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Project Report

TT-12

G. W. Ahlgren

Evaluation of a Mortar Substitute for Firing Weapon Acoustic Studies

4 October 1976

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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Raymond L. Loiselle

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

EVALUATION OF A MORTAR SUBSTITUTE FOR FIRING WEAPON ACOUSTIC STUDIES

G. W. AHLGREN

Group 45

PROJECT REPORT TT-12

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ABSTRACT

This report discusses the investigation of a sound source for studies of acoustic array techniques for the determination of firing weapons. A device which simulates the muzzle blast signals from 4.2 inch mortars was considered. In this device, a modified 4.2 inch mortar, the shell is replaced by a cardboard tube containing a weight of water equivalent to the round weight. Use of this device relaxes the normally stringent safety requirements associated with mortar firings and reduces per round cost to roughly one-tenth that associated with mortar firings.

Recordings were made of the water mortar and a standard 4.2 inch mortar sited side-by-side with microphones at ranges of 1.1 and 1.7 km. The spectral content of the two signals was determined using Fast Fourier Transforms. The results indicate great similarities between the signals from the two sources.

TABLE OF CONTENTS

I. INTRODUCTION

One segment of the Army/ARPA HOWLS Program involves the consideration of acoustic techniques for the location of hostile firing weapons. Primary emphasis is being placed on the development of short base length acoustic arrays to be used for moderate range (5 km) sensing. Arrays with sensor spacings from one to 100 meters are being evaluated. Signals from such arrays would be processed to derive acoustic signal arrival angle and time information using sophisticated signal processing techniques. Data from two or more such arrays at differing locations could then be used to determine weapon locations by triangulation. Alternately, data from one such array could provide area-of-activity cueing for other sensor systems or adjunct information to enhance other sensor system performance.

Measurements to obtain data for an evaluation of short base length arrays are underway within the program. Two goals have been established for the measurements. First, the data will be used to ascertain the measurement uncertainties introduced by moderate range atmospheric propagation. The travel time uncertainties will be obtained through a measure of shot time to array reception time variability. In addition, the relative arrival time variability for the various sensors in the array will be analyzed to determine sensor spacing dependencies. Data from a non-uniform spacing linear array providing a range of sensor to sensor distances from one to 100 meters will be utilized for these analyses. Second, this data will form the basis of an investigation into signal processing techniques to derive angle and time of arrival information. For reasons discussed below, it was deemed desirable to utilize a sound source other than live weapons for these measurements. This report discusses the search for such a source.

The roughly 5 km mission range postulated for the short base array led to the choice of a mortar as the most likely weapon as the acoustic source for the measurements. It is expected that the Soviet 120 mm and 240 mm mortars will be prevelant artillery threats in this region. It was felt that the U.S. 4.2 inch (107 mm) mortar would provide the most realistic source function for these initial measurements. The primary interest in the initial work involves a measure of atmosphere induced variabilities. Since such variabilities are not expected to be very strongly dependent on the source characteristics, the choice of a single representative weapon such as the 4.2 inch mortar would cover the important body of cases. The use of standard 4.2 inch mortars has two major drawbacks and this memo deals with a technique that effectively simulates the standard 4.2" mortar. The two major drawbacks are:

1. The use of mortars (even those firing inert rounds) severely limits the experimental configuration. The designed physical layout called for five firing sites at 1 km spacings on a line perpendicular to the array axis. Three such sites would be occupied at the same time with weapons at these sites firing within a short time period. The mortar safety fan precludes orienting the weapons along the firing line (and thus over the heads of other crews). Shots perpendicular to the firing line would be allowed; this however requires a large range. Such a capability did not exist at the sites considered for the experiment.

2. Approximately 200 rounds total will be required for an adequate statistical measure. If dedicated firings were used to provide these, the experiment cost would be high. Target of opportunity operation would reduce the costs but would likely preclude an orderly, controlled experiment. Conclusive data reduction will require a good knowledge of shot conditions as well as a careful coordination of shots. These would be nearly impossible outside of a controlled experiment.

The Environmental Research Institute of Michigan (ERIM) has developed a mortar modification which replaces the round with an equivalent weight of water. Use of this device would eliminate the safety restrictions and significantly reduce the firing costs. It was felt that the acoustic characteristics of such a device should be nearly the same as for a standard mortar. In order to confirm this assumption, a short experiment was undertaken to compare the acoustic signal produced by a standard 4.2 inch mortar and the ERIM water mortar. Side-by-side firings of the two weapons were recorded for later analysis. This report presents the result of that analysis. In addition, the measurements were used to ascertain other relevant experimental parameters in preparation for the main measurements as discussed in a later section.

Some pertinent characteristics of the two mortars are presented in the following section. This is followed by a description of the experimental configuration, equipment and technique. Results obtained in the equivalency examination analysis and in the determination of other parameters are discussed in succeeding sections. Conclusions based on this effort are then presented.

Following the measurements reported in the body of this report, measurements were made comparing the signals produced by the three water mortars used in later work. The results of this comparison are reported in the Appendix.

II. MORTAR PHYSICAL CHARACTERISTICS

The water mortar used in the experiment is shown on Figure 1. Except for some minor external modifications which aid transportation of the tube, the outward appearance is very similar to that of a standard 4.2 inch mortar. Before describing the internal modifications and the operation of the water mortar, some relevant data on the standard 4.2 inch mortar will be discussed.

A. Live Mortar Configuration

The 4.2 inch (107 mm) mortar round is approximately 26 inches long and weighs 27 pounds. Propelling charge increments are placed on the tail section of the round. The increments are in sheets; the total number may be varied to adjust the shot range up to a maximum of 36 increments. In addition a propellant bag containing flake propellant equal to 5 increments is also used. A primer and ignition cartridge similar in external appearance to a 12-gage shotgun cartridge is located in the tail section.

For firing, the round is released tail first into the mortar tube. It slides down the tube until the percussion primer strikes the firing pin in the base of the tube. The flash from the primer ignites the ignition cartridge which, in turn, ignites the propelling charge. The gases produced exert pressure on the pressure plate at the base of the round and expand the rotating disc thus engaging it in the tube rifling. Thus the projectile is spun up as it travels up the tube providing spin stabilization.

FIG. 1. Photo of water mortar

For the maximum charge available (41 increments) the maximum chamber pressure of approximately 14,000 psi is achieved approximately 3 ms after projectile motion begins. The projectile exists approximately 6 ms later with a nominal 293 m/sec velocity; the chamber pressure at exit is roughly 3600 psi. From the point of ignition to exit, the rotating disk travels 1.37 meters (54 inches) whereas the total bore length is approximately 1.5 meters (60 inches).

B. Water Mortar Configuration

Standard issue 4.2" mortars were modified by ERIM to accept a water round. Modifications include boring to remove the tube rifling and removal of the firing pin at the tube base. The round is then replaced by a cardboard tube arrangement consisting of a large tube which fits tightly into the mortar with a smaller tube at the bottom end for the placement of the propelling rounds.

Standard issue propellant and black powder initiator charges are used for the water mortar. These are placed on the small tube at the base end of the larger tube and secured with masking tape. An electrical blasting cap is imbedded next to the black powder bag. The leads from the cap are placed through a small hole drilled in a cardboard end cap and exit through the large tube at the muzzle end of the weapon. The blasting cap leads are attached to a firing box for weapon firing.

After the cardboard tube with propellant and blasting cap attached is placed into the mortar tube, a long plastic bag is inserted into the cardboard tube. This bag is then filled with water up to the neck of the tube. The volume of water (roughly 3 gallons) provides a weight equivalent to that of the standard mortar round.

Since the propellant and black powder charges are very stable, the round can be configured and fired without restrictive safety measures. During firing the cardboard parts are essentially completely destroyed; small pieces of less than 10 cm^2 are usually found within 20 m of the weapon site. Occasional misfires have been encountered where a slow burning of the propellant has resulted in ejection of the cardboard tube from the mortar tube intact. These have travelled distances of 30-50 meters. During normal operations the water is observed to be ejected in a tube shape initially, spreading rapidly to a mist cloud. The blasting cap leads permit the firing crew to be roughly 30 meters behind the weapon. The safety fan in front of the weapon is considered to extend only approximately 100 m.

For this reason the water mortar presented an attractive alternate source for the measurements of interest. In addition, the major round cost is involved in the propelling and initiating charges; the weapon can be fired for roughly 1/10 the cost of a standard 4.2 round. The water device has been used extensively as a source for seismic investigations in the past. These efforts have observed that the device is a good analog for standard mortars with regard to the seismic signature. In addition, it has been observed that the seismic signature is highly repeatable (except for easily noted occasional misfires) indicating another desirable experimental feature. The efforts reported herein were structured to determine the applicability of the water device as an acoustic analog for the standard 4.2 mortar.

III. EXPERIMENT DETAILS

In order to answer the acoustic equivalency question, a short measurements effort was undertaken at Jefferson Proving Grounds in November 1975. In this experiment a live 4.2" mortar and the water mortar were sited side by side and fired within a short time period. The acoustic signals were recorded and analyzed at the Laboratory to determine if sufficient equivalency existed. Three objectives were specified.

1) Ascertain water mortar utility as acoustic source,
2) Determine expected spectral content in order to specify major effort sampling rates, and
3) Investigate microphone type characteristics.

A. Experiment Configuration

The experiment configuration used during the measurement is shown on Figure 2. A site was chosen which provided essentially level terrain for a range of approximately 1.7 km. The weapon firing sites were located in front of a steel blockhouse normally used for mortar test firings at Jefferson Proving Grounds. Two microphone sites were selected at ranges of approximately 1.1 and 1.7 km from the weapons. The intervening terrain was swampy and covered with 1 meter high dead grass and a few bushes. The live mortar position was constrained to a prepared position approximately 2 meters in front of the blockhouse wall. In order to determine any potential influence due to the blockhouse, two water mortar positions were utilized. The first,

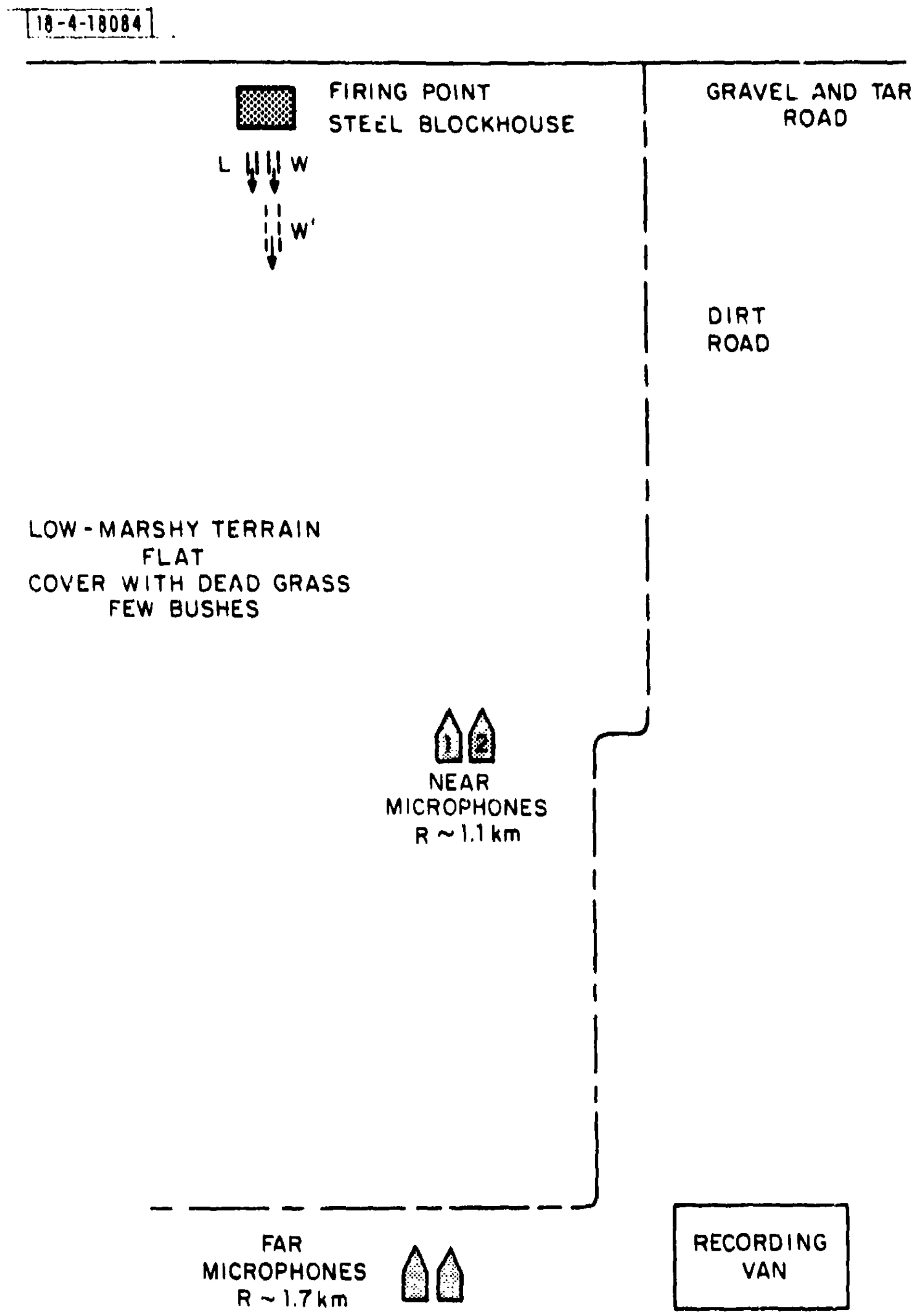

FIG. 2. Experimental configuration, Jefferson Proving Grounds, 3-5 Nov. '75

indicated by W' on Figure 2, was approximately 30 meters in front of the blockhouse; the second was located alongside the live mortar. Shots recorded at the two water mortar positions were compared; no significant differences could be detected.

B. Instrumentation Details

Two microphones were located at each recording site; they were sited side-by-side separated by approximately one meter. They were placed approximately one meter off the ground. Output signals were transmitted via twisted pair field wire to the recording van. A battery powered preampli ier was utilized for each microphone to provide signal and impedance levels sufficient to drive the lines. The lines from the near microphones ran underneath a power transmission line. Although some 60 Hz pickup was observed, the level was well below the microphone signal levels.

Signals received at the recording van were then gain adjusted to provide the required recording levels. The conditioned signals were then recorded on a 7 track FM tape drive. During the experiment the record levels were adjusted in an attempt to provide near peak levels in order to maximize signal to tape noise conditions. Some data was over recorded (saturated on recording) due to the variability in the atmospheric transmission. These signals were not used in the analysis. A tape voice track was used for commentary information.

Two microphone types were utilized. A Bruel & Kjaer Model 4134 capacitor microphone provided a frequency response essentially flat from 50 to 5000 Hz.

This microphone's low frequency response (which is of primary interest here) is quite good; typically it is down 1.5 dB at 20 Hz. An Electrovoice Model RE-55 dynamic microphone was also utilized. This microphone is also fairly flat from 50 to 5000 Hz. However, the low frequency tail-off is sharper; typically the response is down 15 dB at 20 Hz.

C. Shot Record

A total of 22 shots were fired on two days, 12 were water mortar shots and 10 were live shots. On the first day of firing, 4 November, nine water mortar shots and seven live mortar shots were recorded. The sequence for these shots is shown on Table 1. As mentioned earlier, two positions were used for the water mortar on this day. The first position, indicated as W' on Table 1 and Figure 2, was located approximately 100 feet in front of the firing bunker position used for the live shots. Three water shots were taken from this position. The remaining water shots and all live shots were taken from positions (W and L) near the bunker.

As noted on the table, several shots were not available for analysis due to saturation on recording or high wind noise conditions. A second sequence of shots were recorded on a second day (5 November). Three volleys of live and water mortar shots within a short time span were successfully recorded.

D. Data Reduction Methods

The analog tape records were digitized post measurement for analysis on the Laboratory's computing system. The signals were filtered through a low

TABLE 1

4 NOV. SHOT SEQUENCE

SHOT	LOCATION	DATA USED IN ANALYSIS?	
		NEAR MICROPHONE	FAR MICROPHONE
W-1	W'	Yes	Yes
W-2	W'	Yes	Yes
W-3	W'	Yes	Yes
W-4	W	Yes	No - High Wind Noise
W-5	W	No - Saturated Recording	No - High Wind Noise
W-6	W	No - Saturated Recording	No - High Wind Noise
L-1	L	No - Saturated Recording	No - High Wind Noise
L-2	L	No - Saturated Recording	Yes
L-3	L	Yes	Yes
L-4	L	Yes	Yes
W-7	W	Yes	Yes
L-5	L	Yes	Yes
W-8	W	Yes	Yes
L-6	L	Yes	Yes
W-9	W	Yes	Yes
L-7	L	Yes	Yes

pass anti-aliasing filter with a 3 dB point of 1000 Hz and digitized at a 5000 Hz rate. The A-D converter provided an eight bit resolution. The A-D gain was adjusted to maximize signal to digitizing noise thus providing as nearly as possible the 48 dB dynamic range available. An examination of the signals recorded using a microphone calibrator (pistonphone) indicates that the overall dynamic range was available for most of the recorded data. The only exceptions were those early records from the near microphones which were corrupted slightly by the presence of 60 Hz pickup.

The digitized records were analyzed using spectral analysis programs generated for the task. These programs allowed plots of specified portions of the time records as well as software data filtering. The time records were then appropriately windowed and spectrally analyzed using Fast Fourier Transforms (FFT). The spectral plots so obtained were compared to deduce the similarity of the two mortars' signatures as discussed below.

Typical results obtained from the analysis are shown on Figures 3-5. Figure 3 shows the digitized calibrator signal as plotted by the computer. The vertical scale is in A-D counts; the average value has been removed in order to eliminate a potentially large d.c. component on the spectral plots. This d.c. is due to an offset setting on the A-D converter and is not present on the original data. The total spectrum as derived from the FFT is shown on Figure 4. The data has been weighted to maintain 40 dB frequency sidelobes. The vertical scale is the power relative to the maximum power over the frequency range. The horizontal scale encompasses the entire frequency range available of 0-2500 Hz (the Nyquist frequency). The frequency resolution is 4.88 Hz.

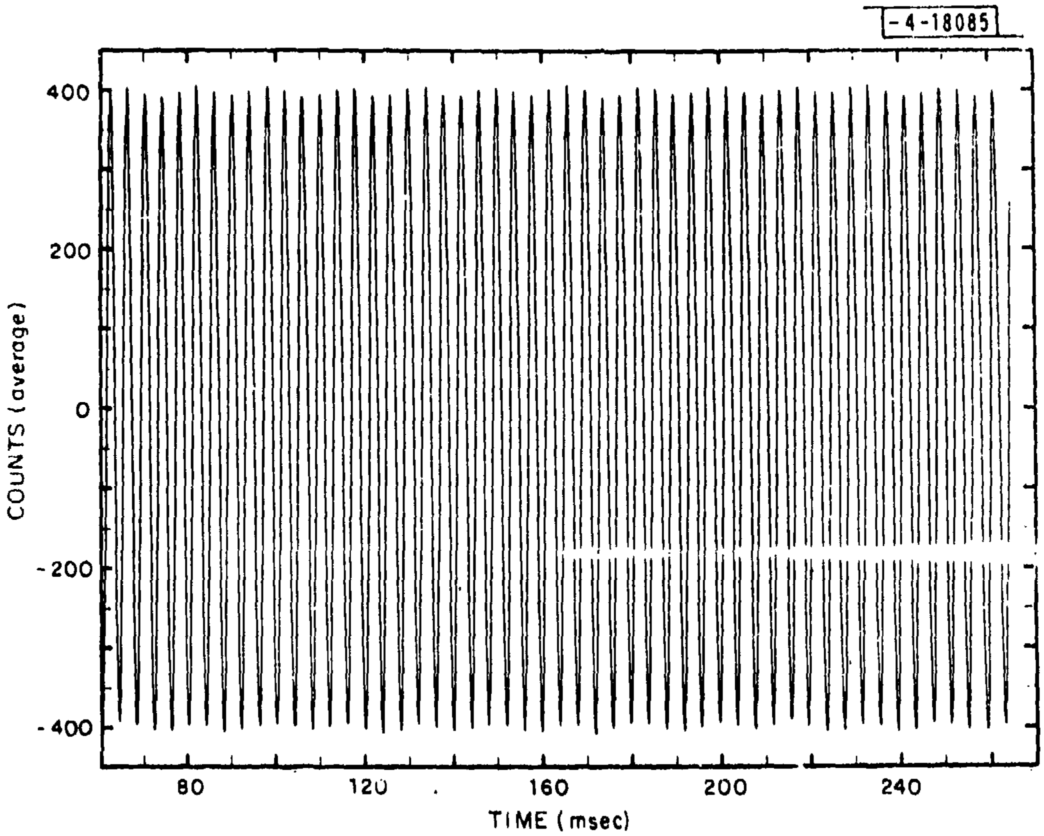

FIG. 3. Pistonphone microphone calibrator signal

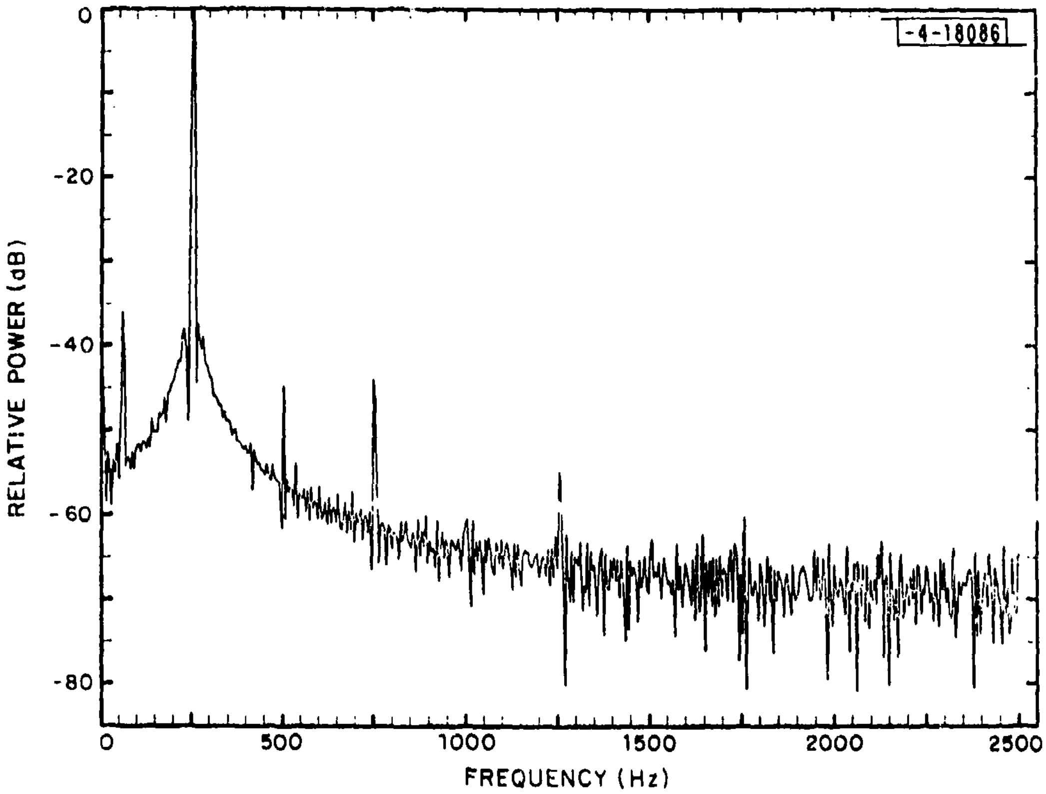

FIG. 4. Calibrator spectral analysis from FFT

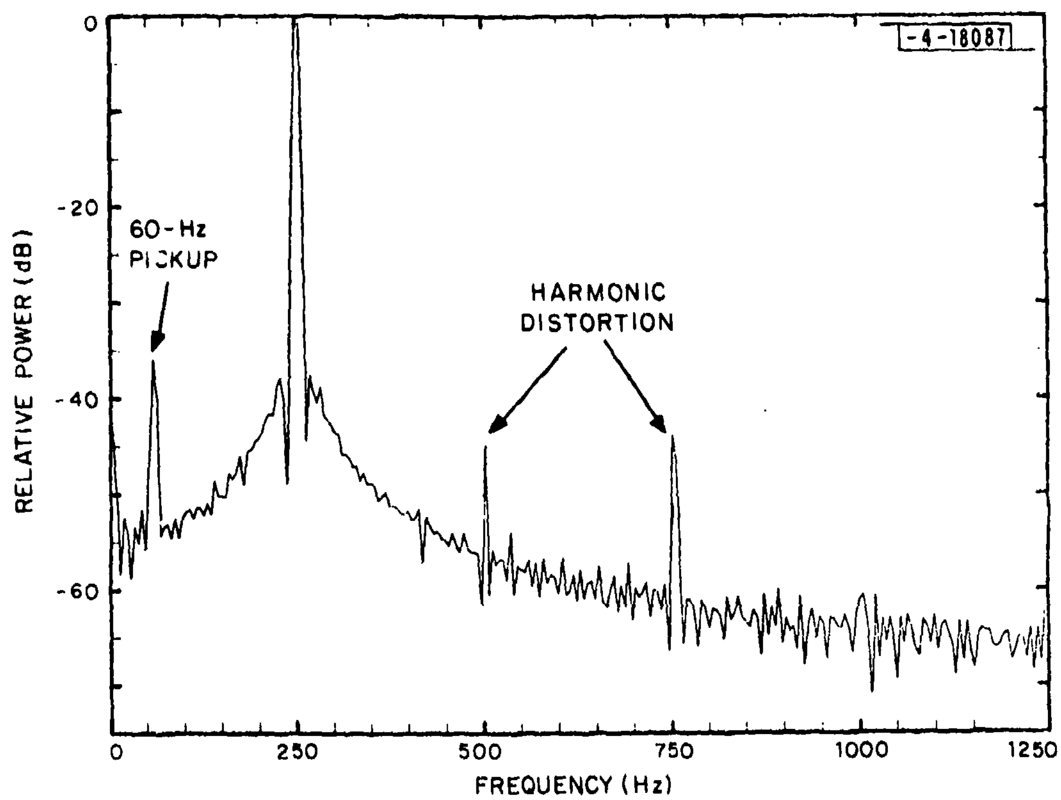

FIG. 5. Expanded view of calibrator spectrum

This figure is expanded to show the region of interest or Figure 5. The microphone calibrator produces a 250 Hz sine wave at a Sound Pressure Level (SPL) of 114 dB relative to .0002 microbar (2 x 10^{-5} newtons/m^2). This level is within ±10 dB of the expected weapon SPL at the ranges used in the present measurements and as such provides a good indication of the recording system - digitizing system capabilities. The resultant spectrum from the FFT shows a peak at 250 Hz (within the 4.88 Hz resolution cell). Also shown are the first two harmonics of the calibrator. These are greater than 40 dB below the main signal. As mentioned earlier, the near microphone (as shown here) signal suffered from a 60 Hz pickup problem due to power line induction into the signal lines. This pickup signal is also indicated; for the gains used, this signal is greater than 30 dB below the main signal peak and is therefore of little consequence. For the early shots, the gains were not as optimum as used here and the 60 Hz pickup is only 12-18 dB below the main signal.

IV. VALIDITY RESULTS

All the shots previously identified as providing good recordings were analyzed. Each shot's time waveform was plotted and then appropriately windowed in order to perform the FFT. The FFT plots were then compared to determine differences between shots and weapons. It is felt that such a spectral comparison provides the most sensitive indication of any significant differences.

A. Typical Results

A typical time waveform is shown on Figure 6 for live mortar shot #6 at the far microphone. The plot format is the same as that for Figure 3. For this shot (and most shots) the signal to background noise level is quite high (> 30 dB). The background noise which is seen before the arrival of the signal is due in this case to wind noise at the microphone. Following the large main signal can be seen a rather long train of signals arriving from different paths. These multipath signals are quite typical; the signals may continue for 200-300 milliseconds after the main signal.

The windowed waveform used in the FFT is shown on Figure 7. The first 250 Hz of the resultant spectrum is shown on Figure 8. The major peak in the frequency domain lies at 25 Hz; above 50-75 Hz there are few frequency components within 30 dB of this peak. There is what appears to be a secondary peak approximately 20 dB below the main peak at roughly 110 Hz.

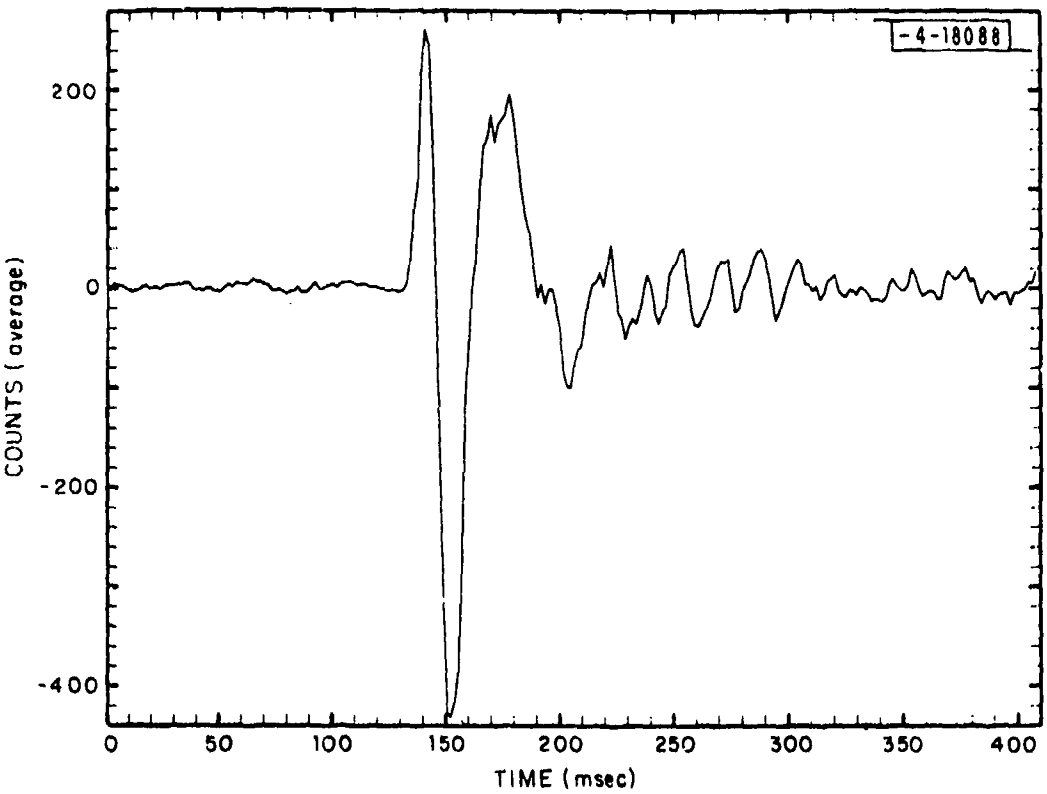

FIG. 6. Typical mortar time waveform (L-6, far microphone)

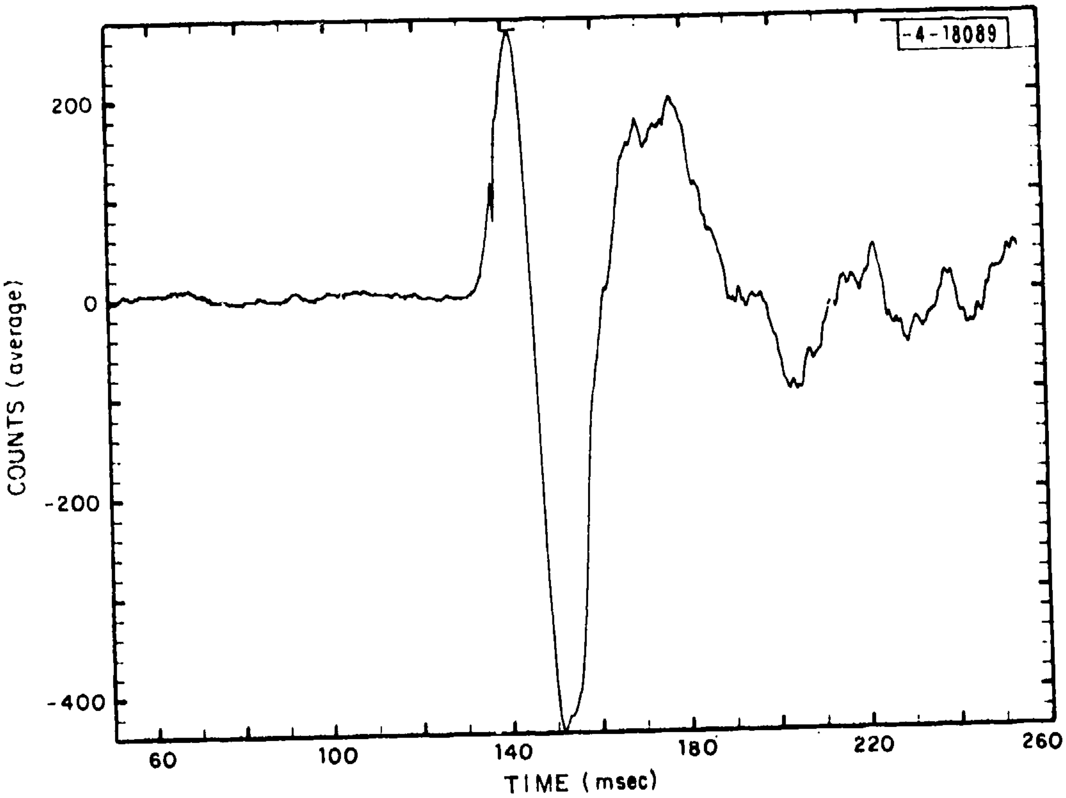

FIG. 7. Typical mortar time waveform - windowed for FFT (L-6, far microphone)

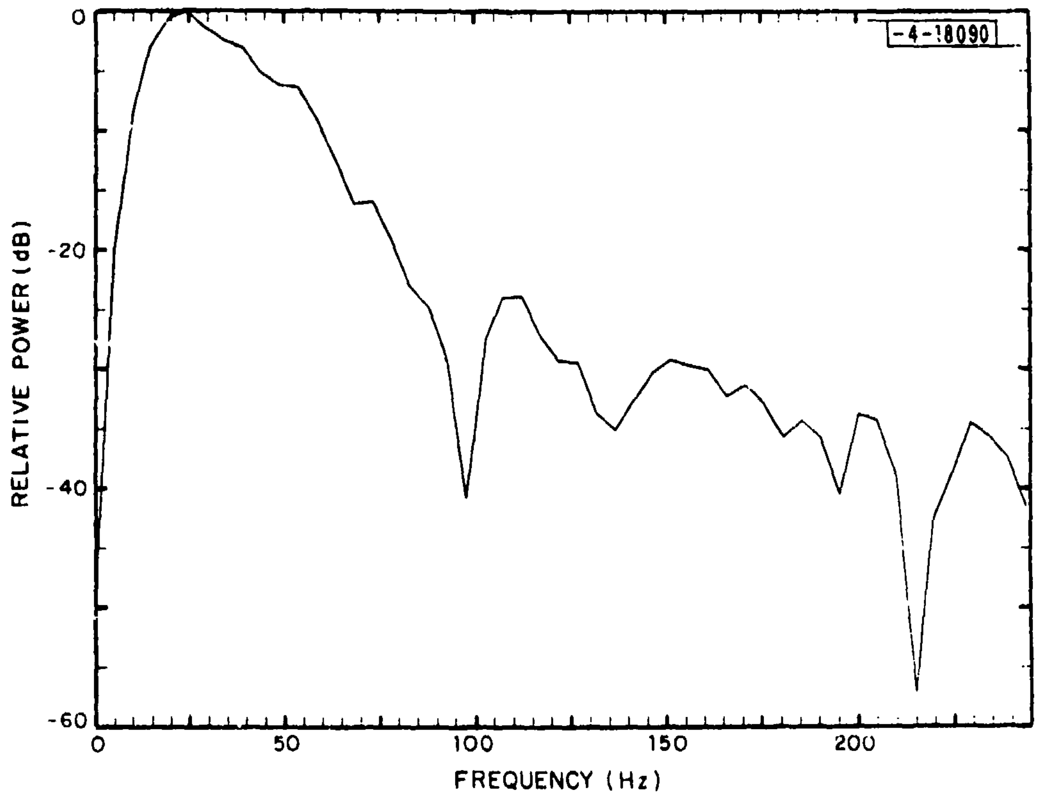

FIG. 8. Typical mortar spectrum (L-6, far microphone)

Figures 9-11 show the same analyses for this shot as recorded by the near microphone. In this case the noise is dominated by the 60 Hz pickup. This level, however, is greater than 20 dB below the signal level. For the near microphone, the large multipath evident on the far microphone is not present. Thus as one expects, the multipath is more severe at longer ranges. Also as expected, the spectrum shown on Figure 11 has higher frequency content than that on Figure 8 at the longer range. The spectral peak is near 30 Hz and shows a lower slope at the higher frequencies. The secondary peak has moved to roughly 120 Hz and is roughly 12 dB below the main peak.

It has been conjectured that these secondary peaks are due to mortar tube resonance phenomena. For a 1.5 meter tube one would expect that the fundamental resonance frequency would be roughly 60 Hz ($f = C/4L$) for a nominal 348.6 m/sec velocity of sound. Since the tube gasses are potentially hotter than 300°K, this number may be low. To achieve the observed 110-120 Hz signal would require a sonic velocity of roughly 700 m/sec. This would require a 1200°K gas temperature. MacMillan* has estimated that the relative magnitude of the tube resonance signal would be given by:

$$\text{Relative Acoustic power (dB)} \sim -20 \log_{10} P(\text{bars})$$

where P is the barrel gas pressure at the exit of the projectile. The 3600 psi exit pressure of the 4.2 inch mortar would, therefore, yield a -48 dB signal relative to the main signal produced by the gasses exiting the tube. Under these assumptions it seems unlikely that the observed secondary spectral peak is caused by a tube resonance phenomenon.

*"Acoustic Weapons Location" (U), Final Technical Report, McMillan Science Associates (31 March), SECRET.

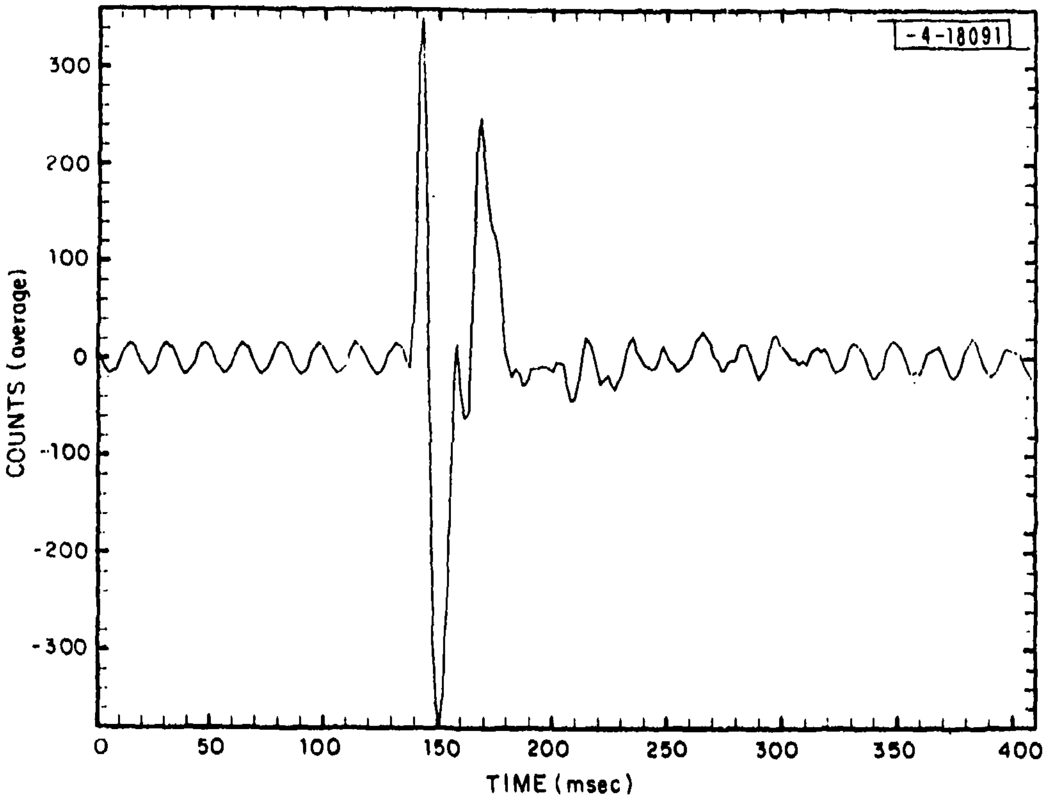

FIG. 9. Typical mortar time waveform (L-6, near microphone)

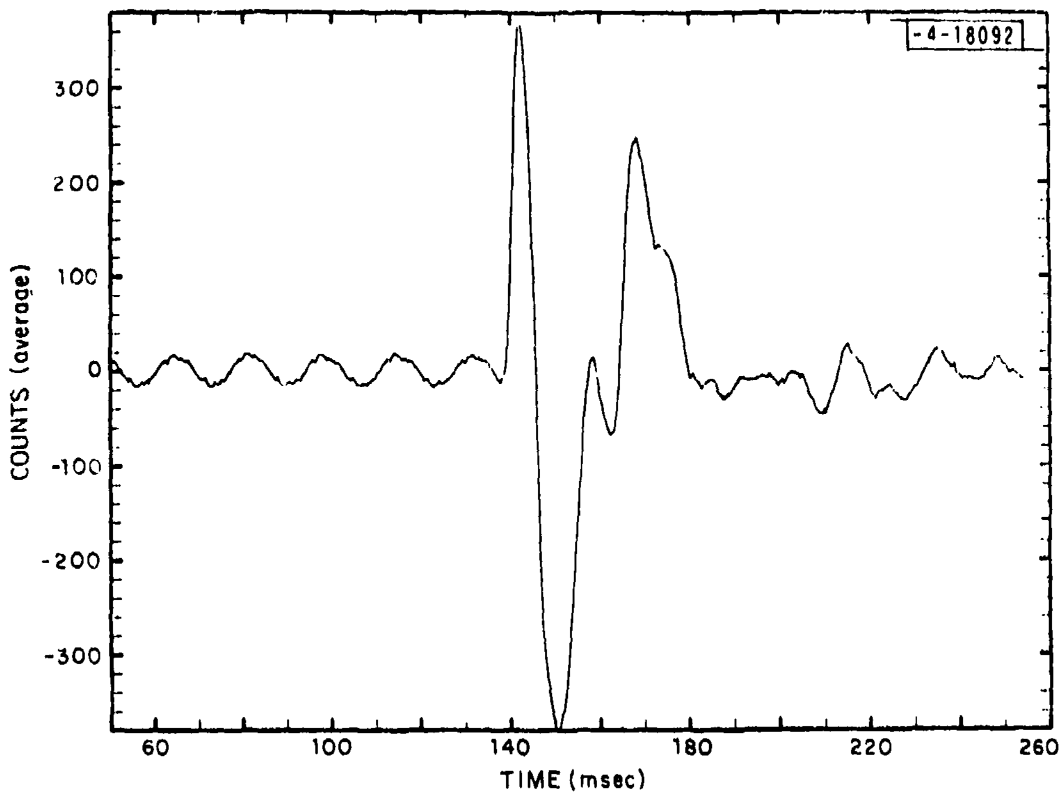

FIG. 10. Typical mortar time waveform - windowed for FFT (L-6, near microphone)

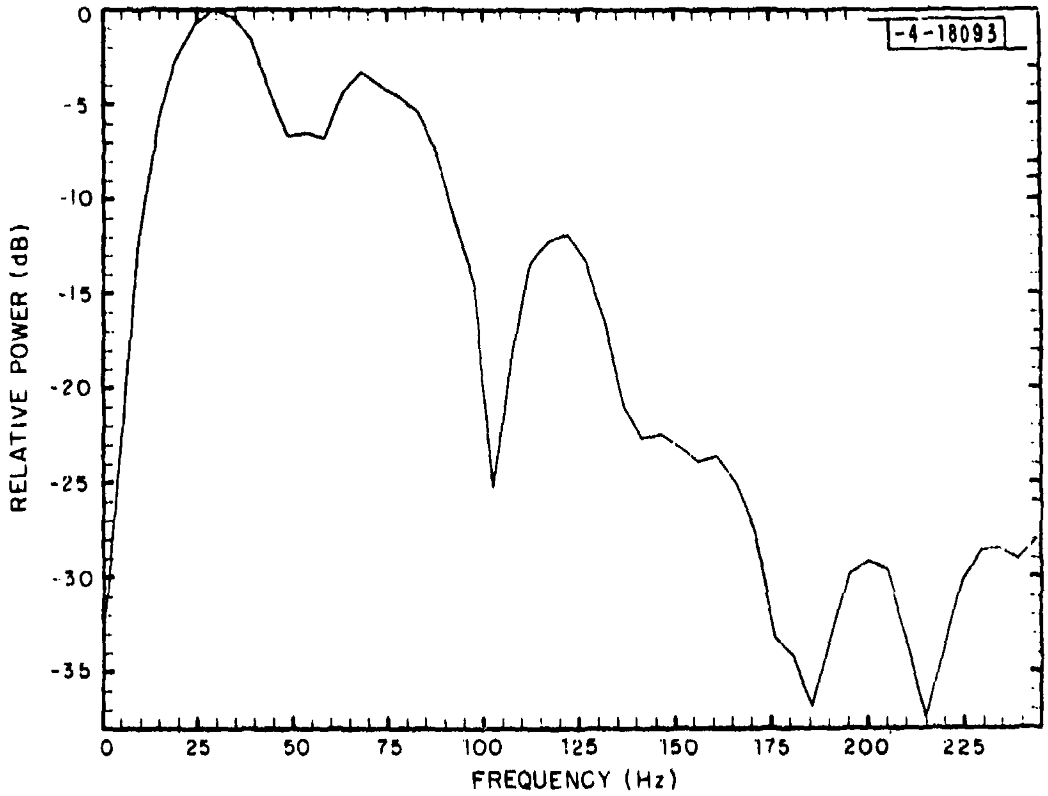

FIG. 11. Typical mortar spectrum (L-6, near microphone)

It should be pointed out that it is difficult to associate a "typical" label to any of the recorded waveforms. Shot to shot variabilities can be noted on the signal structure. For example, the live shot following that shown on Figure 6 is shown on Figure 12. Both records were made from signals at the far microphone from live mortar shots within 20 minutes. The major spectral content is the same (the main signal periods are very similar). However, the structure of what appears to be propagation induced effects differs markedly. (Note that the vertical scales differ.) The relative amplitudes of the positive and negative peaks are changed for example. The latter shot also shows evidence of larger and longer multipath signals.

The consequences of these differences can be seen by comparing the spectrum of this shot as shown on Figure 13 to that of the earlier shot on Figure 8. Although the major peak at 25 Hz remains consistent, the higher frequency character has changed. The main peak width is lower and the spectrum is less smooth. As expected these shot-to-shot variations are more evident on the far microphones and seem to give some indication of the atmosphere dynamics. Accordingly, the comparison of spectra for an evaluation of similarity will not be made on a shot-to-shot basis but rather will be made by averaging a number os shots as described below.

B. Average Spectra Results

In order to compare spectra in a meaningful way, a number of individual spectrum plots were averaged to provide an average response figure. These

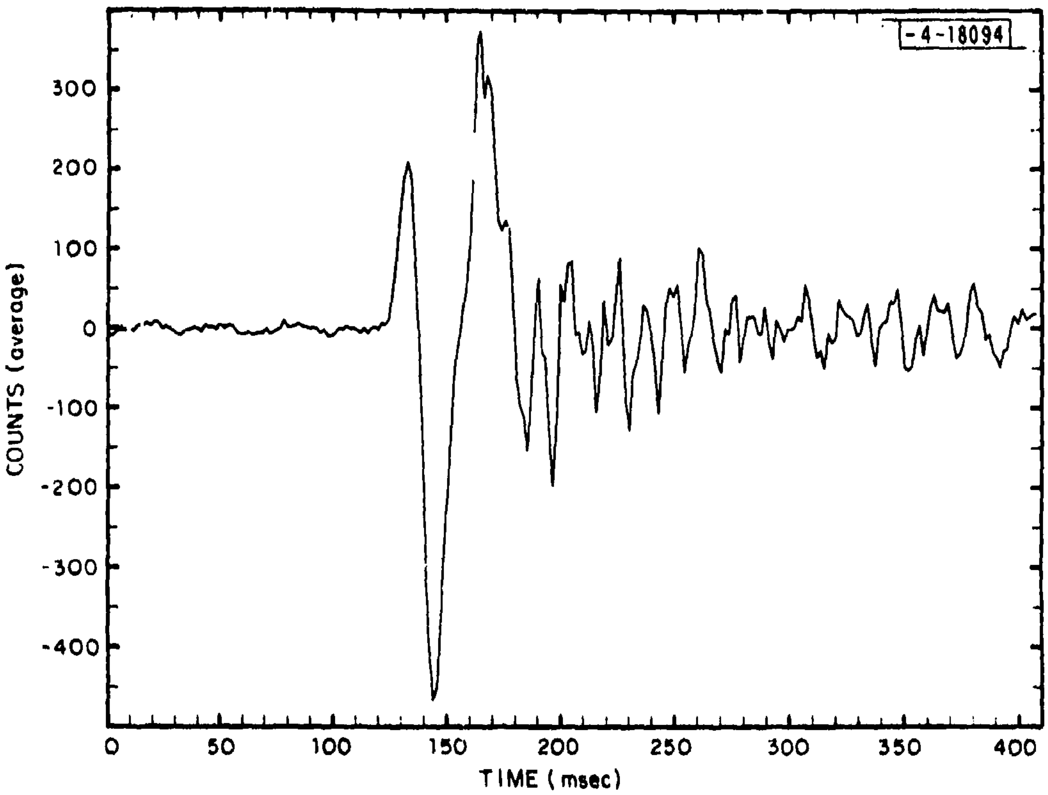

FIG. 12. Typical mortar time waveform (L-7, far microphone)

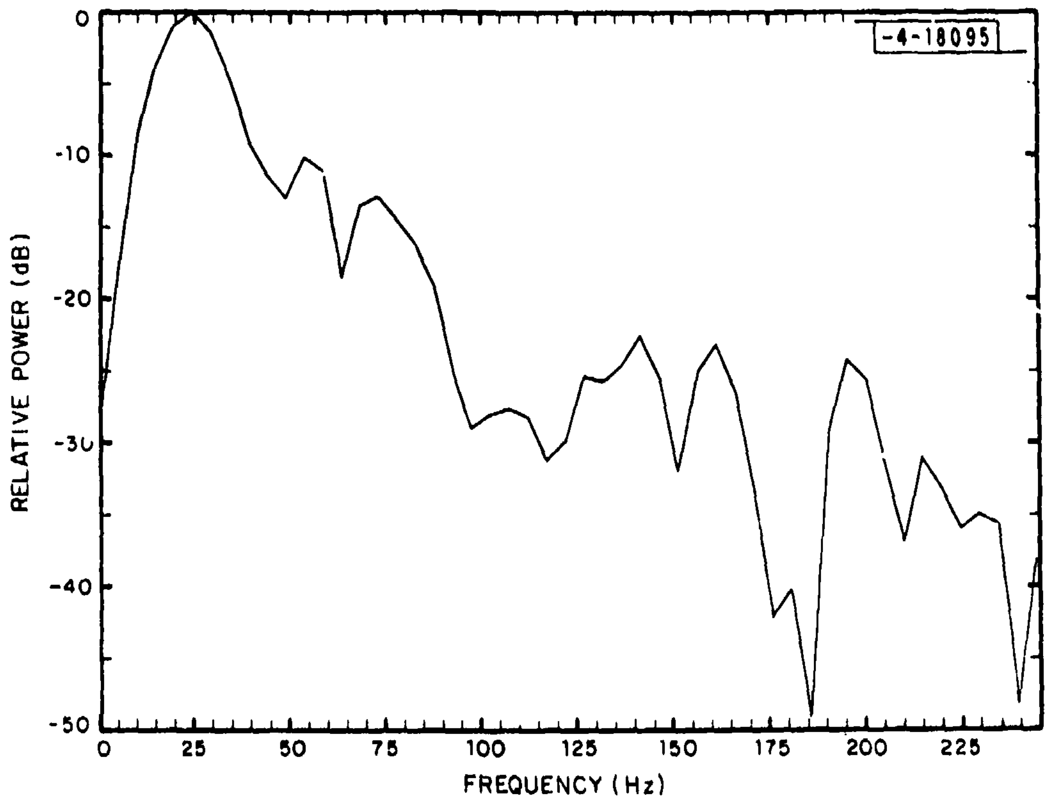

FIG. 13. Typical mortar spectrum (L-7, far microphone)

are shown on succeeding figures under a variety of circumstances. In each the shot numbers used in the averages are noted.

Water Mortar Position - As discussed earlier, the live mortar position was constrained to be immediately in front of a steel blockhouse wall. In order to encounter the same conditions, the water mortar was sited adjacent to the live mortar and likewise in front of the wall for most of the shots. However, three shots were recorded with the water mortar sited in the field 100 feet in front of the blockhouse (position W' on Fig. 2) to ascertain whether the wall introduced any effects. A comparison of the average spectra for the two water mortar positions as measured at the near and far microphones is shown on Figures 14 and 15, respectively. No significant differences are evident. The major differences are seen at the higher frequencies at the far microphone and are most likely attributable to atmospheric propagation variations.

Live vs. Water Comparison - Figures 16 and 17 illustrate the average spectra results for the live and water mortars at the near and far microphones, respectively. As before, the spectra are most similar at the near microphone. The water mortar appears to have a somewhat higher peak frequency. In addition, the secondary peak near 120 Hz is less distinct. However, the two spectra are quite similar and deviate by less than 3 dB over most of the frequency range. The frequency peak differences are somewhat more pronounced at the far microphone. Again the farther range data show more variability than those at the closer range. It is difficult to deduce a physical mechanism at the

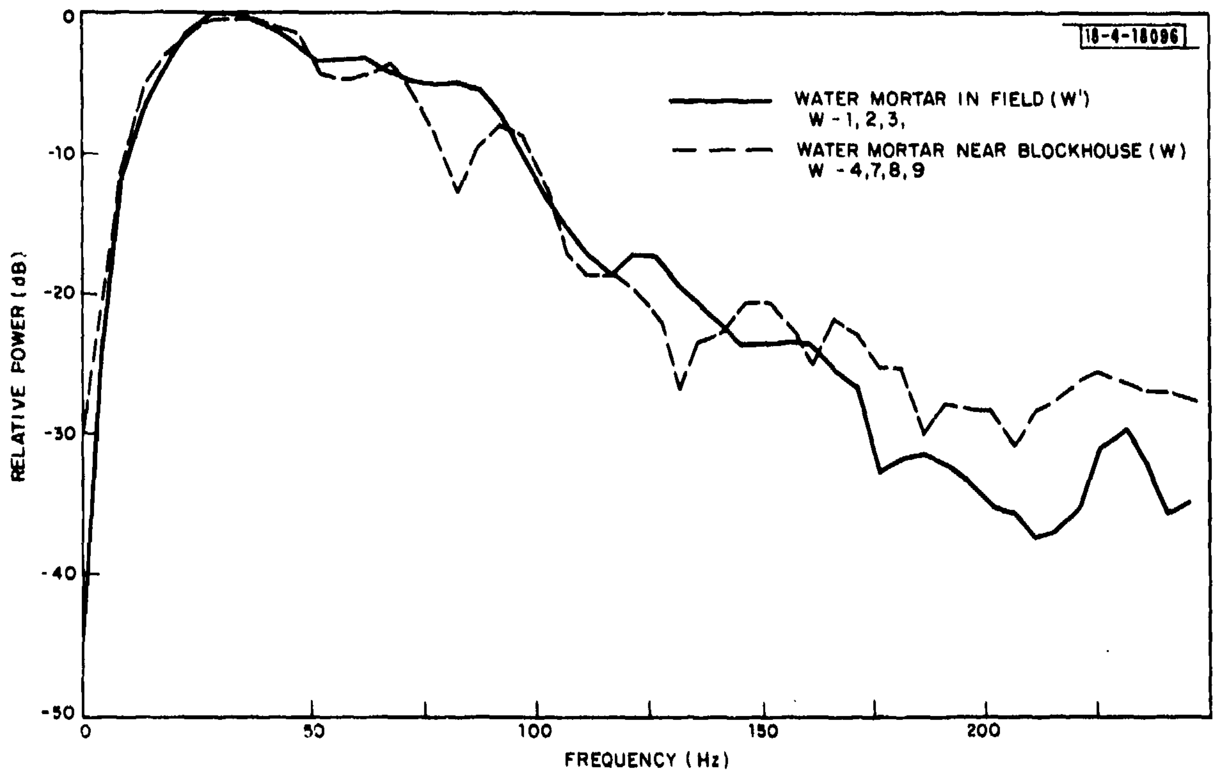

FIG. 14. Average spectra comparison, water mortar position - 4 Nov. data (near microphone)

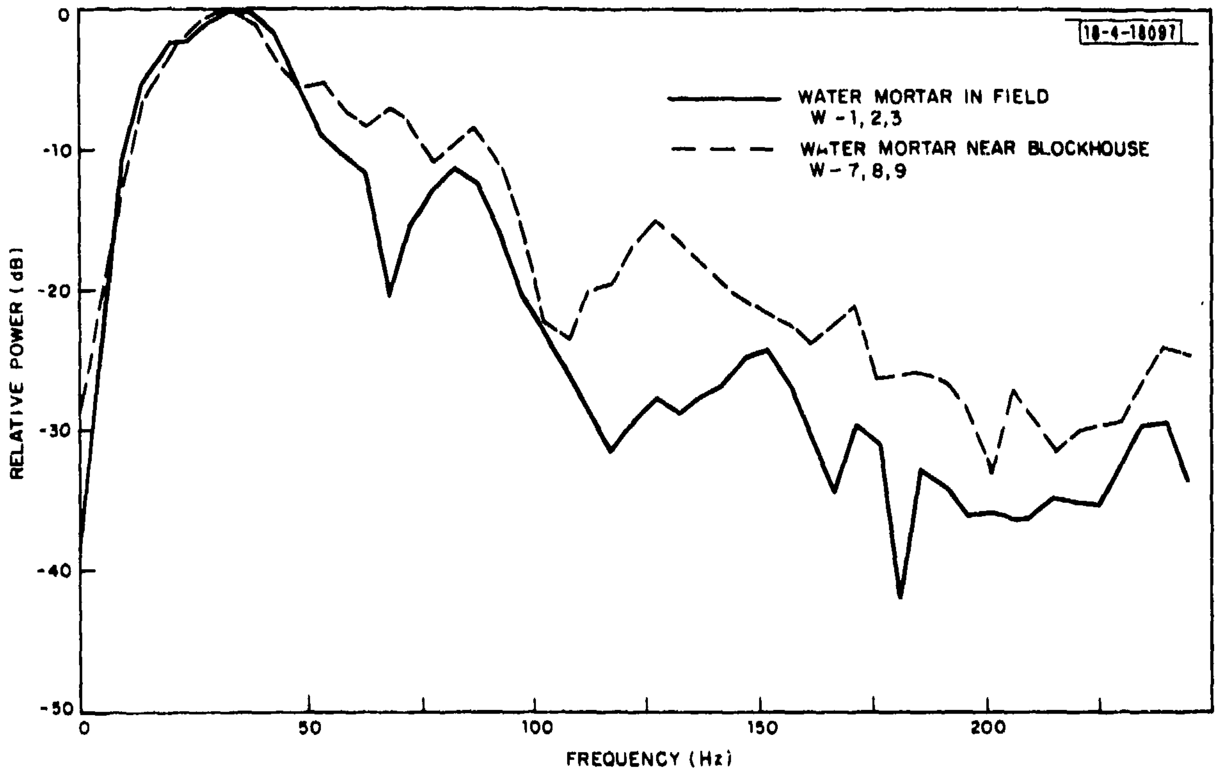

FIG. 15. Average spectra comparison, water mortar position - 4 Nov. data (far microphone)

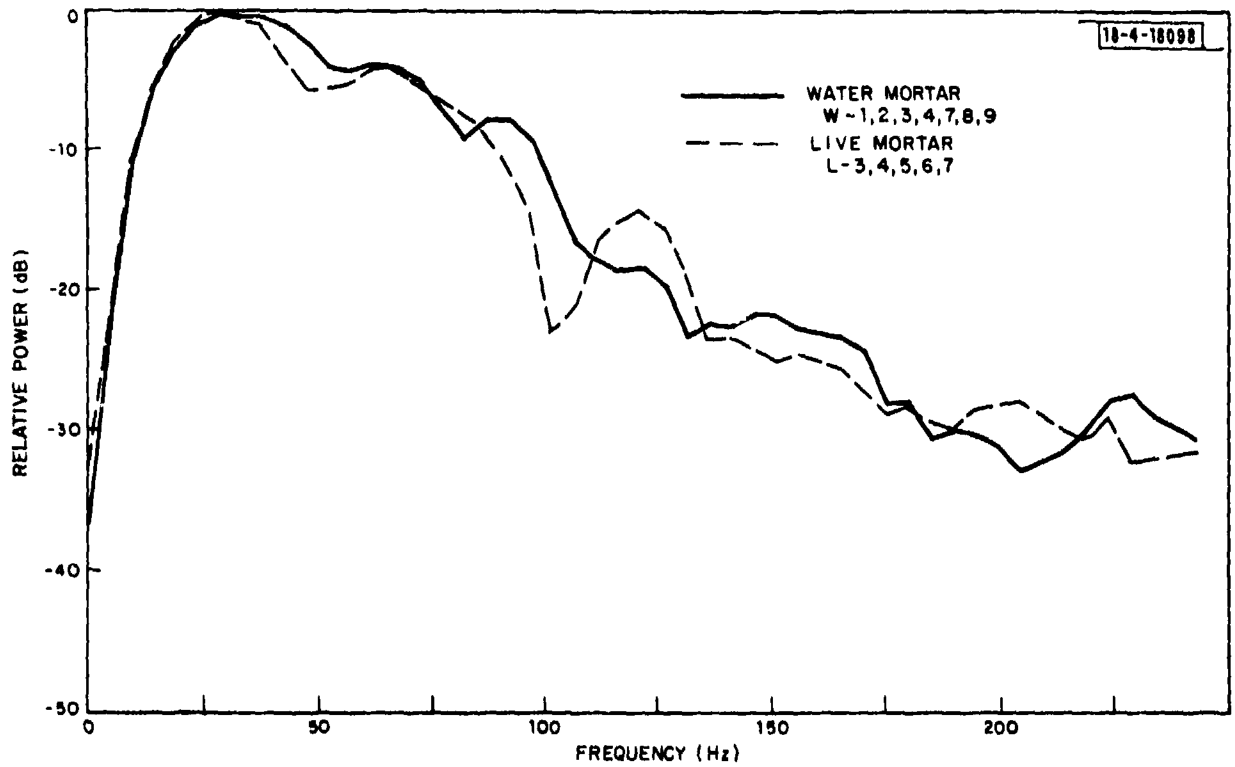

FIG. 16. Average spectra comparison, live vs. water - 4 Nov. data (near microphone)

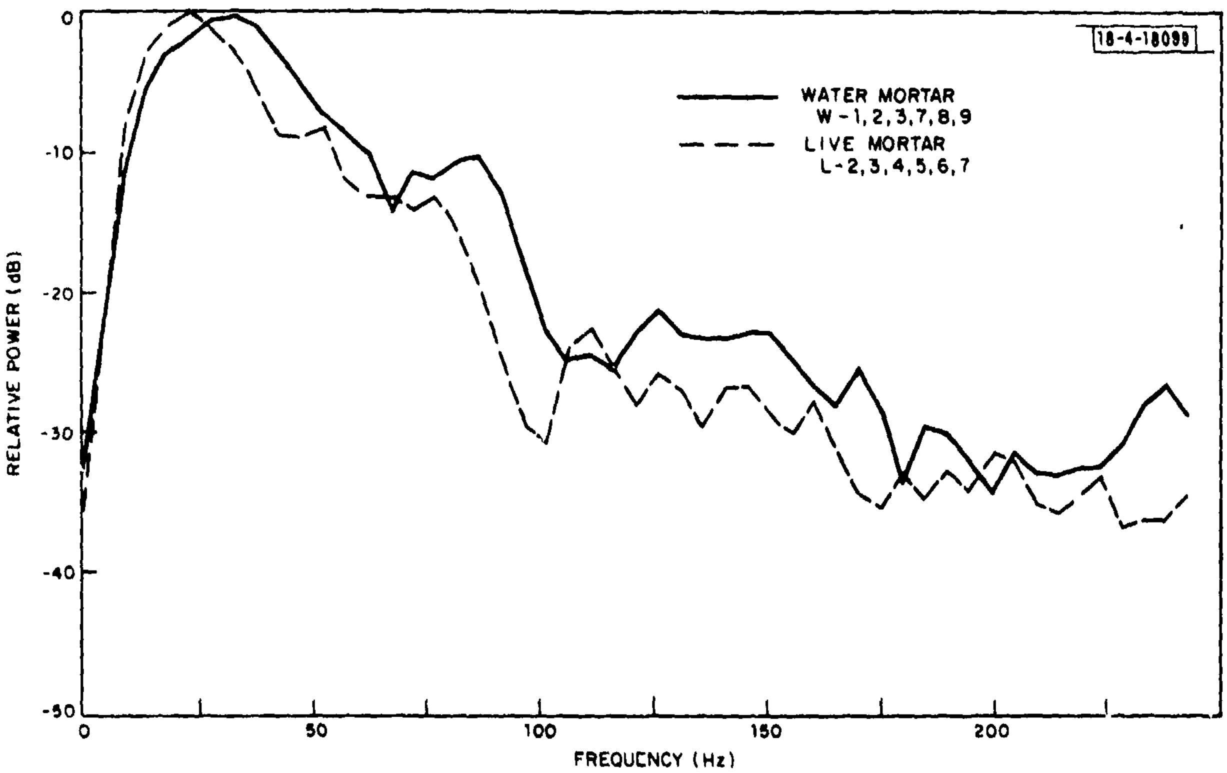

FIG. 17. Average spectra comparison, live vs. water - 4 Nov. data (far microphone)

source which would create similar signals at 1.1 km and different characteristics at 1.7 km. Thus it is felt that any differences at the longer ranges are due mainly to atmospheric effects which the averaging still fails to remove.

Similar results are obtained from the data recorded on the second day of shooting (5 Nov.). These are shown on Figures 18 and 19. The propagation conditions were more favorable and tended to produce less high frequency attenuation on this day. The near microphone used on this day was a dynamic microphone with a higher low frequency cutoff. Thus, the data shown on Figure 18 has a steeper roll off below 25 Hz. This will be discussed in more detail below. As before, the signals are more nearly alike at the near microphone. The far microphone data show more variability than before due to the ensemble sample size (3 shots vs. 6 previously) used for the average. As before, the water mortar has a slightly higher frequency peak in both the near and far signals.

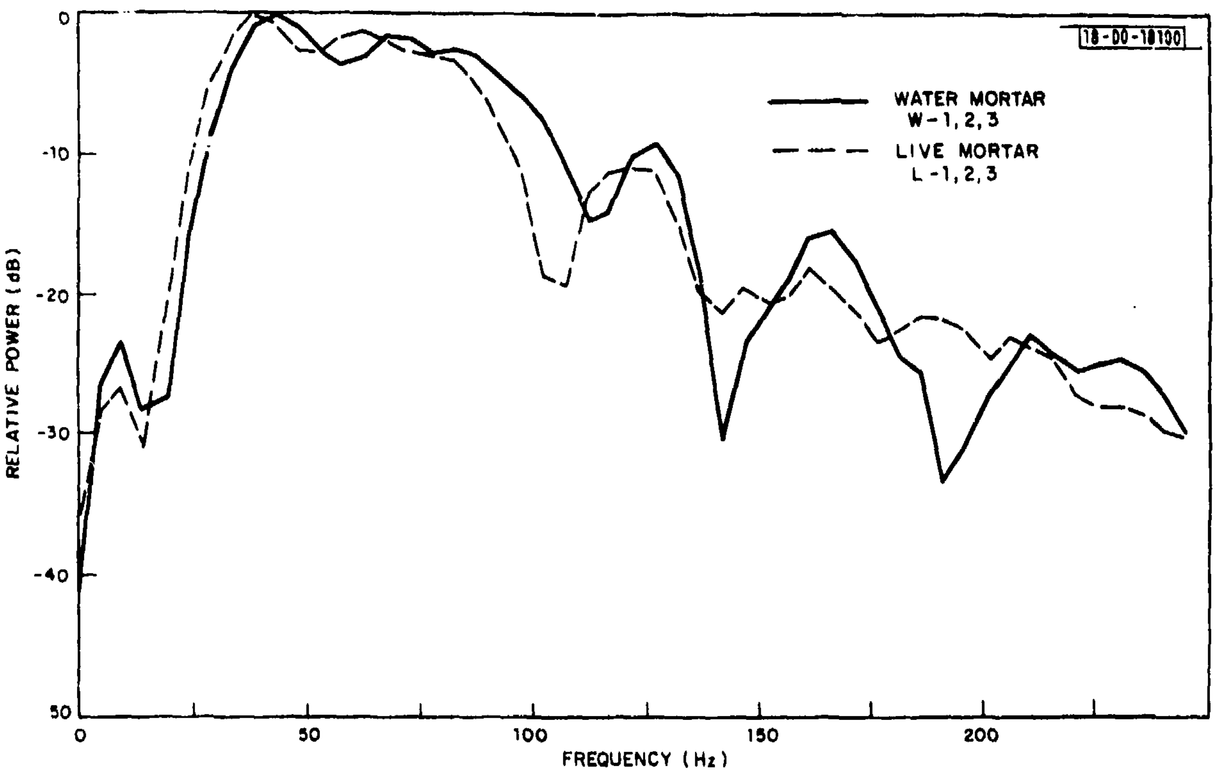

FIG. 18. Average spectra comparison, live vs. water - 5 Nov. data (near microphone)

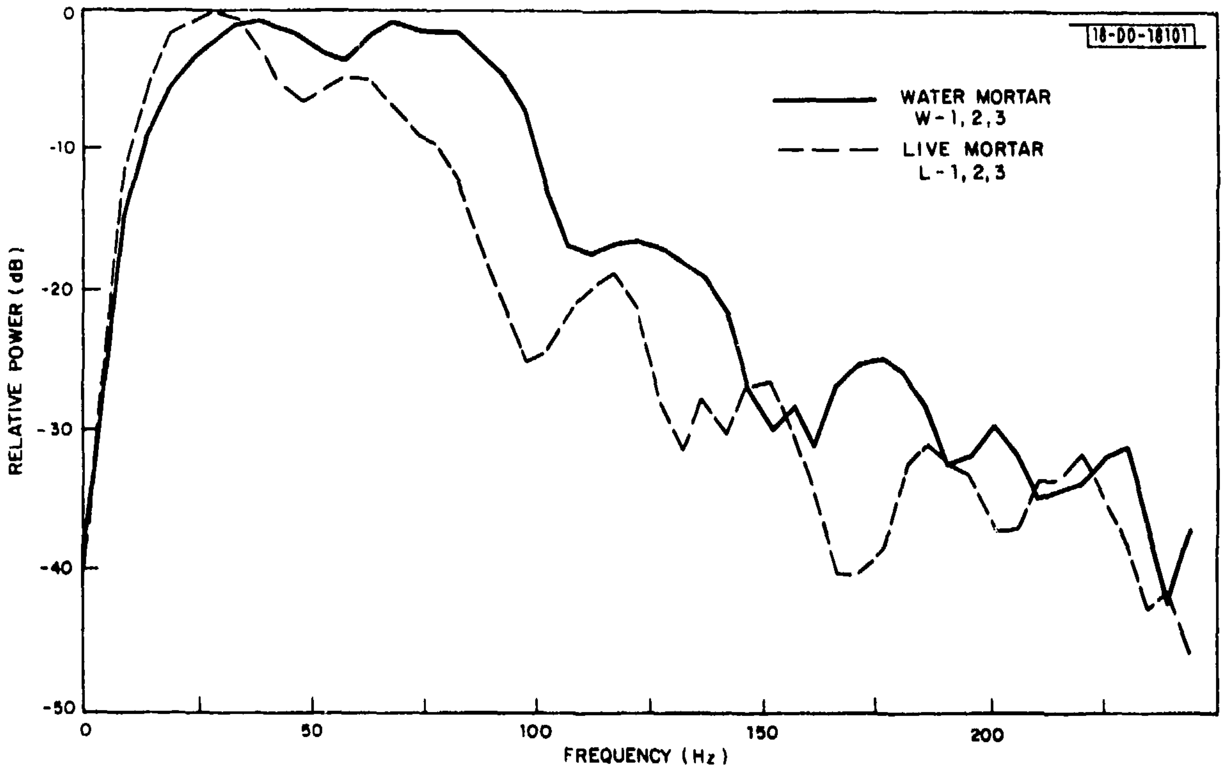

FIG. 19. Average spectra comparison, live vs. water - 5 Nov. data (far microphone)

V. OTHER RESULTS

Several experimental variants were analyzed in order to lay some groundwork for the main measurements exercise. These are discussed below.

A. Microphone Type

Two microphone types were available for this experiment and for the main exercise. The first was a dynamic microphone. This microphone is more rugged and somewhat easier to use, but has a response curve which begins rolling off at about 40 Hz. The second type available was a laboratory grade capacitor microphone with a flat response to roughly 20 Hz. The capacitor microphone is more sensitive but is much less rugged and is sensitive to moisture. In addition, the capacitor microphone requires a polarizing voltage supply of 200 volts.

Both microphone types were fielded; during most of the measurements signals from both were recorded at each position. Typical time waveform results are shown on Figure 20. The higher low frequency cutoff acting on the signal whose major spectral component is near the cut-off produces an approximate time differentiation of the signal. The FFT produced spectra for these two microphones is shown on Figure 21. Above the roll off point (where the responses are nearly identical) the results are very similar. The differing low frequency response character is obvious. The corrections at low frequency to the dynamic microphone results which are indicated were derived from the manufacturer's nominal specification sheets for the two microphones.

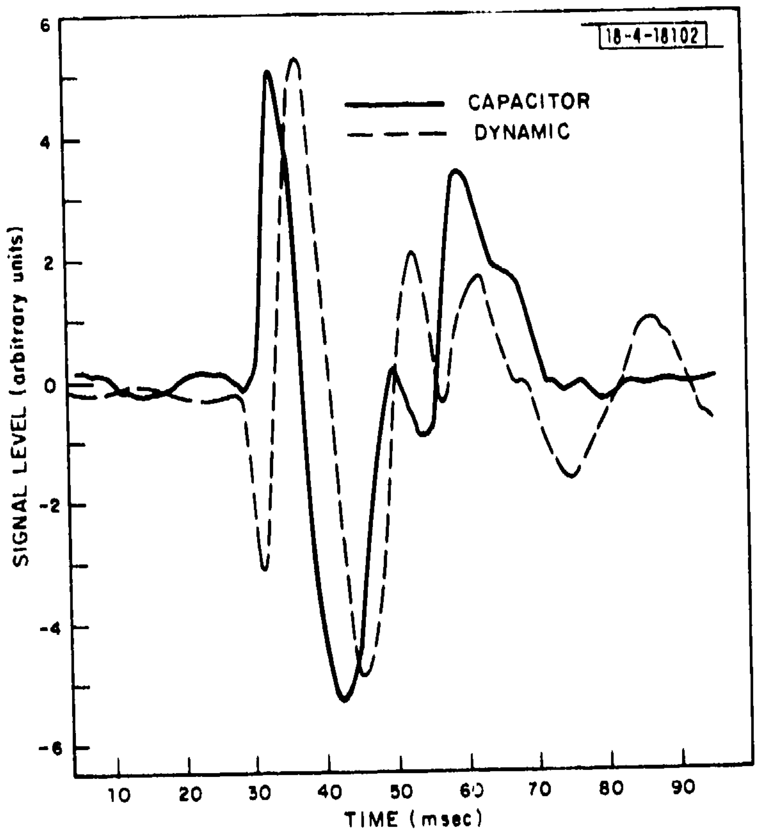

FIG. 20. Microphone type comparison - time waveform (Live Shot 6)

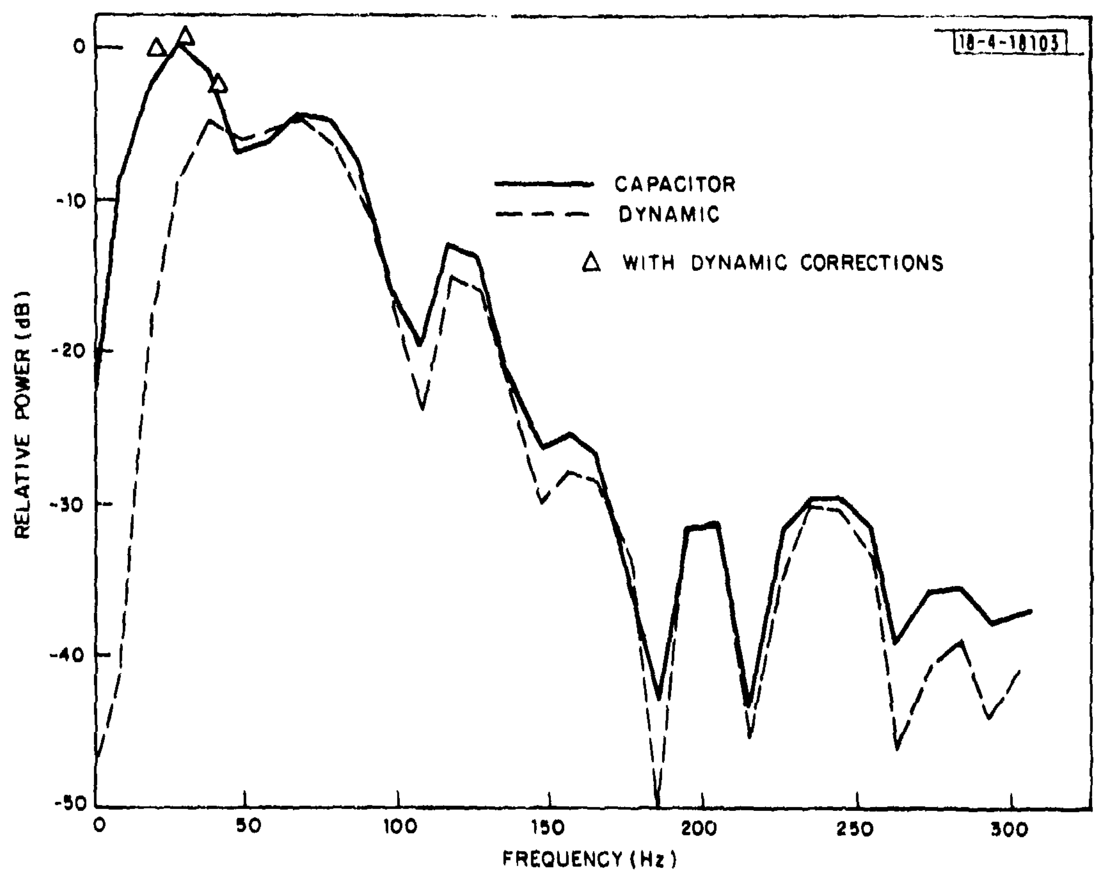

FIG. 21. Microphone type comparison - spectral comparison (Live Shot 6)

B. Amplitude Variability

It was evident during the measurements that significant shot-to-shot amplitude variations are observed during dynamic atmospheric conditions. On the first day of firing it was necessary to change gains often in order to obtain recordings with good dynamic range. At times signals were over recorded in this process. In addition this process introduces uncertainties as to what gain settings were used when many changes are made. The absolute SPL results for the first day of shooting are unknown for some shots because of the changes which were made.

During the second day the atmospheric conditions were more stable and greater care was taken in recording gains. Thus the changes from shot-to-shot can be determined. The SPL of the six shots on 5 Nov. are shown on Fig. 22. It is interesting to note that over the roughly two hour period the intensity as recorded at the near microphone increased while that at the far microphone decreased. In addition, one would expect a roughly 5 dB difference due to spherical spreading loss between the two ranges. While this is approximately true at the outset of the day's shooting, the difference is more nearly 15 dB at the end of the shots. The shots were all taken during late morning under a warming trend. The conditions were favorable for the formation of a shadow zone and this may explain the intensity variations. A comparison of the live and water mortar intensities shows little difference.

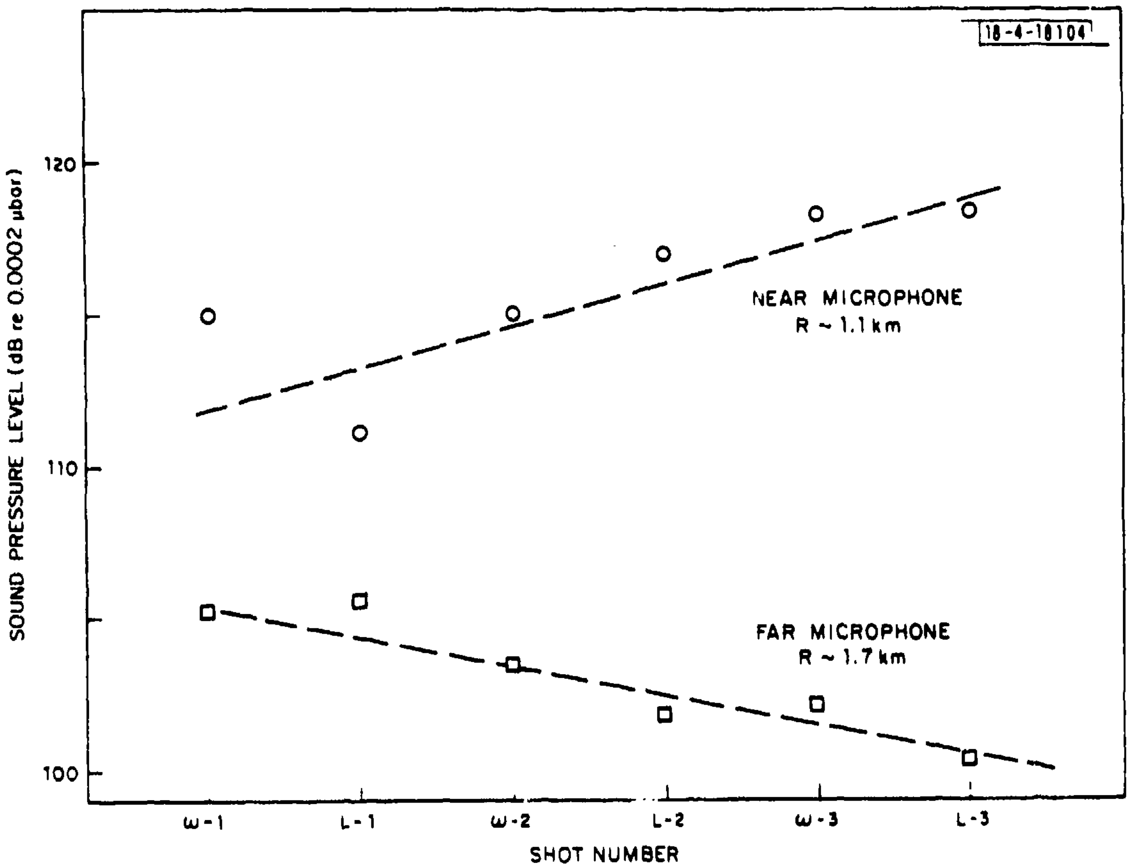

FIG. 22. Shot sound intensity - 5 Nov. data

VI. CONCLUSIONS

Several conclusions which have ramifications for the main measurements program can be drawn from the analyses and experiences during this effort.

A. Water Mortar Validity

The water mortar produces a signal which is very similar to that of a live 4.2 inch mortar. The observed acoustic power levels are nearly identical. Although the water mortar spectra show a slightly greater high frequency content this is not deemed a significant factor. The lower cost, greater flexibility and ease of operation of the water mortar clearly indicate the desirability of using the water mortar for the main measurements.

B. Microphone Choice

The spectral content observed during these measurements indicates that a microphone response down to 20 Hz is needed in order to faithfully record the longer range data. The dynamic microphones are, therefore, not well matched to the recording of this signal. Although the capacitor microphones are more difficult to use, especially in a field operation, their good low frequency response clearly dictates their use for the main exercise.

C. Recording Dynamic Range

The large variabilities encountered in atmospheric propagation and the normal range induced variations in the signal levels require good dyanmic range recording. It was found to be undesirable to change gains often since this can cause questionable data. It would be good to use a wide dynamic range (> 50 dB) digital technique to provide faithful recording and measurement ease.

D. Sample Rate

A digital recording scheme with 4 kHz sampling was designed for the main measurements effort. The spectral content of the signals recorded during this work indicates that this rate provides a more than adequate representation of the signals.

APPENDIX

Subsequent to the measurements described in the body of this report, additional data was taken comparing the signatures of the three water mortars to be used in the main measurements efforts. The three mortars were co-located at a range of approximately 1 km from the recording site. The mortars were fired in a volley mode using the digital recording system to be used in the main recording effort. After firing and recording the first mortar, the second was fired and recorded, etc. A total time span from first to third mortar of approximately 2 minutes was achieved. Besides providing data for a comparison of the three sources, the exercise allowed a validation of the recording technique.

Five volleys of three shots each were fired during a two hour time span. Two individual shots were not recorded due to recording system errors. The remaining shots were analyzed as discussed earlier. Figure A-1 illustrates the resultant spectral averages for the five volleys. The spectral differences are very slight. The sound pressure levels at 1 km from the sources are shown on Figure A-2. For most of the shots, the levels from the three mortars are within 1-2 dB of each other.

Based on these results, it is evident that the three devices are very similar and that no uncertainties will be encountered due to source differences. In addition, the planned recording technique was found to function well and to provide the requisite sampling rate and dynamic range. The two shots which were not recorded were due to errors in setting up the recording parameters and not due to recording system failures.

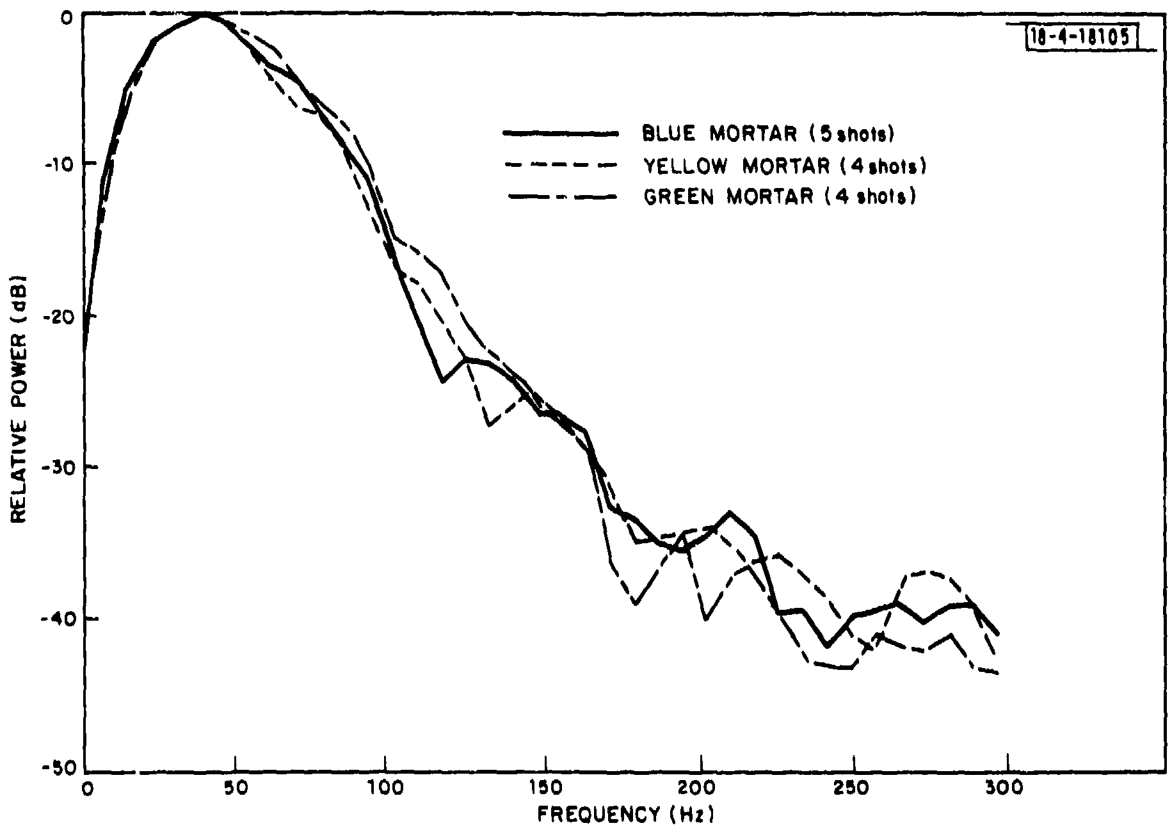

FIG. A-1. Water mortar spectral comparison

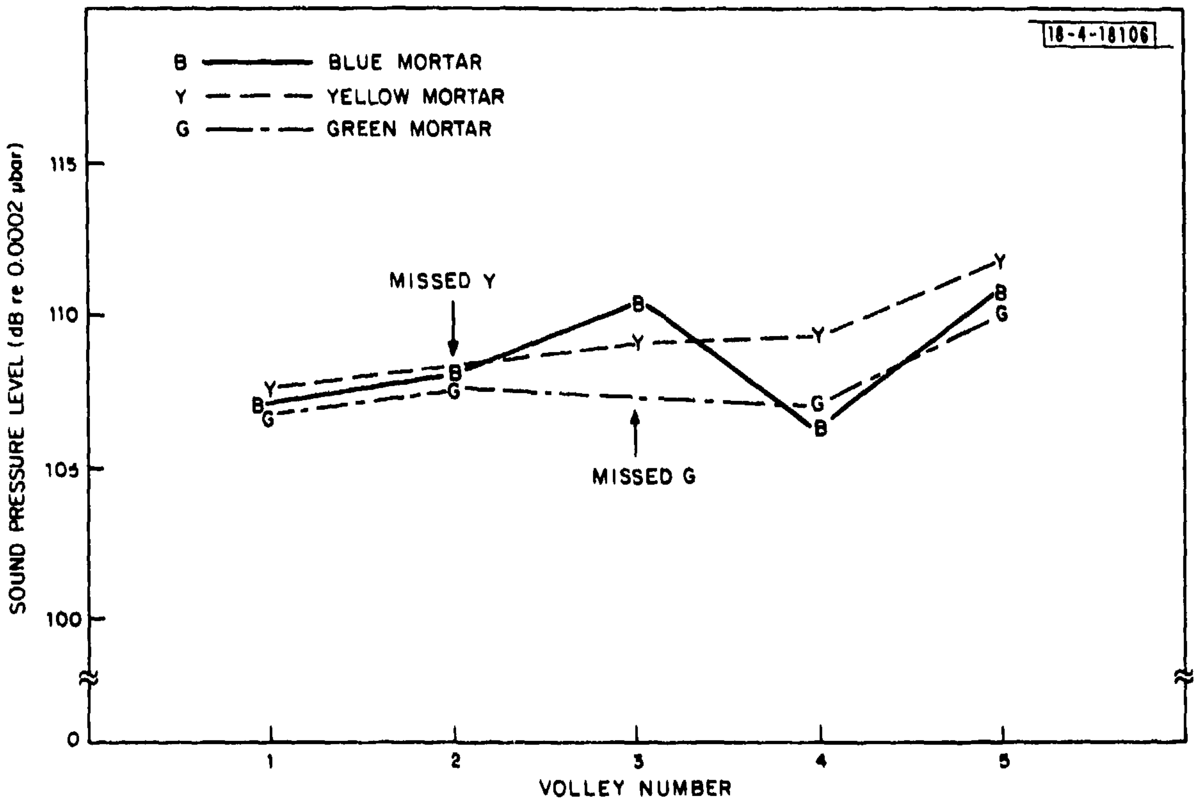

FIG. A-2. Comparison of water mortar sound pressure levels

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The measurements reported herein were performed by the Environmental Research Institute of Michigan and the analysis of the data was done at Lincoln Laboratory. The mortar substitute described in this report was developed by ERIM for seismic work. Comments and suggestions on the use of this device for acoustic studies by Dr. John Hemdal and Dr. Roger Turpenning are appreciated. The assistance of Messrs. J. Adams, L. Leverault and F. Tanis during these measurements is gratefully acknowledged.

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This report discusses the investigation of a sound source for studies of acoustic array techniques for the determination of firing weapons. A device which simulates the muzzle blast signals from 4.2 inch mortars was considered. In this device, a modified 4.2 inch mortar, the shell is replaced by a cardboard tube containing a weight of water equivalent to the round weight. Use of this device relaxes the normally stringent safety requirements associated with mortar firings and reduces per round cost to roughly one-tenth that associated with mortar firings.

Recordings were made of the water mortar and a standard 4.2 inch mortar sited side-by-side with microphones at ranges of 1.1 and 1.7 km. The spectral content of the two signals was determined using Fast Fourier Transforms. The results indicate great similarities between the signals from the two sources.

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