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A Measurement of Sound Levels Associated With the Operation of a Portable Pneumatic Pavement Breaker Equipped with a Muffler/Case Enclosure and Dampened Moils

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A MEASUREMENT OF SOUND LEVELS ASSOCIATED WITH THE OPERATION OF A PORTABLE PNEUMATIC PAVEMENT BREAKER EQUIPPED WITH A MUFFLER/CASE ENCLOSURE AND DAMPENED MOILS

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1. INTRODUCTION

In carrying out the mandate given it in the Noise Control Act of 1972 [1][1], the United States Environmental Protection Agency (EPA) has identified pavement breakers as a major noise source [2]. As a result of this identification process, EPA has the dual tasks of specifying suitable acoustic measurement methods and of studying source noise emission levels which are achievable with known or projected technology. These tasks have previously been systematically addressed in studies by Dames and Moore [3] and NBS [4].

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[1] Numbers in brackets refer to references at the end of the test.

The present study was intended to determine the effectiveness of certain commercially available and experimental noise control devices in reducing the noise levels emitted by the Swiss Industrial Gas (SIG)[1] portable pneumatic pavement breaker shown in Figure 1. The noise control devices consisted of a muffler/case enclosure (shown in Figure 2) and elastomeric moil silencing sleeves (shown in Figures 3 and 4). The muffler/case enclosure was designed to fit snugly over the pavement breaker case, totally covering the entire tool except for the back head (see Figure 5). Moil installation and removal were easily accomplished by opening an access door on the side of the muffler and releasing the moil retaining latch (see Figure 6). The moils were inserted through an opening which was contoured to match the shape of the moil shank (see Figure 7).

NBS measured the noise emission levels of the SIG pavement breaker both with and without each of the noise control devices installed. This report presents the results of those measurements. Section 2 presents a description of the test apparatus and procedure and the data reduction procedure is described in Section 3. The measurement results are presented in Section 4.

2. TEST APPARATUS AND PROCEDURE

The specifications for the test apparatus and procedures used in this study are presented in detail in Appendix A.[2] The purpose of this section

[1] Certain commercial equipment and materials are identified in this paper in order to adequately specify the experimental procedures. In no case does such identification imply recommendation or endorsement of the product by NBS nor does it imply that the equipment or materials are necessarily the best available for the purpose.

[2] The methodology in Appendix A was provided by EPA.

is to describe how those specifications were implemented and to identify any differences between the specifications contained in Appendix A and the actual tests performed.

2.1 Test Apparatus

The SIG portable pneumatic pavement breaker shown in Figure 1 was used in this study. It weighed approximately 33.5 kg (74 lbm) without any noise control devices added and was loaded with an additional mass of 31.8 kg (70 lbm) by using molded lead weights as specified in Appendix A (see Figure A1). The muffler/case enclosure shown in Figure 2 was used in some of the testing and could be easily removed to allow testing in an unmuffled configuration.

Five 3.2 cm (1 1/4 in.) diameter moils were used in these tests. Four of these moils were equipped with different types of silencing sleeves. As shown in Figures 3 and 4, three 17.8 cm (7 in.) long experimental sleeves were molded onto the moils with their metal protective cover either a) unsplit, b) split lengthwise into two equal sections, or c) split lengthwise into three equal sections. A fourth sleeve (Figure 4) was of a commercially available unsplit design and was shorter, 11.1 cm (4.38 in.), than those shown in Figure 3. This sleeve employed a pressure-fit design and was installed by using a hydraulic press requiring no epoxy to secure it because of the tight fit.

Figure 8 is a block diagram of the acoustic data acquisition system used for these tests. Each of the nine channels of the system included a commercially available 1.27 cm (1/2 in.) condenser microphone with a windscreen, protecting grid, dehumidifier, preamplifier, and

battery-operated power supply. The signal from each preamplifier served as input to a precision variable gain amplifier with a dynamic range of 60 dB, selectable in 10 dB increments. The gain settings for the amplifier were set at a level which assured at least a 20 dB signal-to-noise ratio between the pavement breaker noise emission and other ambient noise sources when the data were recorded on magnetic tape. In addition to this system, a Type I sound level meter was also used to monitor the levels measured during the test by Microphone 6 (arbitrarily chosen).

Prior to initiation of the noise measurements, a frequency sweep of each microphone channel (voltage injection at the preamplifier through the tape recorder) was made in the laboratory. A sample result of these sweeps is shown in Figure 9. It can be seen that the system response was flat to within less than 2 dB over the frequency range of 20 Hz to 20 kHz.

One track of the tape recorder was configured for digital recording. The input to this track came from a control module with output coding to identify run number, time of day, amplifier gain settings, calibration indicator, pavement breaker configuration, and start of data. This digital information was used to allow automated computation of the A-weighted, linear, and one-third octave band levels during data reduction.

A block diagram of the data reduction system used for this study is shown in Figure 10. The analog signal served as input to a real time spectrum analyzer which provided (slow-response) A-weighted, flat, and one-third octave band levels. These levels were read every second by the

computer, written on a mass storage disc, and later converted to printed output. The entire data acquisition and reduction system was designed to simulate the performance of Type I sound level meters designated in American National Standard, ANSI S1.1 1971 [5]. Constant bandwidth (12.5 Hz) analyses were also performed on selected test runs by using a 400 line spectrum analyzer (not shown in Figure 10).

2.2 Procedure

The eight acoustic tests shown in Table I were conducted at Ft. Belvoir, Virginia, during the week of September 3, 1978, in accordance with the specification in the Appendix A. (The specification in Appendix A was not developed by NBS). Figure 11 is a plan view of the test arrangement. The concrete test blocks were placed in a hole cut in an existing concrete pad and were made flush with the pad surface.

Nine microphone positions were utilized. Positions 1-4 were 1 m $\pm$ .1 m from the pavement breaker case at a height of 1.5 m $\pm$ .01 m above the concrete test surface. Microphone positions 5-8 were 7 m $\pm$ .1 m from the pavement breaker case and were also at a height of 1.5 m $\pm$ .01 m. Position 9 was 0.25 m $\pm$ .1 m from the breaker casing at a height of 1.5 m $\pm$ .01 m. This last position was used to measure the noise levels at the operator's position.

Initially Position 9 was along the line through Positions 3 and 7; however, during the course of the first two tests, it was observed that this location was so close to the operator that he bumped into the microphone while operating the pavement breaker. Therefore, for subsequent tests, Position 9

was moved in front of the operator. In both cases, it was difficult to place the operator's microphone so that the microphone stand was not resting on one of the test blocks. This is a problem since structural vibrations can easily be introduced into the acoustic signal. Budgetary and time constraints did not allow a more suitable microphone support to be constructed. In future testing, however, specially designed microphone supports may be necessary in order to make acoustic measurements in such close proximity to the operator. Because of this potential problem, caution should be used in drawing conclusions from the Position 9 data shown in Table II.

The noise measurements were made after positioning the pavement breaker (moil embedded to the taper as shown in Figure 12) on the concrete block and positioning the microphones at the appropriate locations. The tape recorder was started ten seconds prior to the commencement of the tool operation. When the breaker began operation, a data ready switch was activated, the digital track was encoded to indicate that the breaker was in operation, and the sound pressure at all nine microphone positions was measured simultaneously. The operator continued breaking concrete for approximately thirty seconds at which time the digital track was encoded to indicate that the pavement breaker operation had ceased. The pavement breaker was then moved to a different location on the test block and the 1-meter and operator microphones were repositioned for a new set of noise measurements. Because all the pavement breaker operations were within 0.3 m of the center of the test block, the 7-meter microphones were not repositioned. This change in pavement breaker position was calculated to affect the direct radiation to the 7-meter microphones by less than 0.5 dB. The same procedure was used for all the tests shown in Table I. Time and budget constraints only permitted one test of each condition.

During the testing it was observed that the moil release access door on the muffler/case enclosure was acting as the exhaust outlet and tended to flap with the exhaust pulses. To determine whether this action made a significant contribution to the measured noise levels, the access door was taped closed and tests numbered seven and eight were performed. The results of these tests are given in Section 4.

3. DATA REDUCTION

The system described in Section 2.1 was used to determine the mean A-weighted and one-third octave band levels and the maximum A-weighted level measured at each microphone position for each test shown in Table I. Initially these values were computed from the data acquired during the entire thirty seconds of pavement operation. This procedure resulted in differences of up to 9 dB between the mean and maximum A-weighted levels. By listening to the data tapes, reviewing test notes, and examining the A-weighted time history, it became apparent (see Figure 13) that unusually high sound levels were sometimes measured at the beginning of the test runs. These high levels were attributed to initially high line pressure and pavement breaker-operator instability when the breaker was first turned on. Although both of these effects may be typical of pavement breaker operation, they are very difficult to control. It was also noted that the levels had usually stabilized to within ±1 dB of a constant value about ten seconds into the test run. Thus, it was decided to compute the mean and maximum A-weighted levels from the second ten seconds of data for each run. These values are recorded in Table II and will be discussed more fully in Section 4.

Mean one-third octave band spectra were obtained by sampling the output of each digital one-third octave band filter once every second and computing a linear average over the entire thirty second run. In order to simulate a slow meter response, the filter output was exponentially averaged, with a one-half second time constant, prior to sampling every second. (These spectra have been submitted to EPA with, but are not included in, this report.)

Constant bandwidth (12.5 Hz) analyses were also performed over the range 0-5 kHz on selected data (Tests 1-4, 7, 8) measured at Position 6. The resultant spectra (Figures 14 through 19) were obtained by averaging 32 spectra from the middle portion of the record. These spectra are discussed more fully in Section 4.

4. RESULTS

4.1 Mean and Maximum A-weighted Levels

The mean and maximum slow response, A-weighted sound pressure levels measured at each microphone position are shown in Table II for each test configuration listed in Table I. These data show that the mean and maximum levels measured at each position differ by no more than 2 dB in all (99 percent) but one case, where a 3 dB difference was observed. Moreover, in 43 percent of the measurements the maximum and mean levels were found to be equal (when rounded to the nearest decibel) and in 44 percent of the measurements the difference was only 1 dB. Table III shows the mean and standard deviation of the 1-meter and 7-meter levels for each test as computed from the data in Table II.

important to recognize that caution must be used to reach generalized conclusions from the data in Tables II and III. Test variables such as mounting of the test block, ground vibrations, initial moil depth, and moil penetration rate may vary enough to cause significant variability in the measured sound levels if a number of replications of each condition are evaluated. Although there are very little data in the literature, one study [3] found the standard deviation of the sound levels measured from repeated tests of six identical (same model) pneumatic pavement breakers to be ± 1.8 dB at a distance of seven meters. With this limitation in mind, the data in Tables II and III seem to imply that the muffler/case enclosure provides about an 8 dB reduction in the measured sound levels (compare the levels from Tests 1 and 3 in Table III). The muffler/case enclosure also reduced the directionality of the pavement breaker noise. This can be seen by again looking at the levels measured for Tests 1 and 3 shown in Table II. The Test 1 data (no case muffler or silencing sleeve) show up to 7 dB variation from position-to-position for the 1-meter levels (9 dB for the 7-meter levels). By comparison, the Test 3 data (case muffler used but no silencing sleeve) show only a 2dB variation among the measurement positions for both the 1-meter and 7-meter measurements.

Each of Tests 2 and 4 was conducted using the moil with the three-section silencing sleeve and, in the case of Test 4, the muffler/case enclosure was also installed. A comparison of the mean sound levels (Table III) for Tests 1 and 2 shows no change in the 1-meter and 7-meter A-weighted levels when the silencing sleeve is used. Also, when the Test 3 and 8 (muffler and no sleeve) data are compared with the data from Tests 4-7 (muffler and each of four sleeves) a maximum difference of only 1 dB is observed at 1-meter and 2 dB at 7-meters. Considering the 7-meter standard deviation of ± 1.8 dB reported by Dames and

Moore [3] when repeatability measurements were made, the levels measured both with and without the silencing sleeves in this study seem about the same.

The data in Table III can be used to evaluate the difference in sound levels measured at 1-meter and 7-meters from the pavement breaker. By using small sample statistical analysis (t-statistics) it is possible to show with 99 percent certainty that, on the average, the 1-meter levels are 11 dB greater than the 7-meter levels. Previous testing [4] had shown a 15 dB difference between the A-weighted levels at 1-meter and 7-meters.

4.2 Constant Bandwidth Spectra

In order to gain a better understanding of the effectiveness of the noise control devices, constant bandwidth spectrum analyses were performed on selected test measurements made at one position (Position 6) seven meters from the pavement breaker. Two such spectra, shown in Figure 14, illustrate the levels measured with and without the muffler/case enclosure in use (Tests 2 and 1, respectively). These spectra show that the muffler/case enclosure has little effect on the sound levels below 500 Hz but becomes increasingly more effective at higher frequencies. Two distinct spectrum peaks are observable at about 3,550 Hz and 4,350 Hz under both conditions. It may also be observed that the spectrum shapes above about 2000 Hz are nearly alike, but the levels are reduced by 6 dB to 11 dB, depending on the frequency. Some variation in these level differences should be expected from position to position since the data in Table II show much more source directionality when the case muffler was not used then when it was used.

Constant bandwidth spectra were obtained for tests with and without the three-section moil silencing sleeve. Figure 15 displays the results obtained from Tests 3 and 4. The two curves clearly show an elimination of the spectrum peaks at 3,550 Hz and 4,350 Hz; however, the spectrum levels have increased at nearly all frequencies above 1 kHz. This same phenomenon was observed in an earlier study by Hosier and Blomquist [4] but the mechanism causing it is not understood.

It would appear from the spectra in Figure 15 that use of the three-section moil sleeve eliminated the high-frequency peaks that were observed without the sleeve. However, the data in Figure 16 make it impossible to conclude that the peaks are eliminated solely by using the three-section moil sleeve. That figure shows spectra measured at seven meters (Position 6) with no case muffler and with and without the three-section moil sleeve (Tests 2 and 1, respectively). Both of these spectra clearly show the spectrum peak at 4,350 Hz. The peak at 3,550 Hz is also visible in both spectra, although it is reduced in amplitude when the moil sleeve is used. Thus, it is not conclusive that the two high-frequency spectrum peaks can be associated with the pavement breaker moil, or their elimination with the three-section moil sleeve.

During the course of the testing it was observed that the moil latch access door on the case muffler (see Figure 6) was flapping with the exhaust pulses. This flapping was eliminated by tightly taping the access door shut. Additional noise measurements were then made with and without the two-section moil sleeve (Tests 7 and 8, respectively). Figure 17 presents a comparison of the spectra from Tests 7 and 8 with those of Test 4 (access door untaped and the three-section moil sleeve in use). The spectra show a clear but small

reduction in the noise levels in the mid-frequency range (1,500 Hz to 3,500 Hz). The two high-frequency peaks are again observable in both the Test 7 and Test 8 spectra. In the Test 7 spectrum, however, the 3,550 Hz peak has shifted to a slightly lower frequency (about 3,450 Hz) and has been broadened. The peak remained at 4,350 Hz in both spectra, although the amplitude was reduced about 4 dB for Test 7. There is also evidence of the same trend noted in conjunction with Figure 15: that is, an increase in levels over much of the spectrum when the moil sleeve is used.

One further observation can be made about Tests 7 and 8. When the moil access door was taped shut, a large amount of dust was blown from the test pad by the breaker exhausting mainly through the moil opening in the case muffler (see Figure 7). This was not observed when the access door was untaped.

4.3 Importance of Crest Factor Capability

As was mentioned in Section 2.1, a Type I sound level meter was used to measure the levels at Position 6 during the day of testing. When compared with the values shown in Table II, the sound level meter readings were generally found to be lower by 2 dB or more. It was reasoned that the differences between the two sets of data were either due to differences in the averaging period (the entire test run for the on-site measurements versus ten seconds from the middle of the run for the computer output shown in Table II) or to the crest factor[1] handling capabilities of the two systems.

[1] The crest factor of a signal F_c is defined by the relationship $F_c = \frac{A_{peak}}{A_{rms}}$, where A_{peak} and A_{rms} are the peak and root-mean-square amplitudes of the signal. The largest value of F_c for which a device such as a sound level meter can accurately measure the signal defines the crest factor handling capability.

To resolve this issue, a controlled experiment was conducted in which two Type I sound level meters without microphones and with different crest factor handling capabilities were used to measure the average (by "eye") sound level recorded at Position 6 over the central ten seconds of each test run as the data were played back. One sound level meter (Meter A) was the same kind that was used to make the on-site measurements. It has the capability to accurately measure the rms value of signals with crest factors less than 5 to within + 1 dB. The second sound level meter (meter B) could accurately measure the rms value of signals with crest factors less than 10 to within + 0.5 dB. The rms detector in the real time analyzer, used to obtain the computer values, could measure the rms value of signals with crest factors less than 21 in the signal range used in this test (accuracy is unspecified by the manufacturer).

The data from this experiment are shown in Table IV. A two-way analysis of variance (AOV) was performed on these data to test the following hypothesis:

> At the 0.05 level of significance there is no statistically significant difference among the three methods (Meter A, Meter B, and the Computer Average) of measuring the sound levels in these tests.

The two-way AOV was used in order to remove the test-to-test variability due to the different tool configurations found in each test. For the hypothesis to be accepted requires the F-statistic must be less than F = 3.74. After carrying out the necessary computations, it was found that the meter-to-meter variation yielded F = 16.78, a value well beyond the region of acceptance. Thus, the hypothesis was rejected; that is, at

the 0.05 level there is a statistically significant difference among the three methods.

In order to identify the magnitude of the differences, post hoc contrasts were made among each of the methods. These contrasts consisted of comparing the 95 percent confidence intervals about the difference of the mean values of each set (column in Table IV) of meter readings. The results of the post hoc testing were:

Comparison	95 Percent Confidence Interval, dB
1. Meter A - Computer	-0.94 ± 0.35
2. Meter B - Computer	-0.31 ± 0.35
3. Meter A - Meter B	-0.63 ± 0.35

From these contrasts it is clear that the confidence interval includes zero only for Comparison 2. Thus, there is no statistically significant difference between the Meter B and Computer Average Levels. There is, however, a statistically significant difference between the Meter A and Computer Average Levels. Thus, if the Computer Average is assumed to yield the "correct" levels, then Meter B (crest factor <10) could be expected to provide equivalent results, but Meter A (crest factor <5) could be expected to provide a significantly different level (in this case about 0.9 dB $\pm$ 0.3 dB lower).

A word of caution is necessary here. The $\pm$ 0.3 dB confidence interval applies only to the variability associated with a comparison of the different meter types. It should not be interpreted to be a repeatability interval associated with pavement breaker sound measurement replications.

5. CONCLUDING REMARKS

Measurements have been made of the sound emission from a portable pneumatic pavement breaker equipped both with and without noise control devices such as a muffler/case enclosure and a variety of elastomeric moil silencing sleeves. The test results, in the form of mean and maximum A-weighted sound pressure levels and constant bandwidth spectra, have shown that:

- The muffler/case enclosure reduces the directionality of the noise emission and provides an 8 dB reduction in the measured A-weighted levels.

- The results of tests to assess the benefit of the moil silencing sleeves were inconclusive.

- The 1-meter and 7-meter A-weighted measurements differed from one another by about 11 dB. This is 4 dB less than had been observed in previous measurements.

In addition, two important conclusions were reached concerning the test procedure and instrumentation:

- By allowing ten seconds for the pavement breaker operation to stabilize, the difference between the maximum and mean A-weighted levels measured at each position was found to be no greater than 2 dB in 99 percent of the measurements.

- There is a statistically significant difference between the levels measured with a sound level meter with a crest factor handling capability of 10 or greater (Meter A) versus one with a crest factor handling capability of no more than 5 (Meter B). At the 95 percent confidence level, the Meter B levels were found to be 0.63 dB ± 0.35 dB lower than the Meter A levels. Thus, in order to improve the test accuracy, the use of sound level meters with a crest factor handling capability of 10 or greater seems to be necessary when measuring pavement breaker noise.

5. REFERENCES

1. Public Law 92-574, Noise Control Act.

2. 42 Federal Register 6722 (3 February 1977).

3. Anon.: Technology Analysis - Noise Pavement Breaker and Rock Drill. (Vol. 1), Draft final report to EPA under contract no. 68-01-3288-phase I, Dames and Moore, Cranford, NJ, October 1977.

4. Hosier, Robert N., and Blomquist, Donald S.: A Test of Portable Pavement Breaker Sound Level Measurement Methodology. NBS Final Letter Report submitted to EPA under Interagency Agreement EPA-IAG-D7-H1087, March 1978.

5. American National Standards Institute, Inc., Specification for Sound Level Meters. ANSI S1.4-1971, April 1971.

TABLE I. - SUMMARY OF TEST CONDITIONS

Tool	Test	Dry Bulb Temp., °C	Wet Bulb Temp., °C	Relative Humidity, %	Baro. Pressure, mb	Line Pressure, psig	Flow Rate scfm*	Configuration
Swiss Industrial Gas	1	31.2	20.2	54	1002	109	120	No case muffler or moil sleeve
	2	-	-	-	-	105	114	No muffler 3 section Soundcoat sleeve
	3	-	-	-	-	108	120	Case muffler, no moil sleeve
	4	-	-	-	-	108	120	Case muffler and 3 section Soundcoat sleeve
	5	-	-	-	-	109	125	Case muffler and unsplit Soundcoat sle
	6	-	-	-	-	108	120	Case muffler and Thor sleeve
	7	-	-	-	-	109	120	Case muffler with moil access taped ar 2 section moil sleeve
	8	29.8	21.8	64	-	106	119	Case muffler with moil access taped and no moil sleeve

*Not corrected for temperature

TABLE II. - SUMMARY OF MEASURED A-WEIGHTED LEVELS, dB re 20μPa

Microphone Position	Descriptor	Test Number 1	2	3	4	5	6	7	8	Ambient
1	Avg.[1]	107	105	97	97	96	96	96	95	54
	Max.[2]	107	106	97	98	96	97	96	95	
2	Avg.	105	104	96	97	94	97	96	95	56
	Max.	105	104	97	98	94	97	97	95	
3	Avg.	100	101	95	95	94	93	96	95	57
	Max.	100	103	96	96	94	94	96	95	
4	Avg.	105	105	96	96	97	94	95	94	57
	Max.	106	107	97	97	97	95	96	94	
5	Avg.	97	97	87	87	86	86	83	83	56
	Max.	98	97	88	87	87	86	84	84	
6	Avg.	93	92	85	88	85	85	84	84	56
	Max.	93	92	86	88	86	86	85	85	
7	Avg.	88	89	83	84	82	83	83	85	54
	Max.	88	91	84	84	82	83	83	85	
8	Avg.	95	95	85	85	84	82	82	84	58
	Max.	96	98	86	86	85	82	84	85	
9	Avg.	101	102	99	101	98	99	99	97	57
	Max.	101	104	100	102	98	100	99	97	

[1] Mean value of levels measured once per second in the interval including seconds 11 through 20 of the tape recorded data.

[2] Maximum level measured in the interval including seconds 11 through 20 of the tape recorded data.

TABLE III. - MEAN A-WEIGHTED LEVELS AND STANDARD DEVIATIONS

Location	Test Number 1	2	3	4	5	6	7	8
1-meter	104±3	104±2	96±1	96±1	95±2	95±2	96±1	95±1
7-meters	93±4	93±4	85±2	86±2	84±2	84±2	83±1	84±1
Difference	11	11	11	10	11	11	13	11

TABLE IV. - COMPARISON OF A-WEIGHTED LEVELS, dB (re 20μPa) FROM SYSTEMS WITH DIFFERENT CREST FACTOR HANDLING CAPABILITIES (Measured at Position 6)

Test Number	Sound Level Meter: A Crest factor Capability <5	Sound Level Meter: B Crest factor Capability <10	Computer Average From Table II
1	92	93	93
2	91	91.5	92
3	84.5	84.5	85
4	86	87.5	88
5	84.5	84.5	85
6	84.5	84.5	85
7	83	84	84
8	83	84	84

Figure 1. - Photograph of test arrangement and portable pneumatic pavement breaker without noise control devices.

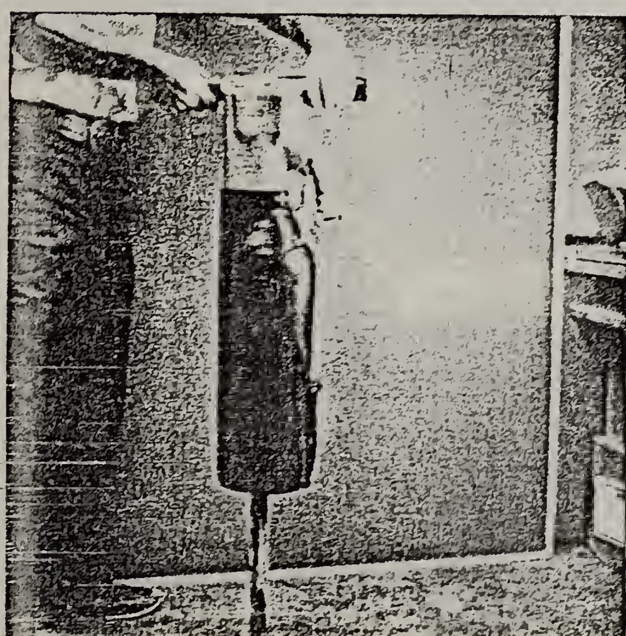


Figure 2. - Photograph of a test pavement breaker with SIG case muffler.

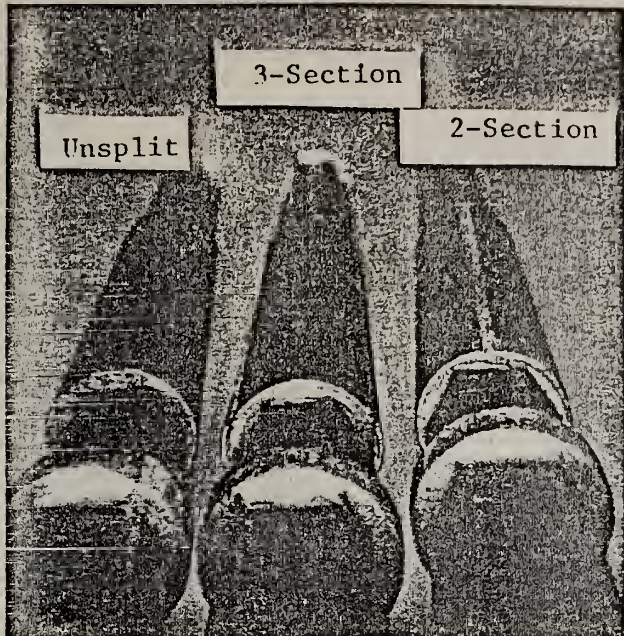


Figure 3. - End-view photograph of the three specially-made, molded, elastomeric moil silencing sleeves used in Tests 2, 4, 5, 7, and 8 (see Table I).

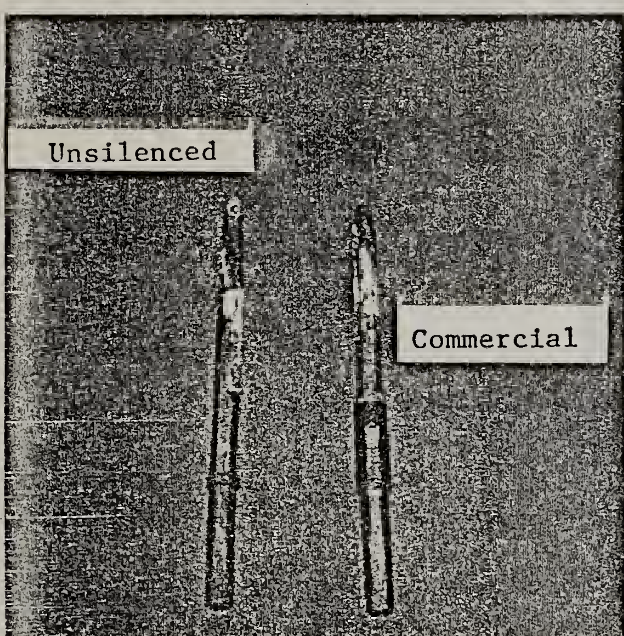


Figure 4. - Photograph of unsilenced moil used in Tests 1, 3, and 8 (see Table I) and the commercially available moil silencing sleeve used in Test 6.

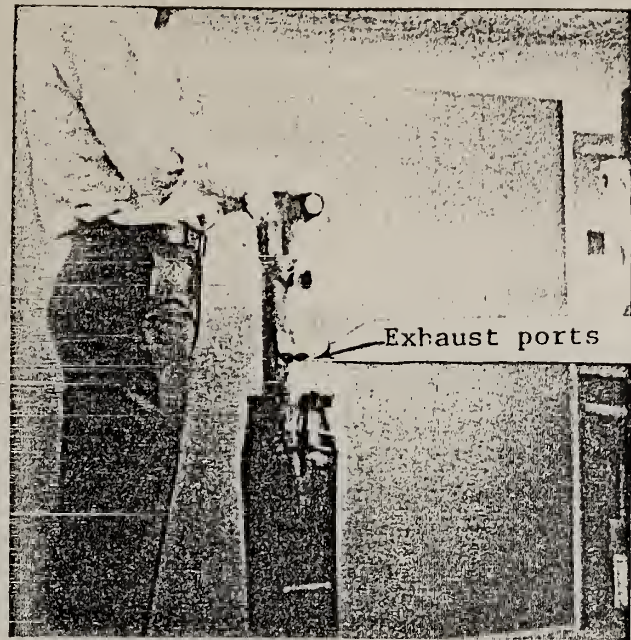


Figure 5. - Photograph of pavement breaker with case muffler lowered to reveal the exhaust ports.

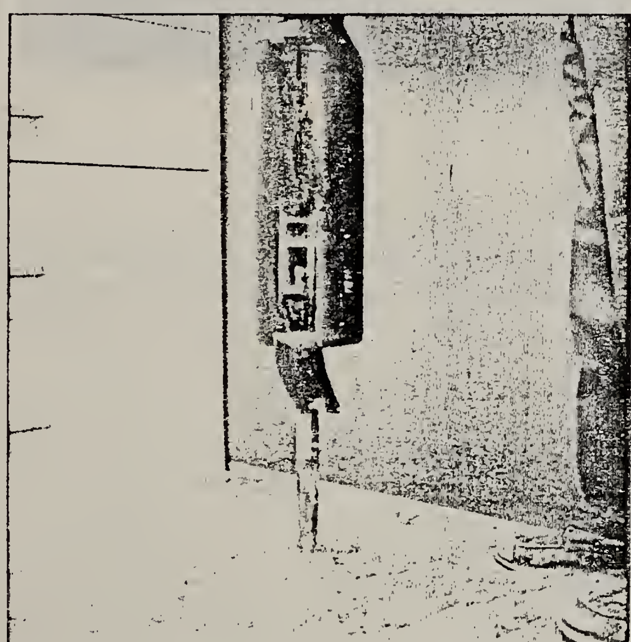


Figure 6. - Photograph of the case muffler with the moil latch access door opened.

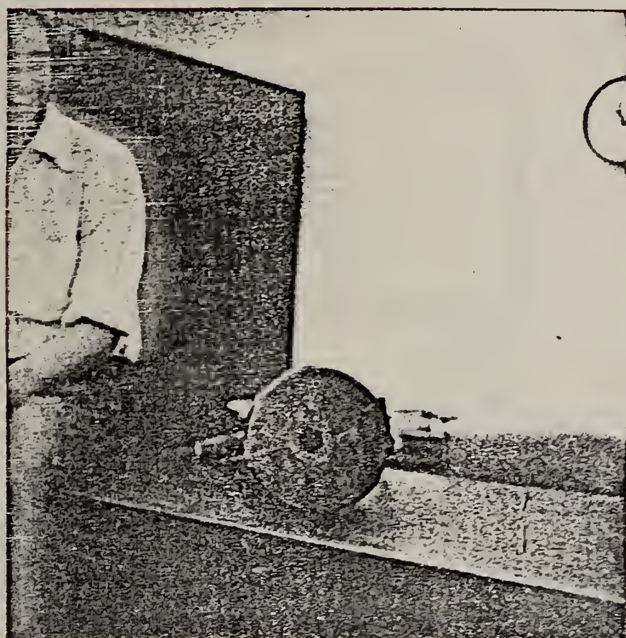


Figure 7. - Photograph of contoured opening in the base of the case muffler for inserting the moil shank.

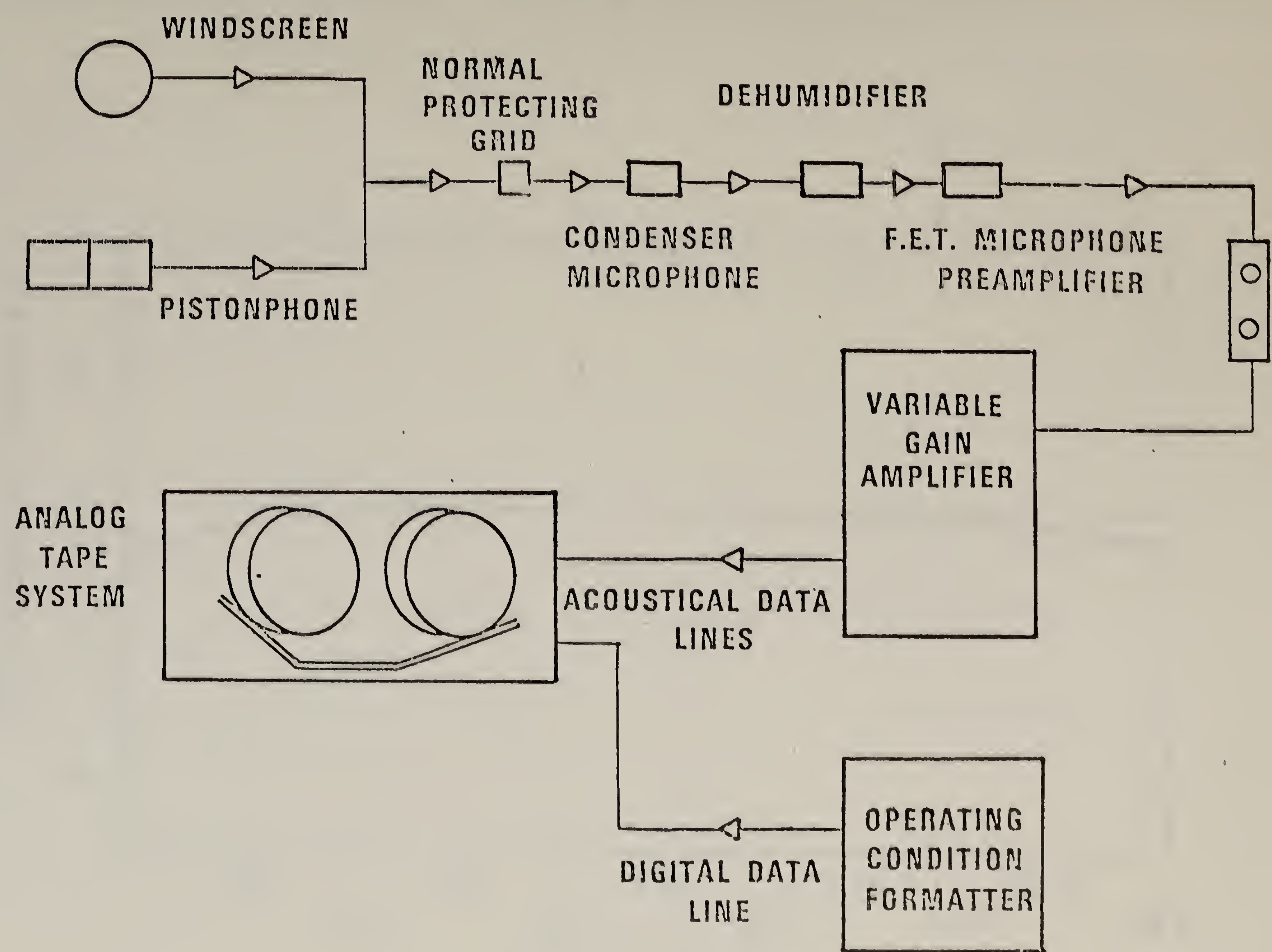


Figure 8. - Block diagram of acoustic data acquisition system.

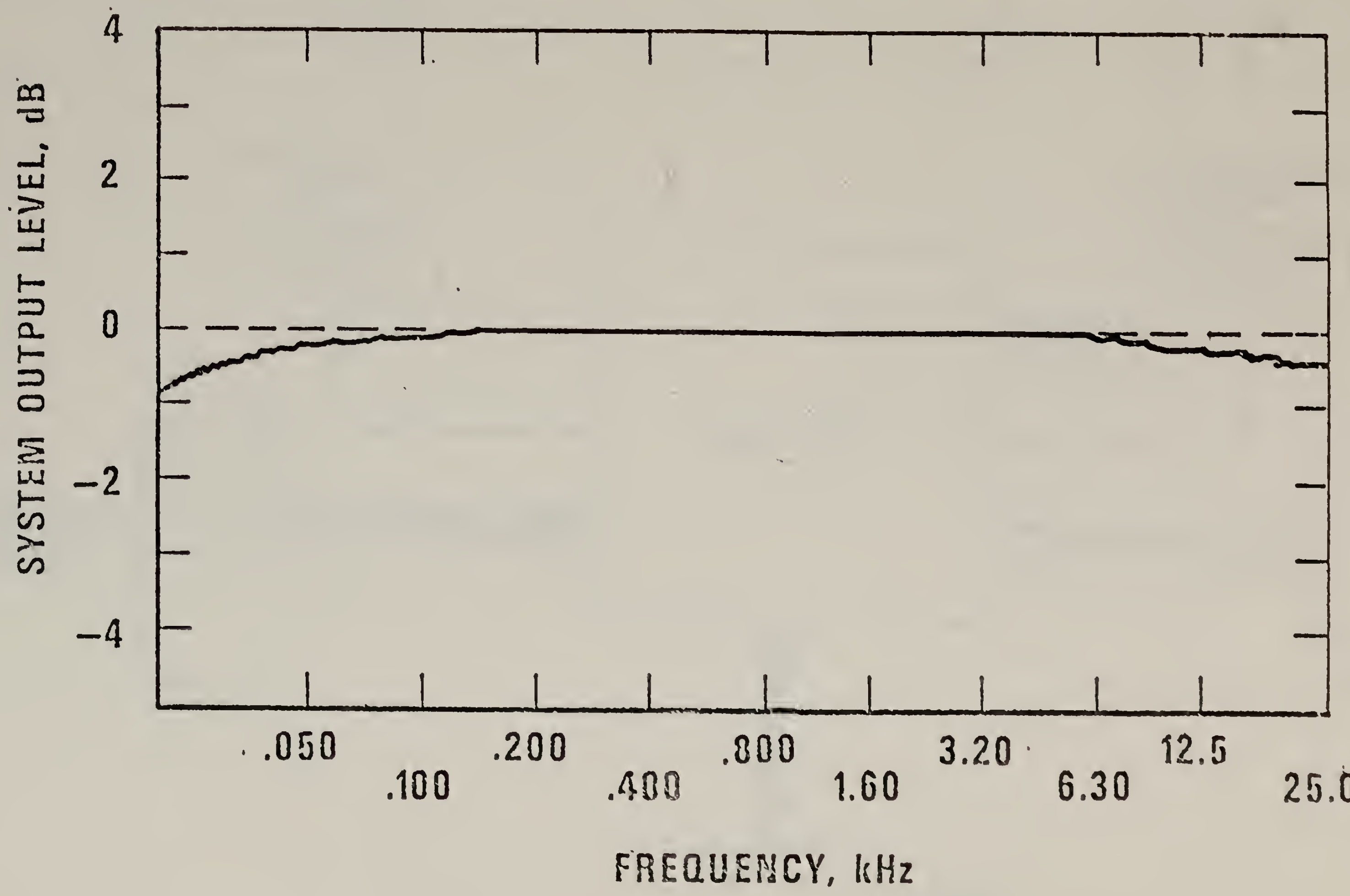


Figure 9. - Sample acoustic system response curve.

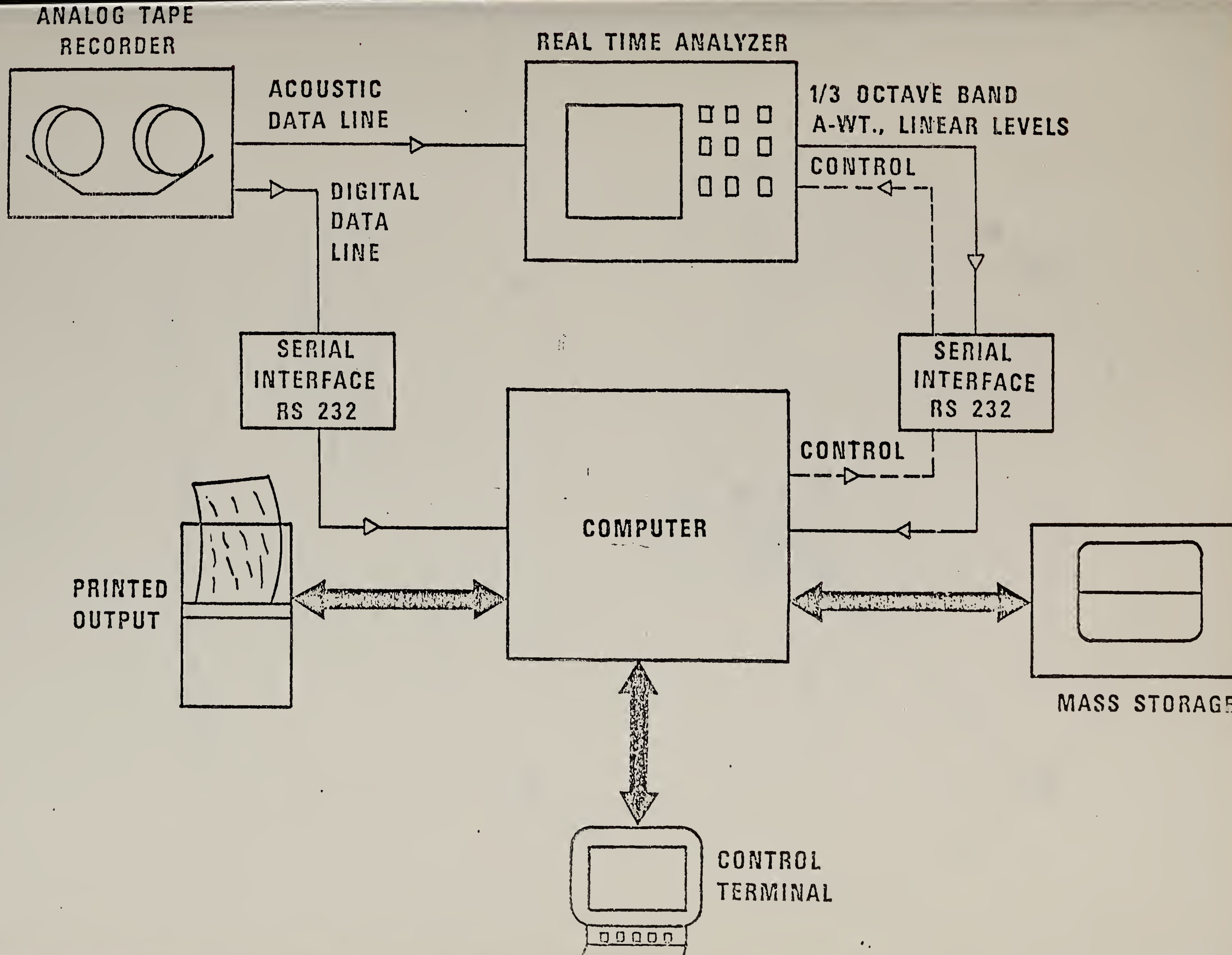
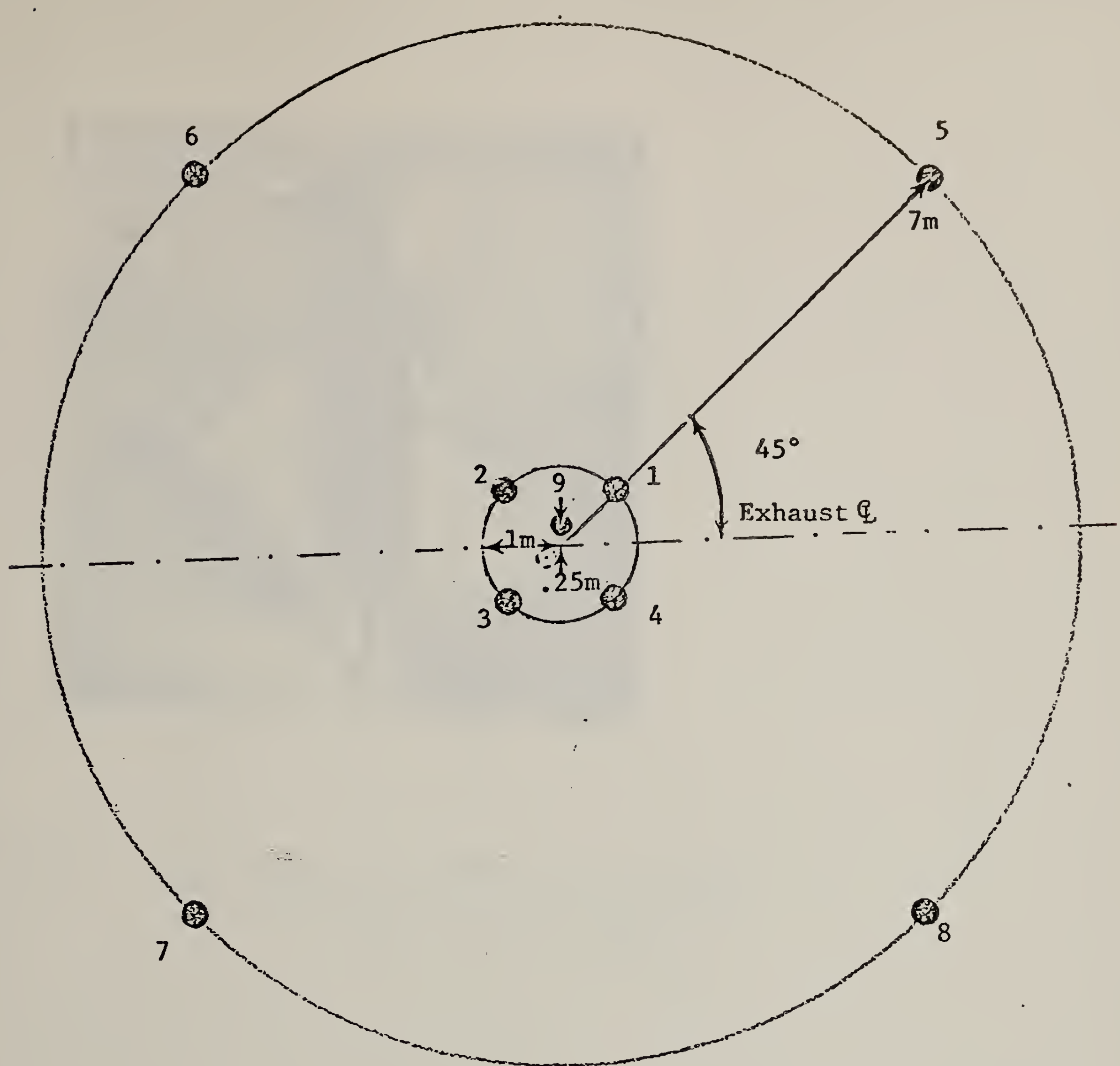


Figure 10. - Block diagram of the acoustic data reduction system.



- Microphone positions

- Position 9 for Tests 1 and 2 only

Figure 11. - Plan view of test arrangement

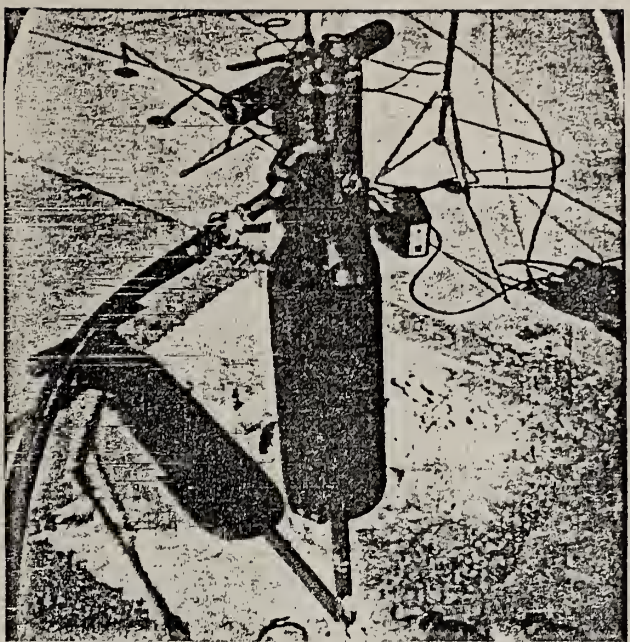


Figure 12. - Photograph of pavement breaker, with moil imbedded to the taper, prior to test run (weights not in place).

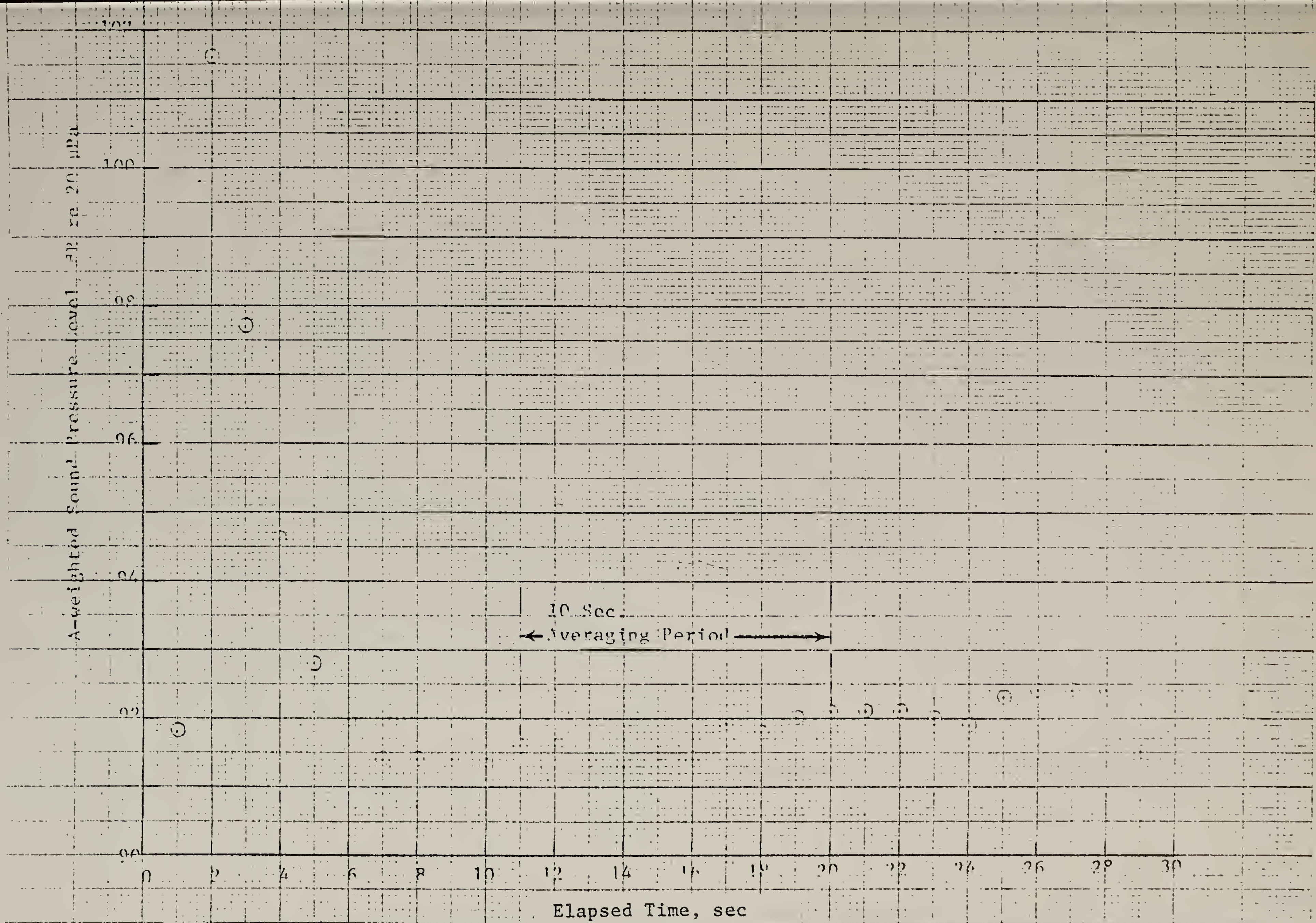


Figure 13. - A-weighted sound level time history measured at 7 meters (Position 6) for Test 2.

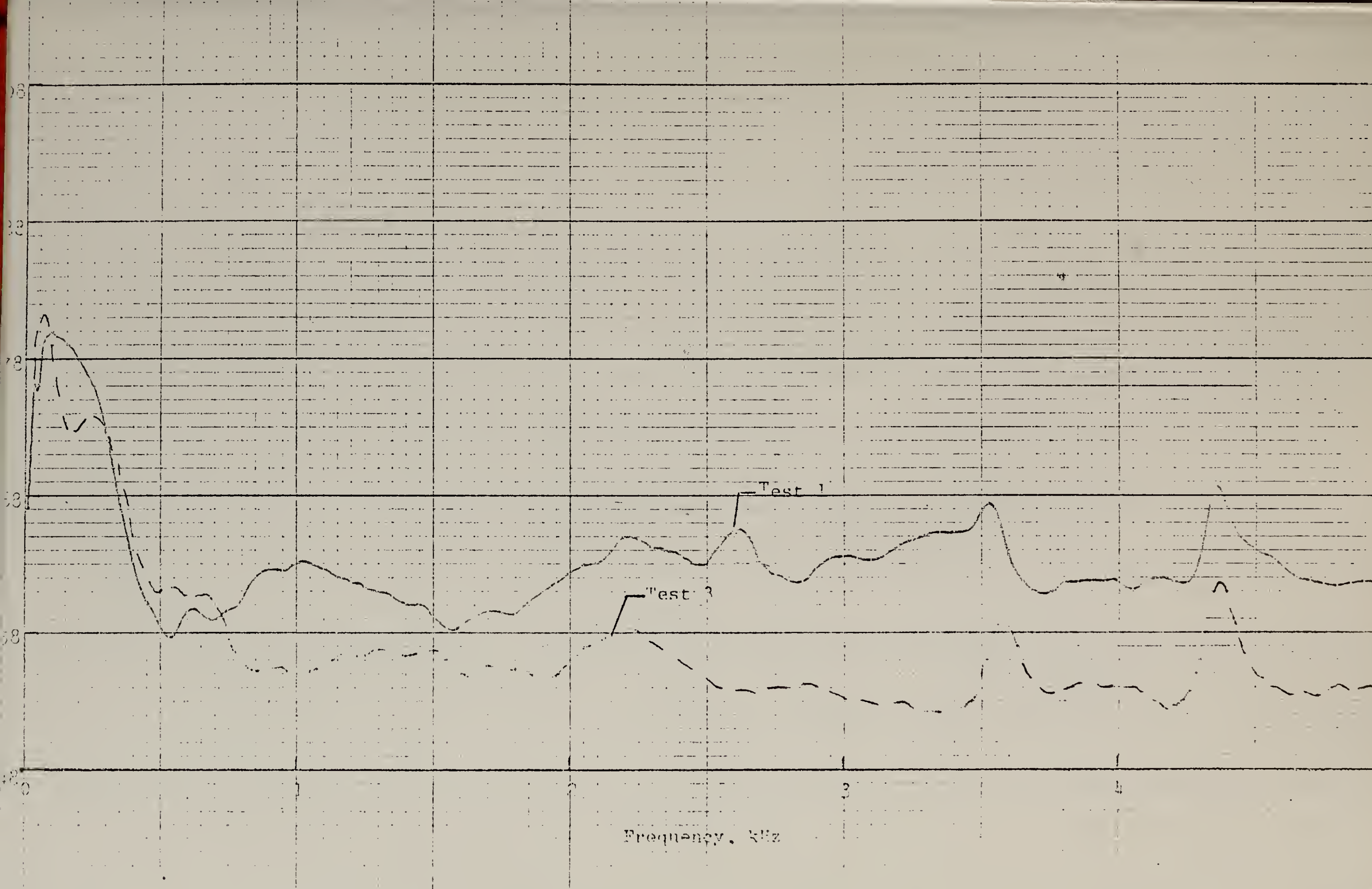


Figure 14. - Comparison of spectra measured at 7 meters (Position 6) for Test 1 (no case muffler and no moil sleeve) and Test 3 (case muffler but no moil sleeve).

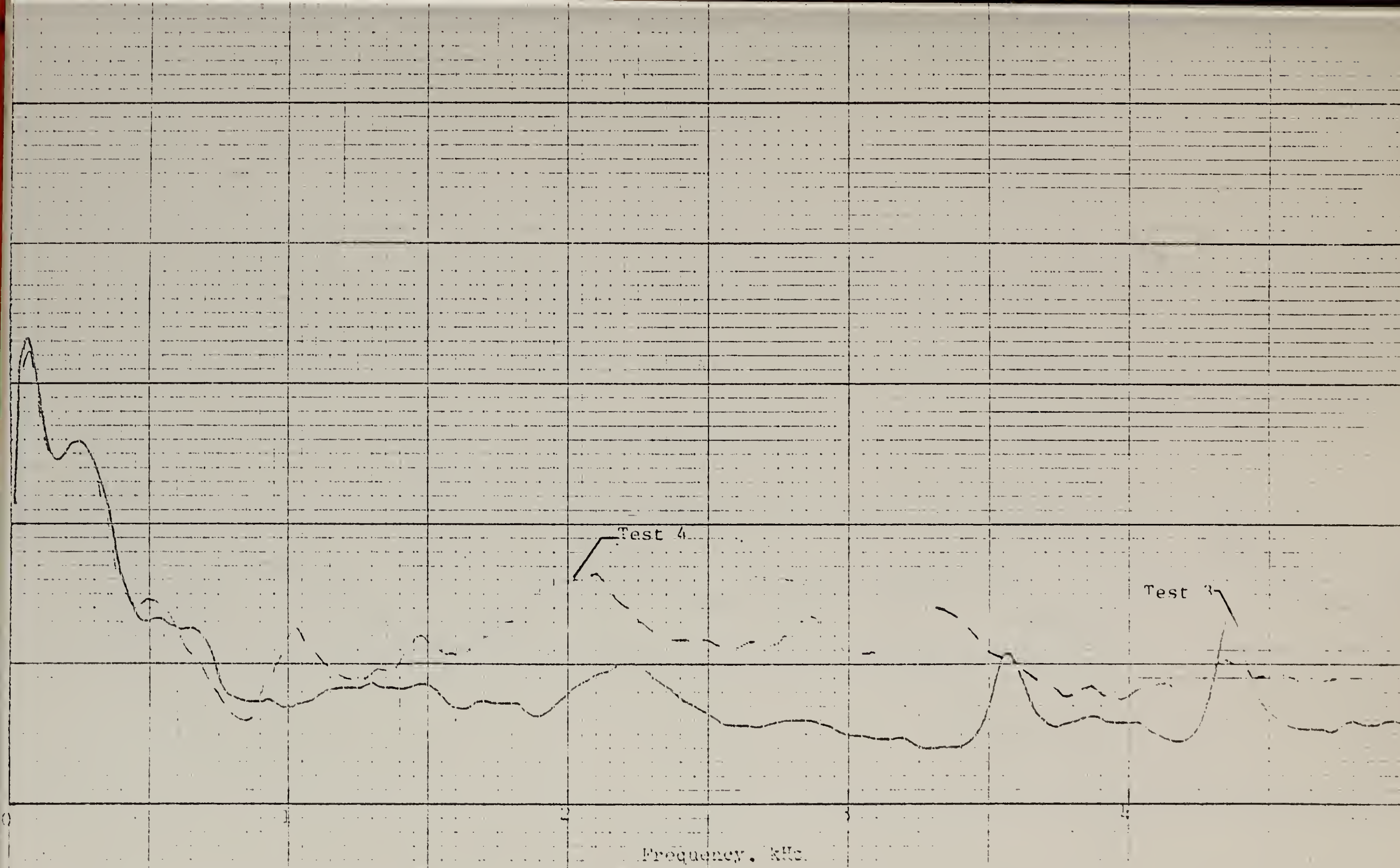


Figure 15. - Comparison of spectra measured at 7 meters (Position 6) for Test 3 (case muffler but no moil sleeve) and Test 4 (case muffler and 3-section moil sleeve).

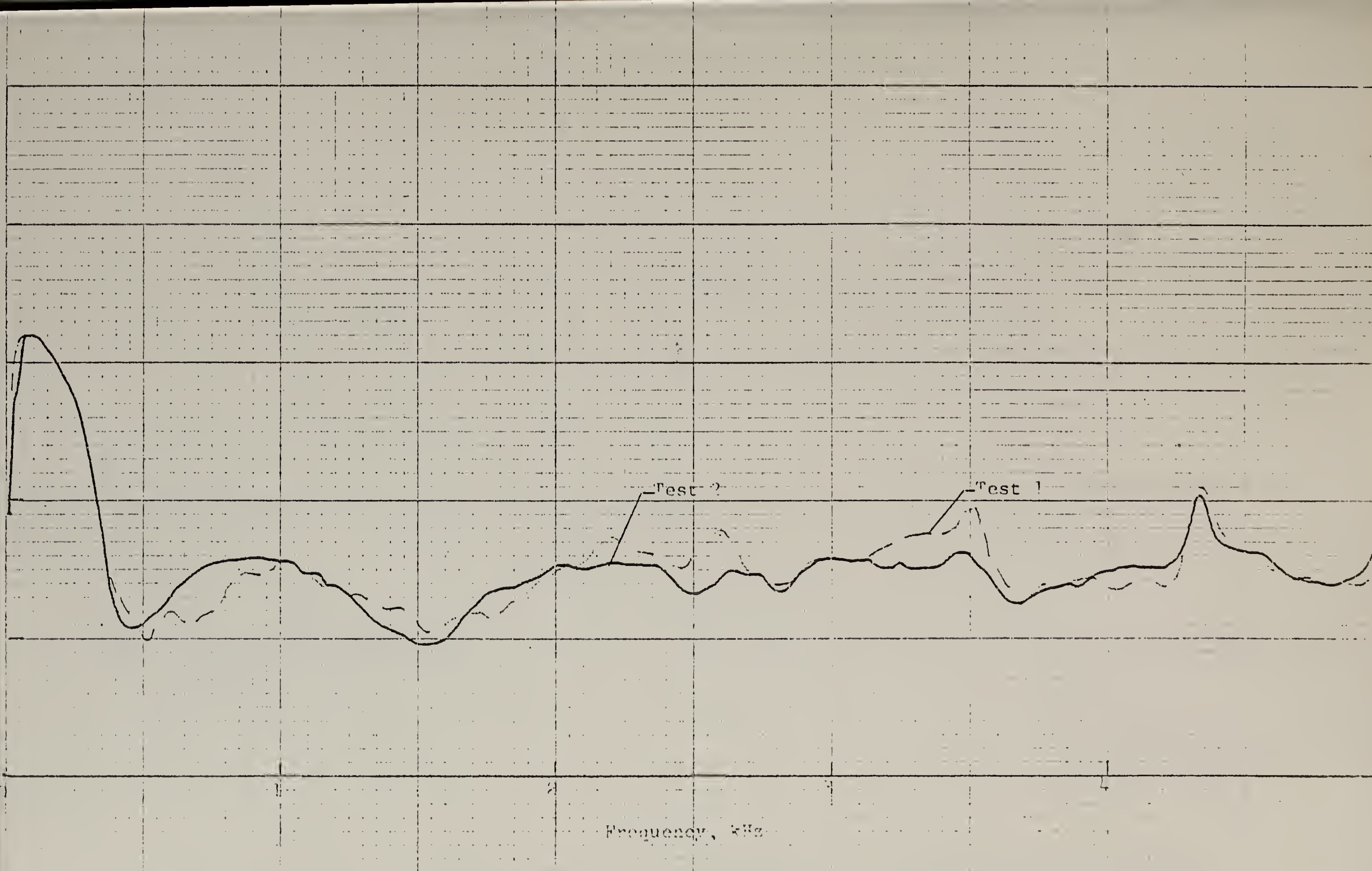


Figure 16. Comparison of spectra measured at 7 meters (Position 6) for Test 1 (no case muffler and no moil sleeve) and Test 2 (no case muffler and 3-section moil sleeve).

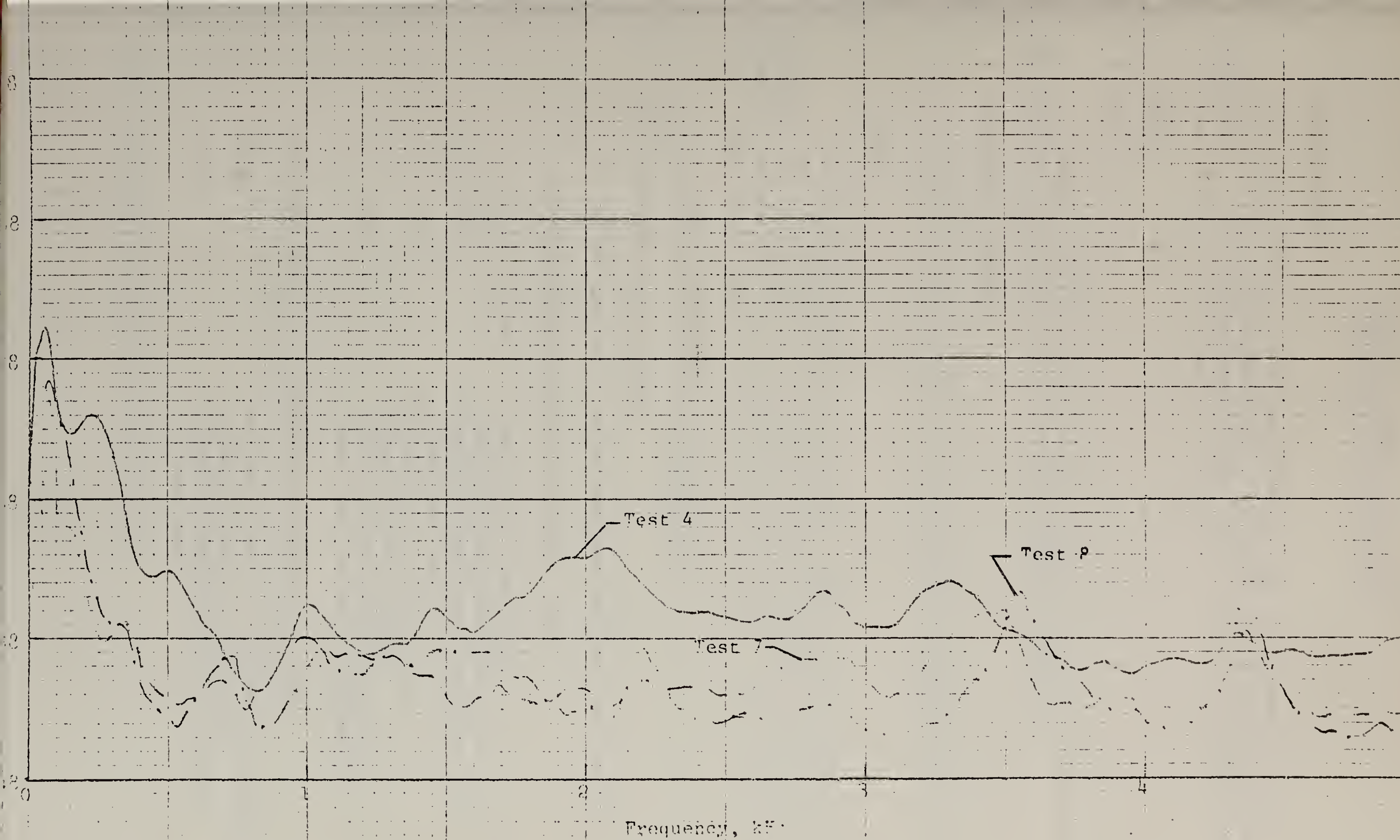


Figure 17 - Comparison of spectra measured at 7 meters for Test 4 (case muffler and 3-section moil sleeve), Test 7 (case muffler with latch access door taped shut and 2-section moil sleeve), and Test 8 (case muffler with moil access door taped shut and no moil sleeve).

PAVEMENT BREAKER SOUND LEVEL MEASUREMENT METHODOLOGY[1]

1.0 INTRODUCTION

The purpose of this measurement methodology is to provide a test procedure for the accurate measurement and reporting of pavement breaker sound levels. The reported sound levels result from the A-weighted network filtering of the emitted acoustic pressure.

2.0 SCOPE

2.1 Tools

The procedures described herein apply to the acquisition and reporting of sound level data of portable pavement breakers.

2.2 Sound Level Reported

The sound level reported is the A-weighted network filtering of acoustic pressure in decibels (dB) referenced to 20 micropascals.

2.3 Accuracy

The limiting elements of this test procedure are assumed to be the component sum of the inherent instrumentation error, the inherent error in observing and transcribing the sound level meter readings, and others which limit the accuracy of this test procedure to $\pm$ 2 dB. (This tolerance is the target which may be corrected after further study.)

3.0 SPECIFICATIONS, STANDARDS, AND TERMINOLOGY

3.1 Specifications and Standards

The following specifications and standards are referenced:

American National Standards Institute (ANSI)

S1.1-1960 (R1971)	"Acoustical Terminology"
S1.4-1971	"Specifications for Sound Level Meters"
S1.8-1969	"Preferred Reference Quantities for Acoustical Levels"
S1.13-1971	"Methods for the Measurement of Sound Pressure Levels"
S5.1-1971	"Test Code for the Measurement of Sound from Pneumatic Equipment"

American Society for Testing and Materials (ASTM)

C39	"Method of Test of Compressive Strength of Molded Concrete Cylinders"
C94	"Standards Specifications for Ready Mix Concrete"

[1] This methodology was not developed by NBS

International Electrotechnical Commission (IEC)

179-1965	"Precision Sound Level Meters"

Society of Automotive Engineers (SAE)

J-184	"Qualifying a Sound Data Acquisition System"

3.2 Terminology

Definitions and terminology used shall be consistent with ANSI S1.1-1960 (R1971).

4.0 INSTRUMENTATION

The sound level meter and microphone system shall meet the requirements of ANSI S1.4-1971 for Type 1 sound level meters. Units meeting the requirements of IEC 179-1965 for precision sound level meters are also acceptable.

4.1 Permanent Record

All data is to be tape recorded on a magnetic tape recorder for post-test analyses.

4.2 Personnel and Measurement Practice

Persons technically trained and experienced in the current techniques of sound measurements shall select the equipment and conduct the tests. Proper usage of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer and ANSI S1.13-1971 should be referred to for both the recommended operation of the instrument and precautions to be observed. Specific items to be considered are:

1. The type of microphone, its directional response characteristics, and its orientation relative to the ground plane and source of noise.

2. The effects of ambient weather conditions (for example, temperature, humidity, and barometric pressure) on the performance of all instruments. Instrumentation can be influenced by low temperature and caution should be exercised.

3. Proper signal levels, terminating impedances, and cable lengths for multi-instrument measurement systems.

4. Proper acoustical calibration procedure, to include the influence of extension cables, etc. Field calibration shall be made immediately before and after each test sequence using an acoustical calibrator (or pistonphone) with an accuracy of $\pm$ 0.5 decibels or better.

4.3 Windscreen

A microphone windscreen shall be used which does not degrade the system below the requirements of ANSI S1.4-1971, for Type 1 sound level meters.

4.4 Power Source Instrumentation

All measurements of input power to the units under test shall be made at a point 10 meters (30 feet) $\pm$ 1 meter from the tool. The following instruments shall be used.

1. For pneumatically powered tools, a pneumatic flow meter, a pressure gage and temperature gage.

2. For hydraulic powered tools, a hydraulic flow meter, pressure gage and temperature gage.

5.0 TEST ENVIRONMENT

The following conditions have been standardized to achieve the desired degree of accuracy for this test procedure. Specific deviation from these conditions to simulate the actual working environment of the tool can be made, provided the modified test procedure is noted and can be shown to provide comparable results.

5.1 Meteorological Conditions

Sound level data shall not be taken when:

1. The wind is in excess of 5 meters per second (12 mph).

2. The relative humidity exceeds 90%.

3. If the air temperature is outside the operating temperature range of the instrumentation or tools.

Meeting the proposed test schedule is thus contingent on having suitable weather conditions.

5.2 Acoustical Conditions

The following acoustical conditions shall be met:

1. Sound level shall not be recorded if the background ambient sound level including wind is less than 10 dBA below the sound level generated by the test unit (tool) at the microphone location. Background ambient sound levels should be recorded prior to each test run for each tool tested.

2. If an external power source (compressor, pump, generator) is required, it shall be located or sound attenuated such that its sound levels are more than 10 dBA below the sound levels of the tool at each microphone location.

3. There shall be no large reflecting surfaces, other than the ground plane, in the immediate area of the test pad. Free field conditions shall be maintained in the test area within 10 meters of each microphone location.

5.3 Ground Plane

A hard surface equivalent to finished concrete or sealed asphalt shall cover a minimum of 90 degress of arc (with the pavement breaker at the vertex) and extend at least one meter beyond a microphone location.

5.4 Test Pad

The test pad shall conform to the following:

For portable pavement breakers, the material in which the pick point (moil) is impacting shall be concrete slabs obtained from Ft. Belvoir.

6.0 OPERATING PROCEDURES

6.1 Set Up

The equipment set up and the operating conditions shall duplicate the design output of the tools being tested. The power source, e.g., compressor, pump, generator, etc., shall be of sufficient capacity for design operation, including the starting requirements. The equipment shall be operated by a person experienced with the tool's operation. In all cases, the tools shall be operated in a vertical position impacting down upon the work surface. The tool shall be operated at the power setting specified by the manufacturer as typical of normal operation.

6.2 Moils

The moils shall be a standard moil (size 1-1/4 inches in diameter) and with a muffler sleeve attachment. Definitive notes shall be kept to indicate whether muffling sleeves are employed.

The moil shall conform to the following:

For pavement breakers, a pick point (moil) of standard commercial quality and availability shall be used. The length of the moils and rods shall be sufficient to allow the operating procedure described in Section 6.3.

6.3 Equipment Operation

Equipment operation shall be:

For portable pavement breakers, the pick point (moil) shall penetrate into the concrete until the taper portion of the bit is embedded. A weight equal to the designed down force shall be fitted over the center of gravity of the tool. (See Figure A1). The operator shall then operate the tool, but not apply any down force to the tool, at its design power setting until the sound level data has been observed.

7.0 MEASUREMENT PROCEDURE

7.1 Microphone Locations

The microphone locations shall be as follows:

For portable pavement breakers, four locations shall be positioned 7 ± 0.1 meter from the moil point of the tool at a height of 1.5 ± 0.01 meter above the ground plane. Four locations shall be positioned 1 ± 0.1 meter from the moil point of the tool at a height of 1.5 ± 0.01 meter. The centerline of the exhaust of the tool, if any, shall be equidistant between two measurement locations at both the 1 and 7 meter distances. The measurement positions shall therefore be located 45°, 135°, 225°, and 315° from this line. In addition, a fifth location shall be positioned 0.25 ± 0.10 meter from the moil point of the tool, at a height of 1.5 ± 0.01 meter above the ground plane. This position shall be located at a point which will detect the noise levels of the tool typical to the operator.

Note: Where the ground plane does not extend 8 meters out from the center of the test block in all directions, the tool may be rotated. The first half set of readings should be taken with the tool oriented in one direction and the second half set taken with the tool and operator rotated 180 degrees.

7.2 Personnel

The operator(s) shall be at the normal operating position(s). The person transcribing the sound levels from the sound level meter shall be positioned at least 10 meters from any microphone position. There shall be no other personnel within 10 meters of a microphone position.

7.3 Measurement Techniques

The microphone shall be oriented in positions, which minimize angle of incidence effects. All measurements shall be tape recorded for post-test analyses. The period of time during which the measurements are made, shall be long enough to allow an average reading to be taken with the slow response setting of the meter and long enough to facilitate frequency analyses.

7.4 Data Required for Presentation

The following data shall be acquired/computed/presented:

1. Background ambient A-weighted sound pressure level at one microphone position.

2. Sound levels - One-third, linear, and A-weighted sound pressure levels at each microphone position for each test performed; and, for a selected position and test, narrow (constant bandwidth) sound pressure spectra.

3. Average sound levels - The average A-weighted sound pressure level must be calculated from measurements performed by using the following procedure:

$$\overline{L} = 10 \log_{10} \left[\frac{1}{N} \sum_{i=1}^{n} \log_{10}^{-1} (L_i/10) \right]$$

where L = average sound level

L_i = sound level at i^{th} microphone

n = number of microphone locations

4. Meteorological Data - the wind speed and direction, the relative humidity measured using a dry and wet bulb.

psychrometer, the temperature and the barometric pressure shall be recorded at least once each hour.

5. Tool Identification - the tool being tested shall be identified by the manufacturer's name and address, the tool's generic name, the model identification(s) and brand name, the tool serial number(s) and the tool bit and/or rod used.

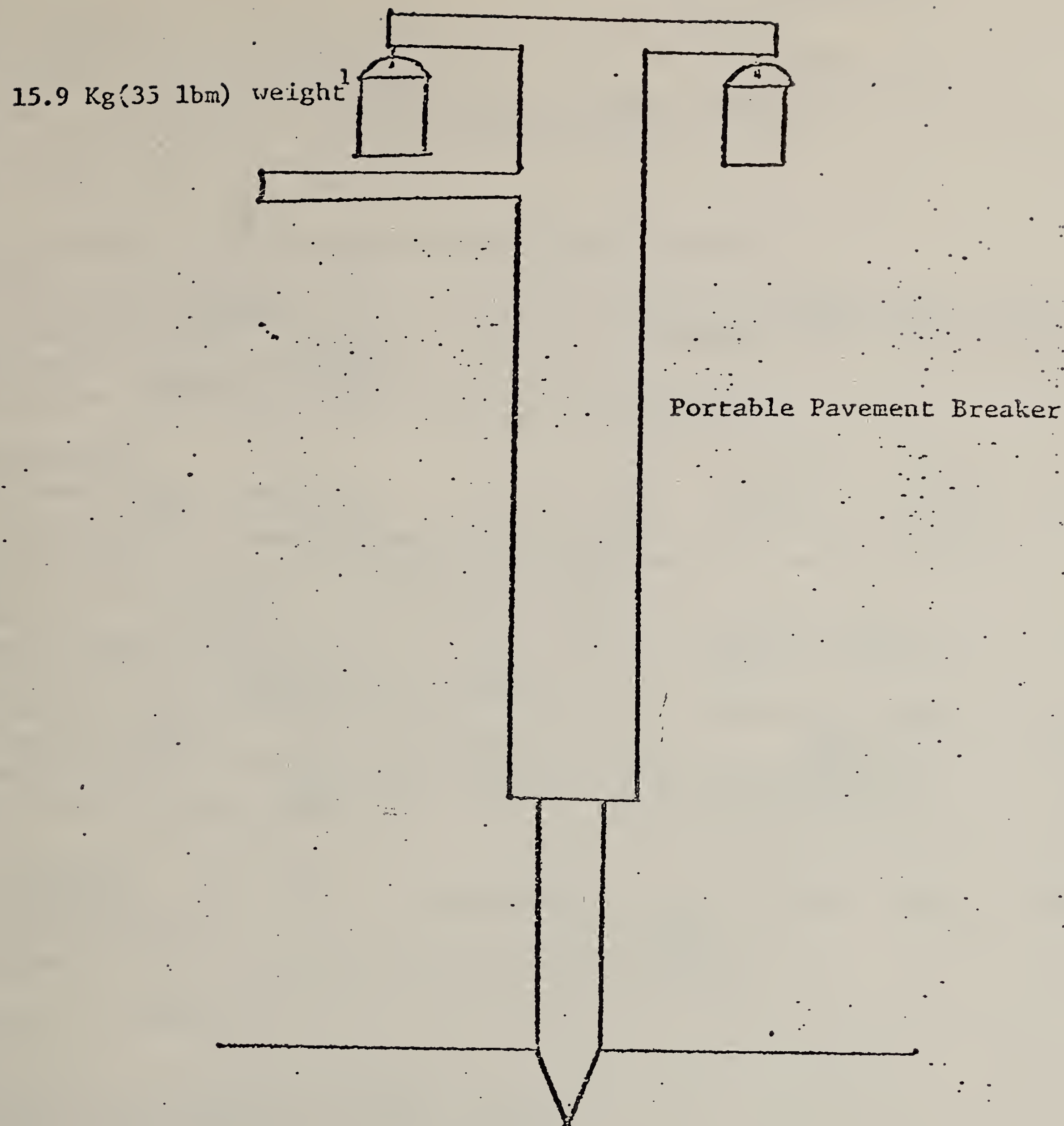
6. Location - the test facilities shall be described by address, date, time of testing and operating personnel present.

7. Operating Conditions - the operating condition and power consumed determined from instruments discussed in Section 4.5 shall be recorded. Explanatory notes shall be made describing the test cycle.

8. Instrumentation - a complete list of instrumentation shall be provided including models and serial numbers.

9. Data Sheets - data called for in Section 7.4 shall be recorded on the accompanying data sheet (Figure A2). A sketch shall be provided showing the microphone locations, tool orientation, location of power source, etc.

FIGURE A1



Weight Applied to Portable Pavement Breakers to Simulate the Designed Down Force

[1] Weight may vary. See Manufacturers' Instruction Manuals for the Designed Down Force.

DATA SHEET

TOOL DATA: TEST DATE: 9/6/78

Model #/Trade Name SIG 81

Catalog Part # ______ Serial # 86601

Manufacturer Swiss Industrial Gas

Address c/o American Jenback Corp., Box 2115, Burlington, NC 27215

Drill Diameter ______ m. Drill Bit ______

Down Force 31.8 kg.

TEST FACILITIES: (Include photograph of test set-up)

Location Ft. Belvoir, VA

Work Material Concrete Date Poured ——

Compressive Strength 5692 kpa(psi) Date Tested 9/6/78

Power Source Chicago Pneumatic

Manufacturer Model/Trade Name ______

INSTRUMENTATION:

Sound Level Meter B&K 2203 Serial # 579906

Manufacturer/Model Bruel & Kjaer

Microphone Type B&K 4165 (See Figure A4 Continued for serial numbers)

Length of Cable 7 m

Windscreen B&K UA0237

Calibrator Type Pistonphone Serial # 236169

Manufacturer/Model Bruel & Kjaer / 4220

Flow Meter Wallace & Tiernan Serial # none

Manufacturer/Model ______

* Correction Factor for Temp $\sqrt{(460+T)/530}$ ** Pressure $\sqrt{\frac{14.7}{14.7+F}}$

Tape Recorder Honeywell 5600 C Serial # 0104166LM77

TEST CONDITIONS: See Table I

Air Temperature ______ C Dry Bulb ______ C Wet Bulb ______ %RH

Barometric Pressure ______ HG

Wind Speed ______ m/sec

TEST DATA: See Table I

Operating Line Pressure (Voltage)
Operating Line Temperature (Power Factor)
Operating Volumetric Flow Rate (Amperes)

A-Weighted Sound Levels at 7 meters from Tool
dBA re 20 microPascals

1. Background Ambient Sound Level-dBA (one only)

2. Sound Level dBA with Power Source Operating

3. Sound Level dBA with Tool Operating

AVERAGE SOUND LEVEL: ______ dBA

* Temperature in °F

** Pressure in psig.

Figure A4 - Example data sheet

EQUIPMENT SERIAL NUMBERS[1]

CHANNEL	B&K 4165 MICROPHONE	B&K 2619 PREAMPLIFIER	B&K 2804 POWER SUPPLY
1	674370	240121	408626
2	682426	312737	408619
3	682393	327626	619048
4	682446	240111	387237
5	682420	240307	619038
6	682388	240099	387238
7	682462	327627	619047
8	682702	240240	588875
9	682787	312708	408619

Figure A4 - (concluded)

[1] Certain commercial equipment is identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.