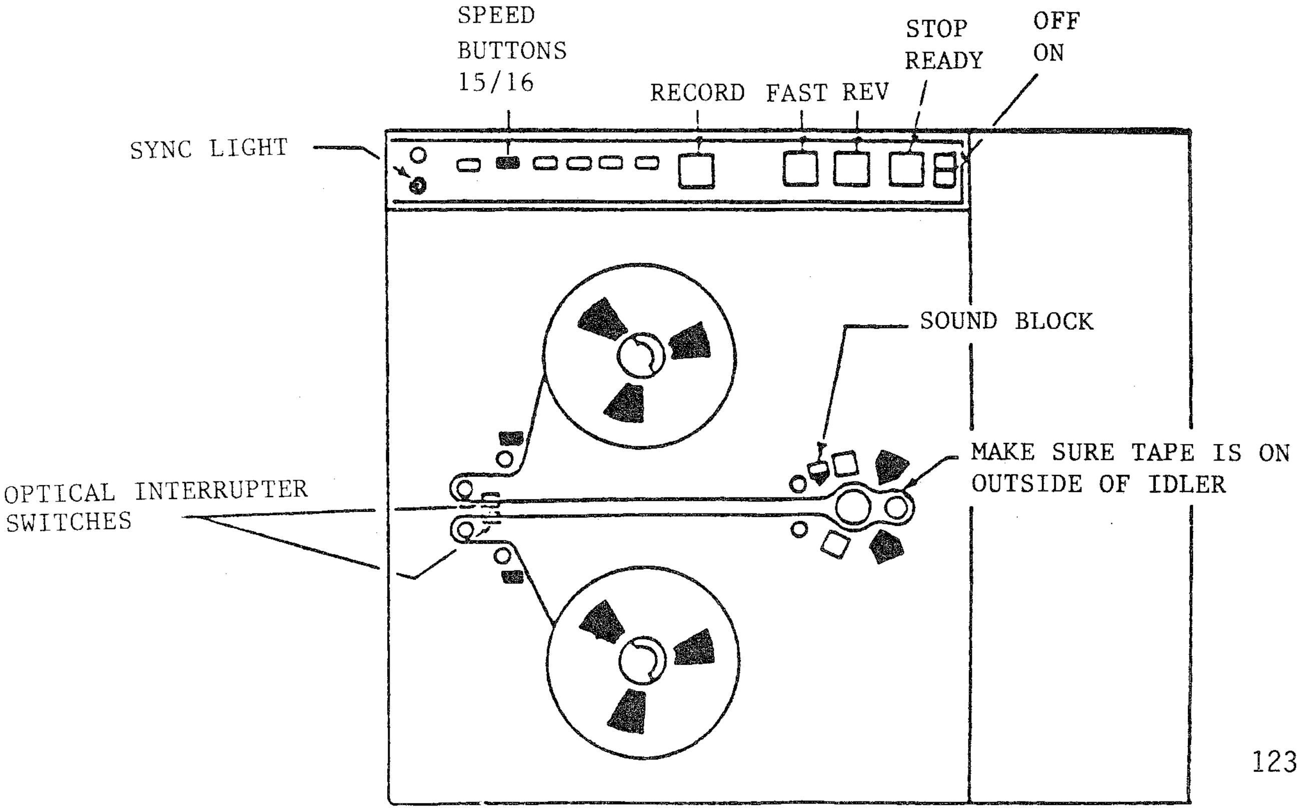
A. Put tape on top spool and latch retention ring.

B. Roll off about 3 feet of tape by hand.

C. Feed tape through head assembly as shown in Figure 1 below.

D. Roll excess onto bottom spool.

(continued)



AMPEX CALIBRATION PROCEDURE

I. Record calibration -

A. Mount old tape (preferably clean of data and degaussed).

B. Select "60" ips.

C. Turn on record test switch (on top).

D. With frequency counter, adjust center frequency (RS"CARRIER ADJ" to output 432 kHz on white jack) for each record card.

E. Input 1.414 V_{dc} from rear panel for full scale.

F. Adjust R7 - "DEVIATION ADJ" potentiometer for 604.8 kHz output on white jack for each record card.

II. Playback calibration -

A. Turn off record test. Select any speed (7 1/2 speed preferred).

B. With no input adjust "ZERO ADJUST" for 0 V at output of each demodulator card.

C. Press "FWD" and "RECORD" and input 1.414 V_{dc} to each channel from rear panel.

D. Adjust "OUTPUT LEVEL ADJ" potentiometer for 1.414 V_{dc} output. (Note: The slower the tape speed, the more delayed the response to changes. Make adjustments slowly).

E. Hand feed tape from top spool to bottom until there are enough layers that tape catches on bottom spool.

F. Press "STOP READY". If bottom spool spins, quickly turn recorder off, wait, and turn back on. Repeat steps E and F.

G. Press footage counter reset button.

III. Now Perform Calibration -

A. On amplifier number 5 mounted in 19-inch rack, switch "MULTR" knob from 10 to 1 and ensure that all other "MULTR" knobs are set to 5, all "GAIN"knobs are set to a and cal voltage thumb wheels are set to 100 on each unit.

B. Start recorder as follows:

C. For each channel amplifier (1-6):

1. Start with amplifier #1 on top unit.

2. Press "CAL" button and hold down.

3. Switch cal voltage toggle switch, on the top unit, form "ZERO" to 0-IV and wait for about five seconds.

4. Continue pressing cal button and switch toggle back to "ZERO" and wait for about five seconds.

5. Release CAL button and repeat steps 2-5 for the other five amplifiers.

6. Repeat the cal sequence for the lower 6 amplifiers using the cal voltage toggle switch on that unit.

D. Switch "MULTR" know back to 10 on amplifier 5.

IV. DAta Recording

The system is now recording data and may be left unattended until tape is nearly expended (approximately 12 hours).

TROUBLESHOOTING

The Ampex

1.	"STOP READY" will light when pressed.	The tape is not breaking the light beam of the optical interrupter switches. Check (2) small black modules on left center of recorder near idlers.
2.	Tape does not advance when "FWD"and/or "record"	(a) "STOP READY" has not been pressed. Press it. (b) "FTG CNTR" switch is on. Turn switch off. (c) Brake locked on. Turn recorder off and back on. Then press "STOP READY". (d) "RFM" button pressed. Press "15/6".
3.	Footage display not lit.	Turn on "FTG CNTR" switch on top of recorder.
4.	Bottom reel spins without moving tape.	Turn recorder off. Hand wind about three feet of tape onto bottom reel until tape catches. Press "STOP READY".

5. Recording error	Check the following switch positions: (a) `A' speed - 60, (b) `B' speed - 15/16, (c) FTG CNTR - off, (d) EXT REF - off, (e) TAPE SYNC/TACH SYNC - TACH SYNC, (f) record test - off, (g) SEQ - OFF, (H) EOT - off, (i) "15/16" selected. Check that the power switch light and SYNC light are both on.

EPI EQUIPMENT LIST
FOR TTI-LUMINAIRE TESTS

CHECK

TO FROM

______________________Ampex Recorder

______________________Preston C.T.'s (2)

______________________Frequency Counter

______________________DC Voltage Supply

______________________Digital Voltmeter

______________________Oscilloscope

______________________Calibration Tape

______________________Small Screwdriver

______________________Jack Input Wire

______________________Card Puller

______________________BNC-Alligator

______________________BNC-Bananna

______________________Alligator Jumper

Report B

Luminaire Evaluation Tests - Instrumentation and Results

LUMINAIRE TESTS

PERFORMED ON 10/2/81

REPORT PREPARED BY PAGE HELLER

ATTENDANCE: Dexter Jones, Texas Department of Highways
Thad Bynum, Texas Department of Highways

Ed Red, Mechanical Engineering, TAMU
Don Russell, Electrical Engineering, TAMU
Page Heller, Electrical Engineering, TAMU
Dick Zimmer, Texas Transportation Institute,TAMU
John Curik, Texas Transportation Institute, TAMU

SYSTEM DESCRIPTION

A General Electric type M-400 luminaire designed for a high pressure sodium lamp was instrumented and mounted on a light pole at the Research Annex to Texas A&M University. In addition to the usual ballast components, the luminaire contained the following measurement equipment. Two Pearson Electronics [1] model 411 wide band, precision current transformers were mounted to provide current measurements on the primary and secondary sides of the ballast transformer (see Figure 1). Two Tektronix[2] p6007 voltage probes were used to monitor the primary and secondary voltages of the ballast. These 100X probes have a bandwidth ranging from D.C. to 25 MHz and are rated to withstand 4 kVac peak-to-peak. Finally eight PCB Model308b10[3] accelerometers were mounted in various positions, as noted in the tests results section, to determine the force applied in torsional and lateral directions. All signals were transmitted via coaxial cable, measuring 370 feet in length, to a Highway

Department trailer housing amplifiers and in Ampex[4] PR7700 wide band FM recorder (D.C. to 80 KHz response).

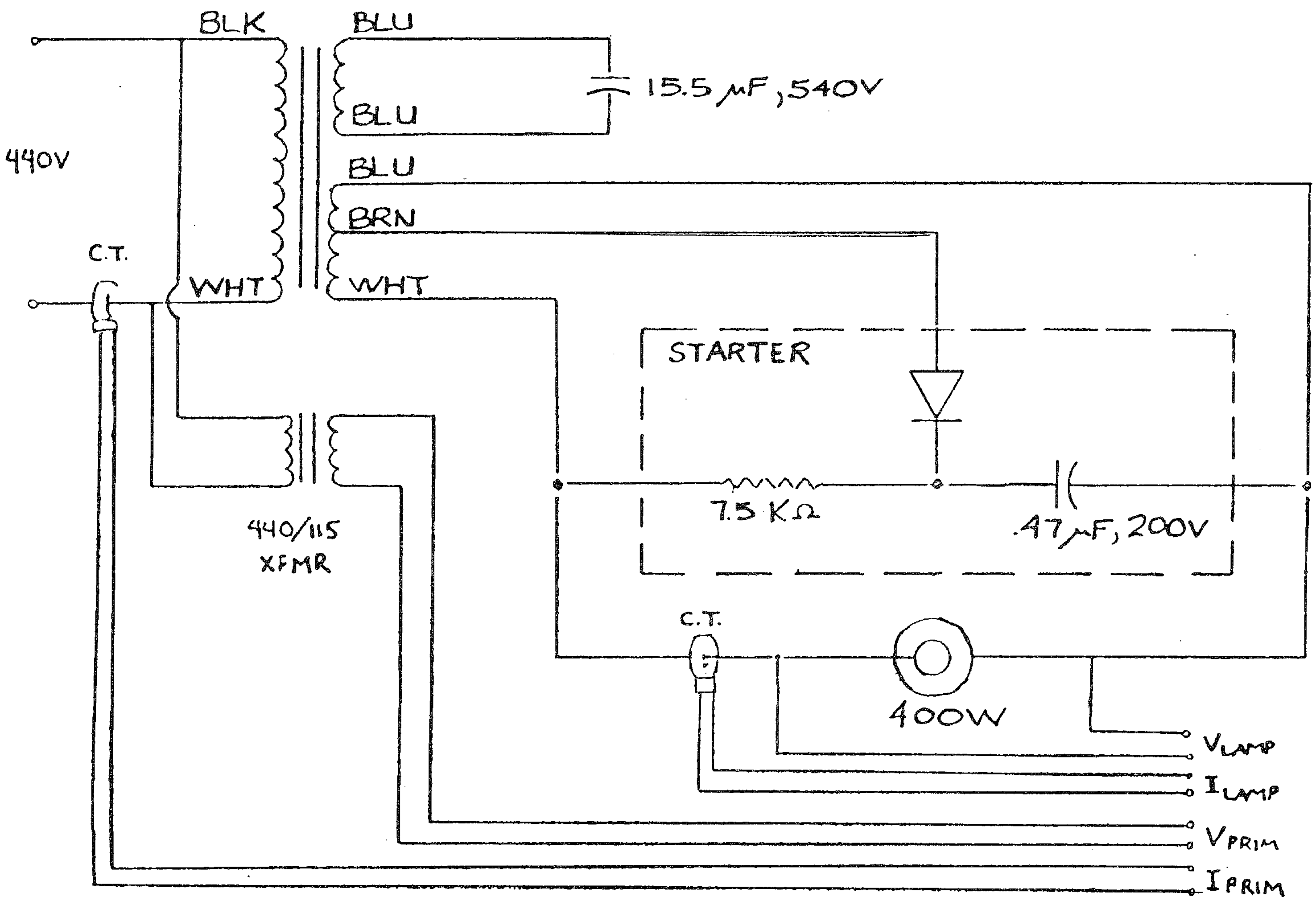
---

[1] Pearson Electronics, Inc; 4007 Transport Street; Palo Alto. CA 94303

[2] Tektronix, Inc.; P. O. Box 500; Beaverton, OR 97005

[3] PCB High Temperature Accelerometer used on the lamp. (Two are high temp 312A models)

[4] Ampex Corp.; Data Products Div.; 401 Broadway; Redwood City, CA 94063



GE LUMINAIRE BALLAST CIRCUIT

FIGURE 1

Two General Electric[5] Lucalox LU400 high pressure sodium lamps were used in the tests. One was a newer design than the other, and is hereby referred to as the "New Lamp." Previous tests (see report for luminaire tests on 9/23/81) using the same bulbs were performed in the Electric Power Institute Laboratories at Texas A & M University to determine the exact electrical characteristics of the bulbs. These characteristics are to be considered as a more accurate representation of the electrical measurements taken in the field. In this light, the very long cables' capacitive effects on the system bandwidth will not be of concern in these tests. The accelerometers, being current-out put devices, do not suffer the same reduction in bandwidth.

TESTS PERFORMED

The following tables are taken from the AMPEX tape log and may be used as a guide to finding data associated with a particular test. Table I describes the data on each channel of the recorder. Table II describes the actual tests performed.

---

[5] General Electric; Lamp Business Div.; Nela Park; Cleveland, OH 44112

TABLE 1

Date: 10/3/81
Tape ID: AMPEX 501274171-9

AMPEX CHANNEL IDENTIFICATION

CHANNEL	DESCRIPTION	COMMENTS
1	UNUSED	SPARE ACCELEROMETER #1
2	ACCEL #2	ON LAMP ITSELF
3	ACCEL #3	ON LAMP SOCKET
4	ACCEL #4	ON LAMP SOCKET
5	ACCEL #5	ON ARM END
6	ACCEL #6	ON ARM END
7	ACCEL #7	ON ARM ROOT (HOOKS TO MAST)
8	ACCEL #8	ON ARM ROOT
9	ACCEL #9	ON MAST TOP
10	ACCEL #10	ON MAST TOP
11	PRIMARY CURRENT	TO BALLAST
12	LAMP VOLTAGE	AFTER FOOTAGE 3331, LAMP CURRENT
13	UNUSED	RESERVED FOR PRIMARY VOLTAGE
14	LAMP CURRENT	AFTER FOOTAGE 3331, LAMP VOLTAGE

CHANNELS 1-12 CALIBRATED FOR 1 V_{rms} PRODUCING 40% DEVIATION.

CHANNELS 13,14 CALIBRATED FOR 2 V_{rms} PRODUCING 40% DEVIATION.

Date: 10/2/81
Tape ID: AMPEX 501274171-9

TABLE II

AMPEX TAPE LOG

TEST #	FOOTAGE	TAPE SPEED (ips)	TEST DESCRIPTION	COMMENTS
-1	240-300	60	5 G Calibration	All Cal buttons held down on accelerometer amplifiers.
0	340-385	60	0 G Calibration	Same as Test # -1.
1	400-488	60	Response Test	Random torsional and lateral vibration to determine accelerometer response; Lamp off.
2	500-925	60	Torsional Test	Torsional vibration only; Lamp off.
3	925-1408	60	Lateral Test	Lateral vibration only; Lamp off.
4	1420-1750	60	Start Lamp	No vibration; Turn on and warm new lamp.
5	1750-1953	60	Warm Lamp	No vibration; New lamp warm for 10 minutes
6	1965-2418	60	Torsional	Torsional vibration only; New lamp on.
7	2418-2731	60	Vertical	Vertical vibration; New lamp on.
8	2748-2900	60	2 X 4 At Base	Striking base of pole with a 2 X 4; New lamp on.
9	2908-3104	60	2 X 4 At Top	Striking mast top with a 2 X 4; New lamp on. Lamp breaks.
10	3120-3331	60	Unknown	
11	3340-3502	30	Start Lamp	Old bulb startup; No vibration.
12	3503-3551	30	Warm Lamp	No vibration; Old lamp warm for 10 minutes.

TABLE II (CONT.)

TEST #	FOOTAGE	TAPE SPEED (ips)	TEST DESCRIPTION	COMMENTS
13	3555-3865	30	Strike Lamp	Lamp struck directly; Lamp extinguished and restarted. Noise on accelerometers.
14	3870-4049	30	2 X 4 At Base	Pole struck at mast base; Lamp does not extinguish.
15	4053-4362	30	Shake Head	Head of light pole shaken only; Lamp extinguished and restarted.
16	4362-4380	15/16,1 7/8,15/16	Shake Head	Same as Test #15. Lamp extinguished and restarted.
17	4380-4398	15/16	Strike Pole	Pole struck with a 2 X 4; Lamp extinguished

OBSERVATIONS

The accelerometers were overranged frequently by the test strikes, meaning the strikes produced forces greater than 10 G's. Also, it was determined that the accelerometers should be shielded electrically since the severe restart characteristics of The lamp caused high noise levels on the accelerometers. Mild strikes producing length-wise forces on the lamp caused the older model lamp to extinguish. Earlier laboratory tests showing increased voltages and high harmonic content on a lamp restart were verified.

LUMINAIRE TESTS

DATA TRANSFER

PERFORMED ON 10/8/81

REPORT PREPARED BY PAGE HELLER, DICK ZIMMER

The following documents the Honeywell model 1508 visicorder output of the Luminaire Tests run on 10/2/81 (See test report for 10/1/81).

Tape ID: AMPEX 501274171-9

Run #	Test #	Description	Tape Speed (ips)	Chart Speed (ips)
1	-1	5g Cal & Og Cal (First 5 channels only)	60	0.3
2	8	2 x 4 at base	60	30
3	8	2 x 4 at base (Incurrs responses near 7 KHz and 1 KHz at mast top, 25 KHz at base)	15/16	15
4	9	Strike mast top	15	6
5	9	Strike mast top (Accelerometers saturating)	15/16	30
6	13	Strike lamp (Lamp extinguished)		
7	13	Extinguished	15/16	15
8	13	Restart	15/16	6
9	16 or 17		15/16	

SHOCK PROTECTED

QUARTZ ACCELEROMETER

Series 308B

PIEZOTRONICS

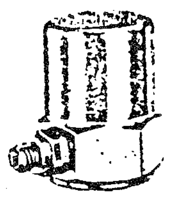
with sensitivities to 1000 mV/g, built-in microelectronic amplifier is shock-motion and shock-voltage protected to above 5000 g.

For measurement of low and medium frequency vibration and shock motion on heavy structures of industrial machines, machine tools, vehicles, suspensions, engines, buildings, bridges and vibration or impact testing machines.

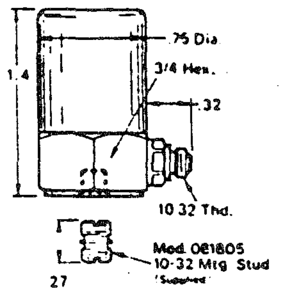
Model 308B is a heavy, rugged instrument for prolonged service in industrial and vehicle environments. It functions to transfer the acceleration aspect of shock and vibratory motion into a voltage signal compatible with readout and analyzing equipment. It measures motion from less than 0.1 g to over 50 g and follow transient events to about 20 milliseconds. It uniquely measures very low amplitudes (0.1 g) at very low frequencies (1.0 Hz), which in the past has been the domain of displacement and velocity sensors. In fact, a special version of the 308B generates an output proportional to displacement.

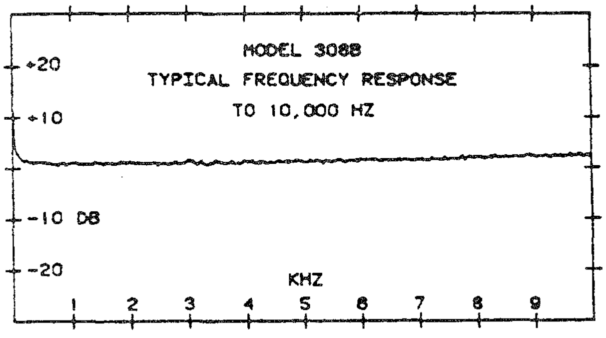
The structure of the model 308B contains a rigid quartz compression-mode element, a microelectronic line-driver amplifier and an overvoltage protective circuit. Dropping the instrument from great heights will not damage the electrical circuits.

Quartz accelerometers install by clamping with an elastic beryllium-copper stud the base surface in intimate contact with a precision machined surface on the structure of the test object or mounting pad. An optional magnetic base functions good below 1000 Hz. For very low frequency measurements, an optional RTV boot protects and isolates against thermal inputs. Electrical connection is usually by means of a single coaxial cable, which conducts both signal and power.



308B



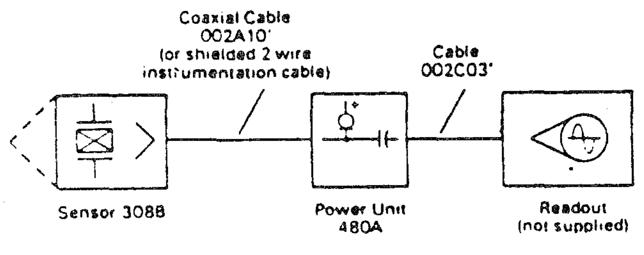


SPECIFICATIONS: Model No.		308B
Range (for ±5Voutput)	g	±50
Resolution	g	0.002
Sensitivity (± 2%)	mV/g	100
Resonant Frequency (mounted)	Hz	25000
Frequency Range (±5%)	Hz	1 to 3000
Linearity	%	1
Output Impedance	ohms	100
Overload Recovery	microsec	10
Transverse Sensitivity (max.)	%	7
Strain Sensitivity	g/μin/in	.05
Temperature Coefficient	%/°F	0.03
Temperature Range	°F	−100 to +250
Vibration & Shock (protected)	g	500/5000
Size (dia. x height)	in	0.75 x 1.4
Weight	gram	87
Connector (side)	micro	10-32
Seal		epoxy
Case Material		S.S.
Excitation (thru C.C. Diode)	VDC	+18 to 24
Excitation Current	mA	2 to 20

OPTIONAL MODELS	Model No.
High Temperature (100mV/g + 325°F)	308A08
Ultra-sensitivity (1000 mV/g ±5%)	308B02
Short version (50 mV/g)	308B03
Welded hermetic seal	308B10
Top connector (100 mV/g)	308B12
Top connector (50 mV/g)	308B13
Built-in L.P. filter −5% @ 20 Hz	308B30
Built-in L.P. filter −5% @ 50 Hz	308B31
Built-in L.P. filter −5% @ 100 Hz	308B32
Built-in L.P. filter −5% @ 200 Hz	308B33
Built-in L.P. filter −5% @ 500 Hz	308B34

ACCESSORIES	Model No.
Adhesive Mounting Base	080A12
Magnetic Mounting Base	080A07
Triaxial Mounting Block	080A11
RTV Thermal Boot	085A01
Conical Probe Tip	080A09
Stud 10-32 to ¼-28	081A08
Solder Terminal Connector Adaptor	070A09
Thick Isolation Base	080A19

TYPICAL SYSTEM (K308B Kit)



APPENDIX C

LUMINAIRE TESTS PERFORMED ON 9/23/81

LUMINAIRE TESTS
PERFORMED ON 9/23/81
REPORT PREPARED BY PAGE HELLER
Electric Power Institute, TAMU

SYSTEM DESCRIPTION

A General Electric type M-400 luminaire designed for a high pressure sodium lamp was instrumented with the following equipment:

2	Pearson Electronics Model 411 wideband (35 MHz), precision current transformer (10 A input = 1 V output).
2	Tektronix P6007 X 100 voltage probes rated for 4 $KV_{peak\text{-}to\text{-}peak}$ and having a bandwidth ranging from DC to 25 MHz. (6 foot coax leads)

Voltage and current on the primary side of the ballast along with voltage and current at the lamp inputs were monitored in a laboratory environment. Photographs of these parameters were taken from the traces on a 20 MHz Tektronix storage oscilloscope to document the electrical characteristics of two styles of G.E. Lucalox LU400 lamps. The bandwidth of the entire system is limited only by the oscilloscope and therefore is DC to 20 MHz.

TESTS PERFORMED

All parameters were measured under the following conditions for both the old style and new style lamps.

Condition #	Condition
1	Cold start transient as power applied.
2	Cold startup; 0 minutes
3	Warming process; 1 minute
4	Warming process; 5 minutes
5	Warm; 10 minutes
6	Restart; After 10 minutes warm, primary power toggled.

OBSERVATIONS

Both lamps were found to be electrically identical. Transients greater in amplitude than 700 volts were observed at the inputs to the lamps at the moment the power was applied by means of a circuit breaker. The primary voltage transients were low amplitude, sub-millisecond events. Primary current, however, was unstable for periods greater than 50 milliseconds and strayed from a nominal 1 amp to peaks of 6.5 amps. The lamp current transients were measured to be of a magnitude up to 12 amps_{pk} in durations on the order of several milliseconds.

Steady state conditions ensued after 50 to 80 milliseconds and were found to be similar to the specifications on the lamp, as stated in G.E.'s lamp specification bulletin LSB#220-6189. The primary current increased from 0.7 amps_{rms} to 1.0 amps_{rms} over a 10 minute span as the lamp current, distorted with harmonics, stayed at approximately 15 $\text{amps}_{\text{peak-to-peak}}$. The primary voltage, as expected, was a well-behaved, steady 440 V_{rms} value. The lamp voltage, however, was highly non-sinusoidal in nature. This waveform alternated positive and negative going, exponentially decaying spikes peaked near start-up around 50 volts and when warm around 150 volts.

During a restart condition, with the lamp warm and a short loss of power, and electrically traumatic period occurs which is not documented in G. E.'s mag-lucalox ballast electrical data sheet (drawing 32-217601-74) which includes test values conducted on the ballast. The primary voltage acquires four spikes per cycle which are very short in duration and approximately 1500 volts in amplitude. The lamp voltage becomes a sharp-edged, ragged waveform measuring 900 $\text{volts}_{\text{peak-to-peak}}$. This value is far above the 140 volt_{rms} (or about 392 $\text{volts}_{\text{peak-to-peak}}$) which is specified as the maximum lamp voltage.

The restart condition requires little current in the lamp circuit and the primary current drops to about 1 $\text{amp}_{\text{peak-to-peak}}$. The third harmonic content of the primary current increases drastically from something less than 5% to 35% at an angle of 315°.[1] This restart phenomenon is continuous for one or two minutes before the lamp lights again and all parameters return to normal.

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[1] Waveform reproduced by a computer-driven arbitrary waveform generator to determine content.

APPENDIX D

SCHEDULING OF THE FIRST FIELD SITE TEST

TEXAS A&M UNIVERSITY
MECHANICAL ENGINEERING DEPARTMENT
COLLEGE STATION, TEXAS 77843

February 23, 1982

MEMORANDUM

TO: Page Heller (EE), Dexter Jones (SDHPT), Don Russell (EE), Dick Zimmer (TTI)

FROM: Ed Red

SUBJECT: Rescheduling of Luminaire Field Site Test, Thursday, March 4, 10:00 a.m.

Our first field test is now rescheduled to:

When: Thursday, March 4, 10:00 a.m.

Where: South approach to ship channel bridge-site is on prestressed unit, approximately 30 feet from a bent

Objective: To acquire vibration and ballast data for a seven day period and record on magnetic tape

We will depart from the front of Zachry.

Vehicles: 1) TTI Insturmentation Van
2) Ed Red's automobile

Departure: Front of Zachry, no later than 7:30 p.m., Thursday, March 4

Arrival: Approximately 9:30 a.m., at Houston Urban Office of SDHPT

In conversations with Dexter Jones, it was decided that:

1. The "yellow elephant" will be picked up on Tuesday, March 2 and moved to Houston.
2. We will provide the #8, 50A wire up to the overhead sign for the 230 V power and also provide the female and male connectors (Hubble type). Dexter will provide the electrician who will make the necessary wiring connections to the overhead sign on the morning of the fourth.

Other necessary tasks are covered in the memo of December 18, 1981 which I have attached for reference. Please review these. In response to some of the questions posed in this memo I note that:

1. The tapes have been procurred
2. We are to use LU400 <u>unimproved</u>, sodium lamps.

cc: Robert Olson (TTI)
Joseph G. Raska (SDHPT, D-9)
Thad Bynum (SDHPT, D-8)

TEXAS A&M UNIVERSITY
MECHANICAL ENGINEERING DEPARTMENT
COLLEGE STATION, TEXAS 77843

December 18, 1981

To: Dexter Jones (SDHPT)
Don Russell/Page Heller (EE)
Dick Zimmer (TTI)

From: Ed Red

Subject: Seven Day Luminaire Field Test

Per our conversations, we will schedule our first field test as follows:

What: 7-Day Luminaire Vibration Field Test

When: Monday, Jan. 11, 1982 - Monday, Jan. 18, 1982. Assembly of data acquisition system to begin at 10:00 a.m. and disassembly to begin at 10:00 a.m., seven days later.

Where: South Approach to Ship Channel Bridge. Site is on prestressed unit, approximately 30 feet from a bent.

Objective: To acquire vibration and ballast data for a seven day period and record on magnetic tape.

Since this field test will involve a certain amount of coordination, I have listed tasks which we should each accomplish and the appropriate completion date (where necessary). If you feel an assigned task is inappropriate to you, please contact me right away.

TELEPHONE 713-845-1251

Dexter Jones:

1. Identify person(s) to change magnetic tapes at site every 12 hours for 7 day period. Preferably, the person should be familiar with electronic equipment.

2. Arrange for transportation of the data acquisition vehicle from the Research Annex to the test site. (Dexter, if you could have the same person move it down who moved it up, this would be helpful. Your personnel are more familiar with the Houston area and will be able to place the "yellow elephant" in the proper place. Our feeling is that the elephant needs to be moved down Friday before the test and not the morning of. Thus, if something happens during transport it will not delay the test). Transport Date: On or before Friday, January 8, 1982 (Please coordinate this with Dick Zimmer at TTI).

3. Move the yellow elephant under the bridge below the luminaire base. Date: On or before Friday, Jan. 8, 1982.

4. Provide 230 V Power from the overhead sign near the luminaire. Dexter, please have someone take the power off the sign and run it to the base of the luminaire column using #8 wire and a female connector that is a 50 ampere (A), Hubble type. Date: Before 10:00 a.m., Monday, Jan. 11, 1982.

5. Provide a bucket truck (capable of extending to top of luminaire) and escort personnel during both the assembly and disassembly test periods. Dates: Assembly - Monday, Jan. 11, 10:00 a.m. --?

6. Arrange to transport and store yellow elephant in Houston area at conclusion of test until next field test.

7. Arrange to have test tapes turned over to Dick Zimmer at conclusion of testing period. Tapes with recorded data not be stored in yellow elephant during testing period. Any vandalism, fire, or malfunction might destroy them, causing the loss of valuable test data. We should avoid this happening. Page Heller will coordinate the appropriate labeling of the tapes with the SDHPT person responsible for changing the test tapes.

8. Dexter, would you have someone measure the distance from the base of the luminaire column to the ground under the bridge where the yellow elephant will be parked, as soon as possible? Then relay information to Dick Zimmer.

Don Russell/Page Heller:

1. Work with Dick Zimmer to minimize the field excitation problem that is occurring between Dick Z's cables and Don R's cables. Dick Z. suggested that Don R./Page H. use twinax cables.

2. Coordinate transportation of electronic equipment with Dick Zimmer. Suggest TTI provide van for equipment and no more than two vehicles be used. Ed Red take his car down at no expense to project.

3. Prepare list of instructions for SDHPT person who will be exchanging tapes; include trouble-shooting instructions also. Prepare to instruct person verbally also at test site.

4. Prepare labels for each of the 14 tapes which include appropriate identification information. Coordinate labelling with SDHPT person.

5. Work with Dick Zimmer to get luminaire test section properly instrumented and ready to mount at test site on Jan. 11, 1982. Date: Before Jan. 8, 1982.

6. Prepare checklists on instrumentation, test procedures, etc., as necessary.

Dick Zimmer/Ed Red:

1. Get luminaire test section properly instrumented and ready to mount at test site. Coordinate this preparation with Don R./Page H. Remember, we will need a drop cable or rope to steady the instrumentation cables.

2. Procure 2 sodium lamps (LU400) and epoxy an accelerometer mount to each. If for some reason, we experience an accident, we will have a reserve lamp. Dick, will you contact Dexter to see whether he wants to test an unimproved (old-type) sodium lamp or an improved LU400?

3. Procure 15 ampex tapes for the tests. Dick Zimmer will contact Don R., identify supplier, and procure tapes using "sole source" justification.

4. Place extra strongbar on rear of yellow elephant and provide lock and two keys. One key will be delivered to SDHPT person changing tapes and Dick Z. will keep other.

5. Schedule van to transport electronic instrumentation and other supplies to and from test site.
6. Prepare checklist of test procedures as necessary.
7. Ed Red will take slides of test.

Suggested Departure Time

Leave: 7:30 a.m., Monday, Jan. 11. Zachry Engineering Center.

Vehicles: 1) TTI Instrumentation Van
2) Ed Red's automobile

Personnel Phone Numbers

	Office	Home
Ed Red	845-4115	693-5389
Dick Zimmer	845-6385 -6375	
Don Russell	845-7441	
Page Heller	845-7441	
Dexter Jones	870-1535	

cc: Robert Olson (CE)

WER/cr

Appendix E

Test Details and Minor Problems

AMPEX INPUT ARRANGEMENT

Project Luminaire IPS 15/16

Test Site 610 Ship Channel Bridge FM or Direct FM

Date 3/11/82 Time

Tape I.D. (s) Luminaire Tests I-XVII & CAL II

Footage Range

Operator(s) Heller/Curik

Channel #	Input Lead #	Description	Comments
1	1	x mast top	x 5 PCB AMP
2	2	y mast top	x 5 PCB
3	3	x arm @ mast	x 5 PCB
4	4	y arm @ mast	x 5 PCB
5	5	y arm end	x 50 substituted acceler.302 PCB
6	6	z arm end	x 5 PCB
7	7	x lamp base	x 5 PCB
8	8	y lamp base	x 5 PCB
9	9	z lamp base	x 5 PCB
10	10	z lamp	x 5 PCB
11	62	Primary voltage	x 1 lead 14 from bridge, Preston 6
12	72	Primary current	x 2 lead PC from bridge, Preston 7
13	82	Secondary current	x 1 lead SC from bridge, Preston 8
14	-	Input shorted	may be used for flutter compensation

Calibration: 40% deviation adjusted for 1.0 V_{mns} for channels 1-10,12,13

2.0 V_{mns} for channels 11

ITINERARY

Begin Taping	Time	Reading	Tape No.	End Taping	Time	Reading
3-11-82	Thurs. 6:30 P.M.	0005	I	Friday 3-12-82 A.M.	6:00 A.M.	3143
Friday 3-12-82	6:10 A.M.	0006	II	Friday 3-12-82 P.M.	6:00 P.M.	3368
Friday 3-12-82	6:08 P.M.	0005	III	Saturday 3-13-82 A.M.	6:00 A.M.	3350
Saturday 3-13-82	6:09 A.M.	0005	IV	Saturday 3-13-82 P.M.	6:00 P.M.	3345
Saturday 3-13-82	6:09 P.M.	0005	V	Sunday 3-14-82	6:00 A.M.	3345
Sunday 3-14-82	6:10 A.M.	0006	VI	Sunday 3-14-82	6:00 P.M.	3345
Sunday 3-14-82	6:15 P.M.	0005	VII	Monday 3-15-82	6:00 A.M.	3300
Monday 3-15-82	6:10 A.M.	0007	VIII	Monday 3-15-82	6:00 P.M.	3345
Monday 3-15-82	6:09 P.M.	0005	IX	Tuesday 3-16-82	6:00 A.M.	3345
Tuesday 3-16-82	6:09 A.M.	0006	X	Tuesday 3-16-82	6:00 P.M.	2610
Tuesday 3-16-82	6:08 P.M.	0007	XI	Wednesday 3-17-82	6:00 A.M.	3345

ITINERARY

Begin Taping	Time	Reading	Tape No.	End Taping	Time	Reading
3-17-82	6:08 A.M.	0006	XII	3-17-82	6:00 P.M.	3345
3-17-82	6:08 P.M.	0005	XIII	3-18-82	6:00 A.M.	3345
3-18-82	6:09 A.M.	0005	XIV	3-19-82	1:46 A.M.	3345
3-19-82	11:30 A.M.	0005	XV	3-19-82	11:27 P.M.	3345

E 4

TAPE REMOVAL LOG

	Date	Time	Tape ID	Footage	Initials	Comments
1.	3-12-82	6:00 AM	No. I	3143	KSW	Stop taping to begin on a 12 hr. schedule
2.	3-12-82	6:00 PM	No. II	3368	KSW	
3.	3-13-82	6:00 AM	No. III	3350	KSW	
4.	3-13-82	6:00 AM	No. IV	3345	KSW	
5.	3-14-82	6:00 AM	No. V	3345	KSW	
6.	3-14-82	6:00 PM	No. VI	3345	KSW	SEE ATTACHED NOTES
7.	3-15-82	6:00 AM	No. VII	3300	KSW	"
8.	3-15-82	6:00 AM	No. VIII	3345	KSW	"
9.	3-16-82	6:00 AM	No. IX	3345	KSW	"
10.	3-16-82	6:00 PM	No. X	2610	KSW	"

TAPE REMOVAL LOG

	Date	Time	Tape ID	Footage	Initials	Comments
11.	3-17-82	6:00 AM	XI	3345	KSW	
12.	3-17-82	6:00 PM	XII	3345	KSW	
13.	3-18-82	6:00 AM	XIII	3345	KSW	
14.	3-19-82	1:46 AM	XIV	3345	KSW	See Attached notes
15.	3-19-82	11:27PM	XV	3345	KSW	

6. Sunday, March 14, 1982, 5:50 P.M. On the recording unit #PR 2200, one of the amplifier lights began to flicker about 3 or 4 seconds. The location of the flickering amplifier is in the bottom section. Upper level Channel #7 in the 1 thru 8 section. The weather was cool & beginning to mist a little about 6:33 P.M.

7. Monday, March 15, 1982, 5:55 A.M. On the recording unit #PR 2200, the bottom section upper level, the amplifier's Channels 1-4 &5 in section 1 thru 8 began to flicker for about 5 seconds. Then in the same section in the lower section Channels 11 & 12 began flickering about 5 seconds, the reading on the recorder was 3245. The same section Channel #12 light came back on at reading 3250 and stayed on until reading 3269. Then at reading 3277 it came back on and stayed on and is still on at the beginning of tape #VIII reading #0007.

   The same section upper level reading 3289 channels #4 & 5 started flickering about 4 & 5 seconds.

   At the beginning of taping tape #VIII, channel #12 amplifiers on the top section & the lower section stayed on, reading #0007.

   The weather was misting rain.

8. At the beginning of tape #VIII, reading 0007 thru 1398, the #12 channel lights were on. Locations of #12 channels were on the recorder upper and lower section. After talking to Prof. Page Heller, I changed the GAIN from 2 to No. 1 on the 8300 XWB (#Z) Amplifier (Date 3-15-82)(11:07 A.M.)(Reading 1398). After this change was made, the lights on channel went out.

9. Monday, March 15, 1982, 6:11 P.M. At the beginning of #IX Taping, reading 0005 to 0012, the #12 Channel light stayed on. I changed the P.C. Board in the bottom section, lower level with one of the spare P.C. Boards. After doing this, the light went off. I waited about 45 minutes and it never came back on.

10. Tuesday, March 16, 1982, 5:45 A.M. Channel #10 in the bottom section, lower level began to flicker about 3 seconds. Reading was 3261. At 5:46 A.M., Channel #11 began to flicker about 4 seconds, reading 3268, in the same section.

10. On Tuesday, 3-16-82, 4:40 P.M., the electrical power was off. Reading at this time was 2256. At 4:45 P.M., restarted the recorder reading 2263 thru 6:10 P.M. reading 2610. This happened on #X tape.

In checking the reading from 4:45 P.M. to 5:45 P.M. for (1) hour reading 2263 to 2540 estimated - 277. The average reading on the recorder for one day - 2988.6, this is taken on a 10 day average.

2988.6	Avg. per day to 6:00 P.M.
-2256	Reading@ 4:40 P.M. when power went off
732.6	: 277 - 2.64 hrs. the recorder was off

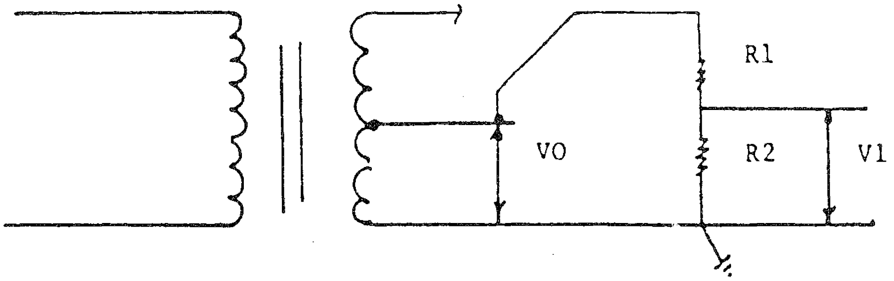
.64 hrs. x 60 min. = 38.4 min.
14 min. x 60 sec. = 2.4 sec.
Actual time off 2 hrs. 38 min. 2 sec.
4:40 P.M. = 4 hrs. 39 min. 60 sec.
- 2 hrs. 38 min. 2 sec.
2 hrs. 1 min. 58 sec.
Approximate time the power was cut off was 2:00 P.M. on 3-16-82 until 4:40 P.M.

14. On 3-18-82, 6:45 A.M., Reading 166, #11 channel began flickering about 3 sec., in REPRO section of the tape recorder.
On 3-18-82 I installed a filament transformer on the back of the recorder to (#14-connector). The reading @ this time was 995, Time 9:41 A.M., #14 tape.

a) Time 9:43 A.M. reading 1002 #10 & #12 amplifiers began to flicker about 3 sec. on the REPRO SECTION.
b) Time 944 A.M., reading #1007, #5 amplifier light came on for 5 sec. REPRO SECTION.
c) Time 9:50 A.M., reading 1036, #11, #12, & #13 flickered about 3 sec. REPRO SECTION. Note: (a)(b)&(c) began reacting after I installed the transformer.

At 5:55 P.M., reading 1139, I noticed the recorder wasn't taping. I restarted the recorder at 5:57 P.M. on 3-18-82, and recalibrated the amplifiers from 1 to 10. I did not turn the dial on #5 Amplifier from 1 back to 10. The channel stayed on 1 from the time 5:57 P.M. to 12:00 P.M. reading 1146 to 2900.
Then from the reading 2900 to 3345, the #5 amplifier was on 10.
I estimated the time the power to the recorder went off approx. 10:20 A.M.

VOLTAGE DIVIER EQUATION



To Find (V1)

R1 = 5600
R2 = 470
VO = 6 volts

$$V1 = \frac{VO \times R2}{(R1 + R2)}$$

$$V1 = \frac{6 \times 470}{5600 + 470} = \frac{2820}{6070} = .4745799 = .47 \text{ volts AC}$$

V1 = .47 volts (AC)

Finding Type of Resistor to Use

$(a + b)c = ac + bc$
$V1\ R1 + V1\ R2 = RO\ R2$
$V1\ R1 = VO\ R2 - V1\ R2$
$V1\ R1 = (VO - V1)R2$

$$V1 = \frac{VO\ R2}{(R1 + R2)}$$

$$(R1 + R2)V1 = \frac{VO\ R2}{(R1 + R2)} = (R1 + R2)$$

$$V1\ R1 + V1\ R2 = VO\ R2$$

$$\frac{V1\ R1}{(VO - V1)} = \frac{(VO - V1)}{(VO - V1)} = R2$$

Equation:

$$\frac{V1\ R1}{(VO - V1)} = R2$$

V1 = .5V
VO = 6V
R1 = 5.6 KΩ or 5600 ohm

$$\frac{0.5 \times 5600}{(6 - 0.5V)} = \frac{2800}{5.5} = 509.09 \text{ ohm } (-10\%) = 458.181$$

Use ≈ 470 ohm resistor is ok
+ 10% Tolerance

Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Grey	White
0	1	2	3	4	5	6	7	8	9

Silver = 10% Tolerance

Gold = 5% Tolerance

No 4th color shown on a resistor = 20% Tolerance

Ω = ohm

≈ = Approximate

Example:

(T) = Tolerance

Green Blue Red Silver
5 6 2=* 10% (T)
= 5600 ohm or 56 x 100 = 5600 ohm

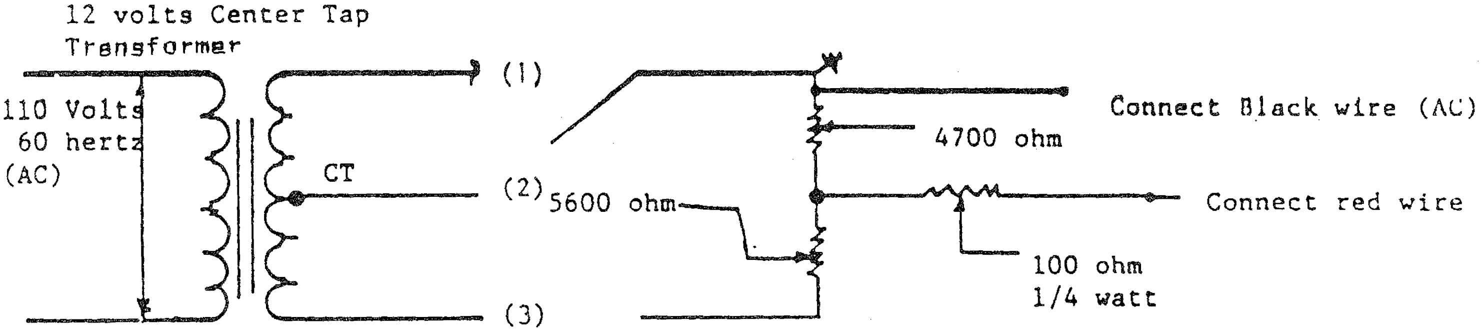
* Red = 2 = 10^2 = 10 x 10 = 100
Add two zeros (00)

Yellow Violet Blue Silver
4 7 1 = * 10% (T)
= 470 ohm

* Blue = 1 = 10^1 = 10
Add one zero (0)

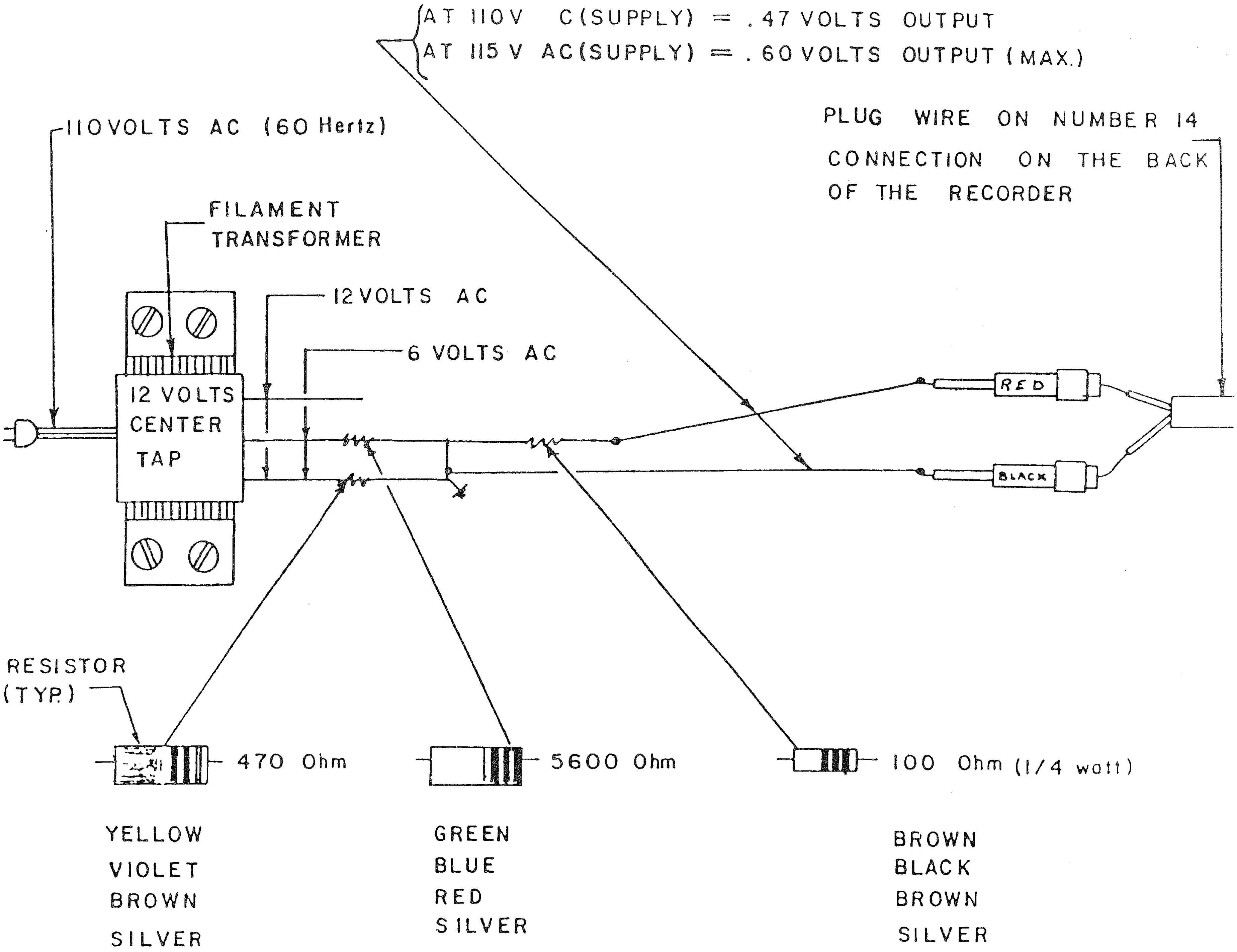
Brown Black Brown Silver
1 0 0 10%
= 100 ohm

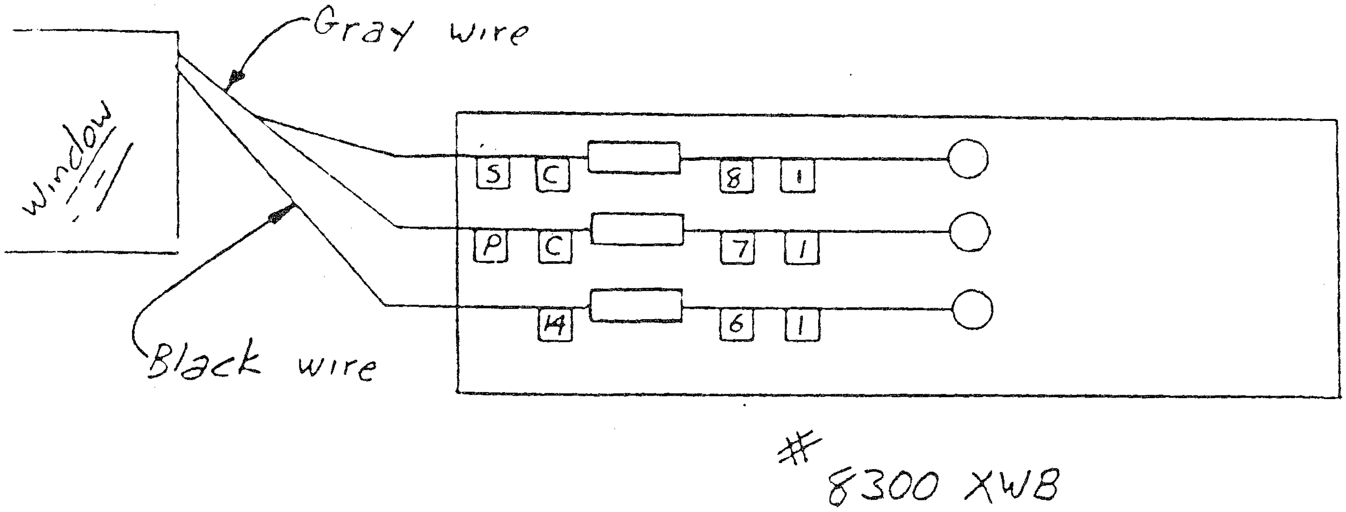
Brown = 0 = 0^{10} = 10
Add one zero (0)

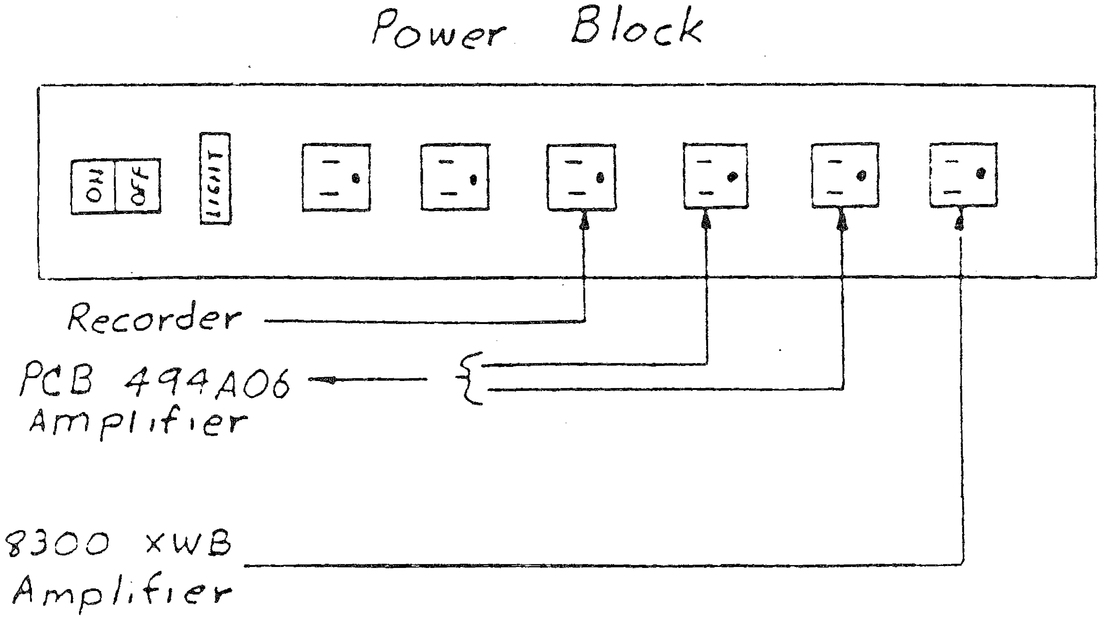


CT = Center Tap
12 volts - use lines (1 & 3)
6 volts - use lines (1 & 2) or (2 & 3)

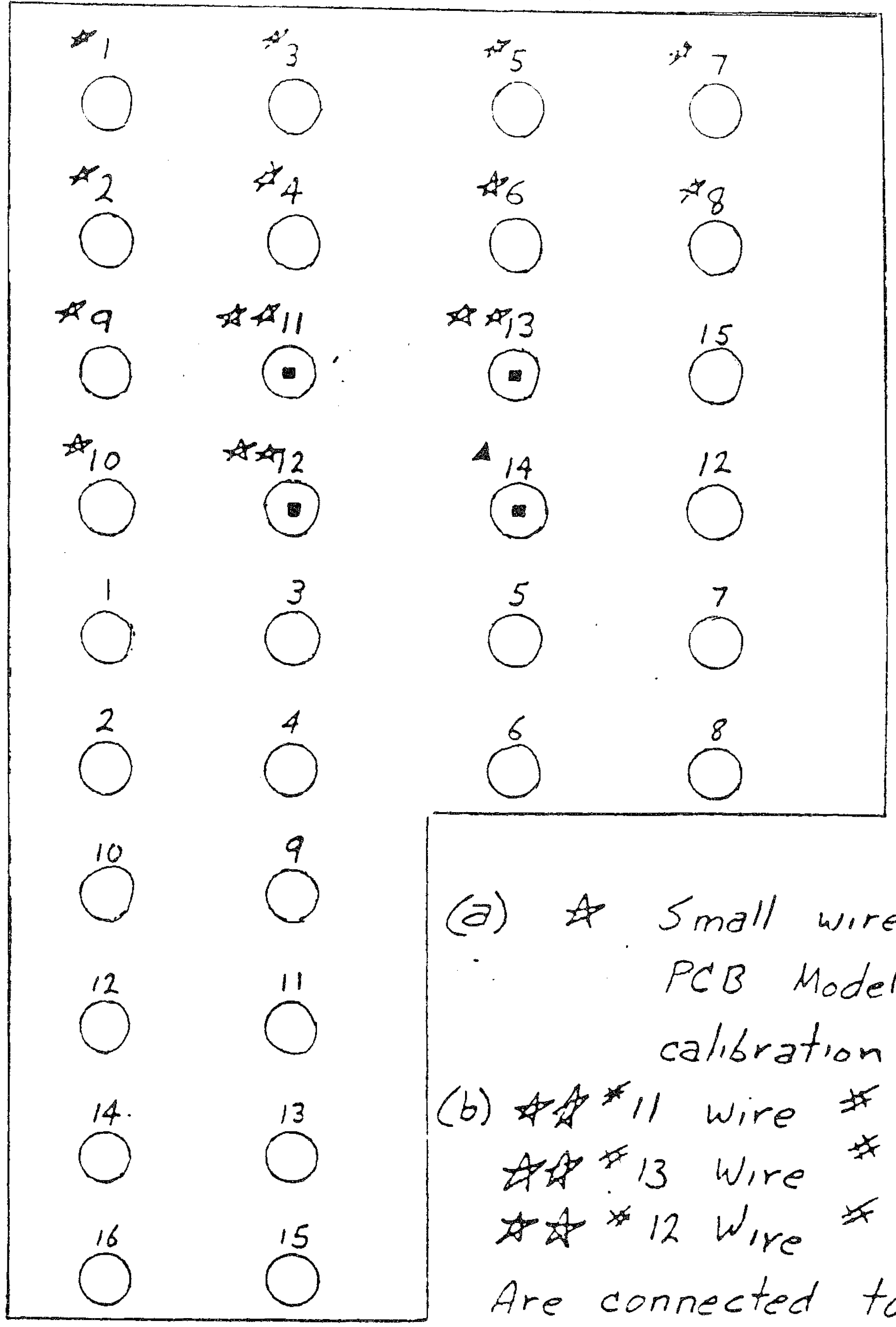
110 VAC Power in = .47 Min. output (AC)
115 VAC Power in = .6 Max. output (AC)


AT 110V C(SUPPLY) = .47 VOLTS OUTPUT
AT 115 V AC(SUPPLY) = .60 VOLTS OUTPUT (MAX.)
110 VOLTS AC (60 Hertz)
PLUG WIRE ON NUMBER 14 CONNECTION ON THE BACK OF THE RECORDER
FILAMENT TRANSFORMER
12 VOLTS AC
6 VOLTS AC
12 VOLTS CENTER TAP
RED
BLACK
RESISTOR (TYP.)
470 Ohm
5600 Ohm
100 Ohm (1/4 watt)
YELLOW
VIOLET
BROWN
SILVER
GREEN
BLUE
RED
SILVER
BROWN
BLACK
BROWN
SILVER


Gray wire
Window
Black wire
S
C
8
1
P
C
7
1
14
6
1
#8300 XWB


Power Block
ON
OFF
LIGHT
Recorder
PCB 494A06
Amplifier
8300 XWB
Amplifier

Back of Recorder



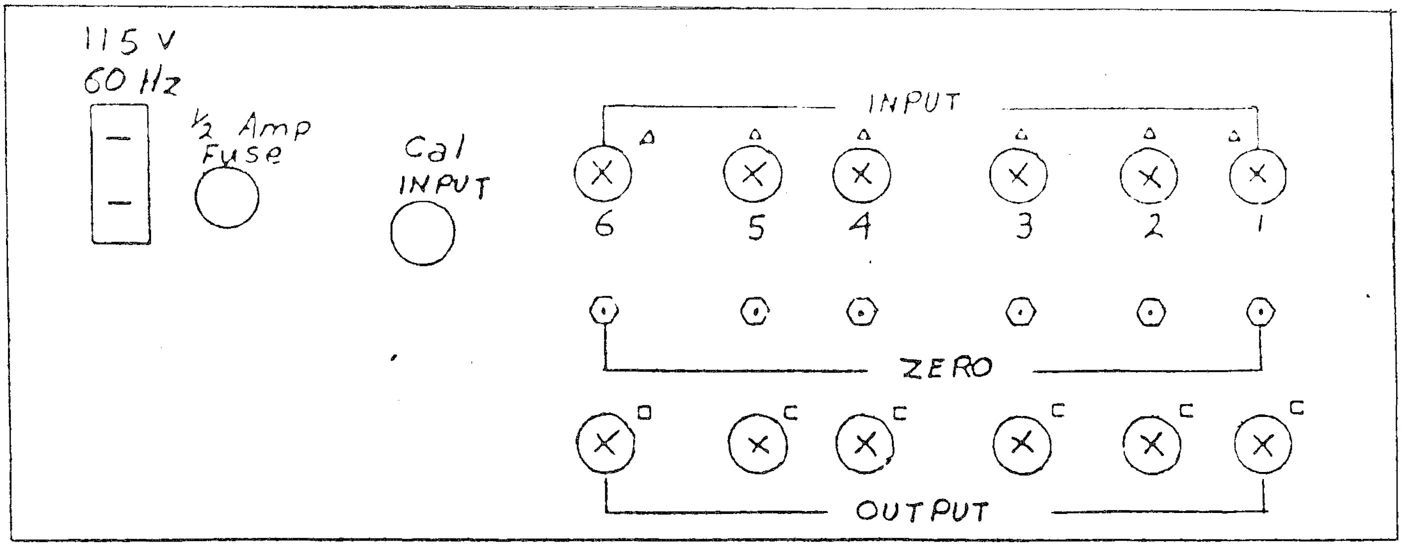
(a) ☆ Small wires connected to
PCB Model 494 A06
calibration Machine Amplifiers

(b) ☆☆ #11 wire # $\boxed{6}$ $\boxed{2}$
☆☆ #13 Wire # $\boxed{8}$ $\boxed{2}$
☆☆ #12 Wire # $\boxed{7}$

Are connected to the power Machine # 8300 XWB Amplifier

▲ # 14 Has clip Blk & Red connected together

Back "Top Level" of the PCB Model 994A06



LEGEND

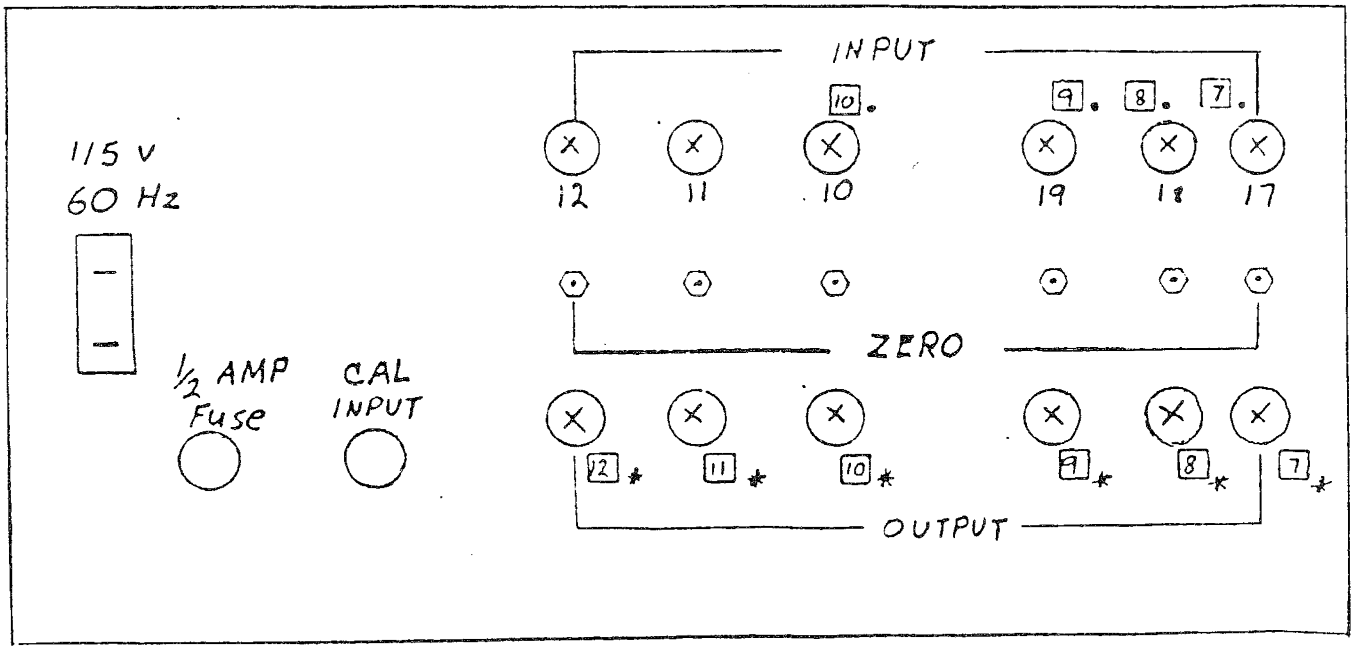
△ Small wires with small Number [3] etc.

□ Small wires with Large Numbers [3] etc.

⊗ Plugs with wires connected to them.

[8]• Small wires with small Numbers, Number of wire shown on (Square)

Back "Bottom Level" of the PCB Model 494A06



[7]* Small wires with large Numbers shown in Squares

REPORT C

THE EFFECTS OF VIBRATION ON HIGH PRESSURE SODIUM LAMPS IN ROADWAY LUMINAIRES:

PART II:

DIGITAL ANALYSIS OF THE ACCELEROMETER SIGNALS FROM SITES 1-5

THE EFFECTS OF VIBRATION ON HIGH PRESSURE SODIUM LAMPS IN ROADWAY LUMINAIRES:

Part II:

Digital Analysis of the Accelerometer Signals from Sites 1-5

April, 1984

Prepared by: W. Edward Red, Mechanical Engineering Department

and

Don Russell, Electrical Engineering Department
Representing the
Texas Transportation Institute
Texas A & M University

Prepared for: Texas State Department of Highways and
Public Transportation
Houston Urban Office
Project #22730

TABLE OF CONTENTS

1.0 Introduction

This report, Part II of a two-part final report, presents a digital signal analysis of the analog vibration data acquired at five luminaire field sites in the Houston area, Table 1. Included in this report are:

1. Time histories of selected vibration events.
2. Fourier analyses of selected waveforms to determine the vibrational frequency characteristics, in particular the acceleration levels as distributed over the lower frequency ranges.
3. Shock level distribution tables for each of the five sites (as induced by wind vortices that trail rapidly moving semi-trucks).
4. Histograms depicting the frequency of occurence of vertical acceleration pulses in the HPS lamp area for several 24 hour periods.
5. Discussion of the results.

2.0 Vibration Environment

As detailed in PART I, the vibration environment experienced by the HPS lamps is postulated to be the result of:

1. Short-term, gust-induced shocks or pulses which result from the upward mobility of trailing vortices that follow rapidly moving semi-trucks.
2. Periodic "modal" vibration at g-levels lower than those resulting from the vortex pulses. This structure vibration often occurs in the lower frequency, cantilevered mode and at g levels which can occasionally exceed 1 g in magnitude. Vibration of this sort can be induced by pulse loading, by a fluctuating ambient wind environment, or by foundation excitation when the luminaire is mounted on a flexible structure such as a bridge or elevated ramp.
3. Vibration of the luminaire structure at or near the frequency of a vibrating foundation. For example, the ship channel bridge vibrational frequency was quite apparent in the luminaire accelerometer data at SITE 1.
4. Unexplained vibration environments. On rare occasions, the vibration environment assumed an unexplainable mode. For example, during one period, accelerometer 5 depicted a rapid, short-duration increase in g levels while the remaining channels appeared undisturbed. On other occasions, all channels would exhibit a sharp, short-duration, rise in acceleration levels not

Table 1 - Field Test Sites

Site No.	Site Description	Test Duration (days)	Notes
1	South approach to Ship Channel Bridge, site on prestressed unit, approximately 30' from a bent	7	Conducted from 3-11-82 to 3-19-82
2	Ground mounted twin arm pole north of Ship Channel Bridge at Clinton Dr. exit	2	Conducted from 3-28-83 to 3-30-83 Originally scheduled for one day at a luminaire located nearer bridge.
3	Side mounted, ground mounted, single arm pole on ramp from I-10 EB to I-610 EB	3	Conducted from 4-25-83 to 4-28-83. Originally scheduled for one day
4	Side mounted, bridge mounted, single arm pole on ramp from I-10 EB to I-610 SB, pole located at midspan	3	Conducted from 5-31-83 to 6-03-83. Originally scheduled for one day
5	Median mounted pole on I-610 North Loop at T.C. Jester Exit	2.5	Conducted from 7-05-83 to 7-07-83. Originally scheduled for one day
6	Test cancelled due to recorder failure		

characteristic of the vertical pulse-induced accelerations caused by trailing vortices. It is postulated that these incidents resulted from either some unexplained electromagnetic disturbance, tape recorder momentary stop-start, or possibly resulted from flying objects impinging on the luminaire.

2.1 Pulse Frequency Distribution

Tables 2-6 contain the vortex-induced pulse frequency of occurrence as recorded by accelerometers 9 and 10 at SITES 1-5. Acceleration level ranges or "bands" from 0.1-1.0 g, 1.0-2.0 g, 2.0-4.0 g, and 4.0 g are used to identify the frequency of occurrence by g level.

As seen, SITES 1, 3, and 5 proved most active for pulse loading. This is expected since SITES 2 and 4 were at locations where vehicle speeds would generally be reduced.

2.2 Pulse Histograms for Selected 24 Hour Periods

Figures 1-4 display the frequency of pulse loading over selected 24 hour periods at SITES 1,3, and 5 (where the more appreciable g levels occurred). Only the more significant pulses are recorded (pulses approaching 0.5 g's and greater). As would be expected, most activity occurs bewtween 8:00 a.m. and 8:00 p.m., with the greatest frequency occurring midday.

3.0 Accelerometer Data Acquisition

Figure 5 illustrates the field site organization of the equipment used in data acquisition. Not shown are the channels used to monitor and record the primary and secondary ballast currents and voltages. Although it was hoped that the ballast "striking" instability could be correlated with severe vibration environments, this instability failed to occur at any of the sites during the data acquisition periods. Figure 6 shows the ballast instrumentation.

Of the ten accelerometers used to monitor the luminaire vibration levels, eight were PCB 308B10's having a sensitivity of 100 mV/g and a frequency range of 1-3000 Hz. Two PCB 312A high-temperature accelerometers were used to monitor the vertical accelerations at the lamp area. One PCB 312A, Figure 7, was mounted on the base of the HPS lamp surface where temperatures fall within the 400°F capability of the PCB 312A. The other PCB 312A was mounted on the frame supporting the HPS lamp, Figure 8.

Because the low mass PCB 312A accelerometers do not have built-in microelectronic amplifiers as do the PCB 308B10 models, it was necessary to amplify the signals using PCB 421A in-line charge amplifiers, Figure 9.

Amplification factors (A_f) used at the five sites are listed in Table 7. Using the 100 kmV/g accelerometer sensitivity, the acceleration level factor G_f (number of g's per volt) can be determined for each of the sites. G_f is listed for each channel at the five sites.

Table 2 - SITE 1 Pulse History

Period	Time	Pulse Frequency in g Bands			
		0.1-1.0	1.0-2.0	2.0-4.0	4.0
	(Begin: 3-11-82)				
1	Th/F 6:30 pm-6:00 am	9	0	1	0
2	F 6:10 am-6:00 pm	15	11	4	2
3	F/Sa 6:08 pm-6:00 am	8	3	1	1
4	Sa 6:09 am-6:00 pm	10	7	1	1
5	Sa/Su 6:09 pm-6:00 am	12	6	2	0
6	Su 6:10 am-6:00 pm	15	11	0	1
7	Su/M 6:15 pm-6:00 am	9	5	0	0
8	M 6:10 am-6:00 pm	18	13	5	1
9	M/Tu 6:09 pm-6:00 am	8	4	1	0
10	Tu 6:09 am-6:00 pm	10	6	3	0
11	Tu/W 6:08 pm-6:00 am	2	0	0	1
12	W 6:08 am-6:00 pm	13	9	3	2
13	W/Th 6:08 pm-6:00 am	8	5	1	1
14	Th/F 6:09 am-1:46 am	15	7	5	3
15	F 11:30 am-11:27 pm	9	6	5	1
	(End: 3-19-82)				

Table 3 - SITE 2 Pulse History

		Pulse Frequency in g Bands			
Period	Time	01.-1.0	1.0-2.0	2.0-4.0	4.0
	(Begin: 3-28-83)				
1	M/Tu 2:06 pm-1:44 am	25	0	0	0
2	Tu 1:55 am-1:49 pm	29	0	0	0
3	Tu/W 1:57 pm-1:46 am	31	0	0	0
4	W 1:55 am-1:50 pm	18	0	0	0
	(End: 3-30-83)				

Table 4 - SITE 3 Pulse History

		Pulse Frequency in g Bands			
Period	Time	0.1-1.0	1.0-2.0	2.0-4.0	4.0
	(Begin: 4:25-83)				
1	M/Tu 6:00 pm-6:00 am	23	0	0	0
2	Tu 6:10 am-6:10 pm	40	10	3	0
3	Tu/W 6:10 pm-6:00 am	20	0	0	0
4	W 6:10 am-6:00 pm	42	11	5	0
5	W/Th 6:10 pm-6:00 am	27	0	0	0
	(End: 4:28-83)				

Table 5 - SITE 4 Pulse History

		Pulse Frequency in g Bands			
Period	Time	0.1-1.0	1.0-2.0	2.0-4.0	4.0
	(Begin: 5-31-83)				
1	Tu/W 6:00 pm-6:03 am	30	0	0	0
2	W 6:25 am-5:55 pm	43	0	0	0
3	W/Th 6:01 pm-6:23 am	40	0	0	0
4	Th 6:31 am-5:55 pm	53	0	0	0
5	Th/F 6:03 pm-6:41 am	45	0	0	0
	(End: 6-3-83)				

Table 6 - SITE 5 Pulse History

		Pulse Frequency in g Bands			
Period	Time	0.1-1.0	1.0-2.0	2.0-4.0	4.0
	(Begin: 7-5-83)				
2	W 6:21 am-6:00 pm	8	3	2	2
3	W/Th 6:19 pm-6:05 am	4	1	0	1
4	Th 6:25 am-6:00 pm	7	3	2	1
5	Th/F 6:21 pm-6:21 am	5	0	0	1
	(End: 7-7-83)				

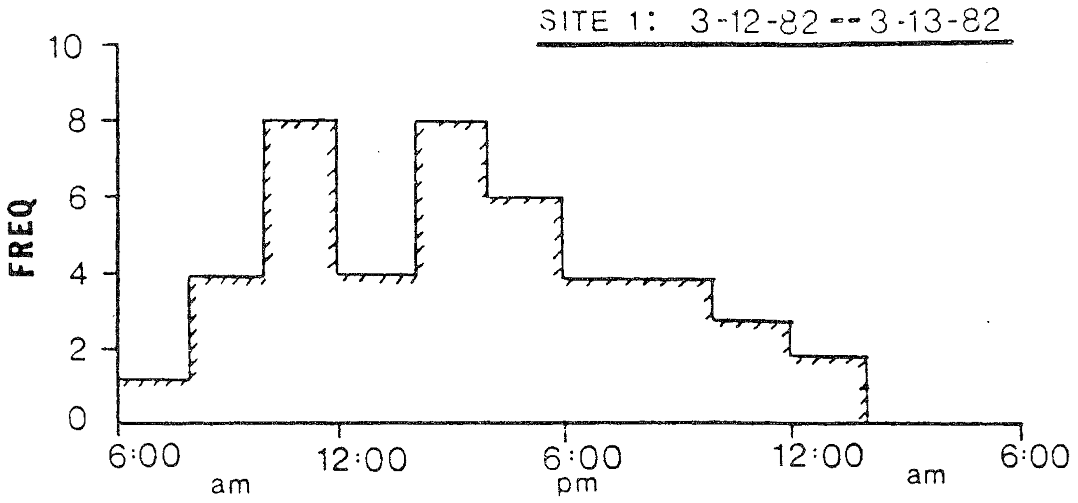


Figure 1-Pulse Frequency for 24 h at SITE 1: Friday/Saturday

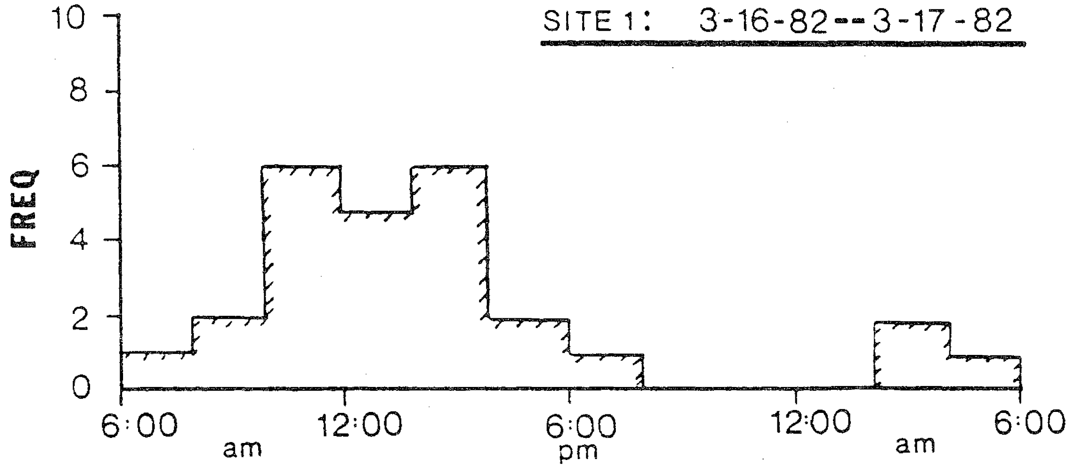


Figure 2-Pulse Frequency for 24 h at SITE 1: Tuesday/Wednesday

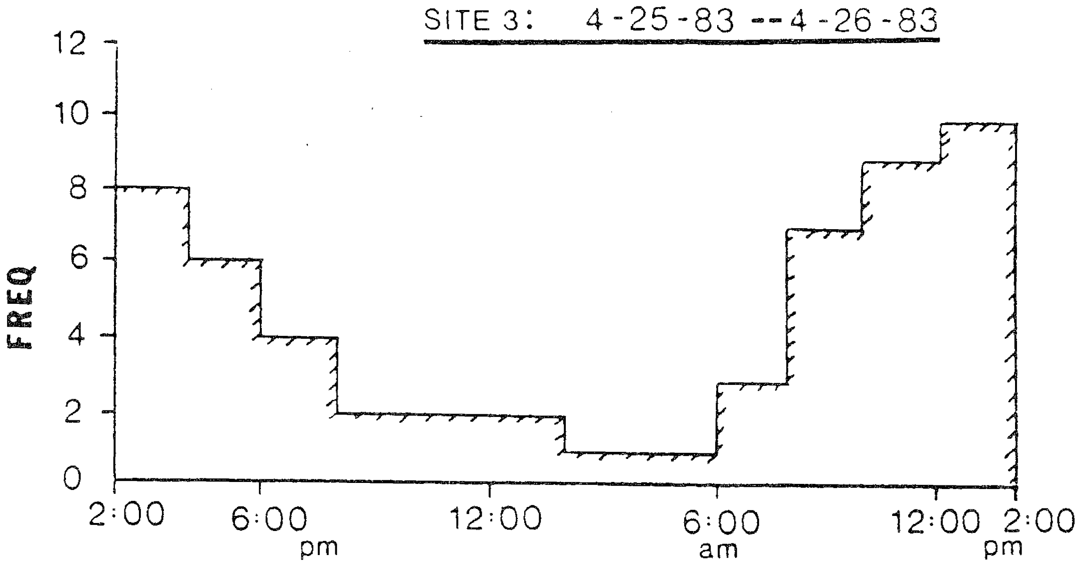


Figure 3-Pulse Frequency for 24 h at SITE 3: Monday/Tuesday

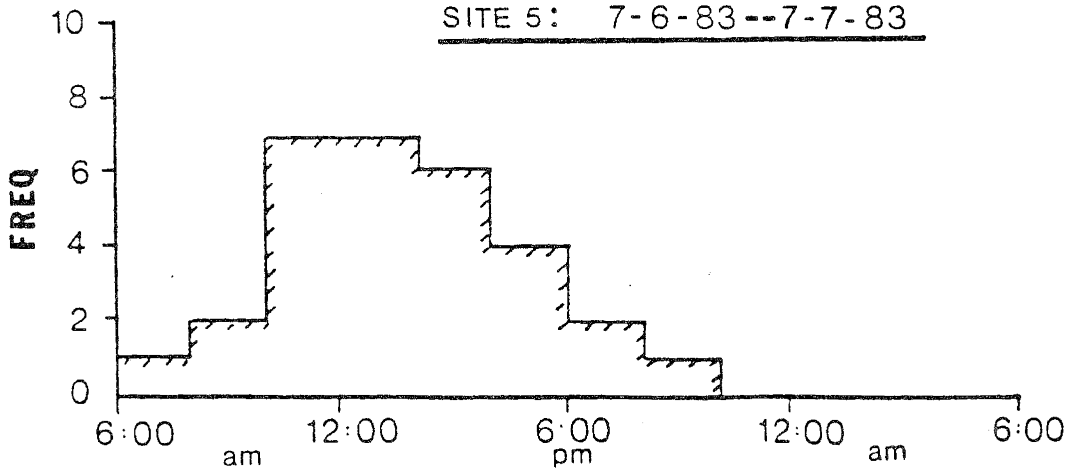


Figure 4-Pulse Frequency for 24 h at SITE 5: Friday/Saturday

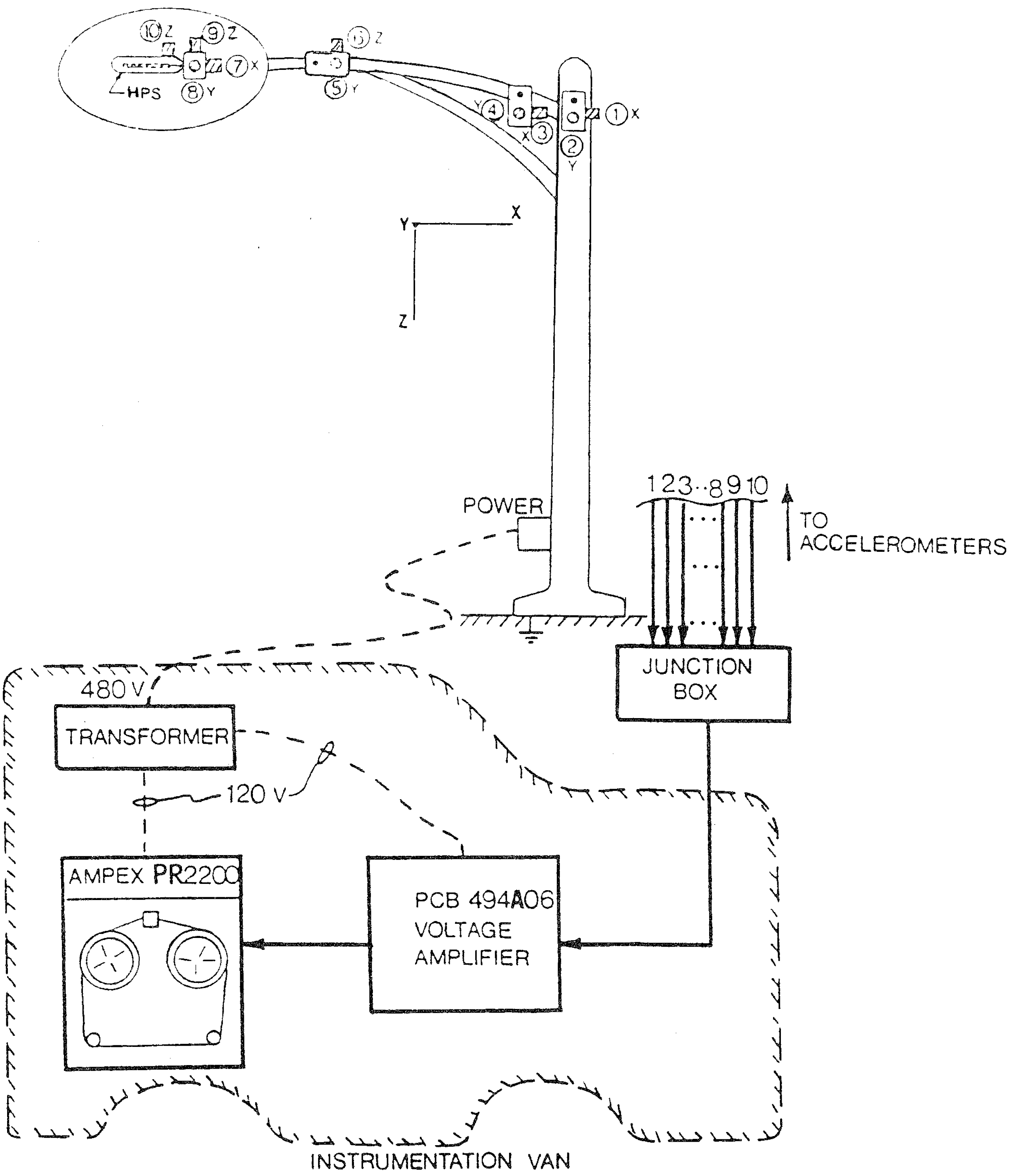


Figure 5 - Field Site Instrumentation

Table 7 - Amplification Factors (A_f) and Acceleration Level Factors (G_f)

Accelerometers	A_f and G_f (g/V) at SITES 1-5									
	SITE 1		SITE 2		SITE 3		SITE 4		SITE 5	
	A_f	G_f	A_f	G_f	A_f	G_f	A_f	G_f	A_f	G_f
Channels 1-8 (PCB 308B10)	5	2	10	1	10	1	10	1	10	1
Channel 9 (PCB 312A; PCB 421A)	5	2	5	2	5	2	5	2	5	2
Channel 10 (PCB 312A; PCB 421A)	5	2	2	5	2	5	2	5	2	5

Figure 6 - Ballast Instrumentation

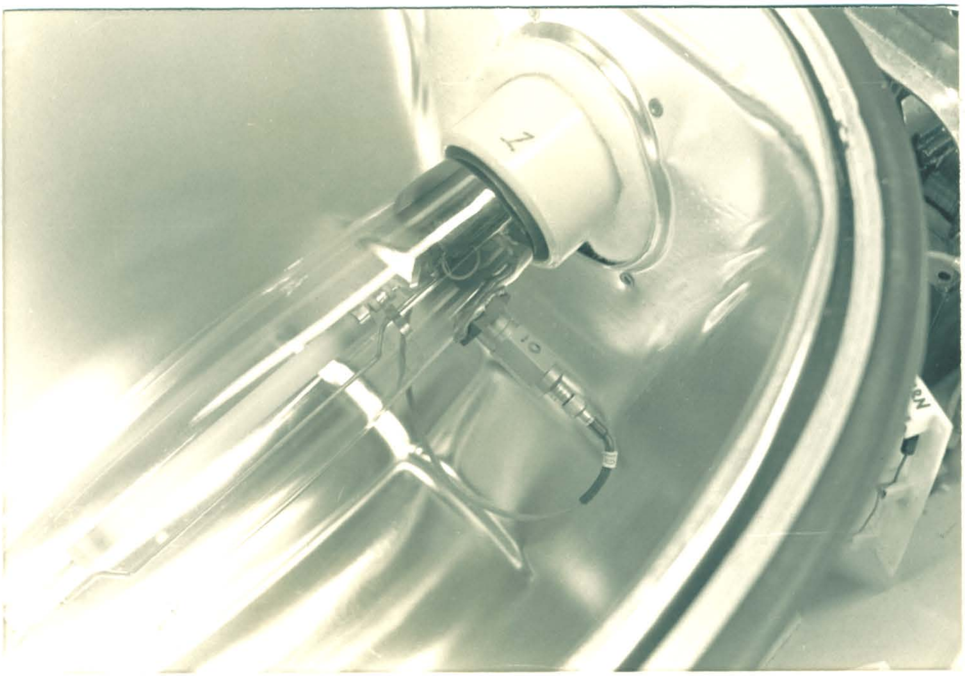


Figure 7 - PCB 312A Mounted on Lamp Surface

Figure 8 - PCB 312A Mounted on Lamp Frame

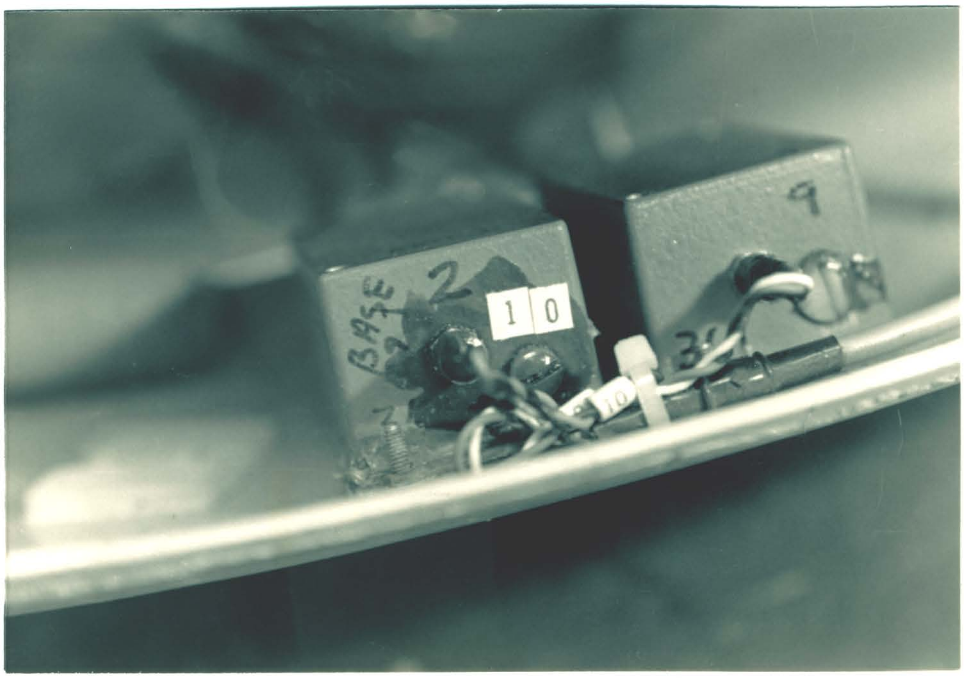


Figure 9 - PCB 421A Charge Amplifiers

4.0 Digital Signal Analysis

The following sections contain digital representations of selected waveforms from SITES 1-5, including linear spectra (Fast Fourier Transforms, FFT) and Power Spectral Densities (PSD's) of the same waveforms. Digital analysis was performed using a Hewlett-Packard 5423A Structural Dynamics Analyzer.

To understand the figures of sections 4.1-4.5, plots of the HP 5423A displays, note the following:

1. TI AVG = time history of selected accelerometer signals where:
   - o ABSCISSA - time in seconds
   - o ORDINATE - acceleration level in volts (V).

   (Note: $m = 10^{-3}$)

2. L SPEC = linear FFT where
   - o ABSCISSA - frequency in Hz (cps)
   - o ORDINATE - signal level in volts rms (V_{rms}).

   (Note: MAG - magnitude of complex Fourier coefficients)

3. A SPEC = auto spectrum which, for random signals, is the same as a PSD.
   - o ABSCISSA = frequency in Hz
   - o ORDINATE = $(V_{rms})^2$/Hz (= Vrms/Hz if MAG)

The ordinate levels in g's or g^2/Hz can be determined by multiplying the ordinate values by the G_f values in Table 7, depending on accelerometer and site.

4.1 SITE 1 Signal Analysis

Figure 1.1 shows a typical pulse which, at 2 g/V, has a maximum amplitude of about 2.2 g's. Comparing Figures 1.1 a) and Figure 1.1 b), channels 10 and 9 respectively, it is seen that a signal attenuation of about 30% occurred across the HPS lamp socket structure between accelerometer 9 (mounted near the socket base) and accelerometer 10 (mounted on the lamp surface). This attenuation of magnitude typically ranges from 25-30% for pulses occurring at other times and sites. Figure 1.1 c) compares the two signals directly.

The spectral analyses of this pulse, shown in Figures 1.2-1.4, indicate major modal frequencies of the bridge structure and luminaire structure, although the PSD Figure 1.4, segregates them more clearly than does the FFT, Figures 1.2 and 1.3. The PSD and FFT spectra are proportional by the square of the signal strength for random signals, given the same pulse. Figures 1.2 and 1.4 do not demonstrate this relationship exactly since the pulse period was different for each spectral analysis type.

The fundamental mode of bridge vibration is indicated by the spike at about 7 Hz in Figure 1.4. Two major modes of luminaire vibration have characteristic frequencies of about 12 Hz and 14 Hz (the other two dominant spikes). Examination of other signals will allow us to postulate the nature of the associated luminaire mode shapes.

Examining Figures 1.2-1.4 at the lower frequencies, it is seen that a number of frequencies below 5 Hz are excited by the wind vortex as it impacts the HPS lamp chassis. These are probably representative of the pressure wave as it impinges on the lamp cover causing a gross, low frequency, vertical displacement at the arm end. The accelerometer frequency range lower limit of 1 Hz is clearly indicated by the spike at 1 Hz.

Figures 1.5-1.18 present other representative time histories. A typical 2g pulse is shown in Figure 1.5. The PSD of this pulse, Figure 1.7, does not show the bridge vibrational frequency as a sharp spike, probably indicating little bridge vibration during the pulse period.

Figure 1.8 depicts extremely high pulse loading. The waveform shapes indicate instrumentation saturation. Nevertheless, the vibration severity demonstraters that vortex-induced pulsers can generate g-levels which far exceed 5 g's, approaching 10 g's, and which can last up to 2 seconds.

The lack of response by accelerometers 1-8 to the pulse of Figure 1.8 shows the one-dimensional nature of the pulse loading, see Figure 1.9 a) for accelerometer 1 and compare it to the onset of pulse loading in Figure 1.9b. The shock spectra in Figure 1.10 a) and 1.11 a) indicate that accelerometer 1 only registered the bridge vibration during the pulse period.

Figure 1.12 illustrates another significant pulse but one much shorter in duration. The maximum g level approached 8 g's.

Figures 1.13 and 1.14 show the ringing mode (at 14 Hz) characteristic of the luminaire as it sways about its column base. The lower frequencies excited in accelerometer 10, see Figure 1.13b) and Figure 1.14 b), probably depict the reaction of accelerometer 10 to changes in the HPS lamp temperature.

Figures 1.15-1.18 present an interesting ringing contrast to the ringing in Figure 1.13. In contrast to the single mode excitation of Figure 1.13, Figure 1.15 depicts a two mode excitation of the luminaire structure. Comparing the spectra for channels 9 and 10, Figures 1.16 and 1.17, to that for channel 1, Figure 1.18, it is postulated that the lower frequency mode at 12 Hz probably represents an arm mode of vibration with a mode shape that is predominantly vertical directed but perhaps coupled to torsional motion of the arm.

4.1.1 SITE 1 Figures

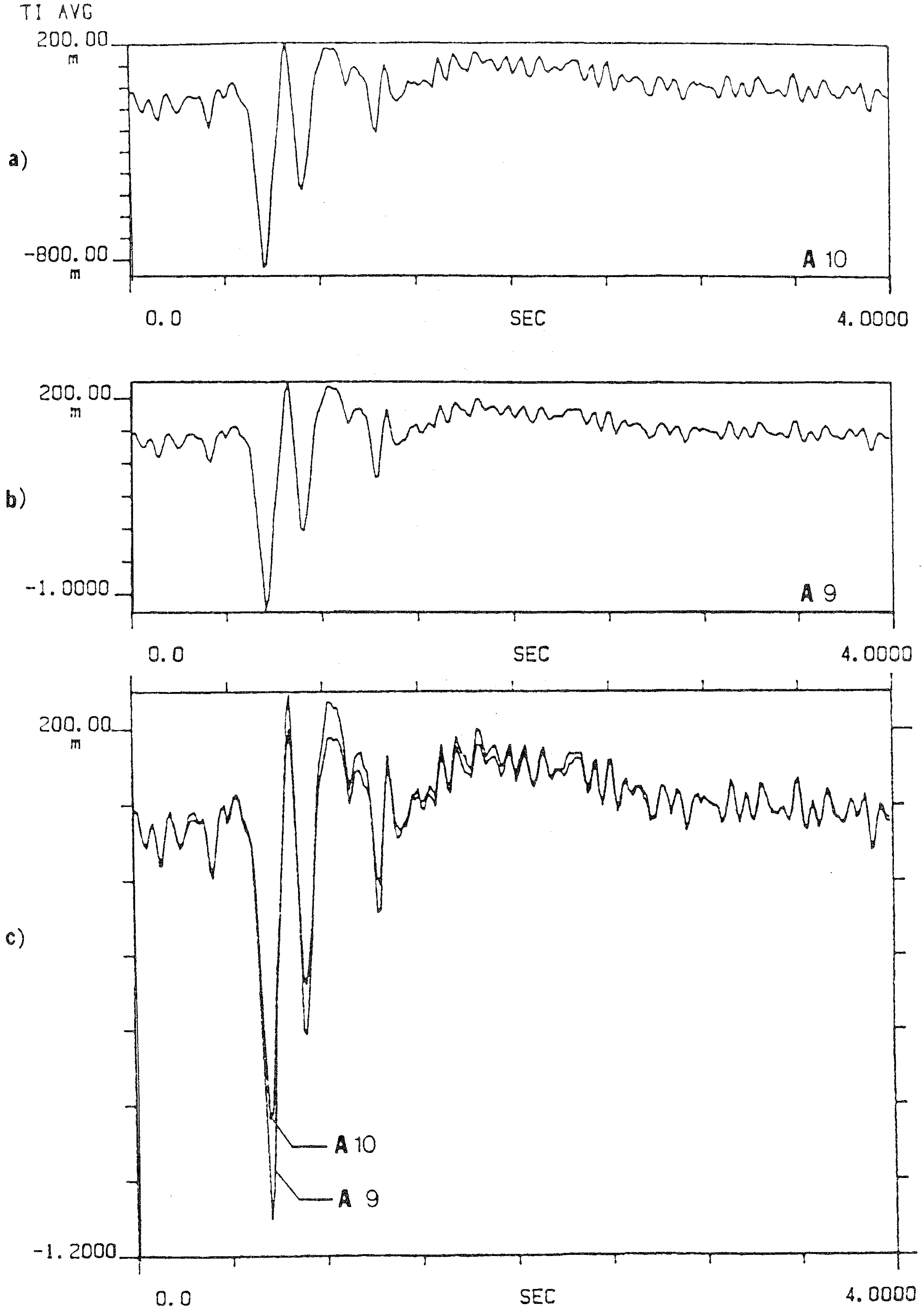


Figure 1.1 - Pulses: SITE 1, 3-11-82, Thursday, 8:43 p.m.
a) Accelerometer 10
b) Accelerometer 9
c) Accelerometer 9 & 10 Comparison

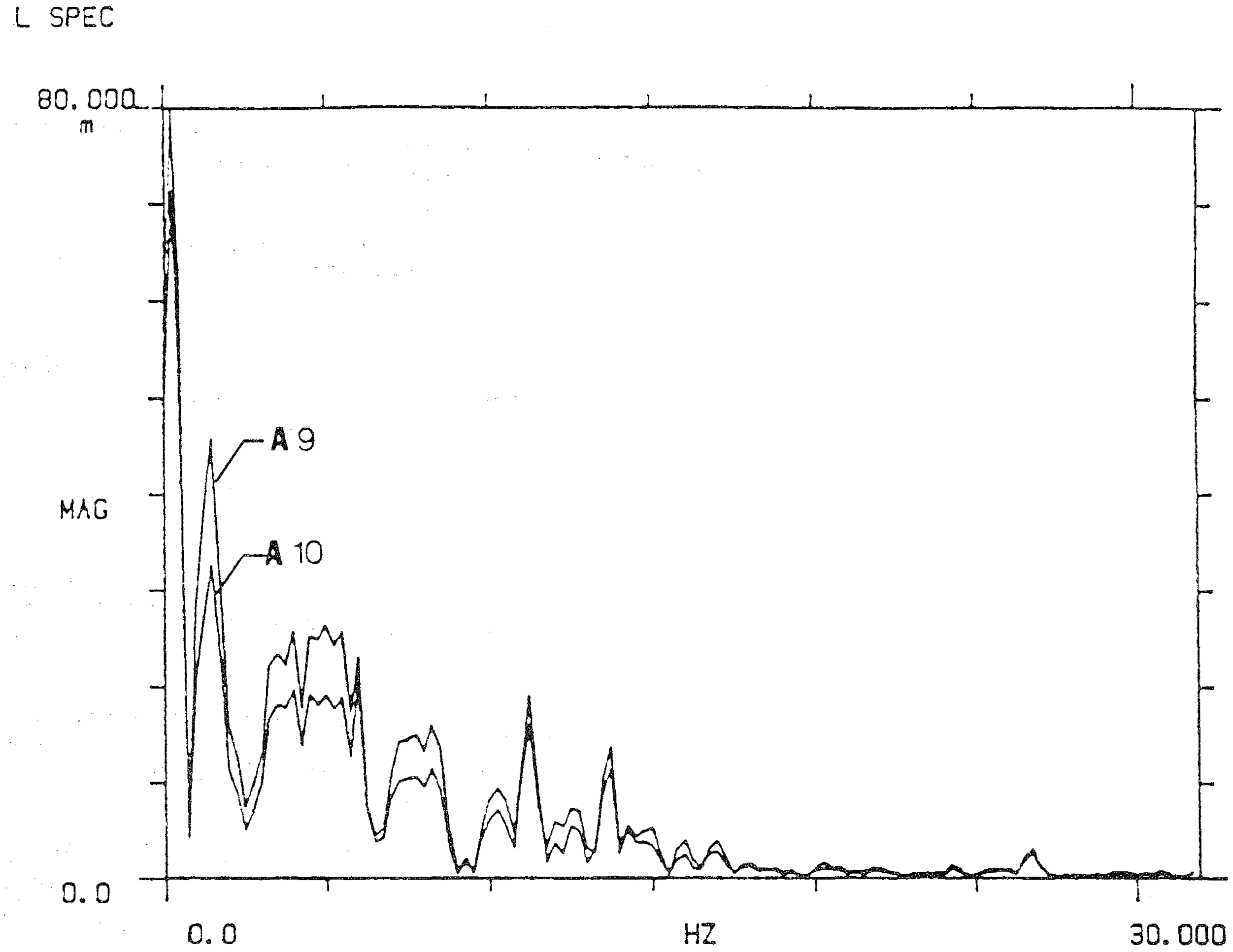


Figure 1.3 - Pulse FFT Comparison: SITE 1, 3-11-82, Thursday, 8:53 p.m.

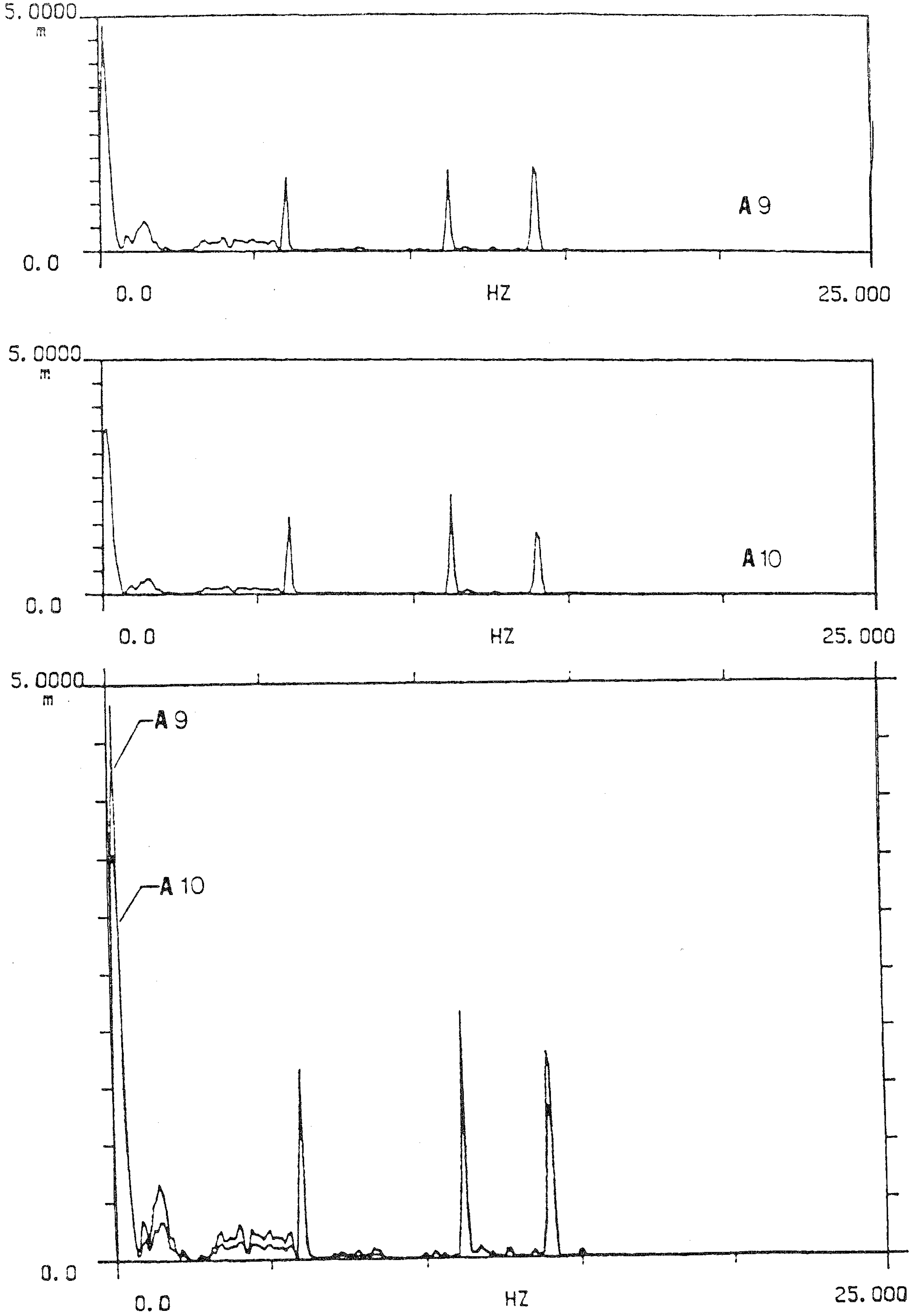


Figure 1.4 - Pulse Auto Spectra (PSD): SITE 1, 3-11-82, Thursday, 8:53 p.m.
a) Accelerometer 9
b) Accelerometer 10
c) Accelerometer 9 & 10 Comparison

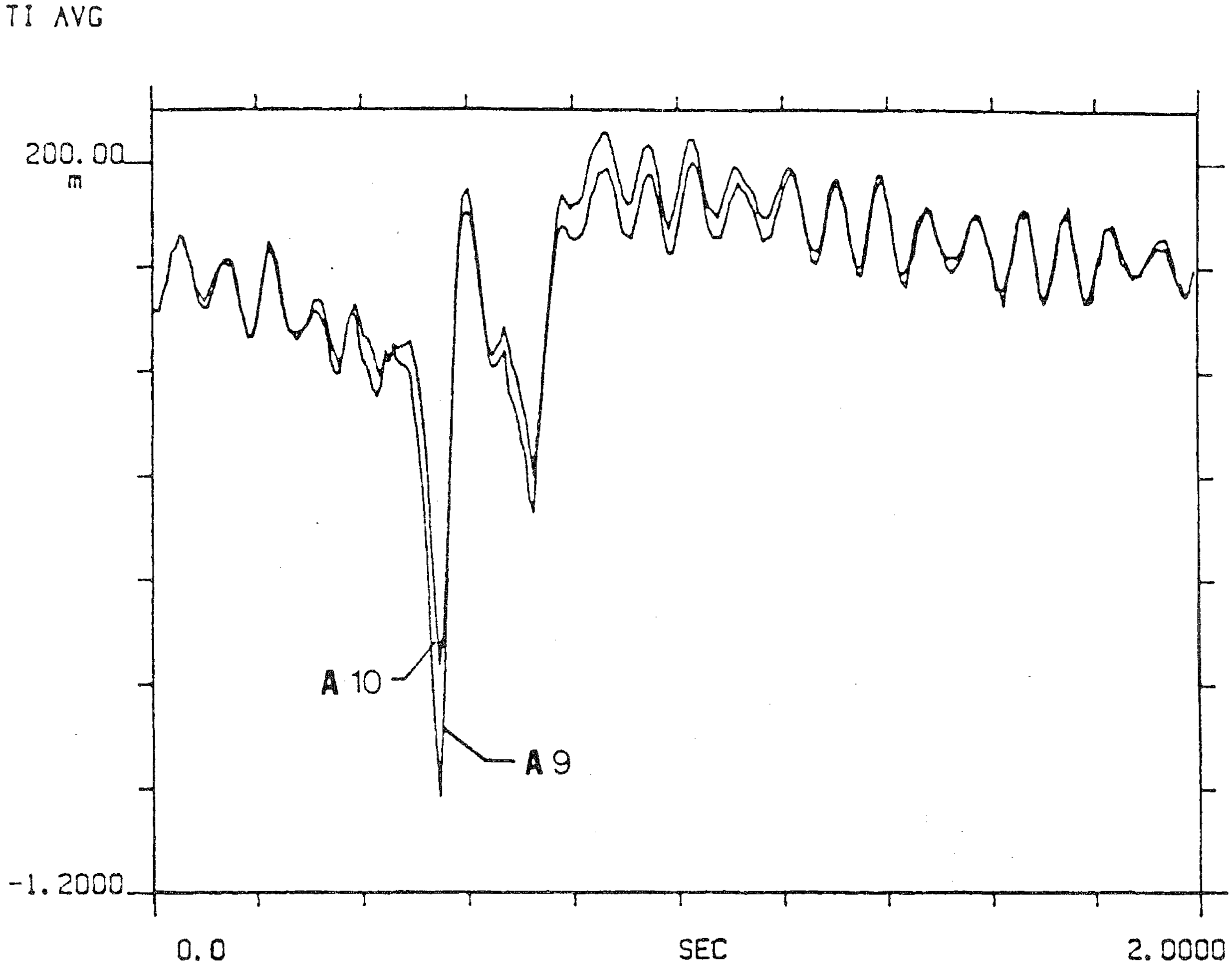


Figure 1.5 - Accelerometers 9 & 10 Pulse Comparison:
SITE 1, 3-12-82, Friday, 11:19 a.m.

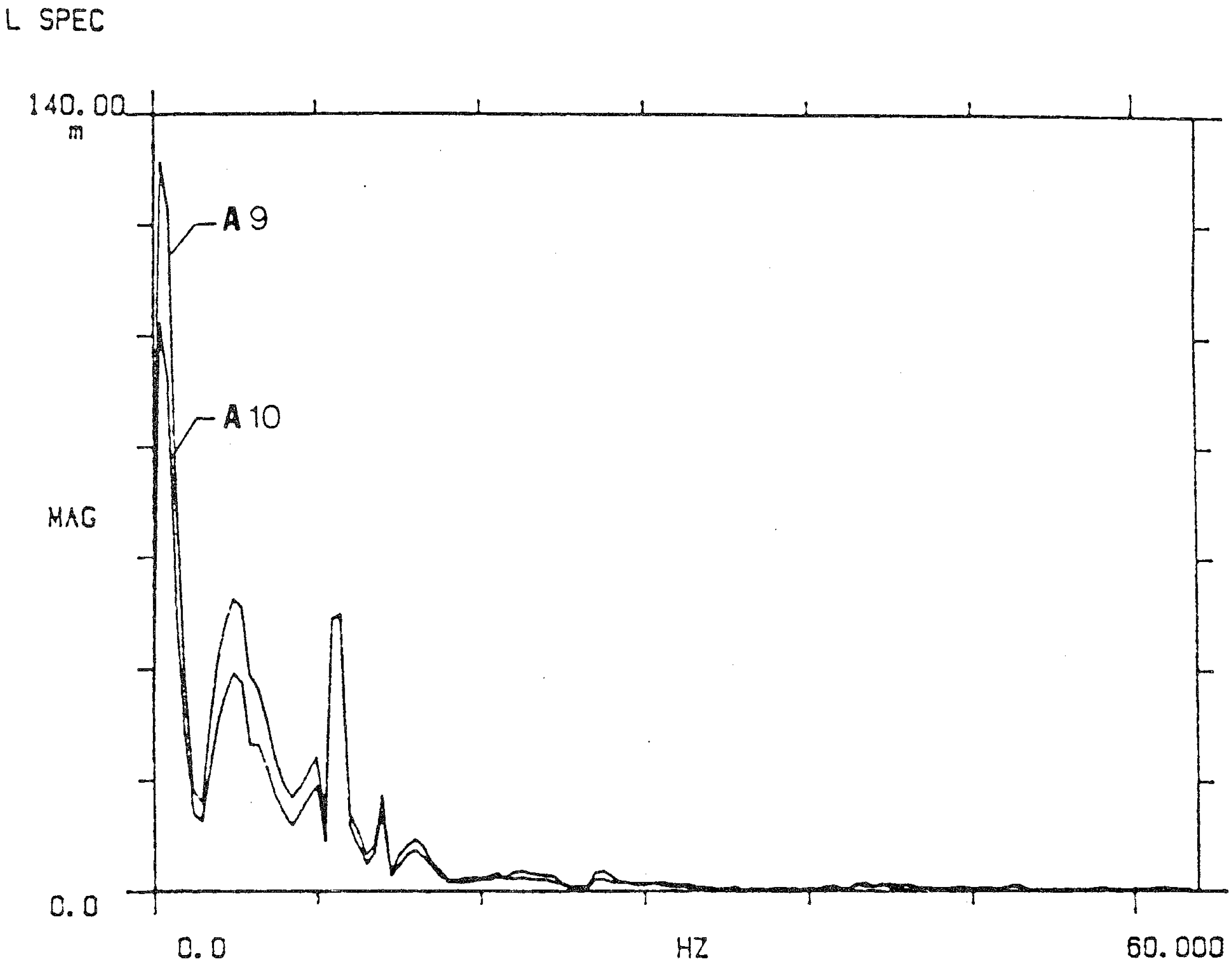


Figure 1.6 - Accelerometers 9 & 10 FFT's:
SITE 1, 3-12-82, Friday, 11:19 a.m.

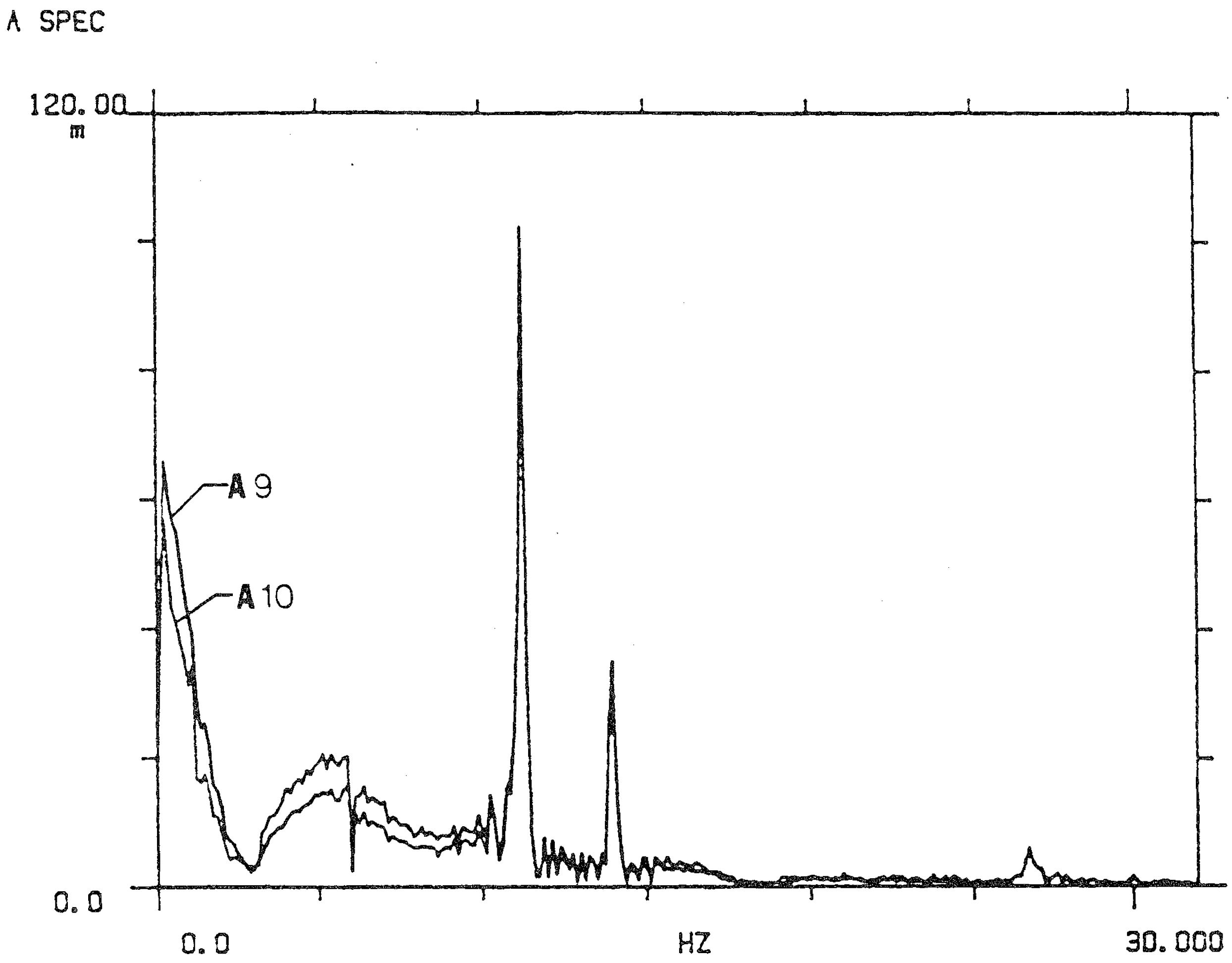


Figure 1.7 - Accelerometers 9 & 10 PSD's:
SITE 1, 3-12-82, Friday, 11:19 a.m.

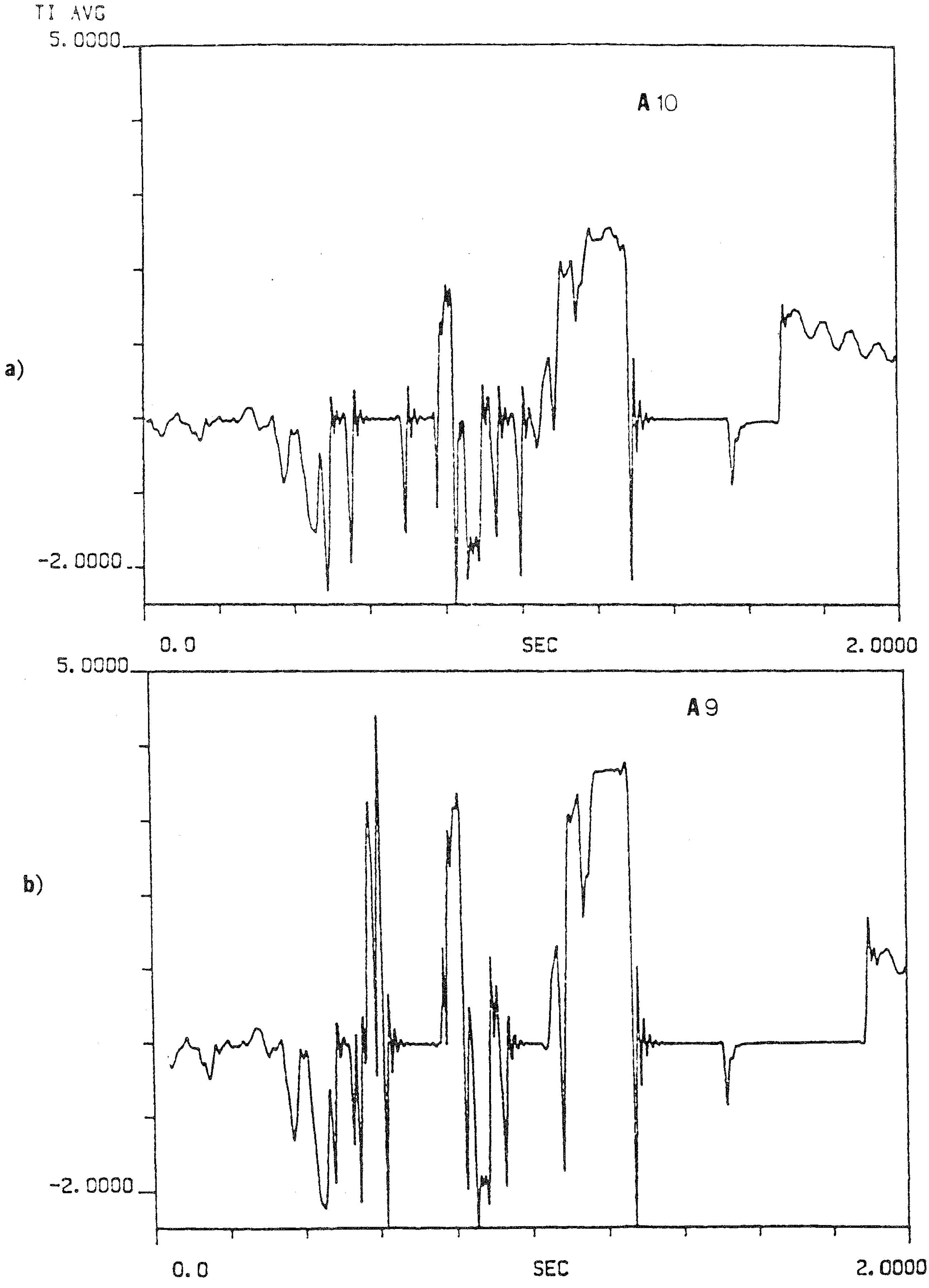


Figure 1.8 - Pulses: SITE 1, 3-12-82, Friday, 11:58 a.m.
a) Accelerometer 10
b) Accelerometer 9

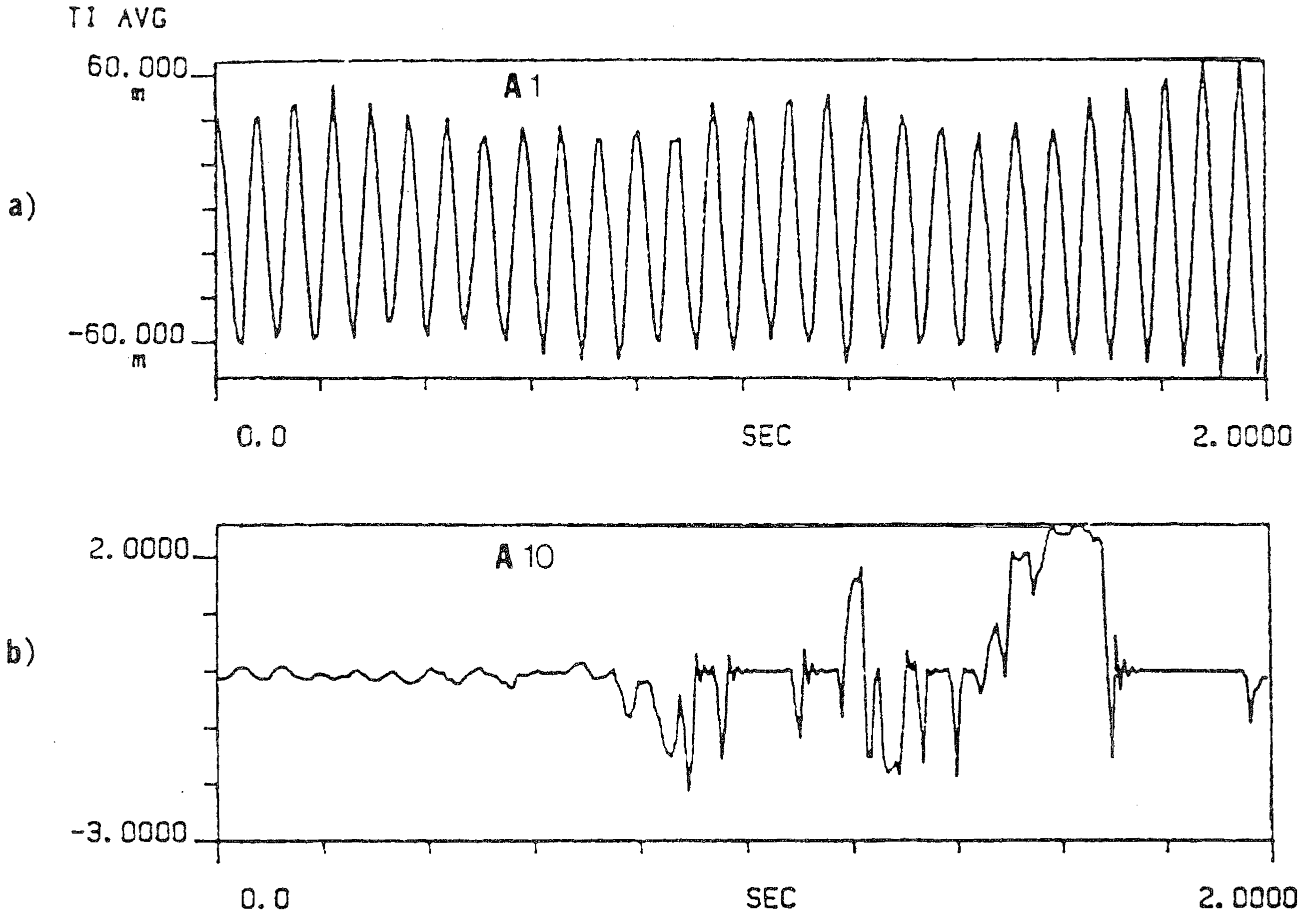


Figure 1.9 - Pulse Effect on Accelerometer 1:
SITE 1, 3-12-82, Friday, 11:58 a.m.
a) Accelerometer 1
b) Accelerometer 10

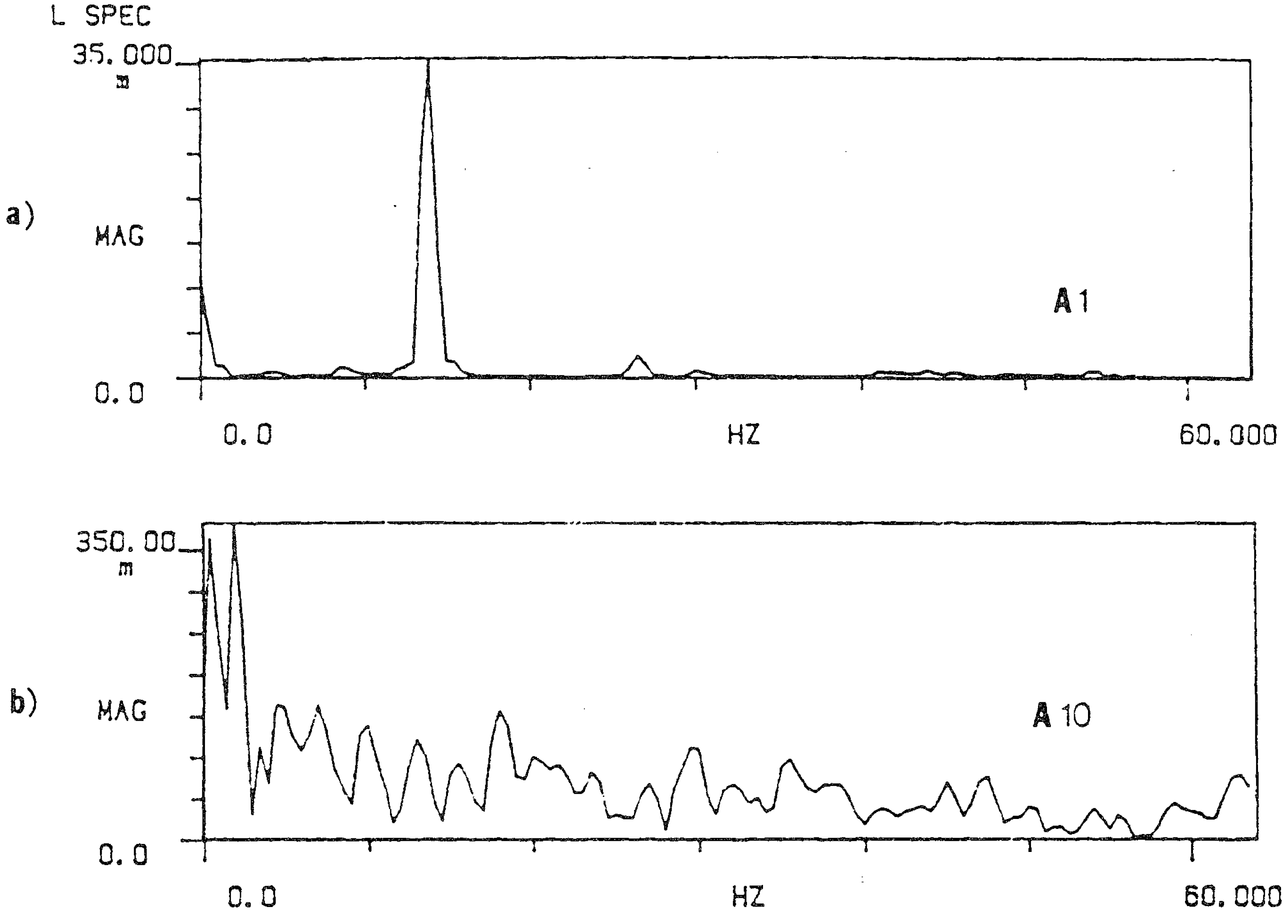


Figure 1.10 - FFT's: SITE 1, 3-12-82, Friday, 11:58 a.m.
a) Accelerometer 1
b) Accelerometer 10

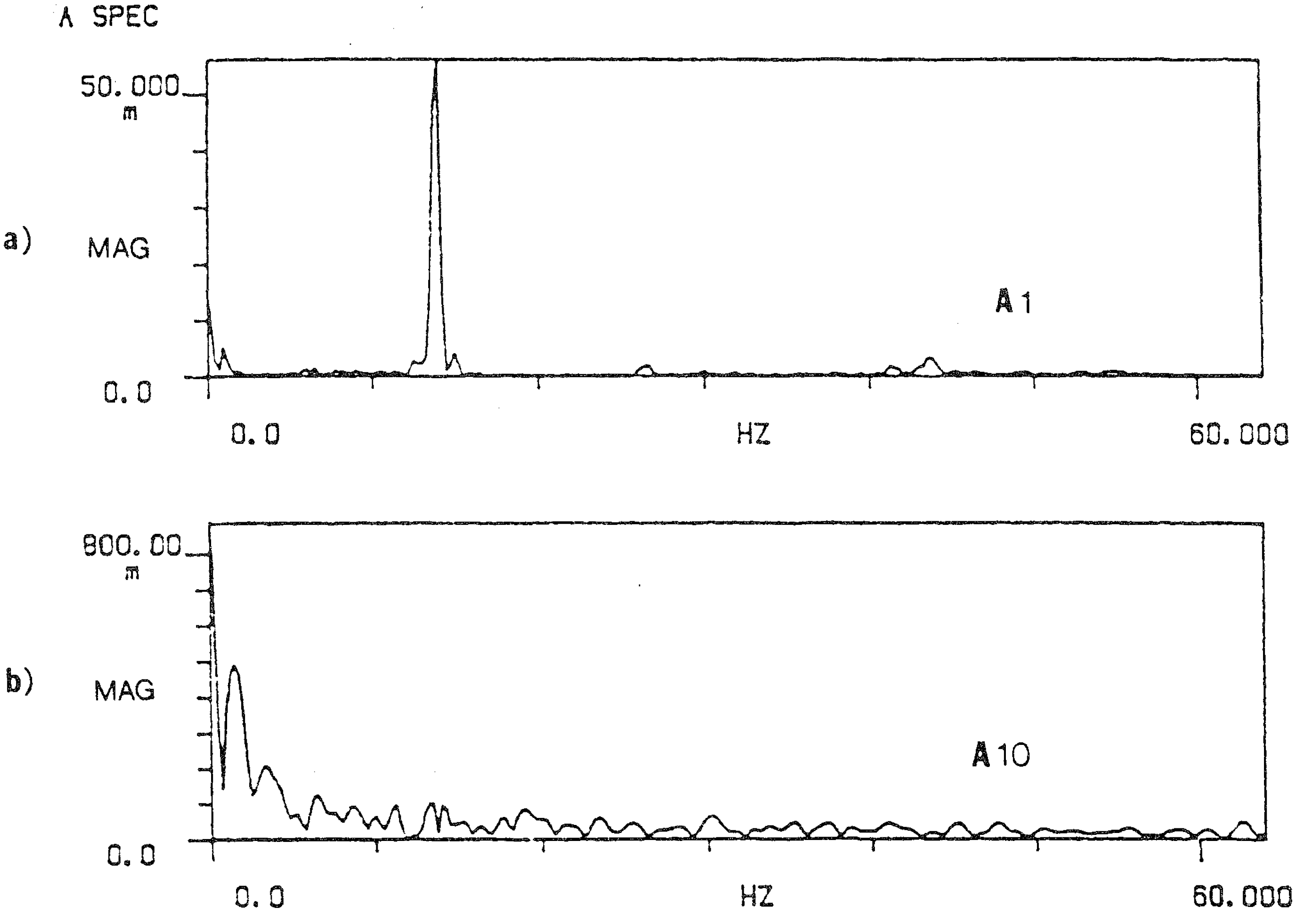


Figure 1.11 - PSD's: SITE 1, 3-12-82, Friday, 11:58 a.m.
a) Accelerometer 1
b) Accelerometer 10

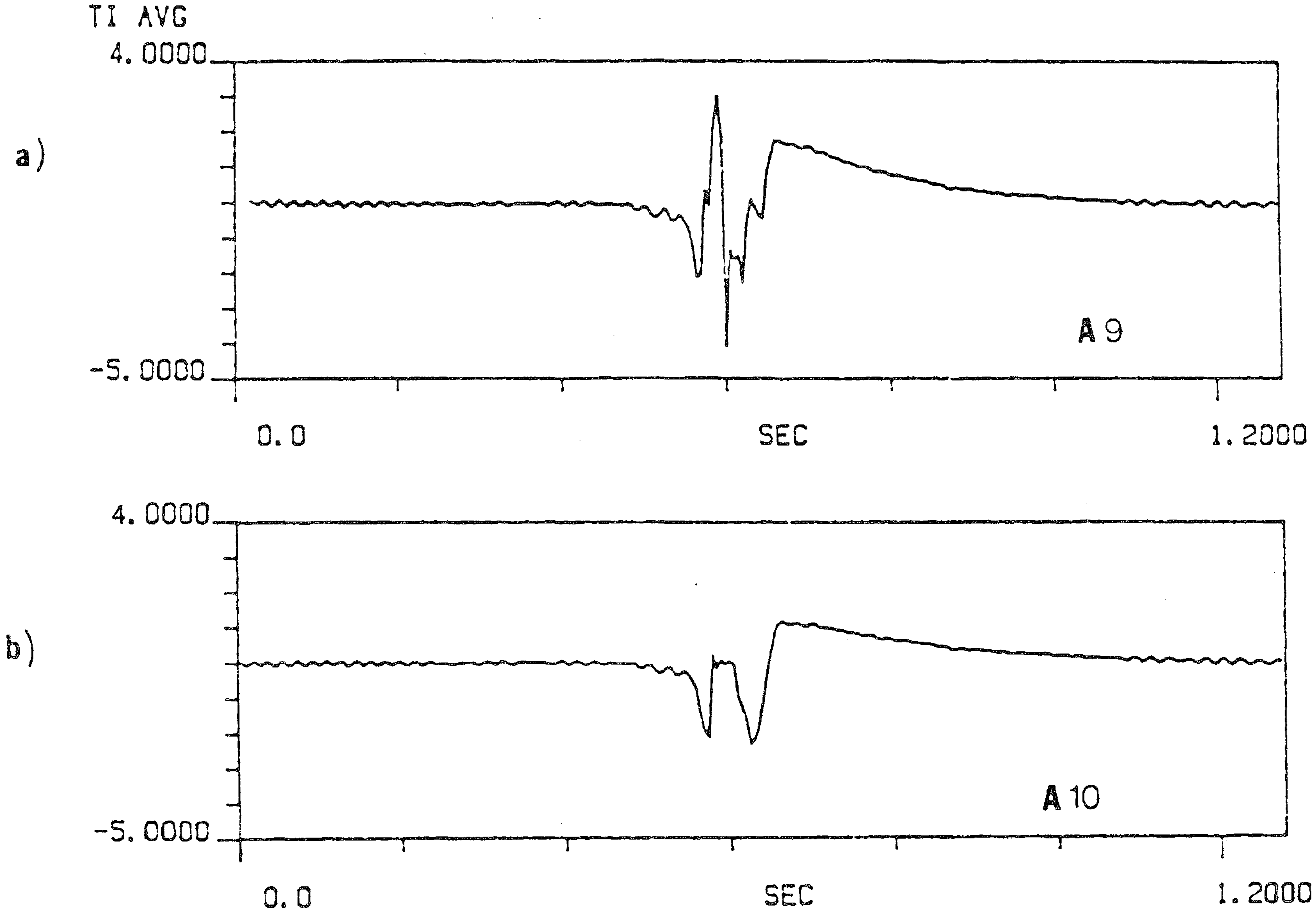


Figure 1.12 - Pulses: SITE 1, 3-12-82, Friday, 4:10 p.m.
a) Accelerometer 9
b) Accelerometer 10

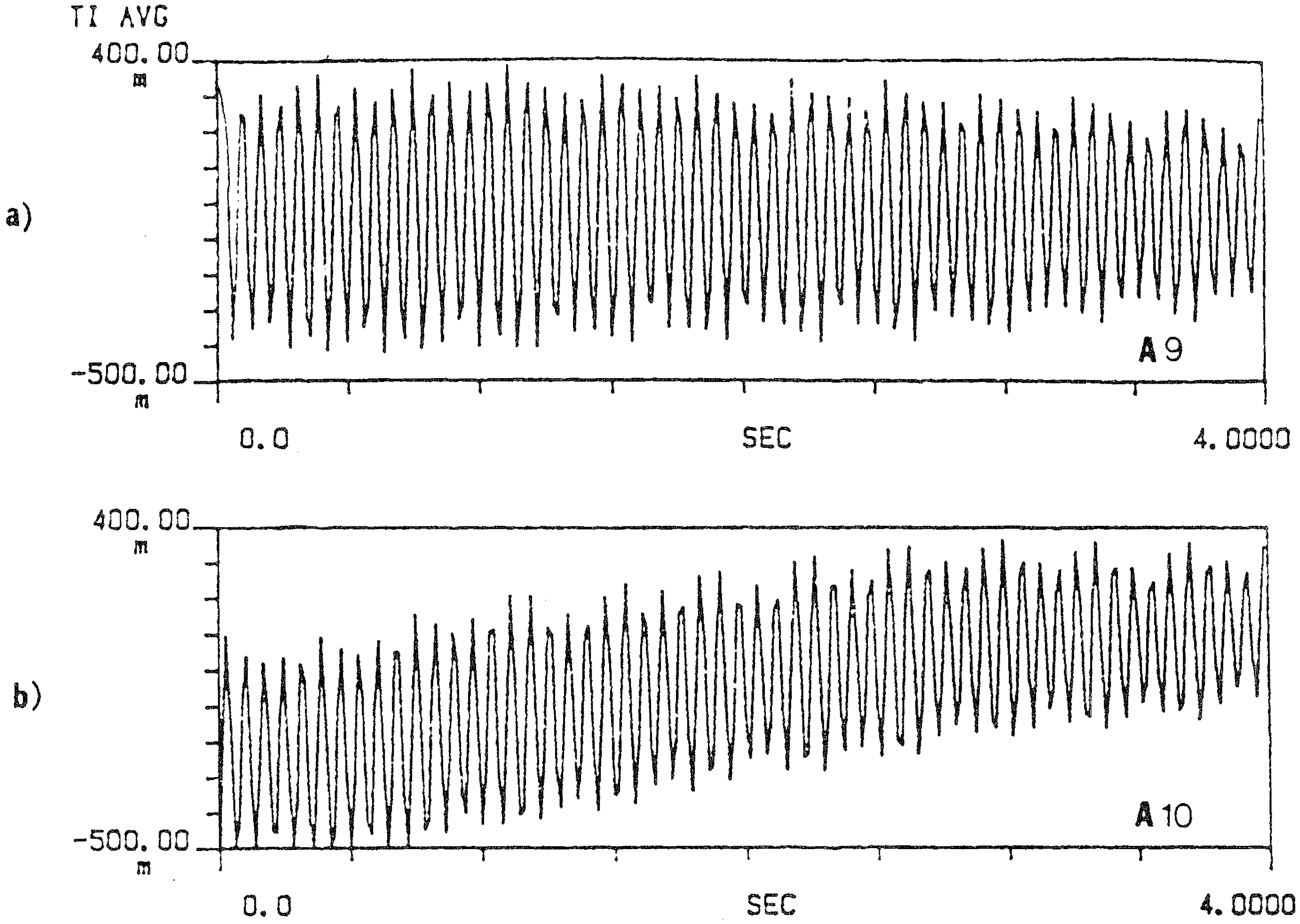


Figure 1.13 - Ringing: SITE 1, 3-14-82, Sunday, 3:29 a.m.
a) Accelerometer 9
b) Accelerometer 10

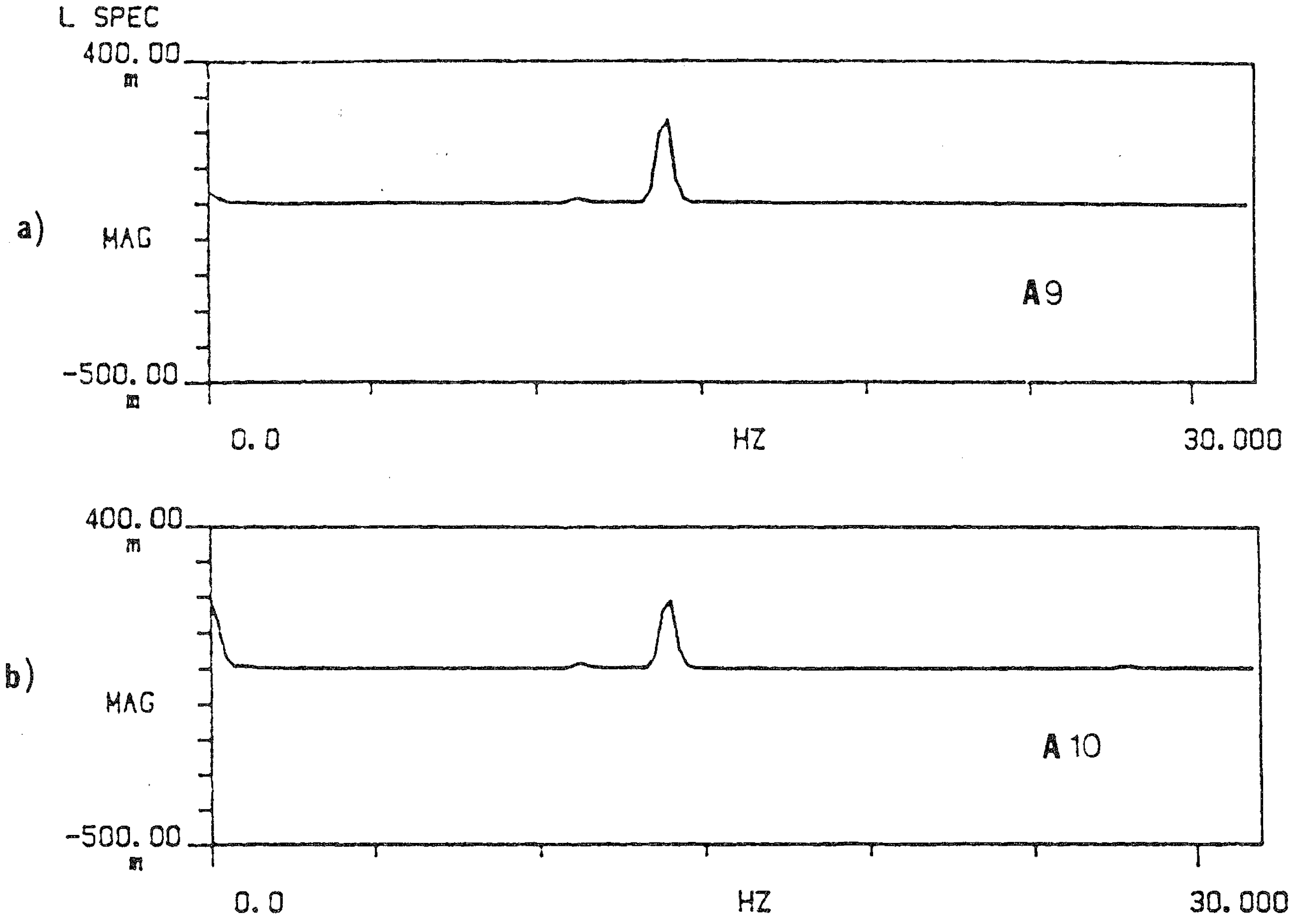


Figure 1.14 - Ringing FFT's: SITE 1, 3-14-82, Sunday, 3:29 a.m.

a) Accelerometer 9
b) Accelerometer 10

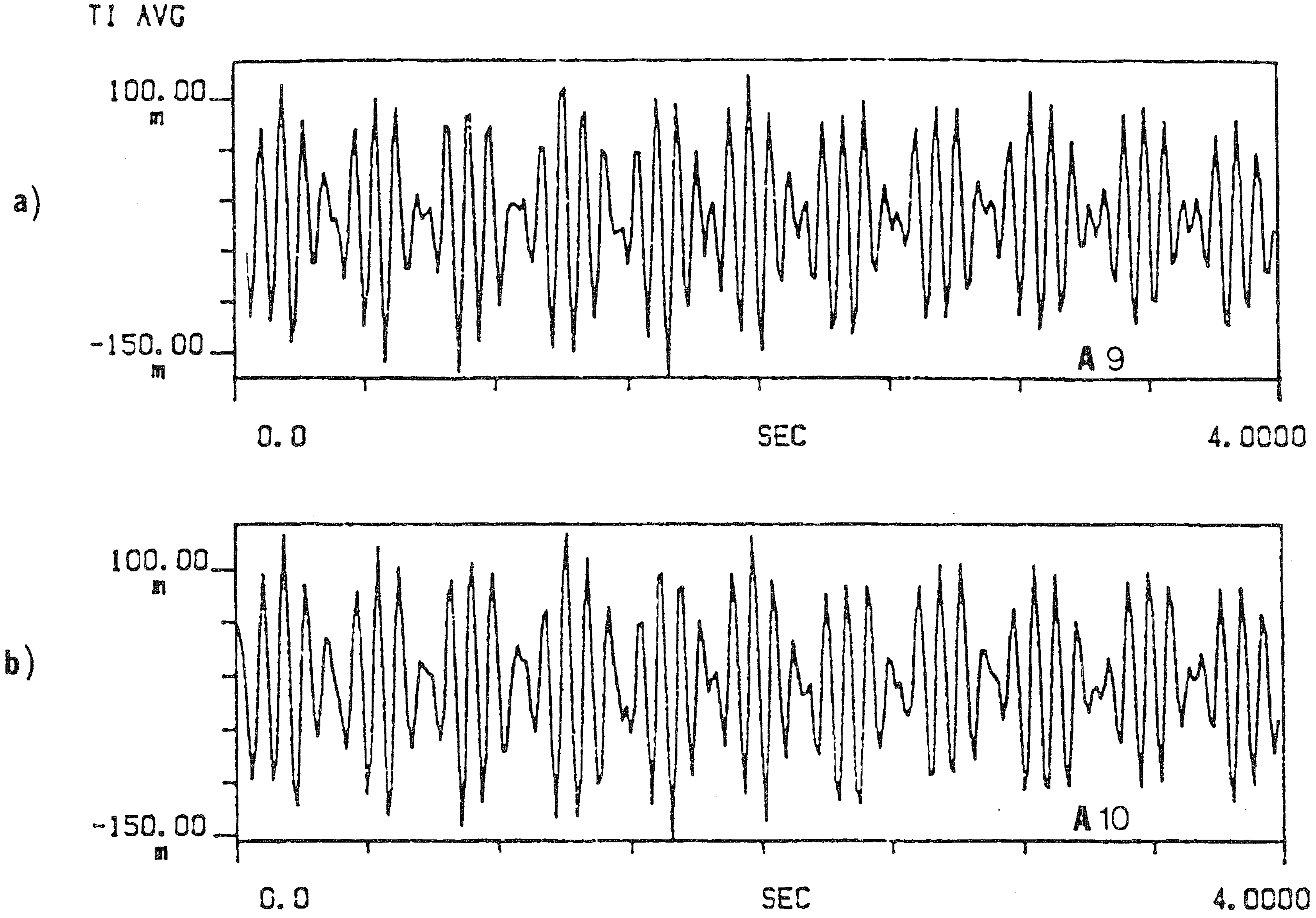


Figure 1.15 - Two-Mode Ringing: SITE 1, 3-15-82, Monday, 1:52 p.m.
a) Accelerometer 9
b) Accelerometer 10

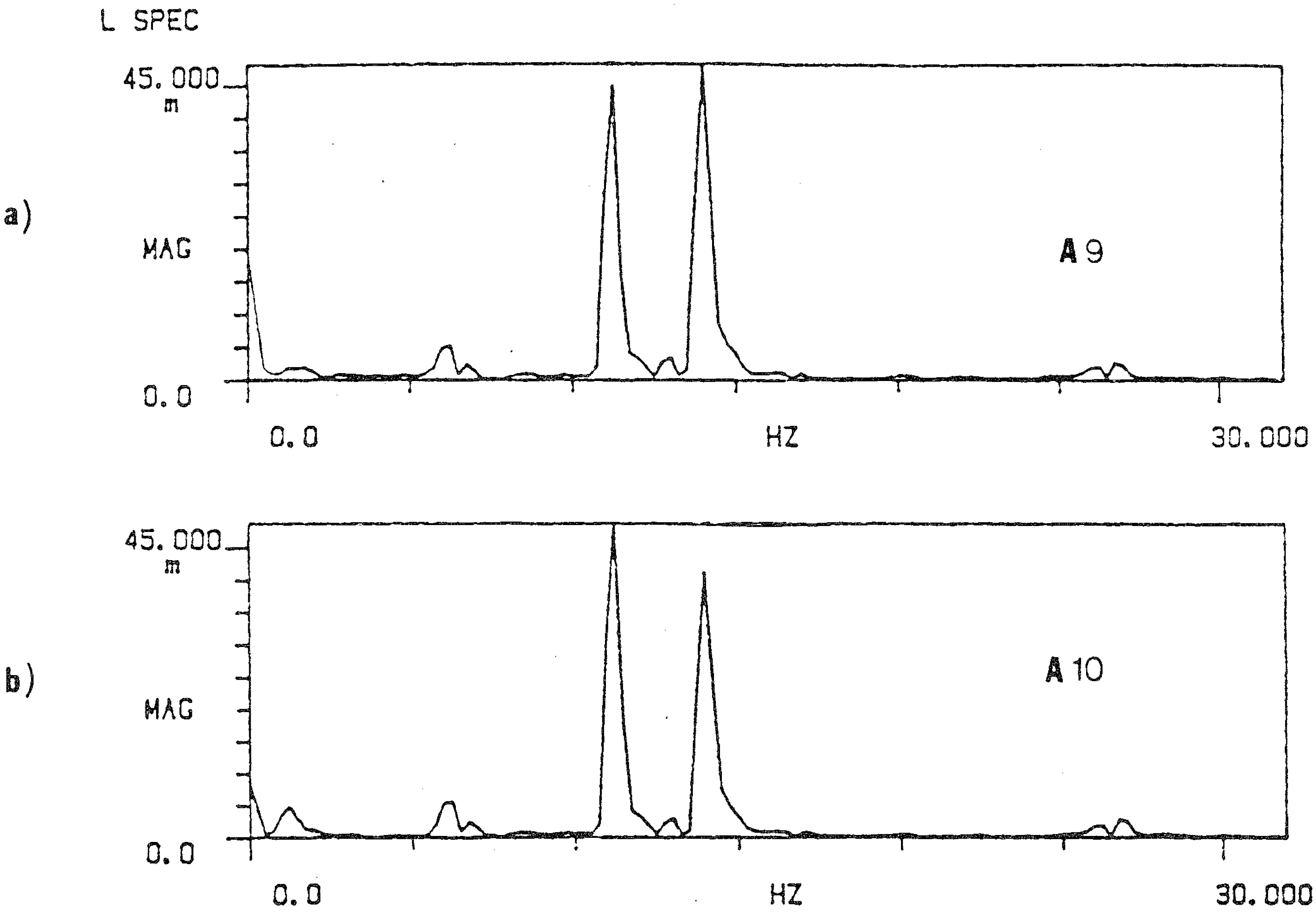


Figure 1.16 - Two-Mode Ringing FFT's: SITE 1, 3-15-82, Monday, 1:52 p.m.
a) Accelerometer 9
b) Accelerometer 10

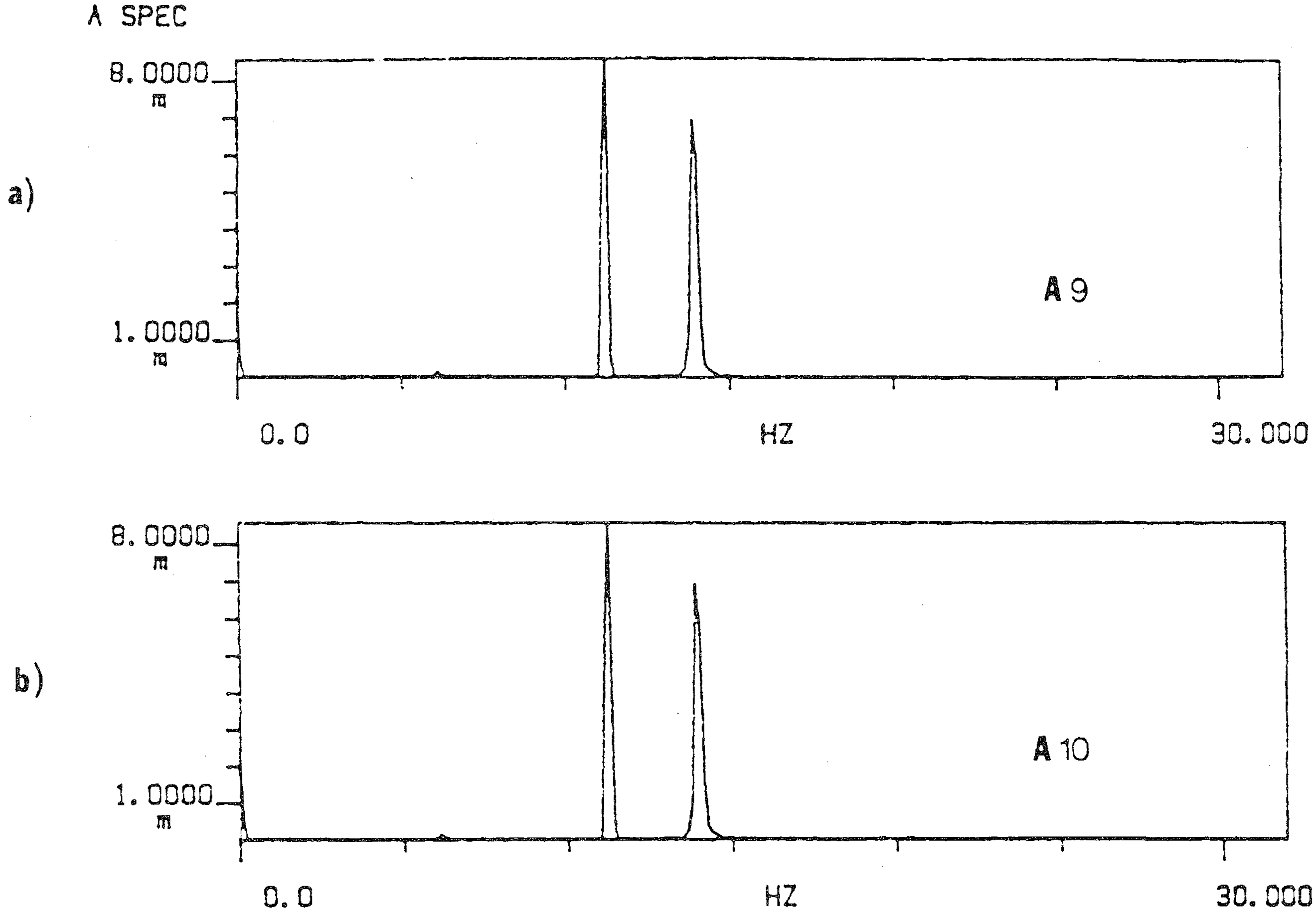


Figure 1.17 - Two-Mode Ringing PSD's: SITE 1, 3-15-82, Monday, 1:52 p.m.
a) Accelerometer 9
b) Accelerometer 10

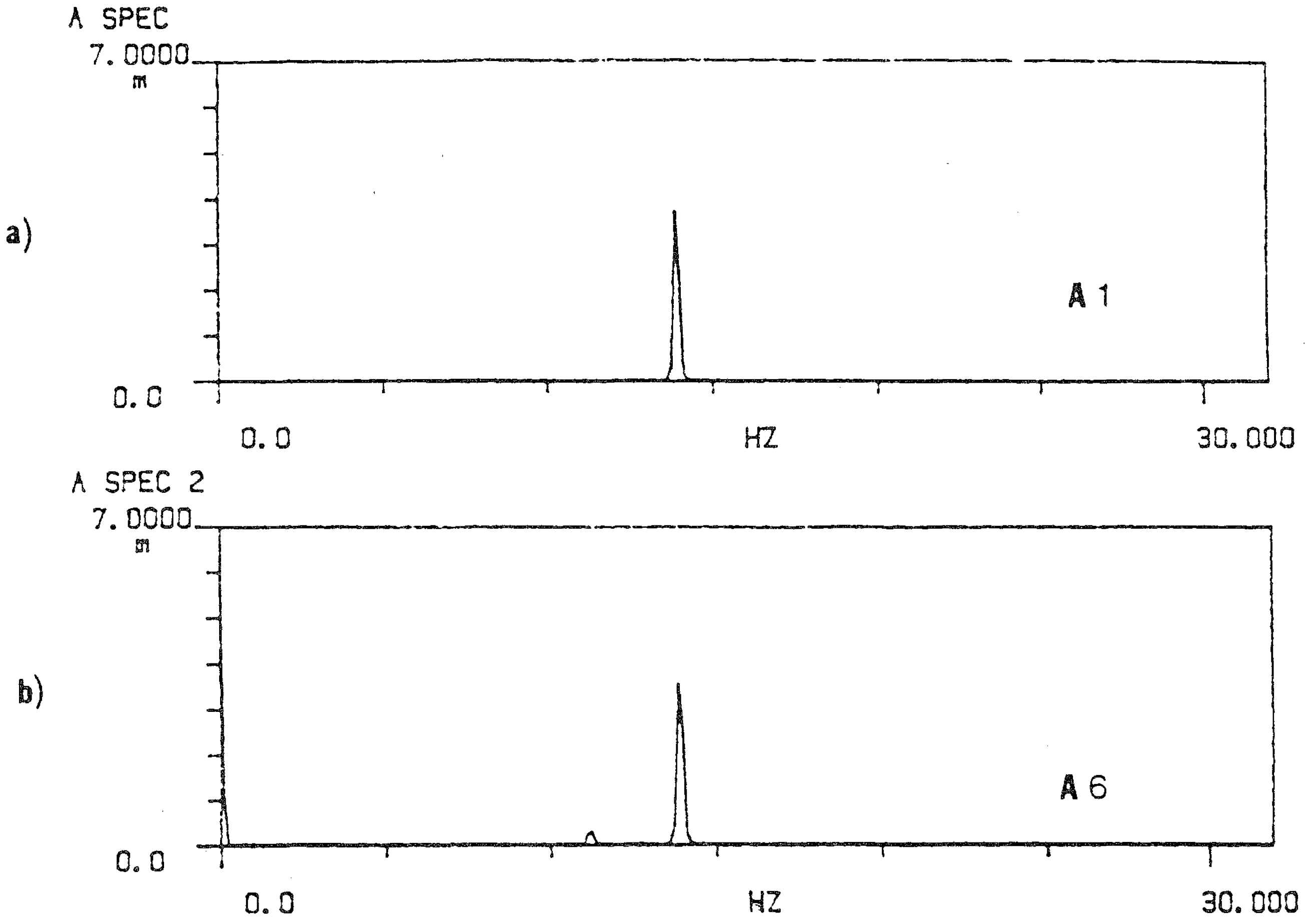


Figure 1.18 - Two-Mode Ringing PSD's: SITE 1, 3-15-82, Monday, 1:52 p.m.
a) Accelerometer 1
b) Accelerometer 6

4.2 SITE 2 Signal Analysis

Because SITE 2 was located near the top of an incline, truck speeds did not reach the levels necessary to pulse the luminaire arm end significantly. Significant swaying of the structure did occur as can be seen by Figure 2.1. Using $G_f = 2$ for accelerometer 10, see Table 7, the periodic vibration amplitude reaches 0.8 g peak-to-peak. Figure 2.2 clearly indicates the swaying modal frequency of 14 Hz.

4.2.1. SITE 2 Figures

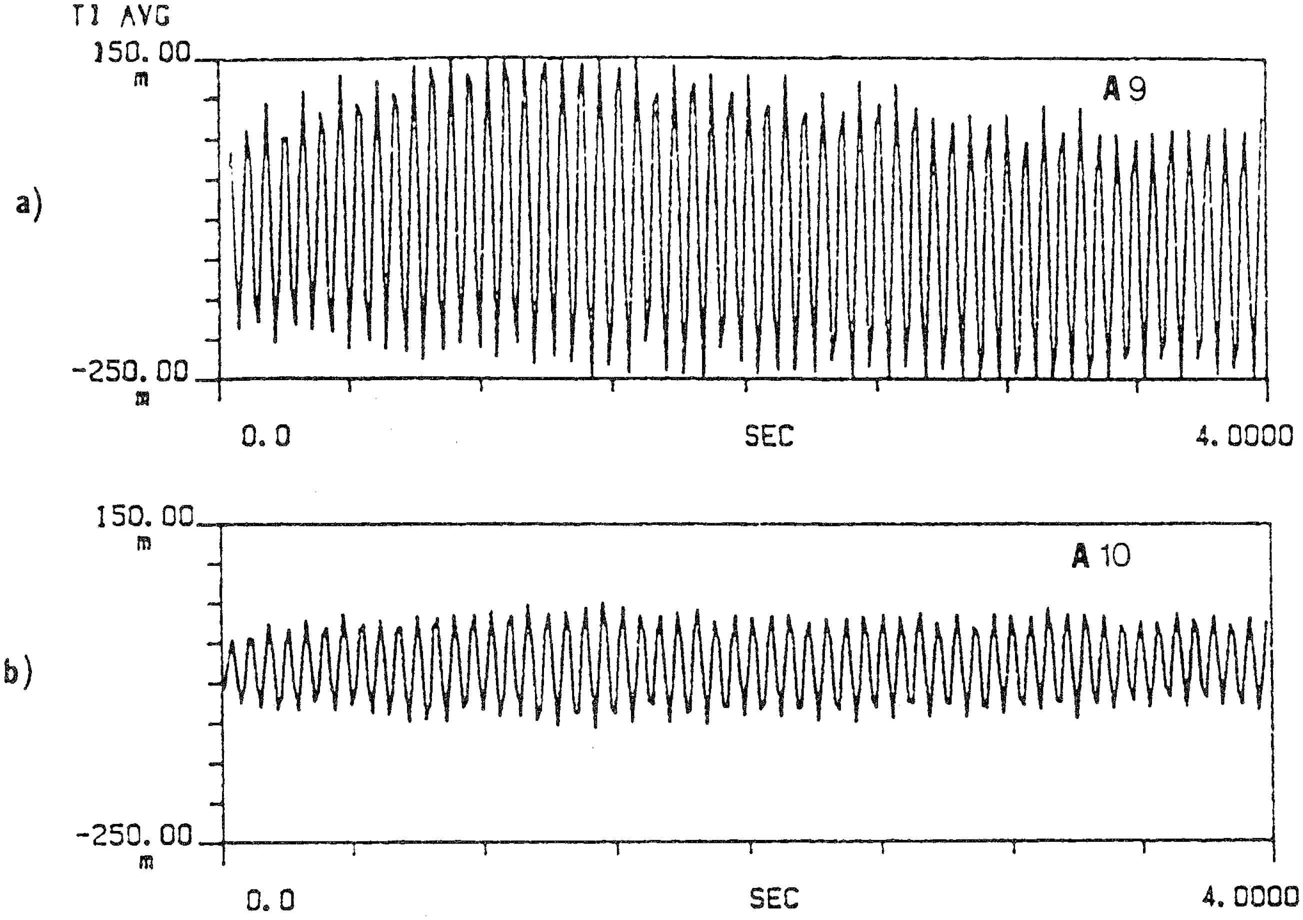


Figure 2.1 - Ringing: SITE 2, 3-30-83, Wednesday, 10:47 p.m.
a) Accelerometer 9
b) Accelerometer 10

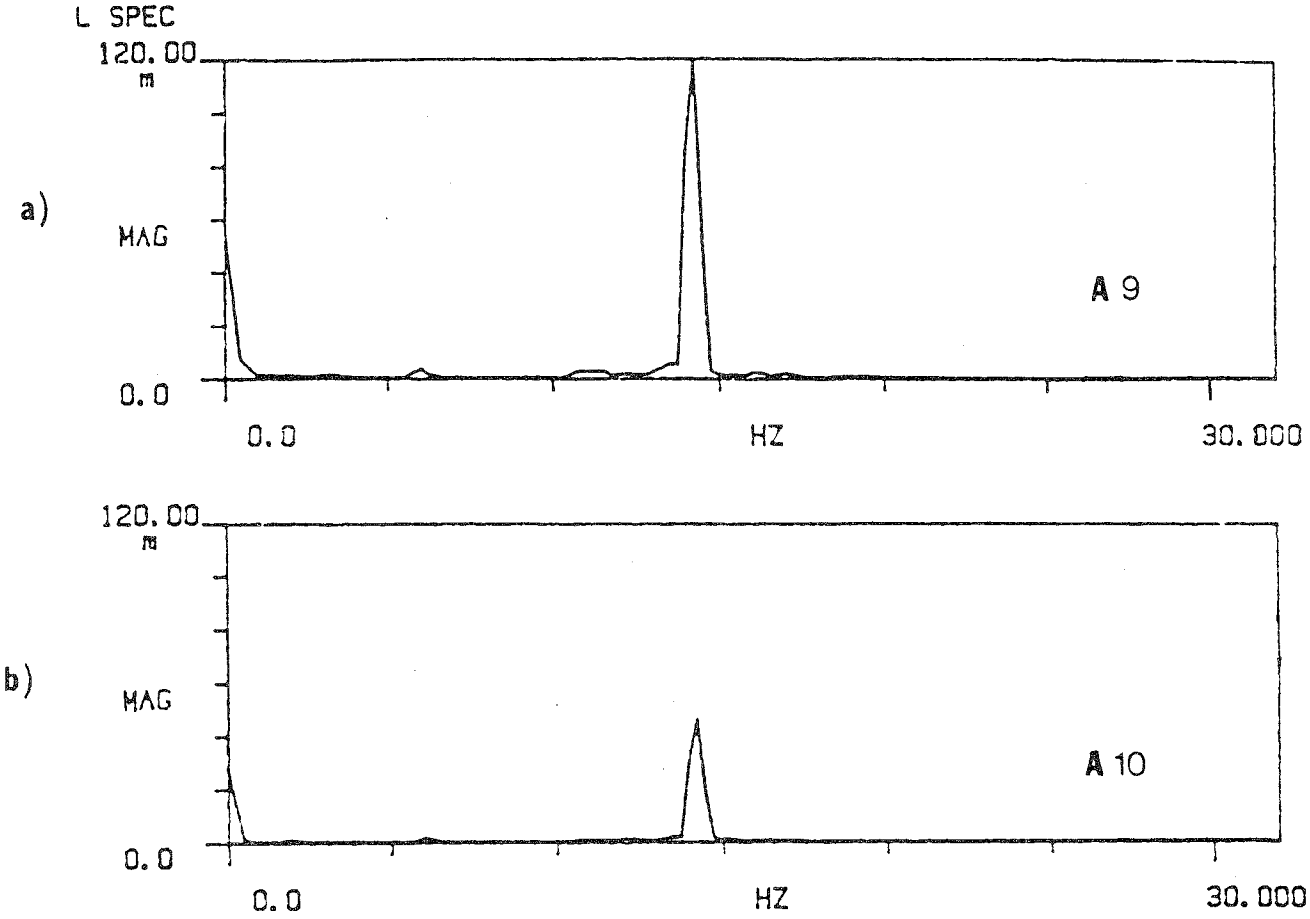


Figure 2.2 - Ringing FFT's: SITE 2, 3-30-83, Wednesday, 10:47 p.m.
a) Accelerometer 9
b) Accelerometer 10

4.3 SITE 3 Signal Analysis

Although the instrumented luminaire at SITE 3 was located on an off-ramp, significant pulses did occur - see Table 4. This is expected since the luminaire was located at the entrance to the off-ramp where vehicle speeds were still high. Pulse shapes were found to be quite similar to those at SITES 1 and 5.

Figure 3.1-3.4 are included in this report to show that swaying vibration levels exceeding 1 g peak-to-peak do occasionally occur.

4.3.1 SITE 3 Figures

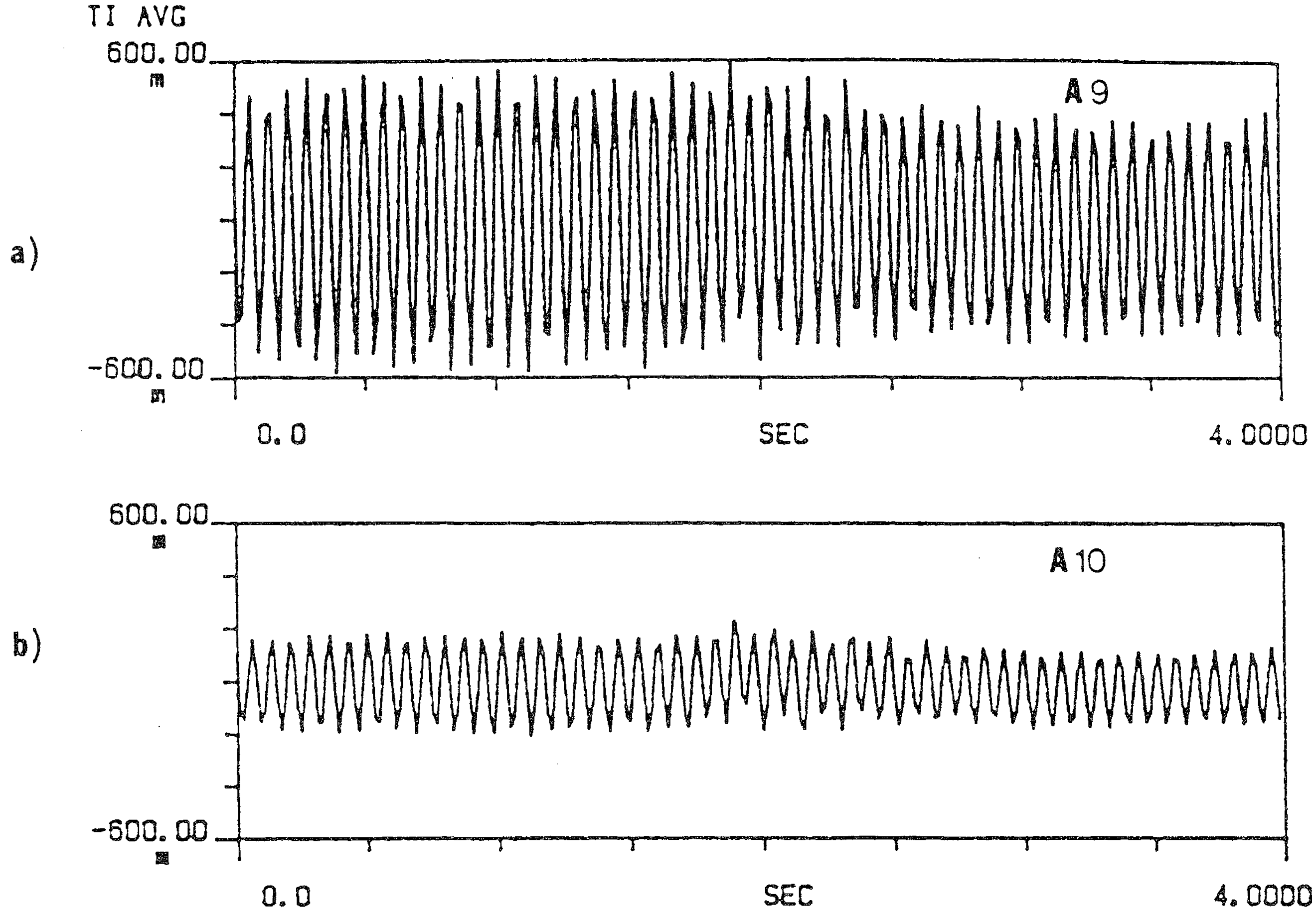


Figure 3.1 - Ringing: SITE 3, 4-26-83, Tuesday, 4:14 a.m.
a) Accelerometer 9
b) Accelerometer 10

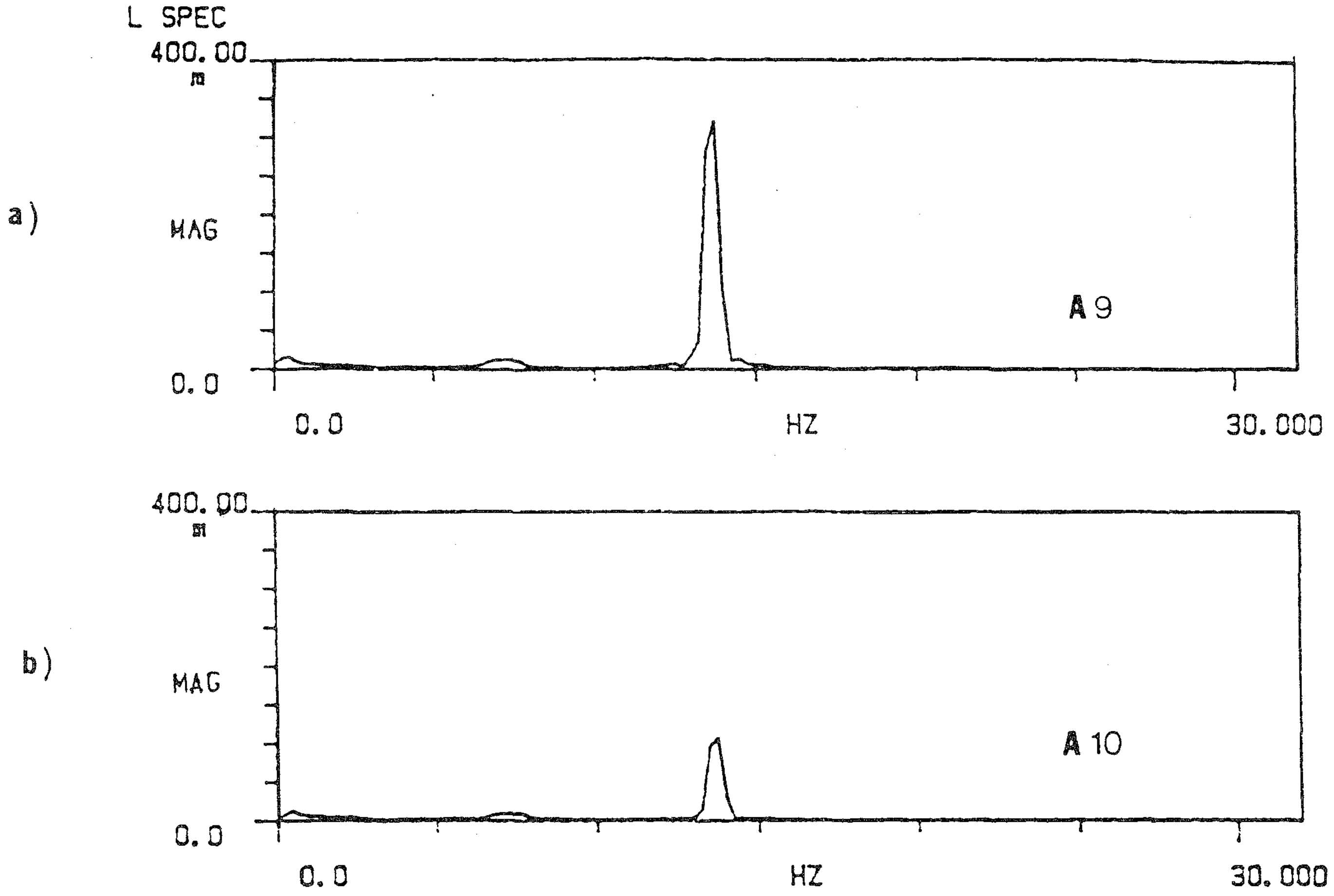


Figure 3.2 - Ringing FFT's: SITE 3, 4-26-83, Tuesday, 4:14 a.m.
a) Accelerometer 9
b) Accelerometer 10

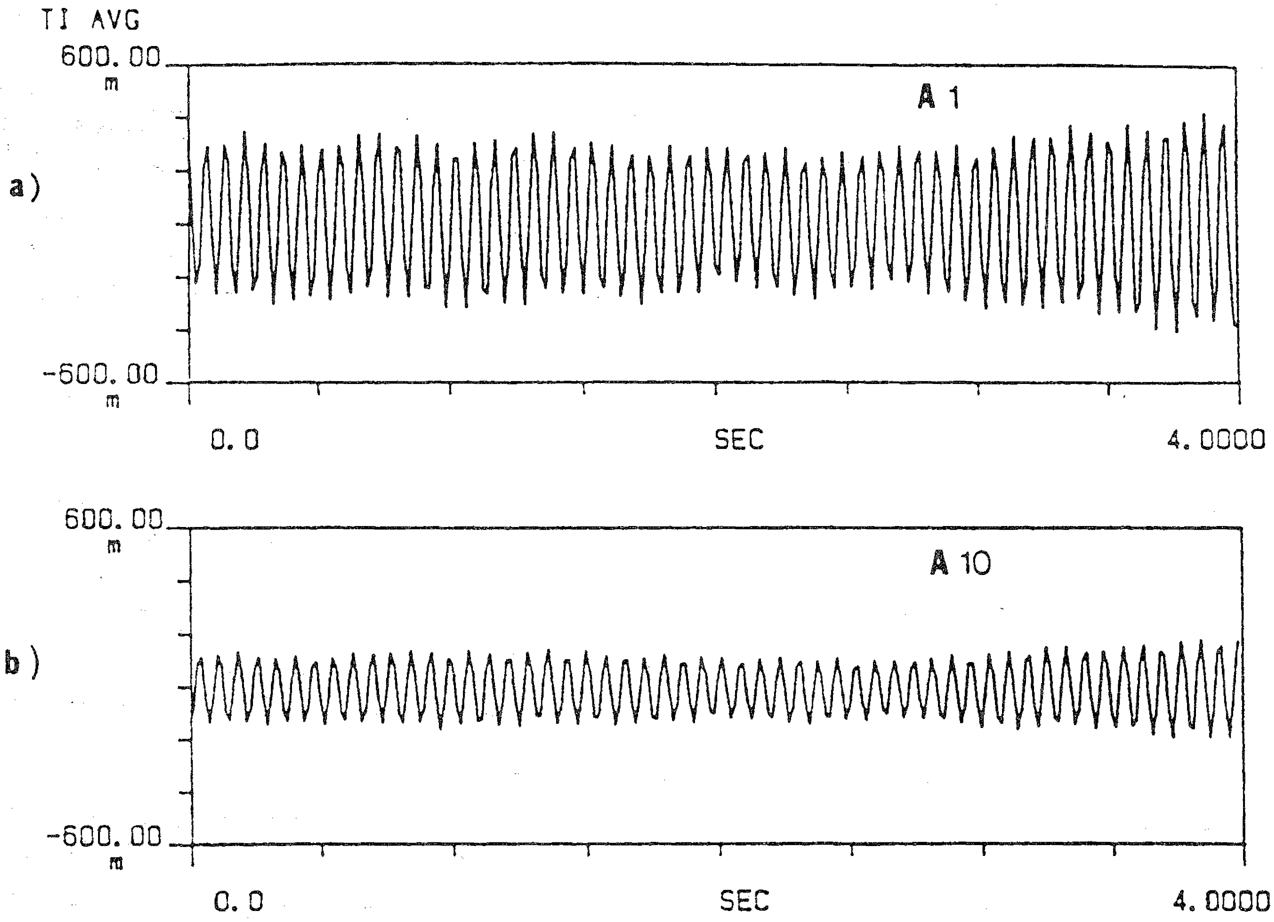


Figure 3.3 - Ringing Comparison: SITE 3, 4-26-83, Tuesday, 4:14 a.m.
a) Accelerometer 1
b) Accelerometer 10

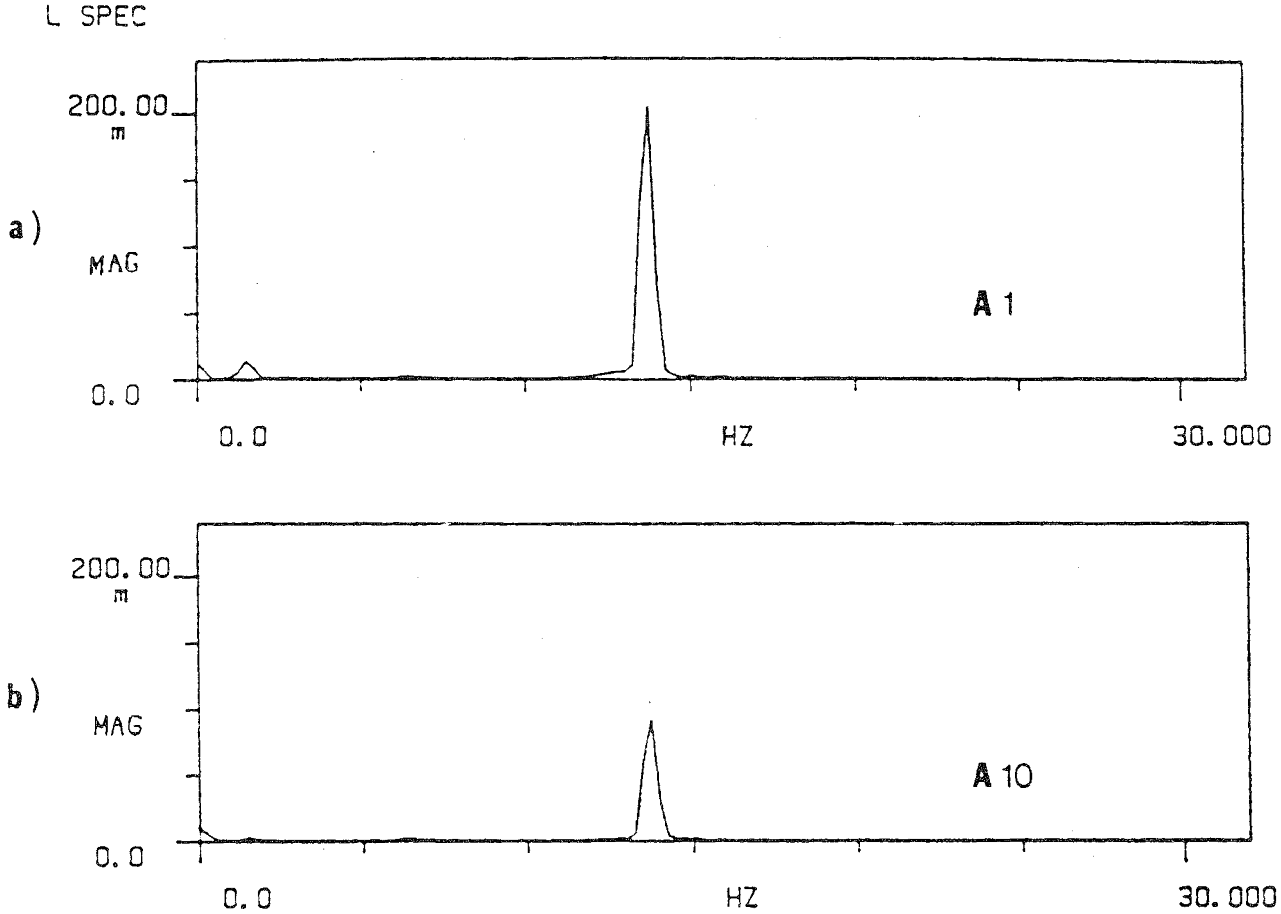


Figure 3.4 - FFT Comparison: SITE 3, 4-26-83, Tuesday, 4:14 a.m.
a) Accelerometer 1
b) Accelerometer 10

4.4 SITE 4 Signal Analysis

At SITE 4, the luminaire of interest was mounted near midspan of a curved bridge on-ramp. As at SITE 2, vortex induced pulses at the arm end were rather insignificant. More characteristic of this site were highly random, low-level vibration of the luminaire structure as a whole - compare accelerometers 9 and 10 in Figure 4.1.

Spectral analyses show the frequency content of the vibration to be broadband - see Figure 4.2.

4.4.1 SITE 4 Figures

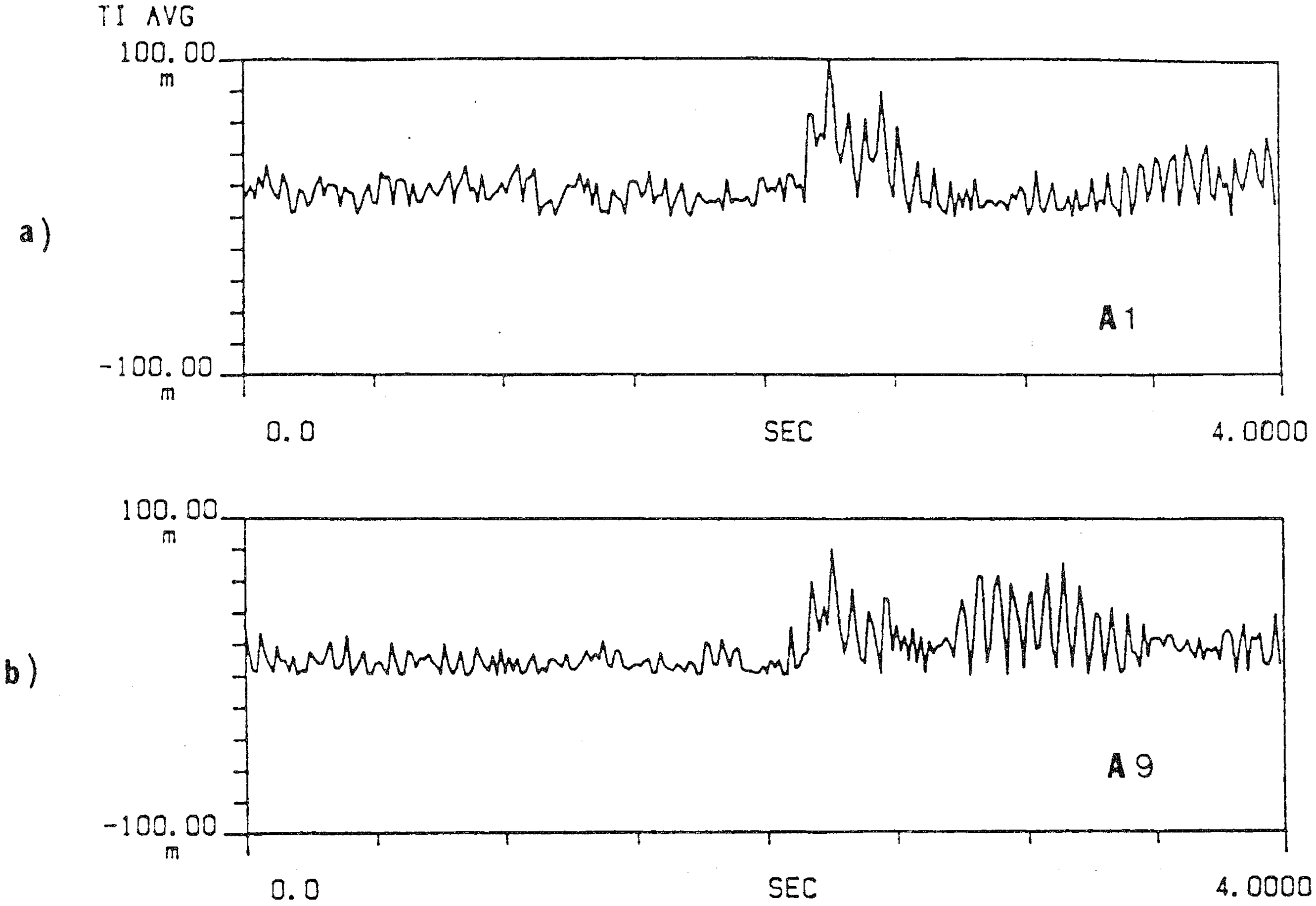


Figure 4.1 - Typical Time Histories: SITE 4, 6-1-83, Wednesday, 6:49 a.m.
a) Accelerometer 1
b) Accelerometer 9

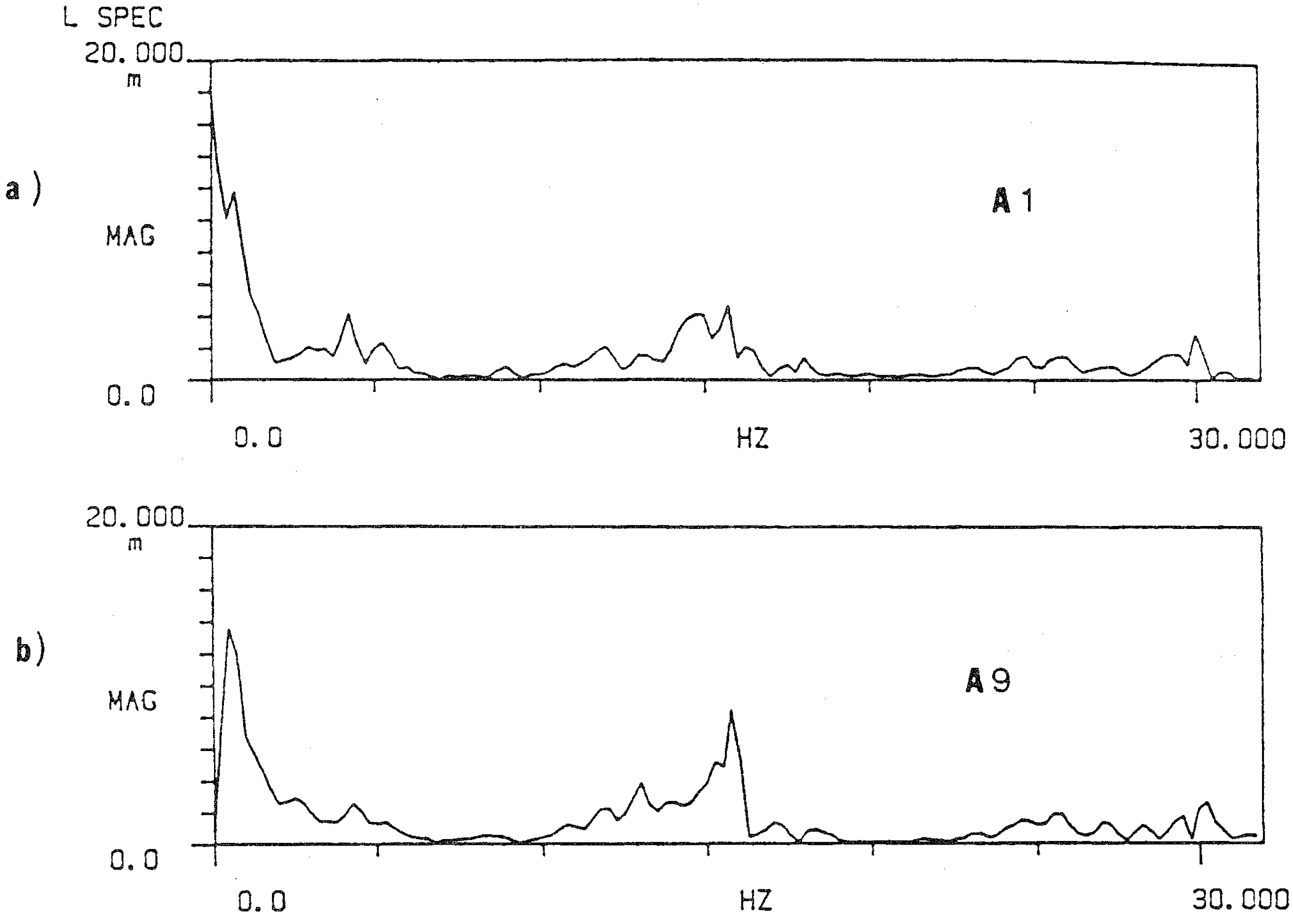


Figure 4.2 - FFT's: SITE 4, 6-1-83, Wednesday, 6:49 a.m.
a) Accelerometer 1
b) Accelerometer 9

4.5 SITE 5 Digital Analysis

SITE 5 proved to be as dynamically active as SITE 1 - compare the pulse level frequency of occurrence in Tables 2 and 6. Figure 5.1 shows one example of a 3g pulse. The PSD of this pulse in Figure 5.2 shows the localized, low frequency nature of the pulse energy. The absence of modal spikes also indicates the localized nature of the pulse.

4.5.1 SITE 5 Figures

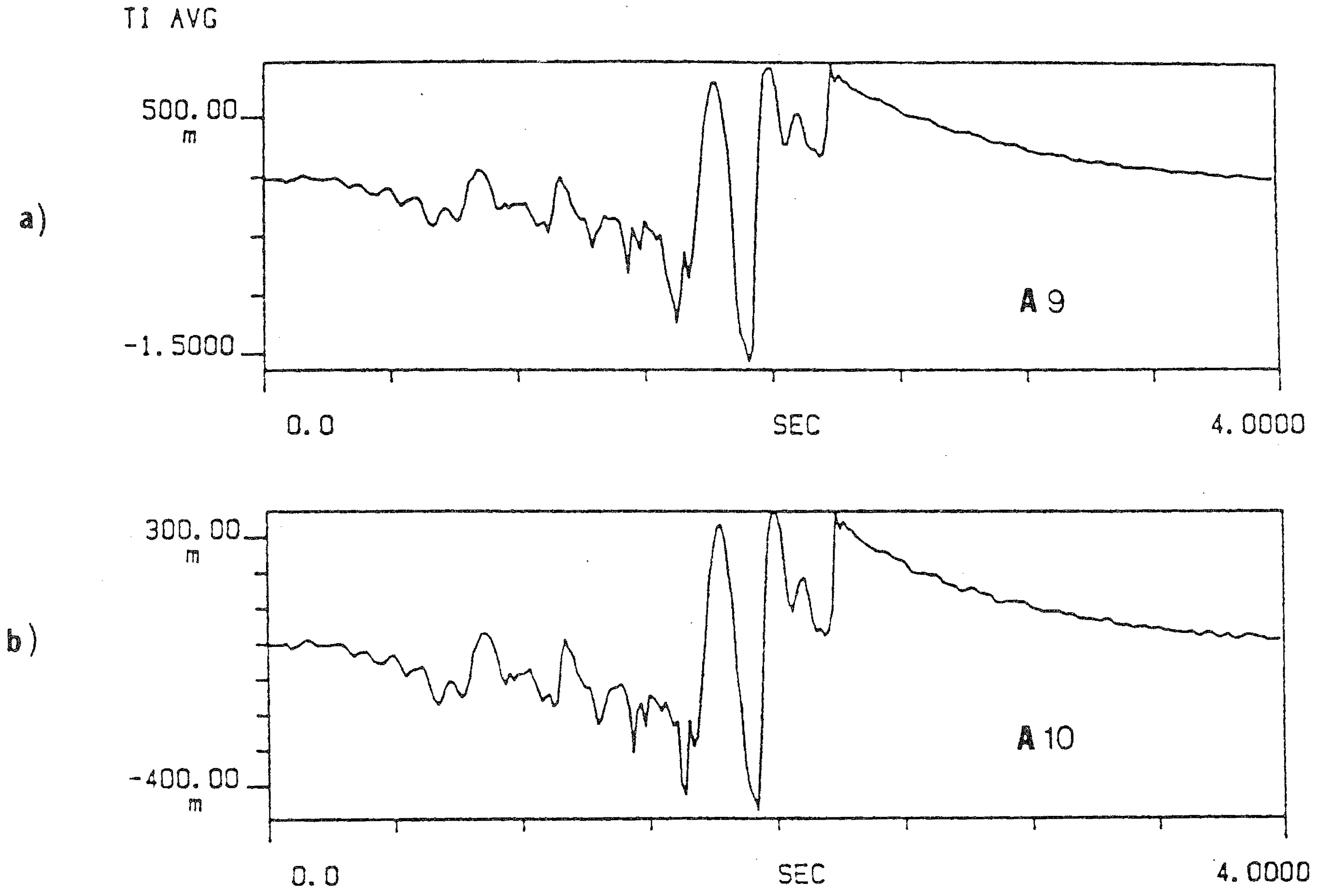


Figure 5.1 - Pulses: SITE 5, 7-8-83, Friday, 6:20 a.m.
a) Accelerometer 9
b) Accelerometer 10

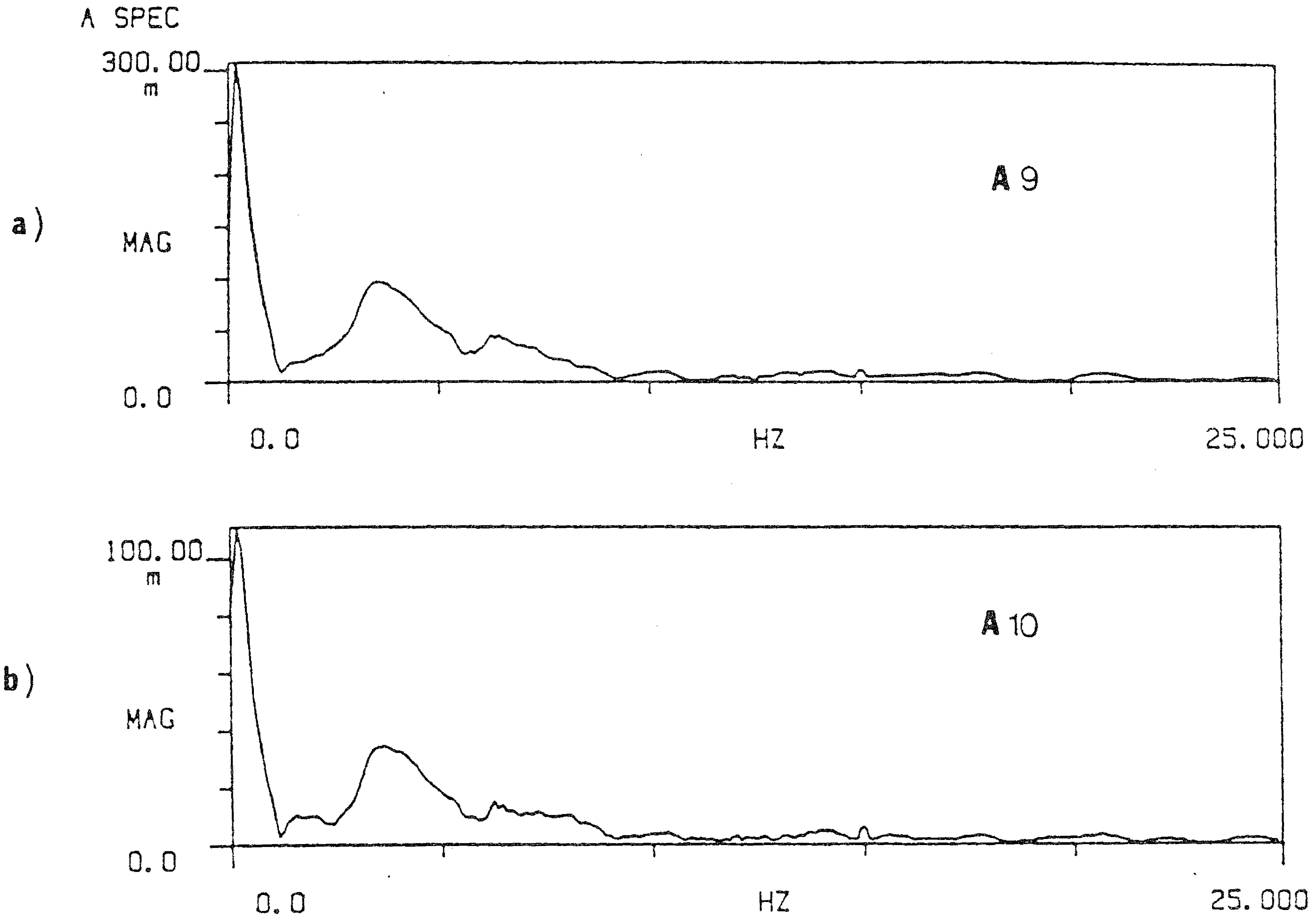


Figure 5.2 - Pulse PSD's: SITE 5, 7-8-83, Friday, 6:20 a.m.
a) Accelerometer 9
b) Accelerometer 10

5.0 Discussion of the Results

As stated in Part I of this final report, it is postulated that pulse loading occurs with relatively high frequency at luminaire sites where vehicle speeds approach or exceed the current limit of 55 mph. Levels exceeding, even far exceeding, 1 g amplitude are not uncommon.

The pulse energy can, but does not always, excite the lower modes of luminaire vibration below 15 Hz. Two such modes having frequencies of 12 and 14 Hz were often apparent, although it proved more difficult to excite the 12 Hz mode.

Much of the pulse energy appears to be distributed over frequencies below 5 Hz. This frequency distribution makes shock isolation of the HPS lamp bulb difficult since it is very difficult to shock isolate a low frequency, low mass object. Perhaps a more viable approach is to incorporate damping into the lamp support structure, at the bulb/socket interface or at the lamp chassis/luminaire arm interface.

Stiffening the luminaire arm in the vertical direction is another alternative approach, but it is expected that this design fix would be quite expensive.

Of course, these considerations are based on the premise that current HPS lamp designs are not suitable for surviving the vibrational environment discussed in this report. It must be noted that no lamp failure/breakage ever occurred in the tests conducted as a result of the vibration environment. Nevertheless, since these tests were of relatively short duration, it cannot be stated that the vibrational environments have no correlation with the high frequency of lamp failure now occurring on Texas highways (and in other states). More likely, there is significant correlation of lamp failures with vibration severity.

6.0 Acknowledgements

This research was supported by the Texas State Department of Highways and Public Transportation (SDHPT), Project No. 22730. Dexter Jones, project monitor, is acknowledged for his support in the field site conduct. Sonny Wong of SDHPT and Dick Zimmer and John Curek of the Texas Transportation Institute performed much of the instrumentation design and assisted with the acquiring and analyzing of the data. Page Heller and Nader Ayoub, research assistants in the Electric Power Institute at Texas A & M University provided much of the data analyses and calibration of the recording equipment.

REPORT D

BALLAST FAILURES CAUSED BY DEFECTIVE HIGH PRESSURE SODIUM (HPS) LAMPS, THE GENERAL ELECTRIC COMPANY

OLP 2298

Straight Talk ...about HID Lighting

LIGHTING SYSTEMS DEPARTMENT, HENDERSONVILLE, N.C. 28739

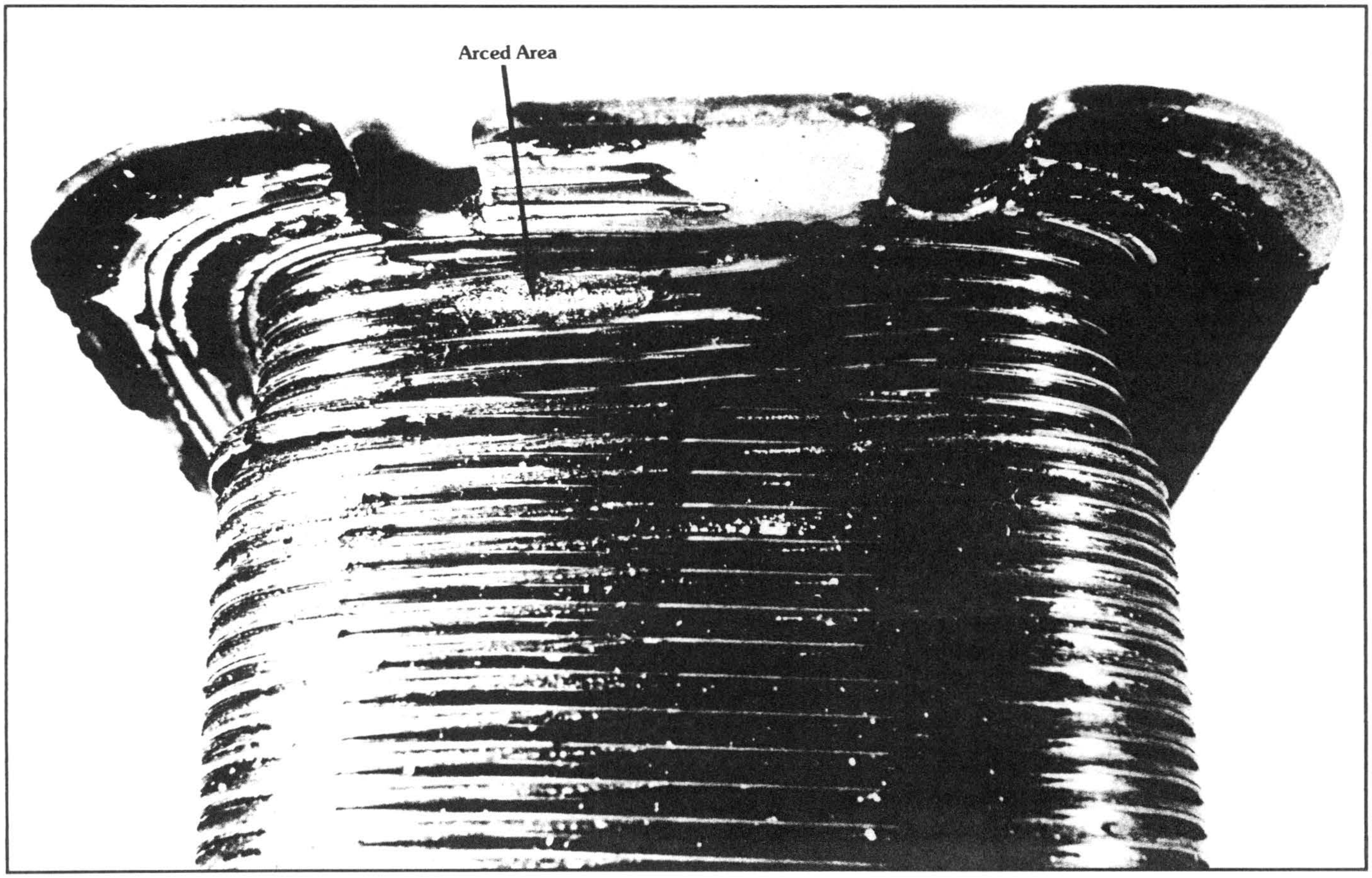


Figure 1
Arced Area

BALLAST FAILURES CAUSED BY DEFECTIVE HIGH PRESSURE SODIUM (HPS) LAMPS

Broken frame welds in HPS lamps can cause impulses and damage to the ballast. The goal of this paper is to increase the industry awareness of the problem and to help motivate lamp manufacturers to improve their process control in this area.

INTRODUCTION

The purpose of this paper is to discuss how open welds in high pressure sodium (HPS) lamps can damage or destroy ballasts. There have been hundreds and possibly thousands of ballasts ruined by this mechanism; but, historically, the cause has not been readily identified. One additional point is that ballasts with electronic regulating circuits can be even more susceptible to broken welds than standard electromagnetic ballasts.

Our goal is to raise the awareness of HPS users to this situation so that it can be readily identified

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and corrective action taken. A great deal of cost, time, and effort has been wasted due to a lack of understanding of this phenomenon.

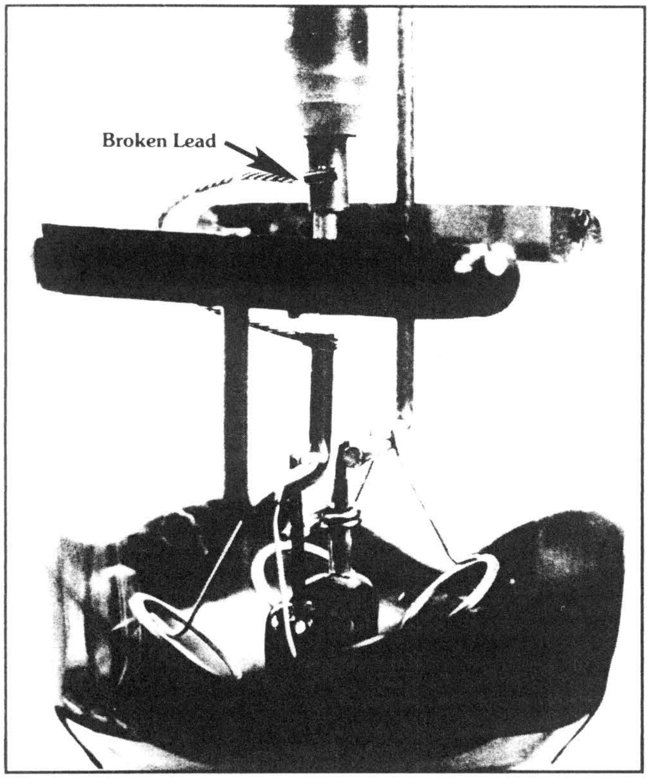

Figure 2
Broken Lead

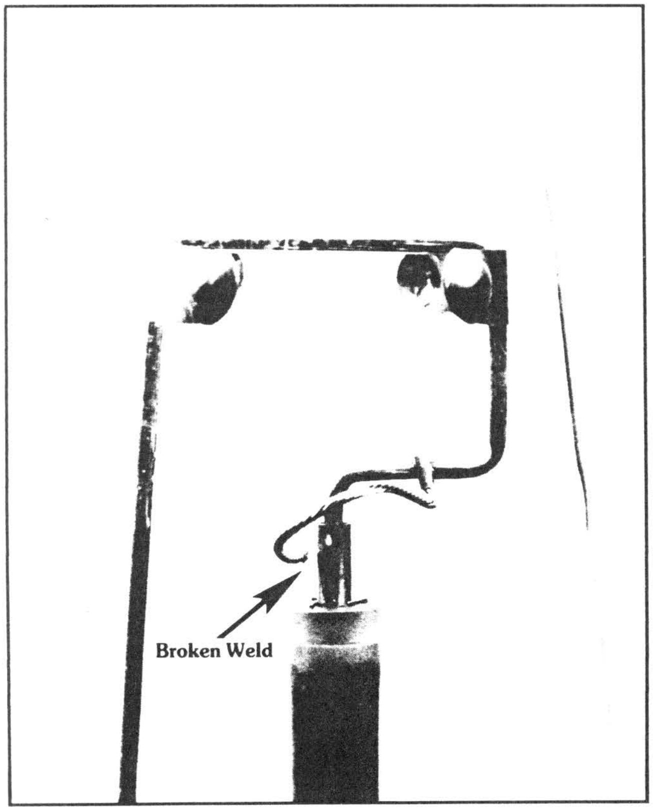

Figure 3
Broken Weld

BALLAST FAILURES

HPS lamps require a current limiting ballast; and in essentially all cases, an inductor is used in the circuit. If the lamp current is interrupted, the energy stored in the inductor can generate a very high voltage pulse. The same phenomenon can occur with other types of high pressure discharge lamps, but the impulse is usually clipped by the gas in the outer jacket before the ballast is damaged.

The actual mechanism is as follows: The current in a typical 400W HPS lamp has a nominal RMS value of 4.7A with a peak of approximately 6A. The energy stored in the inductor is $1/2\ Li^2$ where L is the inductance of the ballast and i is the instantaneous current through the inductor. The stored energy ranges from 0 to 2 joules. The inductor acts like a flywheel in that the current through the inductor cannot instantly change. (This is a consequence of Lenz's Law.) Thus, if current is flowing through the inductor and a lamp weld opens, the voltage will climb to a very high value to maintain the current. The voltage cannot easily arc across the broken weld due to the vacuum in the outer jacket of HPS lamps and arcing generally takes place between adjacent winding layers of the inductor. During tests with actual lamps, voltages up to 20 KV have been measured.

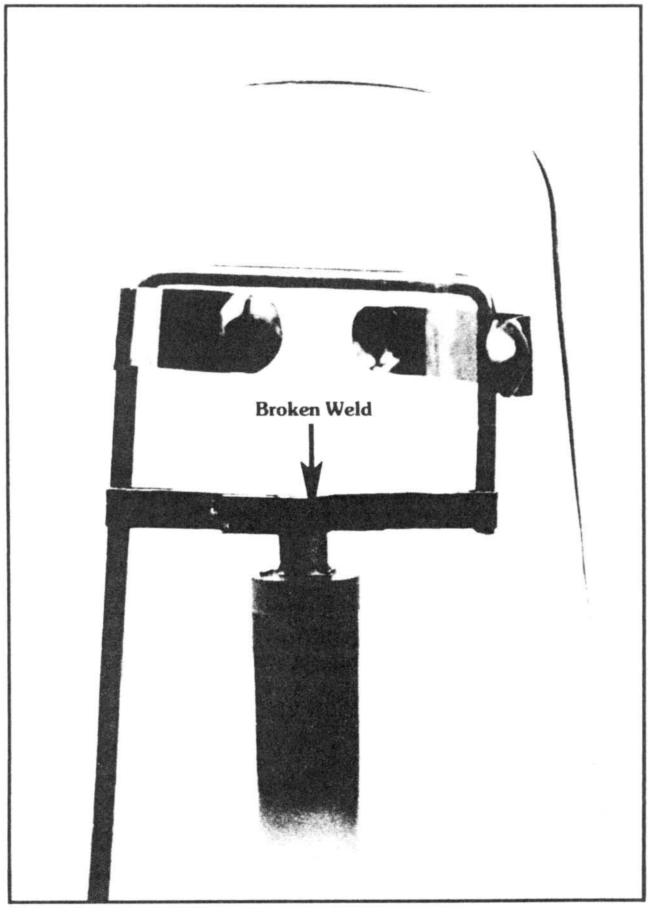

Figure 4
Broken Weld

A single arc-over due to an impulse will not cause a ballast to fail, but it does cause some carbon tracking at the point of breakdown. Successive impulses can lower the breakdown voltage to the point where the normal voltage on the ballast will arc-over. Repeated impulses of this nature can ruin essentially any HPS ballast in use today. An example of a short caused by a broken weld lamp is shown in Figure 1. Note the evidence of prolonged low energy arcing which ultimately led to a layer to layer short circuit.

Lamps with broken welds are shown in Figures 2 through 5. With the first three designs, it is not obvious when a weld is broken. With all four designs, intermittent contact can be made even with broken welds.

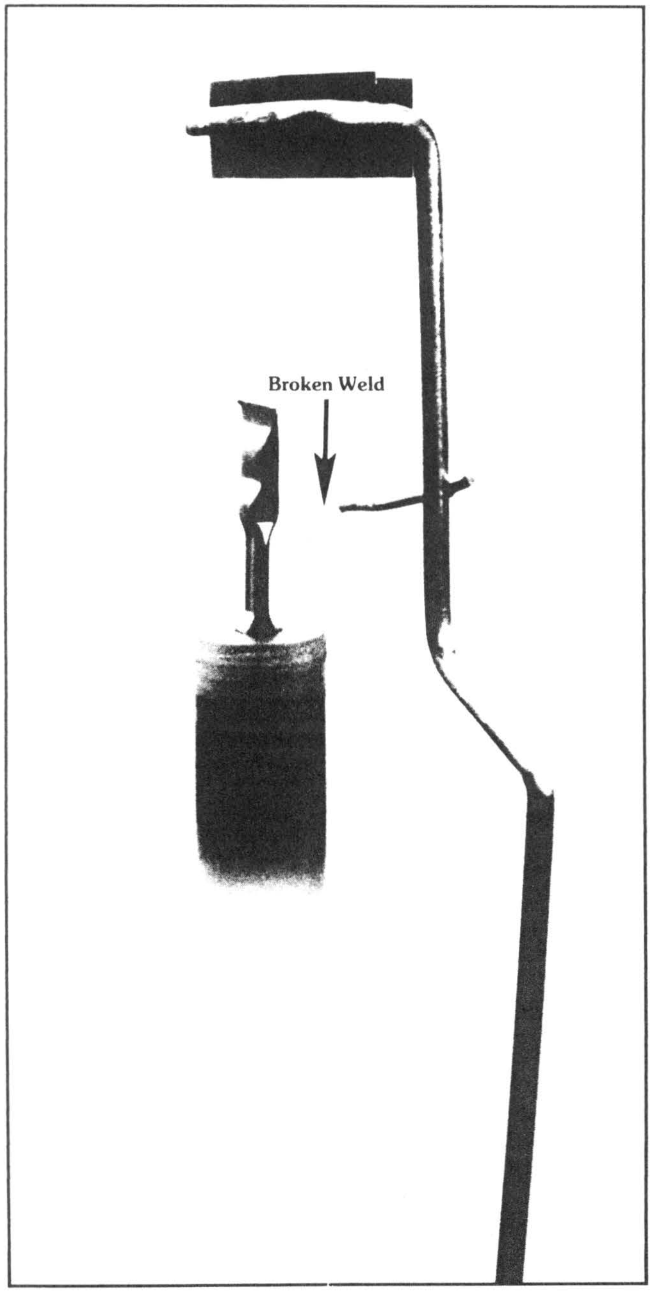

Figure 5
Broken Weld

LAMP DESIGN

The design of the mount for a HPS lamp has to meet several requirements:

1. Suitable materials must be chosen that can operate at high temperature without melting, evaporating or warping.
2. The ceramic in a 400W HPS arc tube operates at approximately 1000° Centigrade and expands more than 1/10 of an inch during operation. The mount is much cooler and generally does not expand as much. The mismatch in expansion must then be taken up by the mount.
3. The spot welds which are generally used to assemble the mount must have adequate strength, without embrittling or oxidizing the matal parts.
4. The weld strength must be adequate to withstand shipping, and for thousands of on-off cycles with vibrations as high as several g's.

Two areas that seem to result in broken welds are designs which are inherently difficult to weld and poor process control of the welding operation.

In the first case, one of the best and most reliable welds is the cross wire weld as shown in Fig. 5. For this weld, the cross sectional area of the weld can be consistent, and there should not be any burrs or parallel current paths during welding. A difficult weld is shown in Fig. 4. Note that the forces during welding and the area of the weld will probably not be consistent. Also, there is a parallel path for current during welding which can vary the weld current by a factor of two or more. Refer to the designs in Figures 2, 3, and 4. Note how the arc tube ends are "trapped" by the mount and how a broken weld can appear to be intact. These lamps may start and warm up normally, but can "open" temporarily due to vibration or thermal expansion. The lamps may or may not "drop out" depending on how long the connection is broken, but the ballast will be impulsed by this temporary break. If the lamps "drop out," they will probably start within a minute and the process starts again.

A second cause for broken welds is inadequate process control. Specifically, even with the best design, the condition of the welder electrodes, proper use of cover gas, forces and current during welding, and actual weld strength must be monitored.

We now get to the reason why this problem can be so difficult to diagnose. The lamps in Figures 2, 3, and 4 have broken welds, but appear to be perfectly normal. Thus, even if they cause ballast failures, they will have a high probability of being reused. In fact, we have documented cases of a single lamp destroying both the initial ballast and a replacement ballast before we became involved.

DIAGNOSIS OF DEFECTIVE LAMPS

The first signs of broken weld lamps will probably be flickering or flashing of the lamp as intermittent contact is made. Lamp cycling could also be a sign of broken welds. However, these symptoms can appear for other reasons, and it is not likely that the problem will be found in this manner.

The impulsing will probably cause the ballast secondary to short and the symptom here would be an open fuse or circuit breaker or failure of the lamp to start.

A visual inspection of lamps with clear outer jackets may show open connections. A technique which can be used on a suspicious lamp that appears normal is to gently tap the fixture while it is running. (Caution: do not touch the lamp while it is operating since is very hot and has a vacuum outer jacket.) If an operating lamp flickers or drops out when vibrated, it may be a sign of a broken weld (or high lamp voltage).

POTENTIAL SOLUTIONS

It would be difficult for ballast manufacturers to prevent this occurrence since such high voltage can be generated. Ballasts can typically withstand 10,000 volt impulses (5,000 to 15,000 depending on the design) and these values could be increased, but that would not necessarily help since the broken welds can easily generate 20,000 volts or more. A second approach would be to limit the impulse to an acceptable level. The difficulty here is that approximately 3,000 volt pulses are required for lamp starting and any "clipping" networks would have to take this into account.

The situation can be virtually eliminated at the source by ~~approximate~~ lamp design and attention to process control. appropriate

CONCLUSION

High voltage impulses caused by HPS lamps with broken welds can damage or destroy ballasts. This fact has not been generally recognized by the industry; and in many cases, the ultimate cause was never determined primarily because it is difficult to diagnose and the defective lamps are frequently discarded or reused.

It is hoped that this paper will raise an awareness and help in the diagnosis of this type of occurrence. This is especially important since it is not practical for ballast manufacturers to prevent these occurrences due to the very high voltages which can be generated by lamps with broken welds.

General Electric Company
Lighting Systems Department
Hendersonville, N.C. 28739

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