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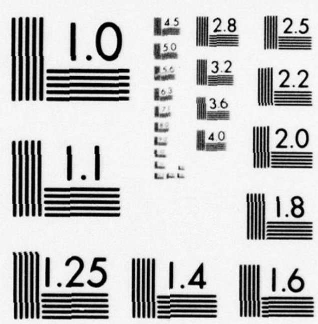

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PREINSTALLATION SURVEY GUIDE FOR MAID-MILES SYSTEM

by

Charles A. Miller

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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Final Report

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Prepared for Sandia Laboratories
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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The study ~~reported herein~~ was conducted to investigate various field techniques to be used to identify the seismic response of the MAID-MILES system at a site. This report also presents a description of the steps needed to perform a preinstallation seismic survey for the MAID-MILES system. The general purpose of this survey is to determine the suitability of an installation for the deployment of the MAID-MILES system. This survey is designed to be used by the engineering personnel available at Department of Energy (DOE) installations. (Continued).

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CONT

Two transducer systems were investigated and field tested in this study. The first system consisted of a short length of MILES cable (10 m) having electrical connections equivalent to the standard length cable. The second system consisted of four surface-emplaced geophones connected in a series-subtracting array and adjusted by a series-variable resistor. Field tests showed that the short cable system has essentially the same response as the standard length cable and the geophone array system provides a reasonable simulation of MILES cable response to both intruders and background noise sources.

A guide for the conduct of a preinstallation seismic survey for the MAID-MILES system is presented. In this survey, initial information would be obtained from a mapping study and field reconnaissance and final indications of problem areas would be obtained by a MAID-MILES performance survey using a MAID-geophone array and a MAID-short cable system. The guide also recommends a postinstallation survey by which areas of unsatisfactory MAID-MILES performance would be located after a standard MAID-MILES system is deployed.

Appendix A contains a description of the "calibrated creeper," a pendulum device used in the test program to provide a controlled source of seismic energy.

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PREFACE

This study was sponsored by Sandia Laboratories, Albuquerque, New Mexico, under Purchase Order No. 05-4855 having the project title, "Development of Preinstallation Survey Guide for Perimeter Seismic Sensors." This study was also conducted in support of the U. S. Army Material Development and Readiness Command in furtherance of Department of the Army Project No. 4A762730AT42 A4/E3/001, "Analytical Techniques for the Design of Environmentally Insensitive Seismic and Acoustic Sensors." Certain equipment and facilities were used in cooperation with the Program Office, Base Installation Security Systems, Hanscom Air Force Base, Bedford, Massachusetts.

The work was conducted at the U. S. Army Engineer Waterways Experiment Station (WES), CE, during the period January 1977 to September 1977 under the general supervision of Messrs. W. G. Shockley, Chief, Mobility and Environmental Systems Laboratory, B. O. Benn, Chief, Environmental Systems Division (ESD), and Dr. L. E. Link, Chief, Environmental Research Branch (ERB). Project manager was Mr. J. R. Lundien, ESD. Project leader was Mr. C. A. Miller (ERB). Other personnel making contributions to this study were Mr. M. Carlson, Earthquake Engineering and Vibrations Division, Soils and Pavements Laboratory, who aided in the conduct of the field data collection and Dr. D. H. Cress, ERB, who provided technical assistance. This report was prepared by Mr. Miller.

The organization of laboratories underwent a structural change since this study was conducted. Organizations and individuals listed above as incremental to the Mobility and Environmental Systems Laboratory are now engaged under the Environmental Laboratory, Dr. John Harrison, Chief. Mr. Carlson is now engaged under the Geotechnical Laboratory.

Commander and Director of WES during this work and preparation of this report was COL J. L. Cannon. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, METRIC (SI) UNITS TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Metric (SI) units of measurement in this report can be cor[illegible]ted to U. S. customary units as follows:

Multip[illegible]	By	To Obtain
centimetres	0.3937007	inches
metres	3.280839	feet
grams per cubic centimetre	0.0361273	pounds (mass) per cubic inch
newtons per cubic metre	0.0063659	pounds (force) per cubic foot
microbars	0.002089	pounds (force) per square foot
metres per second	3.280839	feet per second
kilometres per hour	0.6213711	miles (U.S. statute) per hour
Celsius degrees	1.8	Fahrenheit degrees*

* To obtain Fahrenheit (F) temperature readings from Celsius (C) readings, use the following formula: F = 1.8(C) + 32.

PREINSTALLATION SURVEY GUIDE FOR MAID-MILES SYSTEM

PART I: INTRODUCTION

Background

1. The use of buried line intrusion detection systems such as the MAID-MILES system has become a common method for providing basic perimeter intrusion detection around areas containing high value assets. The MILES (Magnetic Intrusion Line Sensor) is a specially designed cable used as the transducer for the system; the intruder alarms are generated by the MAID (Magnetic Anti-Intrusion Detector) processor. The MAID-MILES system is intended to detect personnel moving within two metres of the cable and to reject far-field seismic background noise.

2. The MILES cable is a shielded coaxial cable with an inner core of stranded heavy gauge Permalloy wire having magnetostrictive properties. Surrounding the core is a continuous coil of copper wire which is electrically insulated from the core and the outside shielding. During operation, an electrical current is induced in the coil of wire due to either tension loading of the cable which causes a change in the magnetic flux of the core or by changes in magnetic fields external to the cable. The tension loading of the cable is caused by transient displacements in the media (soil) surrounding the cable. As an intruder travels in the vicinity of the cable, each footstep generates soil displacements radiating away from the foot in all directions in the ground. One component of these displacements will produce a transient tension loading on the cable. To suppress the response of the cable to background seismic energy, the direction of the sensing winding is reversed at regular intervals. These transpositions have a typical spacing of 1.05 m. Previous studies have shown that within the frequency limits of the MAID processor (i.e. less than 5 Hz) the transducer output is dependent on the frequency and amplitude of the tension loading on the cable.*

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* Starr, J. B., "Energy Propagation and Coupling Studies for Line Transducers," Final Technical Report, USAE Contract F30602-75-C-0186, August 1976, RADC-RE-76-239, (A031741).

3. Although the MAID-MILES system usually provides reliable information regarding intrusion detection with low false alarm rates, there have been some instances where the system has not operated properly. In some cases the passing of an intruder over "dead areas" along the cable has not activated an alarm, and in other cases various types of background noise have generated unacceptable false alarm rates. Since the sensitivity of cable varies with the properties of the media in which it is deployed, variations in detection distance and response to background noise occur at different installations. In the case of the MAID-MILES system, detection distance is defined as the maximum perpendicular distance from a source to the cable that will cause the MAID processor to consistently generate a single alarm during each intrusion.

4. The variations in response of MILES cables to targets at various installation sites are usually attributed to one or a combination of the following three factors:

a. Nonuniformity in the emplacement of the cable

b. Nonuniformity in the fabrication of the cable

c. Variations in the soil stiffness

Nonuniformity in the emplacement of the cable includes inconsistent depth of burial or variations in the compactive effort applied to the backfill material. An example of the nonuniformity in the fabrication of the cable is variations in the residual magnetic field of the core material. Soil stiffness influences cable response since the amount of deformation of the core material is dependent on the total deformation of the surrounding material. This deformation is directly proportional to the applied load and inversely proportional to the shear modulus of the media.

5. The influence of background noise is usually attributed to:

a. Type (amplitude and frequency content) and location (range and orientation) of source.

b. Seismic characteristics of the propagating medium.

In the case of wind noise the term "location" may be defined as the direction in which the wind is moving.

6. The ability to anticipate cable performance prior to installation using a preinstallation survey would be extremely useful. The

nonuniformity in the emplacement and fabrication of the cable cannot be readily determined in a preinstallation survey, but it is anticipated that the preparation of more scientifically based emplacement specifications along with good quality control tests on the cable can significantly reduce cable and emplacement-induced malfunctions. Further, procedures for studying variations in local terrain conditions including soil stiffness and sources of background noise can be developed and applied to provide a basis for optimizing the total intrusion detection system performance. The preinstallation survey technique should provide a rapid and precise determination of the suitability of the soil for MAID-MILES installation and delineation of problem areas along the perimeter where other types of security may be needed to supplement this system. Also, a means of determining the amount of local seismic background activity which interferes with the normal seismic operation of the sensor system should be included. Finally, the survey technique should use readily portable equipment that can be operated by personnel not intimately familiar with the collection of seismic environmental characteristics data.

Purpose

7. The purpose of the study reported herein was to define and evaluate a concept and equipment for use in preinstallation seismic surveys at sites where the use of the MAID-MILES system is contemplated.

Approach and Scope

8. The preinstallation survey concept developed for evaluation requires the completion of three basic steps. First, a topographic and soil map study is conducted to determine the general range of variation in terrain and background noise conditions at the site. The result of this study is a tentative selection of sensor routes along which seismic response measurements are to be taken. In the second step, a field reconnaissance is conducted to verify that the selected sites represent the full range of conditions and that the selection does not contain an

excessive number of similar sites. The result is a list that identifies each site to be investigated. The third step involves the conduct of expedient and precise field measurements that can be used to delineate perimeter areas where the MAID-MILES system will work well or poorly.

9. The selection and evaluation of equipment sets to be used in the third step received the most emphasis in this study. Two transducer systems, i.e. one each for the expedient and more precise systems, were investigated. The expedient transducer system consisted of an array of four geophones, and the transducer whose output could be more closely correlated with standard MILES cable consisted of a short length of MILES cable.

10. Part II of this report describes the equipment sets as well as the tests, test rationale, and test site conditions used to demonstrate their applicability in predicting the performance of the MAID-MILES system. Part III presents a brief discussion on how to make a preinstallation survey. Part IV contains conclusions of this study and presents recommendations. Appendix A describes the "calibrated creeper," a pendulum device used in the test program to provide a controlled source of seismic energy.

PART II: INVESTIGATION AND EVALUATION OF CANDIDATE PREINSTALLATION SURVEY SYSTEMS

11. Two candidate sets of equipment were investigated for use in preinstallation seismic surveys. The first set was a short length (10 m) of MILES cable that would be buried on site and connected to the MAID processor. The second set used surface-emplaced seismic geophones assembled in an array and connected to the MAID processor. The short length of MILES cable was selected because it was hypothesized that its output could be directly correlated with the output of the standard length (100 m) MILES cable. The disadvantage of its use was the necessity of burying the cable at test sites. The geophone array was selected to provide a more rapid method of measuring ground motion; however, the geophones' mechanism for sensing ground motion is unlike that of the MILES cable. Thus, it was not expected that the results from the geophone array would be as consistently correlatable to the standard MILES as the output of the short MILES.

12. The following paragraphs explain these equipment sets in greater detail, describe the field tests which were performed, and present the results of the tests.

Short MILES Cable Evaluation

Transducer description

13. The construction of the short MILES cable system is relatively simple. The standard MILES cable is 100 m in length, and to make a short MILES cable it is necessary to cut it to a 10 m length and make the proper connection (equivalent to the standard connections of the 100-m cable). The short cable consists of ten transposition sections (i.e. a 1.05-m section of cable bound at both ends by reversals in the sensing winding). A 1-m length of two-wire, flexible shielded cable is connected to the output end of the MILES cable. A three-pin female plug that fits the receptacle of the MAID processor is fixed to the other end of the flexible cable. The "A" and "B" connections of the plug are connected to the coil wire and the core of the cable, respectively,

while the "C" connection is affixed to the shield. At the other end of the short MILES cable, the coil wire (paragraph 2) is reconnected to the core with the shielding insulated from this connection. All connections are waterproofed with epoxy or a similar sealant.

Comparative Tests

14. Field tests were performed to compare the output of the short cable with that of the standard 100-m MILES cable under controlled ground motion conditions. Ground motion was induced using two mechanical devices developed to provide a repeatable stress on the ground surface. The first device is a drop hammer (Figure 1a) that has been calibrated to produce ground motion that corresponds quite well to that produced by a single footfall of a walking man.* The second device makes use of a pendulum attached to a portable frame (Figure 1b), that has been designed to generate ground motion similar to a man walking stealthily (creeping). A description of the pendulum device, referred to as the calibrated creeper, is presented in Appendix A. Cable output data from the tests during which the drop hammer was used consisted of recordings of the analog voltage generated by each of the cables. The output data from the tests simulating a creeping man (calibrated creeper) consisted of the number of MAID processor alarms as a function of distance (perpendicular to the longitudinal axis of the cable) from the pendulum to the cable. The test site, methods, and results are described in the following paragraphs.

15. Site description. The field tests were conducted at a site known as Brown's Farm, which is located approximately 8 mi southeast of the WES at lat. 32°16'04"N, long. 90°44'57"W. The soil at the site was a wind deposited clayey silt (loess), a common material found in this area. The seismic terrain characteristics tests which were conducted at this site indicated a deep homogeneous material having a compression wave velocity of 300 m/sec, a shear wave velocity of 125 m/sec, and a wet density at 10 cm of 1.90 g/cm^3. Vegetation consisted of various grasses which were cut to a level of 4 cm during periods of testing.

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* Link, L. E., West, H. W., and Benn, B. O., "Seismic and Environmental Characteristics of the Sensor Test Areas in the Panama Canal Zone," Technical Report M-72-2, Report 1, Jun 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

16. Installation. Both cables were installed using the standard procedures prescribed for the standard MILES cable. A 100-m and a 10-m cable were installed in parallel trenches at a depth of 23 cm with 5 cm of sand above and below the cables. The distance between the cables was 50 cm (Figure 2). The trenches were backfilled with clayey silt, which was then compacted with hand tampers. Final compaction was made by making several passes with the wheels of a 1/2-ton commercial pickup truck on the backfill material. A period of five weeks was then given to allow for further settlement before the comparison tests were made.

17. Drop hammer tests. As shown in Figure 2, the tests which employed the drop hammer were conducted by activating the instrument twice at ten corresponding locations directly over the long and the short cables (i.e. 40 recordings were made). The voltage output of each cable was amplified (SIE, Incorporated, Model 44-DC amplifiers) in such a way that the voltage gain settings for all tests and each cable were identical. The amplified signals were recorded using an AC-powered strip chart recorder (Consolidated Electronics, Incorporated, Model 124, Oscillograph).

18. Figure 3 shows a comparison of the 10- and 100-m MILES cable outputs for drop hammer tests. This comparison shows that there is no significant difference in the drop hammer-generated waveform recorded from the 100-m and 10-m cables. It is also readily apparent, however, that considerable variation exists in the peak amplitudes of the signals recorded from both the cables. To verify similarity of cable output, it was necessary to determine if the signal amplitude variation in the 10-m cable is the same as that observed in the 100-m cable. For the comparison of the peak signal outputs of the long and short cables, the maximum displacement (cm) of each drop hammer-generated signal was measured directly from the oscillograph and tabulated. From this tabulation, the maximum peak signal measured (i.e. the signal from the 100-m cable obtained from the first hammer drop at Station 7) was used to normalize each peak signal value to a percentage of the maximum signal. Figure 4 presents a comparison of the normalized peak signal levels of the long and short cables with respect to the location of the drop

hammer activation. The plot illustrates that the variation in output levels of both the long and short cables as a function of the location of the signal source along the cable (i.e. 15 to 100 percent) was approximately 85 percent of the maximum signal recorded. This range of variation in response for MILES cables is not uncommon; it illustrates that a direct comparison of a 100-m cable output with that of a single output of the 10-m cable would not be meaningful. For this reason, further comparison of the two data sets was made by calculating their mean and standard deviations (see Table 1).

19. The results column of Table 1 shows only a small difference in the means of the peak signal amplitudes of the two sets (i.e. 5 percent). This is well within the standard deviation of each set (27 and 26 percent), suggesting that the signals from both cables came from the same population. These results also indicate that since there is a difference in individual signals and the similarity of the data sets must be statistically measured, it will be necessary to take several (at least 5) measurements along the short cable to provide an adequate basis for predicting long cable performance.

20. Calibrated creeper tests. The calibrated creeper was used to compare the distance of detection (MAID alarms) of the standard and the short cables. This was accomplished by positioning the creeper at known perpendicular distances from each cable and tabulating the number of MAID alarms obtained when the pendulum was allowed to swing for 30 sec. The device was positioned so that the pendulum moved directly toward and away from the cable. The maximum detection distance was defined as the perpendicular distance (cm) from the closest creeper pad to the cable that would consistently activate a single alarm during each of five 30-sec tests. Data were obtained for six locations along each cable.

21. The results of the calibrated creeper tests are also presented in Table 1. The comparison of maximum, minimum, and average detection distances for both transducers shows an excellent agreement between the MAID processor responses to the long and short cables from ground motion similar to that caused by a creeping man. This comparison further

confirms that the short cable can be used to gather data to project how the 100-m cable would perform.

Geophone Array Evaluation

22. The second set of equipment investigated for use in preinstallation seismic surveys was commercially available ground motion transducers (geophones). Although there are some basic differences in the phenomena by which the MILES cable and geophones produce electrical signals, both rely on transient, elastic movements in the soil induced by loads acting upon the soil surface. A geophone system, if capable of providing a reasonable simulation of MILES cable response to a MAID processor, could be used most expeditiously in a preinstallation survey because it can be readily installed at a measurement site. Also, it has been demonstrated that geophones can be designed to be rugged field devices, and therefore, a geophone system can be expected to be relatively maintenance free.

23. As stated in paragraph 2, a predominant feature of the MILES cable is the construction of transpositions to suppress far-field background noise. Also, the cable is a line transducer that can respond to a signal source over its entire length. Since a geophone is a point sensor, it is not capable, individually, of suppressing far-field energy in the same manner as the cable. However, a linear array of geophones can be arranged in a manner which will cancel out far-field signals and simultaneously respond to ground motion sources at various locations along a line (Figure 5).

24. In an attempt to make a geophone array that would generate an output similar to the MILES cables, the geophones were placed in a straight line with a spacing equivalent to the distance between transpositions of the MILES cable (1.05 m). Also, the transducers were electrically connected in a series-subtracting fashion (alternate positive and negative terminals connected) to correspond to the transposition points in the cable. Theoretically, a far-field signal will be sensed by all geophones, and if they have the same sensitivity (volts/cm/sec),

the signal will cause each of the transducers to output equivalent waveforms of equal amplitude. Since the transducers are in a voltage-summing network, the far-field signal will nearly cancel and the net output will be considerably smaller than the output sensed by the individual geophones. However, the geophone closest to a near-field signal will sense a signal amplitude that is significantly different from that of the other geophones in the array, thus providing the means for generating an output in a manner similar to the cable.

25. The output voltage generated by an identical source will not be the same from the geophone array as from the cable due in part to the fact that the cable is sensing the ground motion at a depth of 23 cm, whereas the geophone is sensing it at the ground surface. Also, there is considerable difference in their sensitivities and frequency response. Because of differences between the MILES cable and the geophone array system, feasibility tests were conducted to determine if the geophone array system would produce signal waveforms comparable to the output of the MILES cable. A calibration test was then conducted to adjust the response of the geophone array network so as to achieve similar MAID processor alarms from the geophone array system and the MILES cable. The final step consisted of verification tests in which the response of the geophone array system was compared with MILES cable response at three sites having a variety of terrain (soil stiffness) and background noise conditions. The feasibility, calibration, and verification tests are described in the following paragraphs.

<u>Feasibility tests</u>

26. <u>Site description</u>. The feasibility tests were conducted at a site at WES (lat. 32°18'23"N, long. 90°51'14"W) at which numerous MILES cable tests have been conducted.

27. The natural soil at this site consisted of essentially the same type of deep clayey silt (loess) found at the Brown's Farm site described in paragraph 15. Seismic wave velocity tests showed that the material had a compression wave velocity of 350 m/sec and a shear wave velocity of 135 m/sec. The vegetation at the site consisted of short grasses and a wooded area having trees with an average height of approximately 15 m.

28. System construction and installation. The feasibility tests were performed using five Mark Products, Inc., L-1-3D, 1-Hz ground-emplaced geophones (scientific geophones) and necessary equipment for recording the outputs of the five transducers and a MILES cable on magnetic tape. The MILES cable consisted of a 10-m length of cable installed at a depth of 23 cm with 5 cm of sand above and below the cable. The cable was installed in the same manner as that used at the Brown's Farm site (paragraph 16). The geophones were installed 30 cm west of the MILES cable and were placed 1.05 m apart, at points corresponding to the center distance between the transpositions of the cable (see Figure 6). The geophones were positioned along the center portion of the length of the cable to negate the possible influence of end effects during testing.

29. Test procedures. In the feasibility tests, analog signals were simultaneously recorded from the vertical component of the five individual geophones and from the 10-m MILES cable. The transient load sources included the drop hammer, the calibrated creeper, and a man creeping parallel to the cable. The pendulum device was oriented so that the mass moved parallel to the cable to obtain data comparable to the man-creeping tests. The orientation of the pendulum and the man creeping parallel to the cable is a deviation from orientation of the signal source in the short-line tests (paragraph 20). This orientation was selected as the most appropriate way to get the needed signal source repetitions (paragraph 19) at a constant distance. As shown in Figure 6, the man creeping and pendulum tests were performed with the sources located at equal distances from the line of the geophones and the cable, while the drop hammer tests were made at a 2.3-m distance from the cable. To negate the possible influence of the magnetic sensitivity of the cable, no metal objects were worn by the person performing the man-creeping test.

30. Data analysis. To make a comparison of the geophones and the MILES cable, the individual geophone signals were applied to a low-pass filter network and then alternately added and subtracted in a summing network (see Figure 7). The filter network was used because it was

desirable to compare only the waveforms that would most influence the MAID processor (low-frequency information). An 80-Hz low-pass filter was used in the reduction of the drop hammer data since the main portion of the input energy of this device is above 12 Hz. A 5-Hz filter was used to reduce the pendulum and the man-creeping data. The resultant signal was the summation of the alternate positive and negative polarity signals of the consecutive geophones along the array. As explained in paragraph 24, this series-subtracting concept was used to provide a simulation of the basic mechanical nature of the MILES cable. The MILES cable signals were applied to equivalent low-pass filter networks for the drop hammer, pendulum, and the man-creeping data, respectively.

31. Feasibility tests results. The results of the feasibility tests are shown in Figures 8, 9, and 10 for the drop hammer, the pendulum, and the man creeping, respectively. The comparisons showed that a series-subtracting geophone array is capable of providing a waveform response somewhat similar to that given by the MILES cable. On this basis it was hypothesized that the geophone array output processed by the MAID processor may give a response similar to the MILES cable, provided the amplitudes of the two transducer outputs could be made similar over a wide range of soil conditions. To accomplish this, additional tests, referred to as calibration and verification tests, were run.

Calibration test

32. Site description. The calibration test was conducted at the same WES test site at which the feasibility tests were performed. Paragraphs 26 and 27 present a general description of this site.

33. System construction and installation. In the calibration tests, more rugged equipment was used than in the feasibility tests. Four Mark Products, Inc., Model L-1-4, surface-emplaced geophones were used. These geophones have a resonant frequency of 4.5 Hz.

34. Figure 11 is a schema of the connections made for the geophone array system used in the calibration tests. This schema has essentially the same appearance as Figure 5 except four geophones (more could have been used but four is convenient for field operations) were used, and a 50,000-ohm variable resistor was connected in series with the geophone

circuit to adjust the output signal level of the geophone array to the output level of the MILES cable. The outputs of both transducers were connected to the MAID processor to provide a way to obtain alarm data for both the geophone array and the MILES cable.

35. Test procedures. The calibration tests were performed using a man creeping, a source which inputs a broad frequency spectrum of loads to the ground surface. For each setting selected on the variable resistor, the number of MAID processor alarms for the cable and the array during each of repeated parallel passes of the source at a 0.75-m distance from the transducers was recorded. The length of each pass was limited to the region of the cable in which the geophones were located.

36. Calibration test results. The calibration was made by selecting the series resistance in the geophone array (Figure 5) that resulted in approximately the same average number of alarms by the MAID processor for the cable as for the array. At this site an average of three alarms was recorded during each parallel pass by the man creeping at a distance of 0.75 m. A series resistance of 13,000 ohms was found to provide matching results for the MAID-geophone array and the MAID-MILES systems.

Verification tests

37. Verification tests were conducted to examine the relative performance of the MAID-MILES and the calibrated MAID-geophone array in areas of known variations in MAID-MILES performance. Tests were performed at three sites having different terrain characteristics to determine if the MAID-geophone system could consistently predict the MAID-MILES performance using a single series resistance (13,000 ohms). The following paragraphs describe the test sites, the types of tests conducted, and the results.

38. Test site descriptions. The tests were conducted with MILES cables installed in a Vicksburg loess soil, in a soil-cement bed, and in a sandy clay soil. The sites of the loess soil and the soil-cement are located at the WES installation (described in paragraph 26), and the sandy clay site is located on a military reservation in Louisiana.

39. The loess soil site was the same as that described in the geophone feasibility tests in paragraphs 26 and 27.

40. The soil-cement site, a relatively small (6-m x 5.5-m) section of the WES MAID-MILES test area, was chosen for geophone array testing because of the known low response of the MILES cable in this area. The natural soil was removed to a depth of 1 m, mixed with 33 percent sand and 6 percent portland cement, and mechanically recompacted to a density of 1.92 g/cm^3. The purpose of fabricating this site was to construct an area for MAID-MILES testing which would reasonably simulate rigid (e.g. frozen) ground conditions. Measured seismic characteristics data indicated that this area had a compression wave velocity of 1100 m/sec and a shear wave velocity of 375 m/sec. The MILES cable used in this test site was located at a depth of 23 cm with 5 cm of sand above and below the cable.

41. The sandy clay site located in Louisiana was chosen because of the relatively good performance of the standard length cables except for a frequent occurrence of false alarms due to active background noise. Tests at this site indicated that the MAID-MILES system was capable of detecting a man creeping parallel to the cable at a distance of 1 m. Measurements indicated a compression wave velocity of 200 m/sec and a shear wave velocity of 100 m/sec. Background noise sources included large taxiing aircraft and train traffic located approximately 2 km away.

42. Tests procedures. At all three sites, geophone array and MILES cable responses were obtained with the MAID processor. The geophone array system was installed as described in paragraph 24 using the series resistance (13,000 ohm) used in the calibration tests.

43. The following four signal sources were used in this test series (see Table 2):

a. A man creeping parallel to the cable. Three distances were used at each site, i.e. 50-, 75-, and 100-cm, at the Vicksburg loess site and the Louisiana sandy clay site; and at the Vicksburg soil-cement site, distances of 0, 30, and 50 cm were used. Eight trials were made at each distance.

b. A 1/2-ton commercial pickup. The vehicle was driven in a 20-m-radius circle around the transducers at the Vicksburg loess site. It was driven in a 5-m-radius semicircle around the transducers at the Vicksburg soil-cement site. At the sandy clay site, it was driven parallel to the sensors at a distance of 10 m. Four passes were made at each site.

c. A train. The train traffic presents a background noise problem at the sandy clay site in Louisiana. The train track was located approximately 2000 m from and parallel to the MILES cable.

d. Taxiing aircraft. Taxiing aircraft present a background noise problem at the sandy clay site in Louisiana. During the tests reported herein, this included large jet aircraft being towed and also aircraft taxiing under their own power at a distance of approximately 500 m parallel to the MILES cable.

44. Test results. Table 2 presents a summary of the results obtained from the verification tests for the MAID-MILES cable and the MAID-geophone array adjusted with a series resistance of 13,000 ohms. These results show that all the MAID processor alarms obtained from the MILES cable and from the geophone array were very similar for all sources and site conditions. For example, the test results indicated that the MAID processor alarms from the geophone array for the train traffic were slightly lower, but both systems indicated a significant number of alarms. Also, for the taxiing aircraft, the geophone array indicated some alarms whereas the long cable did not, implying that the geophone array may provide a conservative estimate of MILES cable performance for some background noise sources.

45. Although the MAID-geophone array provided agreement for both the intruder and background noise tests, some differences occurred. It is assumed that the major cause of these differences was the frequency response of the surface-emplaced geophones (4.5 Hz) used in the tests. Below 4.5 Hz the sensitivity of the transducer will decrease. The MILES cable, however, has a nearly constant response for signals less than 5 Hz. Supplementary tests taken at the sandy clay site in Louisiana showed that a strong 3-Hz signal was produced by the train traffic, and the taxiing aircraft produced higher frequency signatures of a lower

amplitude than the train. This could explain why the MAID-geophone array produced fewer alarms than the MAID-MILES cable during the tests on the train traffic. Further, this frequency sensitivity phenomenon could cause the erratic alarms from the MAID-geophone array during the tests on the taxiing aircraft. Although not available during the period of testing, surface-emplaced geophones which provide a frequency response value of 2 Hz are commercially available. These geophones, used in a series array, should provide even better simulations of MILES cable response than indicated by the test results summarized in Table 2.

46. The main difference in the layout of the geophone array with respect to the MILES cable is that the cable is installed at a specific depth below the ground surface. For this reason, the actual source to sensor distance for the MILES cable and the geophone array is not exactly the same. Consequently, when the series resistance of the geophone array was adjusted in the calibration tests to provide the best simulations of MILES cable response for an intruder located 75 cm from the geophone array line, the best simulations occurred *at other sites* when the intruder was located at this distance.

47. Even though some differences were indicated in the preceding paragraphs, the results of the verification tests indicate that the geophone array system used in this study can provide a reasonable simulation of MILES cable response in a variety of soil stiffness and background noise conditions. For this reason it appears that a surface-emplaced geophone array system can be used as an equipment set in a preinstallation survey for the MAID-MILES detection system.

PART III: GUIDANCE FOR PREINSTALLATION SURVEY

Introduction

48. This portion of the report presents a guide for the conduct of a preinstallation site survey based on the equipment sets described in Part II. The guide is intended to aid in determining the feasibility of deploying the MAID-MILES system as a part of a security system for a specific installation. Also, it may be used to designate specific locations at a site where supplemental intrusion detection systems would be required.

Steps in Survey Procedure

49. The conduct of a preinstallation survey can be outlined by three basic steps in which a thorough examination of a site can be made to estimate the performance of a MAID-MILES system. These three preinstallation steps are as follows:

- a. Mapping study
- b. Field reconnaissance
- c. MAID-MILES performance survey

The MAID-MILES performance survey consists of using the geophone array or short cable discussed in the previous section. A final step would be executed if the MAID-MILES system is installed. This would consist of a postinstallation survey to assure that no detection problems or background noise interference exists. Most of the preinstallation survey can be conducted by personnel having little experience in seismic terrain characterization, although it may be necessary that the initial steps be conducted by on-site engineering personnel familiar with the interpretation of soil strength characteristics from geologic and topographic maps. The following sections describe the three preinstallation steps and the postinstallation survey.

Mapping study

50. The main objective of the preinstallation survey is to locate areas at the site where MAID-MILES seismic performance would be less

than acceptable. Since it would be very impractical to physically test every square metre of the site, it is necessary to have a general knowledge of the site with respect to variations in the soil stiffness. This can be accomplished by the inspection of soil and topographic maps of the area.

51. In general, a qualitative relation exists between the stiffness properties of a soil and the soil type (USCS classification). Also, since the stiffness (shear strength) of one type of soil is dependent upon its moisture content, various topographic associated features that affect moisture content (i.e. local relief, external drainage patterns, internal drainage characteristics, and vegetation density) will influence soil stiffness. For this reason, general preliminary data can be compiled from large-scale soil and topographic maps of the area in consideration.

52. Data acquisition. Although topographic maps are usually available from the facility engineer at most DOE installations, detailed surface soil maps are not as readily available. Detailed surface soil surveys have been performed by the United States Department of Agriculture and have been documented for most state's counties within the continental United States. However, in many instances, these surveys were not conducted within the boundaries of military reservations. In these cases, only preliminary information can be obtained from topographic maps alone.

53. Data collection and display. Those areas having consistent soil and topographic features are delineated on a scale drawing of the site. As a general rule, the site is divided into areas having similar soil types. These areas are then subdivided into areas of either high, medium, or low local relief. Areas around streams or creeks and around portions of excess or sparse vegetation should be delineated. Thus, the total number of areas depends on the complexity of the site. The final product of this exercise should be a scale drawing of the site, the sections of which represent units of similar terrain (i.e. having common soil and topographic associated features). If the units are truly similar, they will define areas having similar MAID-MILES response. This drawing can then be used to identify the preliminary location where on-site tests (using the geophone array discussed in Part II) will be made.

Field reconnaissance

54. Data collection. The objective of field reconnaissance is to make the final selection of the locations where MAID-MILES performance surveys will be made. In this step, obvious changes in soil strength and other terrain characteristics not observed during the mapping study are noted. This information could either replace or supplement the data obtained from the mapping exercise. A tabulation of the location and type of background noise sources and their frequency of occurrence should be made. The types of background sources should include vehicles (cars, trucks, trains, aircraft, etc.), heavy machinery, power lines, wind/vegetation systems, and any other cultural or natural features that could induce background noise. Also, note should be made of those areas in which installation of the MAID-MILES system might be difficult or conducive to poor performance (due to topography, vegetation, man-made structures, electromagnetic interference, etc.).

55. Display of results. Based on the above data, the locations of the MAID-MILES performance survey test points can be selected. The number of the test points will depend upon the complexity of the site, the size of the site, and time constraints placed on the user. However, it is recommended that at least one test point be designated for each unit of similar terrain (as identified in paragraph 53 or modified by field reconnaissance, paragraph 54). Test points on the perimeter to be protected should also be designated at locations nearest to background noise sources that are likely to cause false alarms (train or highway traffic, operation of heavy machinery, large vegetation, etc.).

MAID-MILES performance survey

56. In this step the geophone array system (Figure 11) is used to identify the units of similar terrain for which acceptable or unacceptable performance of the MAID-MILES system can be anticipated or for which further investigation is necessary. If further investigation is necessary, it is carried out using the MAID-short cable survey also discussed in this section. Acceptable performance for intrusion detection sensors is usually specified in terms of the probability of detection and the false alarm rate. The probability of detection is, by

definition, a statistical parameter requiring a number of repeated runs for a particular sensor-intruder geometry and is, therefore, difficult to use in an expedient survey procedure for estimating performance. A performance descriptor that is more easily used and is qualitatively related to the probability of detection is the average distance at which detection occurs for an intruder moving a fixed distance from the sensor. The distance at which alarms occur for a man creeping parallel to the geophone array and the background noise false alarm rate are used in the following paragraphs to provide guidance for evaluating whether or not the MAID-MILES system will be adequate for security protection.

57. It is beyond the scope of this study to establish the maximum (acceptable) false alarm rate (MFAR) or the minimum acceptable detection distance (MADD) for security applications of the MAID-MILES system. The MAID-MILES system has been commonly used to provide security even though the detection distance and false alarm rates have not consistently met Department of Defense performance specifications. Continued use of the MAID-MILES system has occurred because the system has filled a gap in security protection despite shortcomings relative to desired performance. The identification of the MFAR and the MADD will continue to rest with the user of the security system. Inasmuch as existing security systems employing the MAID-MILES are able to effectively use the system with detection distances as small as 75 cm for a man creeping parallel to the MILES, the MADD could be defined as 75 cm. Identification of the MADD implies that there also exists an associated minimum acceptable alarm criterion (MAAC) that defines the MADD. For example, for a man creeping parallel to the MILES at a rate of two steps every three seconds, the MADD could be defined as the distance from the MILES at which at least one alarm occurs for every 5 metres of movement of the man. Such a criterion on the definition of the MADD is an example of a MAAC.

58. Identification of an MFAR that can easily be used in an expedient survey technique is difficult because specifications for maximum false alarm rates are commonly expressed in terms of the number of false alarms (usually less than ten) in a 24-hour period. The time required to execute 24-hour surveillance or even some portion thereof

at each test point is unacceptable. For purposes of providing guidance concerning adequate performance of the MILES as it relates to the MFAR, the definition of the MFAR must be modified so that it applies to the particular background noise source identified in the field reconnaissance (paragraph 54). In practice, the MFAR is dependent upon such factors as the duration of activity of the source, its predictability, frequency of occurrence, time of day, and the performance capabilities of supplemental security measures, such as adding guards to the security system during the background noise activity. Therefore, it is not possible to suggest values of the MFAR. Once the existence of a background noise source that can induce alarms is identified and an alarm rate during its activity is measured, a judgment must be made by the user concerning the adequacy of the MAID-MILES system.

59. Application of the geophone array to estimating the adequacy of performance of the MAID-MILES system is based on the degree of correlation between the responses of the geophone array and those of the MAID-MILES system presented in Table 2. From Table 2, it is reasonable to project that the detection distance for the geophone array is correlated to that of the MAID-MILES system with a distance differential of less than 30 cm for a man creeping parallel to the geophone array or the MILES. For example, for the Vicksburg loess site and sandy clay site, at least one alarm occurs at 100 cm (under column Output Results) for the MAID-MILES for both sites, and at least one alarm occurs at 75 cm for the geophone array for both sites. Similarly, on the soil-cement site, no alarms are obtained by either transducer type for the man creeping parallel to the transducer line. Alarms were obtained from the geophone array for the soil-cement when a man steps within 25 cm (one foot) of a geophone. Although care should be taken in projecting these results to a wide range of soil conditions, the data presented in Table 2 are drawn from three different sites representing two distinctly different soil shear-strength conditions. As such, the results can be used in a preliminary fashion to form an intuitive basis for estimating adequacy of the detection performance of the MAID-MILES system prior to installation.

60. The responses of the two transducers (i.e. MILES cable and geophone array) to background noise induced by train and vehicle traffic

are encouragingly similar. However, the applicability of the geophone array to estimating the response of the MAID-MILES system to background noise sources having air-pressure origins (i.e. either from wind turbulence or low-frequency acoustic source components such as occur for jet blast) has not been sufficiently tested. The geophone array responded with more alarms for the taxiing aircraft source (Table 2) at the sandy clay site than did the MAID-MILES system. Inasmuch as the jet blast associated with such a background noise source contains low-frequency components not associated with the other background noise sources in Table 2, it is hypothesized that the geophone array (when the geophones are placed above the ground) is more susceptible to alarms induced by low-frequency acoustic sources than is the MAID-MILES system. Furthermore, when sources with air-pressure origins are being investigated, it would be advisable to bury the geophones.

61. Intrusion detection tests. The application of the MAID-geophone array for evaluating the adequacy of the response of the MAID-MILES system to intruders is dependent on the specification of a MADD and a MAAC (paragraph 57). These performance descriptors could be selected, respectively, as 75 cm and at least one alarm for each of five man-creeping tests (for the man creeping parallel to the geophone array at a distance of 75 cm) without conflicting with the performance commonly associated with currently deployed systems. Based on the data obtained in this study, the MAID-MILES performance can be specified as unacceptable if no alarms occur for a man creeping parallel to the cable at a distance of 30 cm (paragraph 59). If the MAAD exceeds 30 cm and the MAAC is not met, it would be desirable to bury a short cable in order to obtain a more accurate estimate of the response of the MAID-MILES system.

62. The geophone array, short cable, and selected values of the MADD and the MAAC can be used to implement the MAID-MILES performance survey for intrusion detection as indicated in the decision schema presented in Figure 12. Principal steps in the decision schema are:

a. Select a MADD and MAAC.

b. For each test point (paragraph 55), place the geophone array parallel to the perimeter to be protected in accordance with the layout in Figure 11.

c. Creep parallel to the geophone array at a distance equal to the MADD and compare alarm results with the MAAC. For example, if the MAAC is at least one alarm for each of five man-creeping tests, the test would be repeated five times and the alarms recorded for each pass.

d. If the alarm response in c meets the MAAC, the MAID-MILES response can be judged as adequate. If the alarm response does not meet the MAAC, additional steps are necessary as discussed in e, f, g, and h.

e. Creep parallel to the geophone array at a distance of 30 cm. Repeat test five times.

f. If no alarms are obtained in e, the MAID-MILES response is inadequate. If some alarms occur, an additional step is necessary to more accurately project the response of the MAID-MILES system as discussed in g and h.

g. Fabricate and bury a MAID-short cable system in accordance with the procedures in paragraph 13 and repeat creep tests identified for the geophone array (c), being careful that the creeping man carries no metallic objects.

h. If the MAID-short cable results meet the MAAC, the MAID-MILES response is judged adequate. If alarm response does not meet the MAAC, the MAID-MILES response is judged inadequate.

63. Background noise tests. The geophone array, short MILES, and user's criteria for the MFAR for a particular background noise source (paragraph 58) can be used to implement the MAID-MILES performance survey for background noise sources as indicated in the decision schema in Figure 13. Principal steps in the decision schema are:

a. Summarize potential background noise sources, predictable periods of activity (if any), and frequency of occurrence.

b. Determine whether the sources are characterized by air-pressure origins (wind turbulence or low-frequency acoustic components), electrical or electromagnetic origins (transmission lines, radio signals, power transformers, etc.) or seismic disturbances.

c. Deploy a MAID-geophone array at test points identified for background noise sources (paragraph 55), bury geophones if sources have air-pressure origins, and monitor alarms during periods of activity of sources. The geophones should be buried so that the top of the geophone is 2 cm below the ground surface.

d. Postulate MFAR for each source based upon the total number of source types that induce alarms, their frequency of occurrence, duration, predictability, and other factors (paragraph 58). Ultimately, the decision as to the acceptability of a false alarm rate for a particular source will depend upon the user and his ability to compensate for the resulting security problem by using an alternate security system during activity of the particular background noise source.

e. If the false alarm rate induced by background noise sources having seismic origins (i.e. not air-pressure origins) does not exceed the MFAR for that source, then the MAID-MILES system is adequate. Otherwise, the MAID-MILES system is inadequate. Acceptance of the decision that the MAID-MILES system is adequate should be tempered by the fact that the geophone response diminishes with frequencies below the natural frequency of the geophones (paragraph 45) and that it remains to be demonstrated that their response is sufficient for identifying potential false alarms at, for instance, 0.5 Hz.

f. If the false alarm rate induced by background noise sources having air-pressure origins is less than the MFAR, the MAID-MILES system is adequate (subject to the limitation of frequency response of the geophones in e). However, if the false alarm rate exceeds the MFAR, the geophone array may overestimate the severity of the false alarm rate of the MAID-MILES system (based upon the data obtained in this study and discussed in paragraph 60), and it will be necessary to bury a short MILES cable and monitor the alarms during activity of the sources for which the MFAR was exceeded.

g. If the source is attributed to electrical or electromagnetic disturbances, it will be necessary to use a short MILES cable and monitor the alarms during activity of the sources. Since, in most cases, the interference due to electrical and electromagnetic phenomena is not dependent on the depth of burial of the MILES cable, it will not be necessary to bury the short MILES cable during this test. The decision as to whether or not the MAID-MILES system is adequate should be made based on the MFAR selected.

h. If the false alarm rate for the short MILES exceeds the MFAR, the MAID-MILES is judged inadequate. Otherwise, it is judged as adequate.

Postinstallation survey

64. If the decision has been made to implement the MAID-MILES system, a final survey of the system should be conducted to insure satisfactory performance throughout the system. This survey should again consist of intrusion detection and background noise tests run on each cable installed, individually.

65. Intrusion detection tests. The intrusion detection tests should consist of a man creeping parallel to the cable at the selected MADD while MAID-alarm data are being tabulated. A display should be constructed to show where along the cable the MAAC was not met. From this display any "dead areas" along the cable can be outlined.

66. Background noise tests. Using the summary of background noise sources, their characteristics, frequency of occurrence, etc. (paragraph 58), alarm rates should be tabulated and compared with the MFAR for the particular sources. Enough active background noise and "quiet time" data should be collected to fully describe any problem areas for each cable. The data should be tabulated and displayed so as to show the source of the background noise, its location, and the occurrence.

67. Compilation of results. From the displays described in the previous paragraphs, decisions can be made as to the type and the extent to which supplementary security measures are necessary to acquire the degree of security specified fcr the site. Also, comparisons of the displays from the postinstallation and the preinstallation surveys can provide information regarding unsatisfactory cable performance due to problems caused by phenomena other than soil stiffness conditions.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

68. Based on the field tests results, the following conclusions are made:

a. The short (10-m) MILES cable provides an excellent simulation of the standard length (100-m) MILES. Data show that the standard length cable may provide a rather large variance in response at various portions along the cable (paragraph 18).

b. Scientific geophones, when analyzed in a series-subtracting configuration, will provide a voltage output quite similar in waveform to that measured from a MILES cable during excitation by a number of seismic sources (paragraph 30).

c. Surface-emplaced geophones with a natural frequency of 4.5 Hz can be connected in a series-subtracting array and voltage attenuated to provide input to the MAID processor (paragraph 47).

d. Alarms obtained from a MAID-geophone array system compare favorably with MAID-MILES alarm data obtained from a man creeping and active background sources at sites which produce various degrees of MAID-MILES performance. The MAID-geophone array system works best for sources that transmit higher frequencies (exceeding half the natural frequency of the geophone) to the transducer and at nominal distances (0.5 to 1.0 m) (paragraphs 40 and 41).

e. Comparison of the performances of the short cable and the geophone array as related to MILES cable performance showed that a preinstallation survey can be formulated using these systems (paragraph 47).

Recommendations

69. From the above conclusions it is therefore recommended that:

   a. Commercially available refraction geophones capable of providing a flat frequency response at 2 Hz be calibrated and tested, based on the procedures used in this study. The lower response of these transducers should provide an even better simulation of the MILES cable response than those used in this study.

   b. Additional comparative field tests be conducted at installations where problems of unsatisfactory performance of a MAID-MILES system exist. These tests would aid in building confidence in the use of the MAID-geophone array system and could also serve to identify problem areas at the site that are not directly related to soil stiffness conditions.

   c. Background noise tests should be conducted to compare the response of short (10-cm) and the standard length (100-m) MILES cables. These tests would further confirm the similarity in the overall responses of the short and standard length MILES cables.

Table 1

Short Cable Versus Long Cable Results

Site	Source	Type of Output	Transducer	Output Results
Brown's Farm, Vicksburg, Miss.	Drop hammer	Normalized signal amplitude statistics	Long cable	mean = 49 percent std. dev. = 27 percent
			Short cable	mean = 54 percent std. dev. = 26 percent
	Calibrated creeper	Maximum* MAID alarm detection distance	Long cable	maximum = 90 cm minimum = 40 cm average = 75 cm
			Short cable	maximum = 90 cm minimum = 35 cm average = 70 cm

* The perpendicular distance from a specific location on the cable at which one MAID alarm will occur during five 30-sec tests of the calibrated creeper.

Table 2

MILES Cable Versus Geophone Array Results

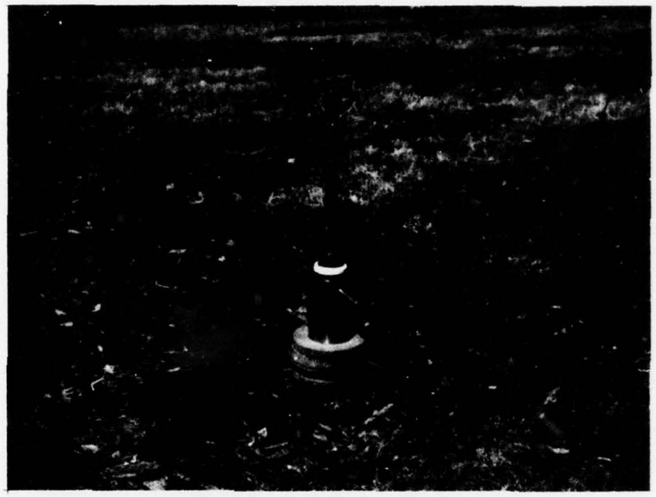
Site	Source	Type of Output	Transducer	Output Results
WES Installation Loess Site, Vicksburg, Miss.	Man creeping parallel	MAID alarms (8 trials, each distance)	Short cable	50 cm = 6 alarms 75 cm = 3 alarms 100 cm = 1 alarm
			Geophone array	50 cm = 5 alarms 75 cm = 3 alarms 100 cm = 0 alarm
	1/2-ton commercial pickup 20-m circle	MAID alarms (4 trials)	Short cable	2 alarms (average)
			Geophone array	2 alarms (average)
WES Installation Soil-Cement Site, Vicksburg, Miss.	Man creeping parallel	MAID alarms (8 trials each distance)	Short cable	50 cm = 0 alarm 30 cm = 0 alarm 0 cm = 0 alarm
			Geophone array	50 cm = 0 alarm 30 cm = 0 alarm 0 cm = 2 alarms
	1/2-ton commercial pickup 5-m circle	MAID alarms (4 trials)	Short cable	0 alarm (each trial)
			Geophone array	0 alarm (each trial)

(Continued)

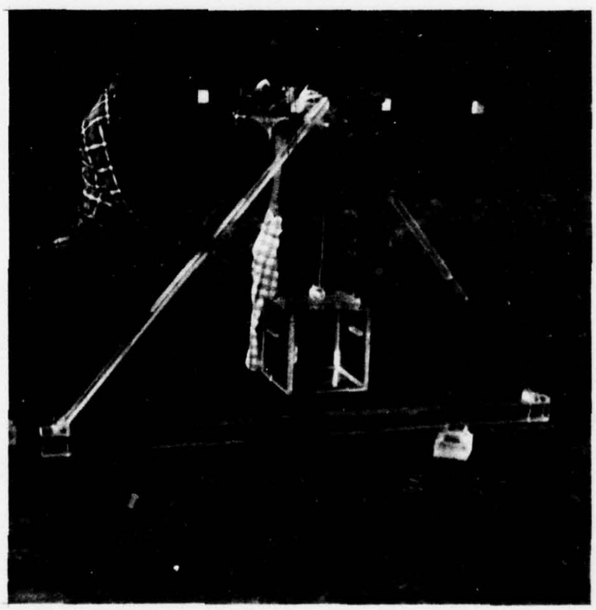
Table 2 (Concluded)

Site	Source	Type of Output	Transducer	Output Results
Sandy Clay Site, Louisiana	Man creeping parallel	MAID alarms (8 trials, each distance)	Long cable	50 cm = 6 alarms 75 cm = 4 alarms 100 cm = 3 alarms
			Geophone array	50 cm = 4 alarms 75 cm = 3 alarms 100 cm = 3 alarms
	1/2-ton commercial pickup, 10 m, parallel	MAID alarms (4 trials)	Long cable	0 alarm
			Geophone array	0 alarm
	Train traffic 1 pass	MAID alarms	Long cable	72 alarms/5 min
			Geophone array	63 alarms/5 min
	Aircraft in tow	MAID alarms	Long cable	0 alarm
			Geophone array	0 alarm
	Aircraft in tow	MAID alarms	Long cable	0 alarm
			Geophone array	1 alarm
	Taxiing aircraft (3 occurrences)	MAID alarms	Long cable	0 alarm
			Geophone array	3 alarms (average)

(Sheet 2 of 2)



a. Drop hammer



b. Pendulum

Figure 1. Calibrated force-time sources

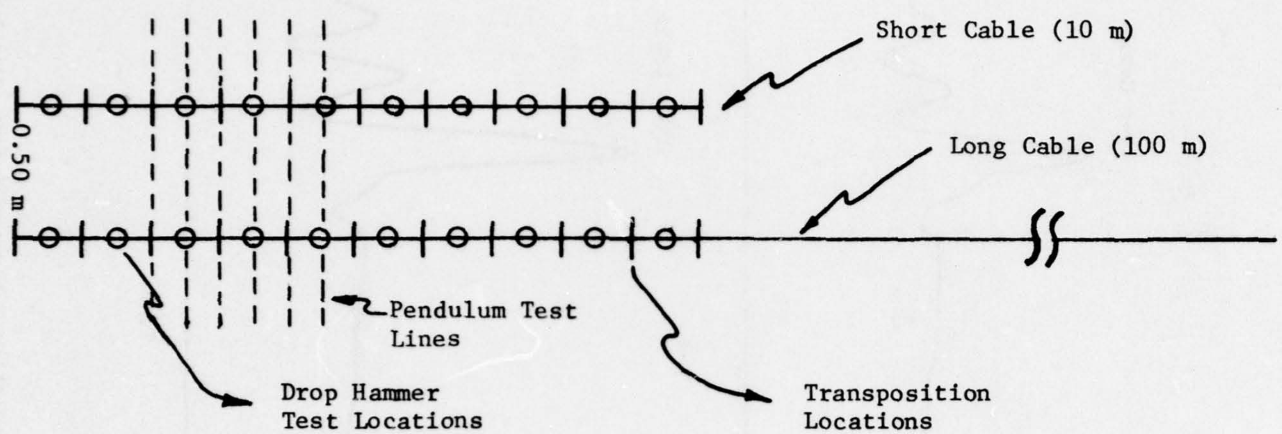


Figure 2. Test site layout, Brown's Farm Site

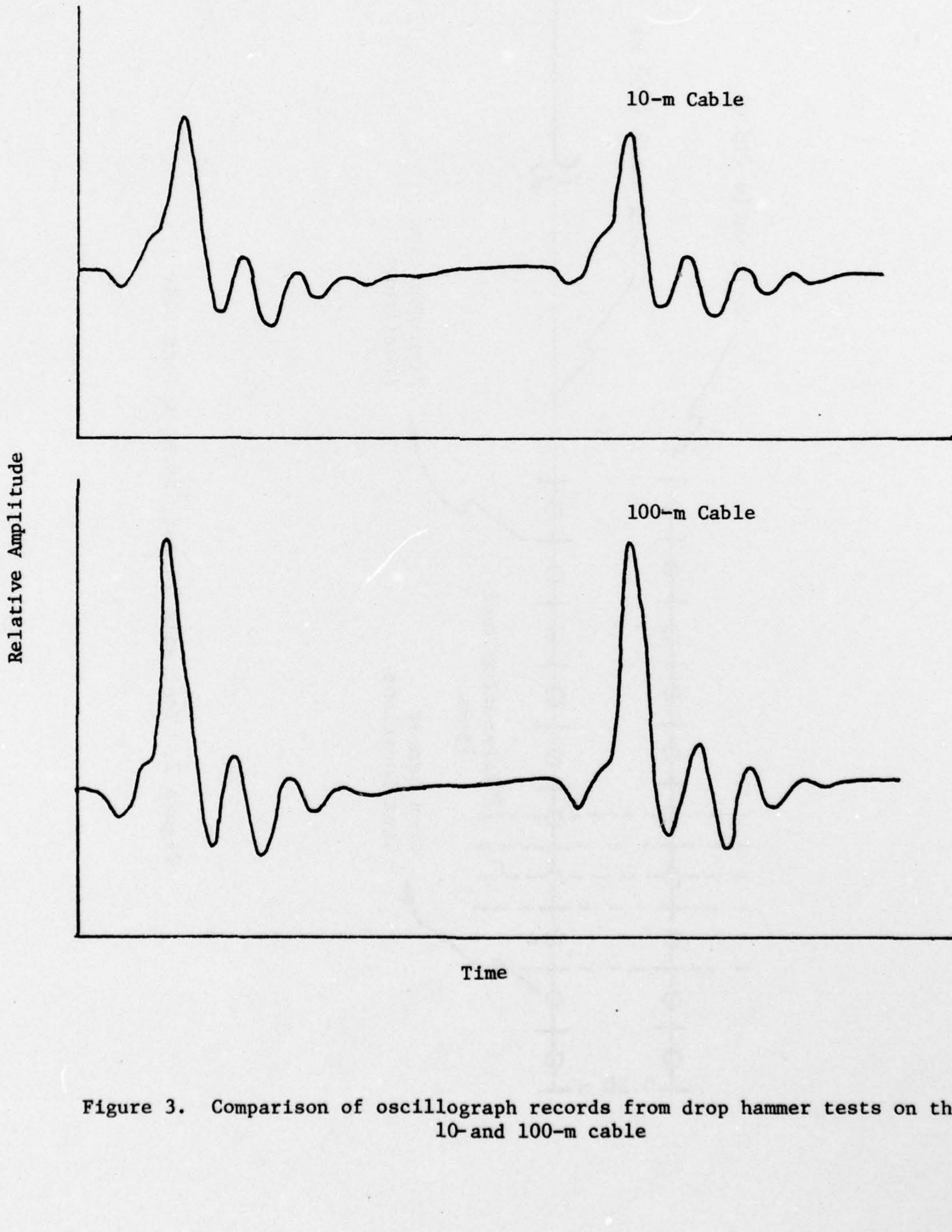


Figure 3. Comparison of oscillograph records from drop hammer tests on the 10- and 100-m cable

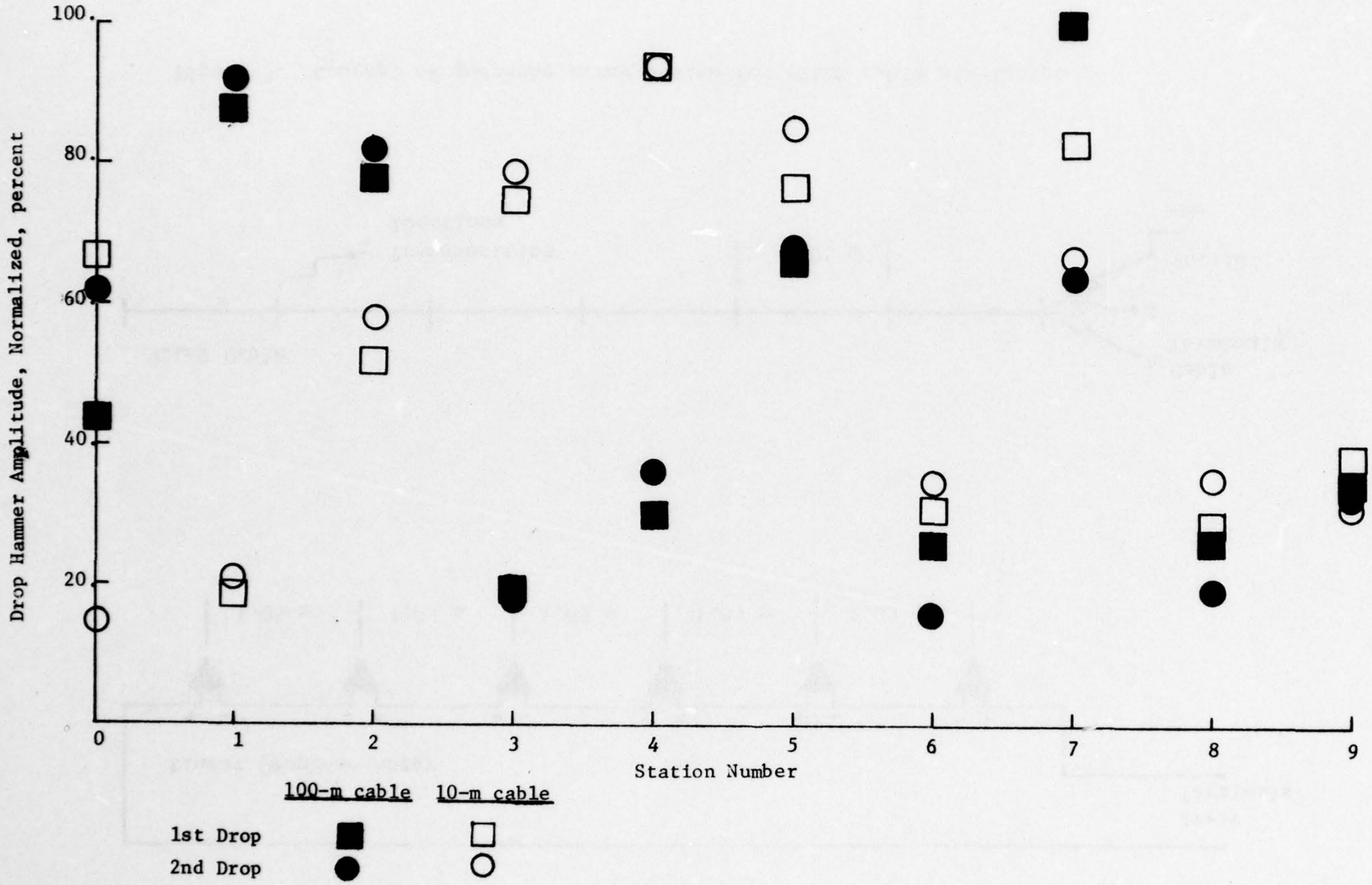


Figure 4. Comparison of normalized drop hammer-generated peak signal amplitude from the 100-and 10-m cable

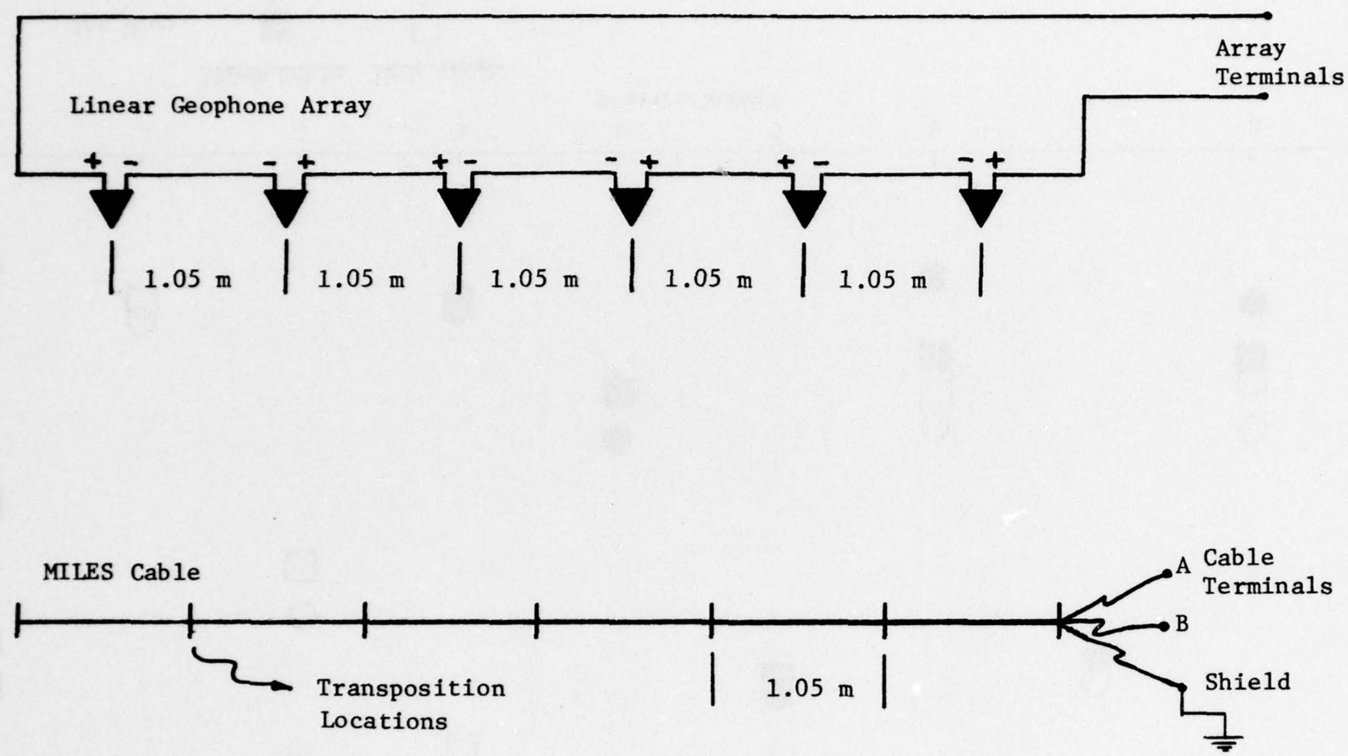


Figure 5. Concept of geophone array system for MILES cable simulation

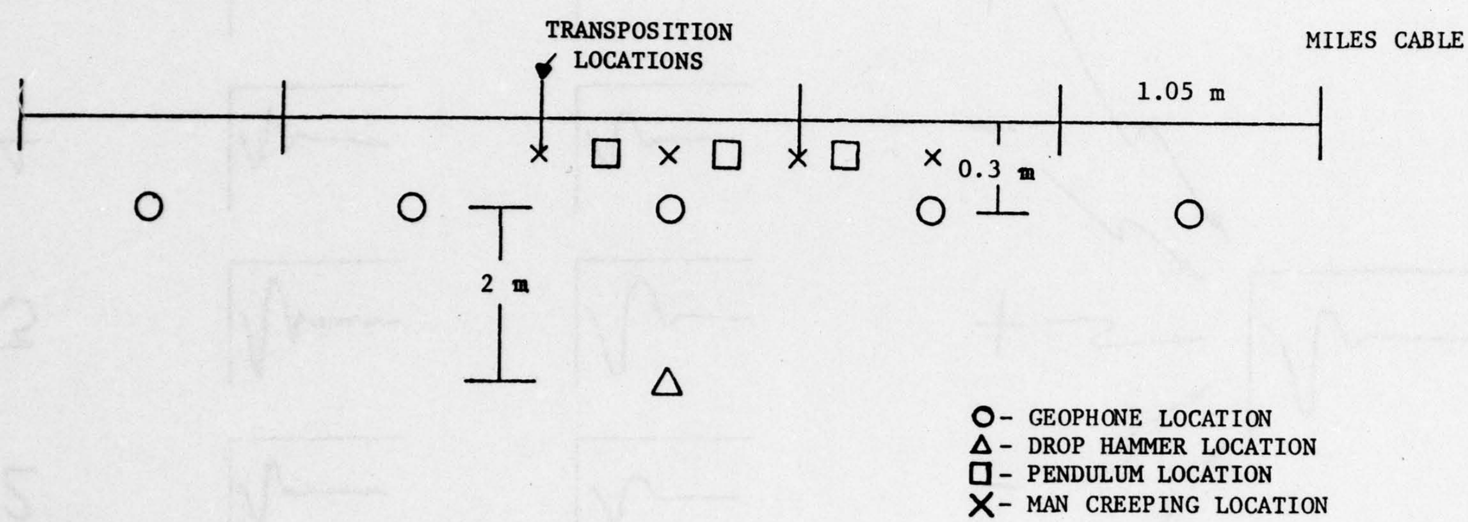


Figure 6. Geophone array system feasibility test site layout

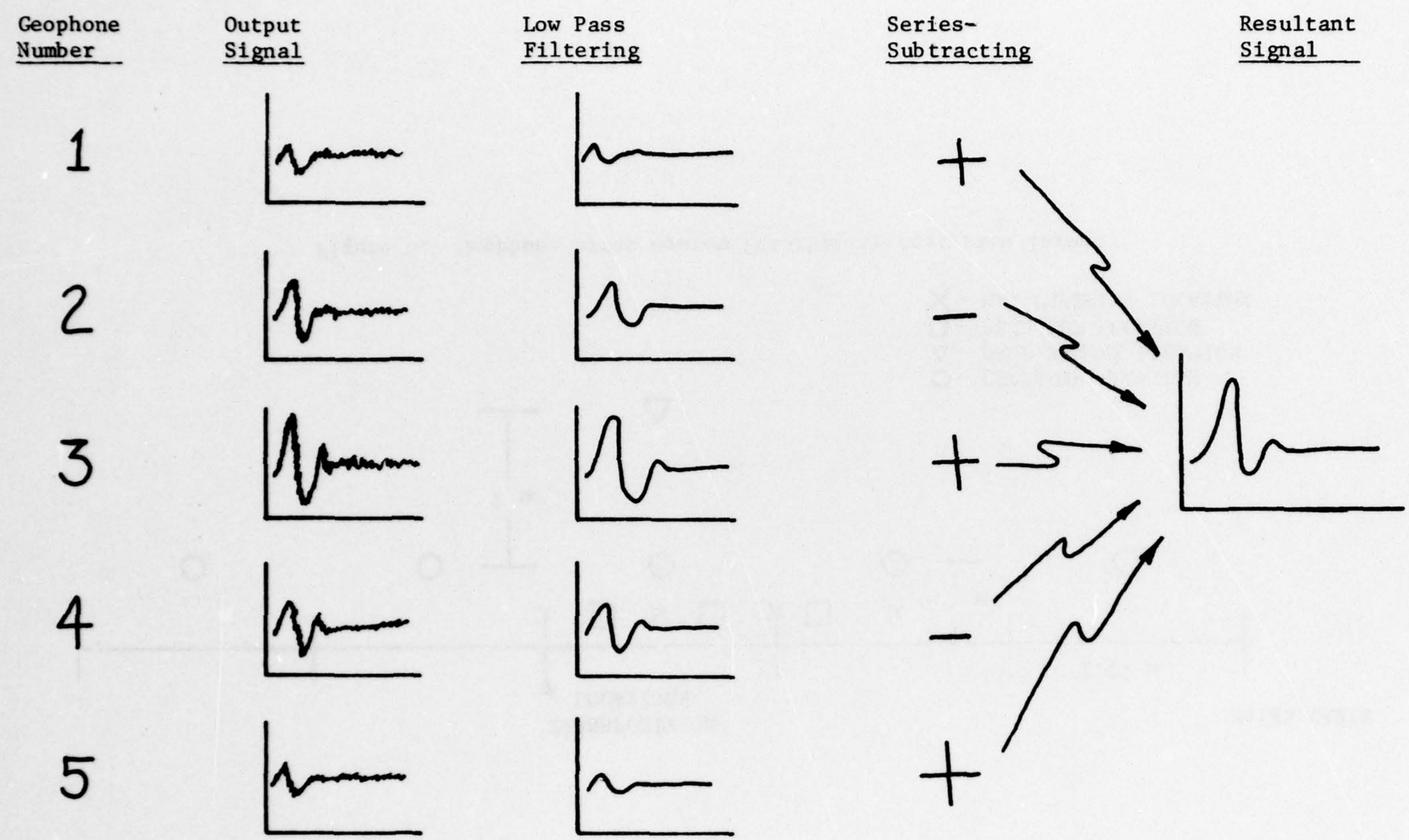


Figure 7. Description of data reduction process for feasibility tests

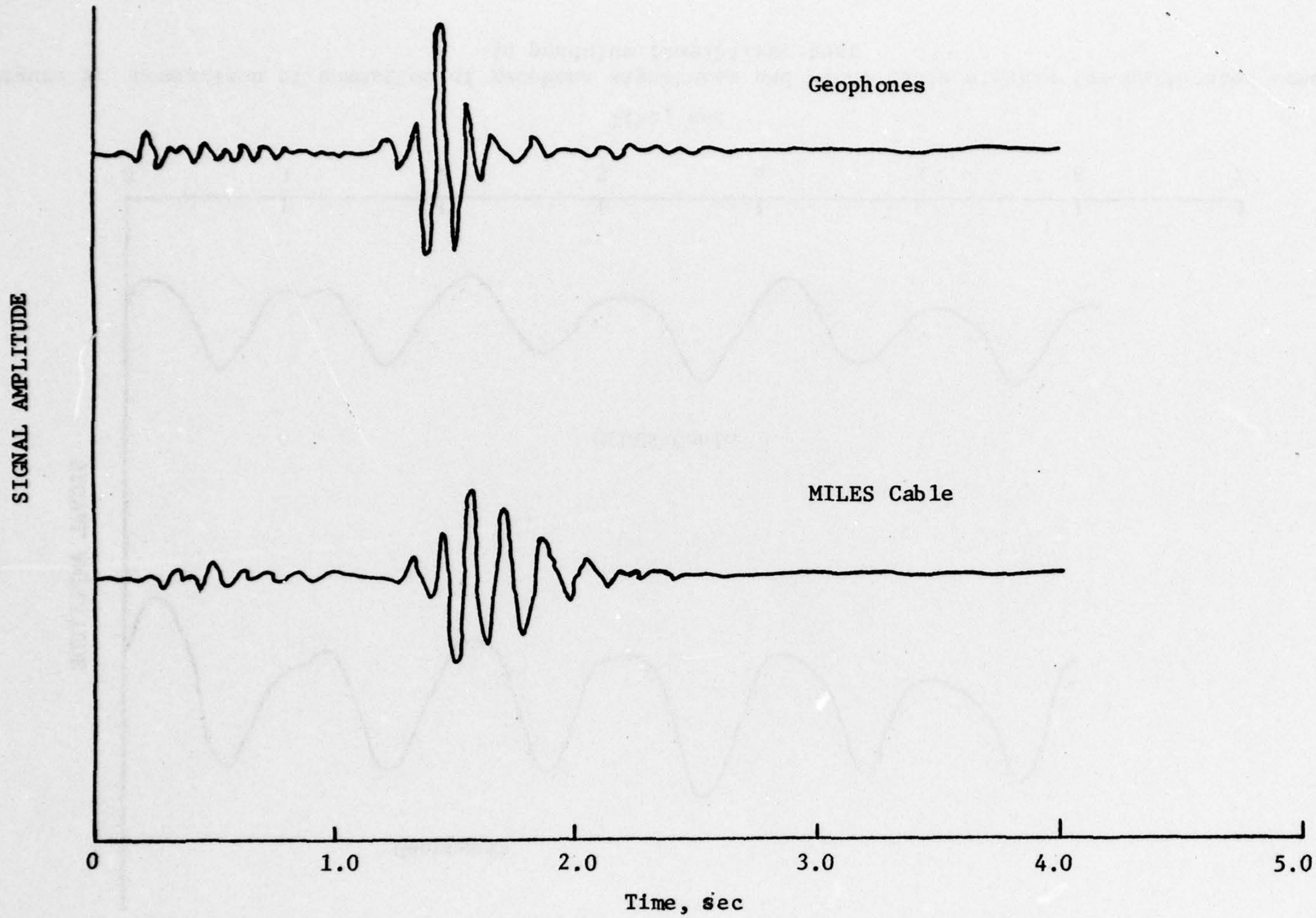


Figure 8. Comparison of summation of geophone signatures and MILES cable signals in drop hammer feasibility test

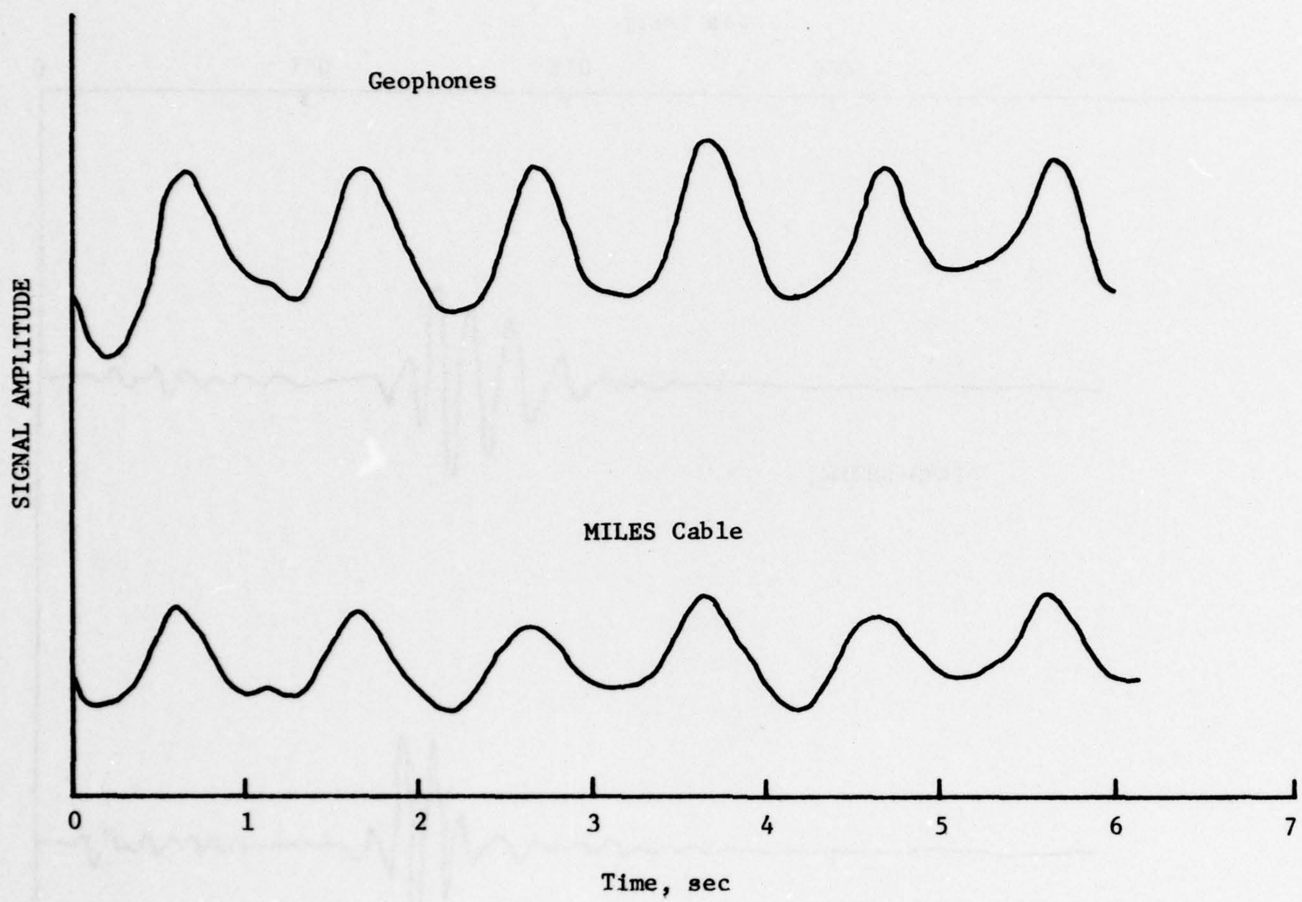


Figure 9. Comparison of summation of geophone signatures and MILES cable signals for calibrated creeper in pendulum feasibility test

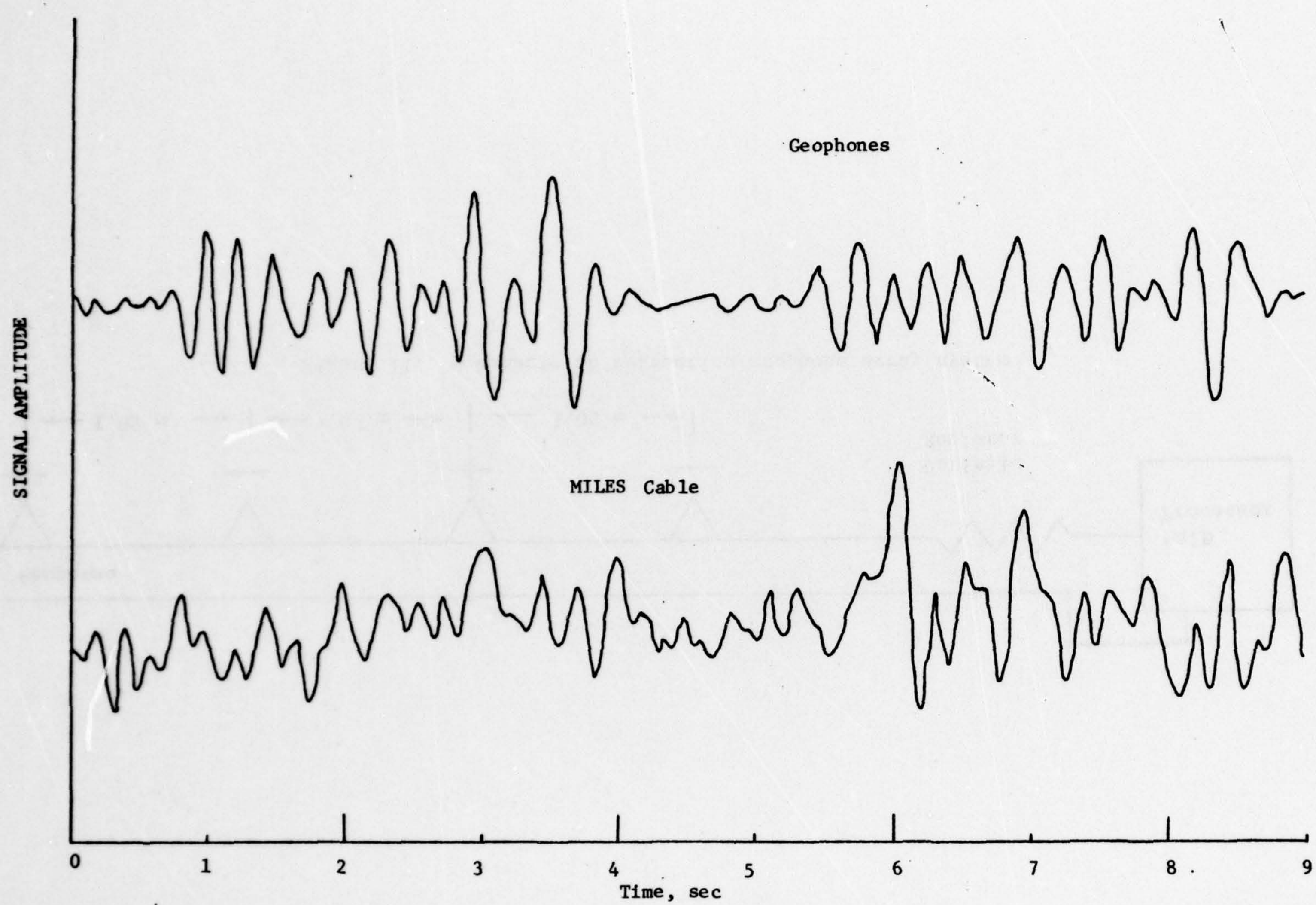


Figure 10. Comparison of summation of geophone signatures and MILES cable signals in man-creeping feasibility test

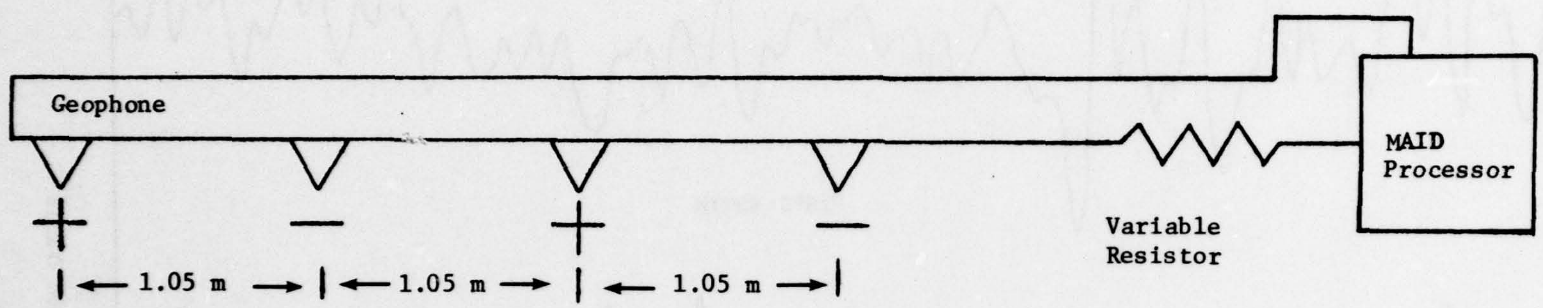


Figure 11. Schematic of refraction geophone array system

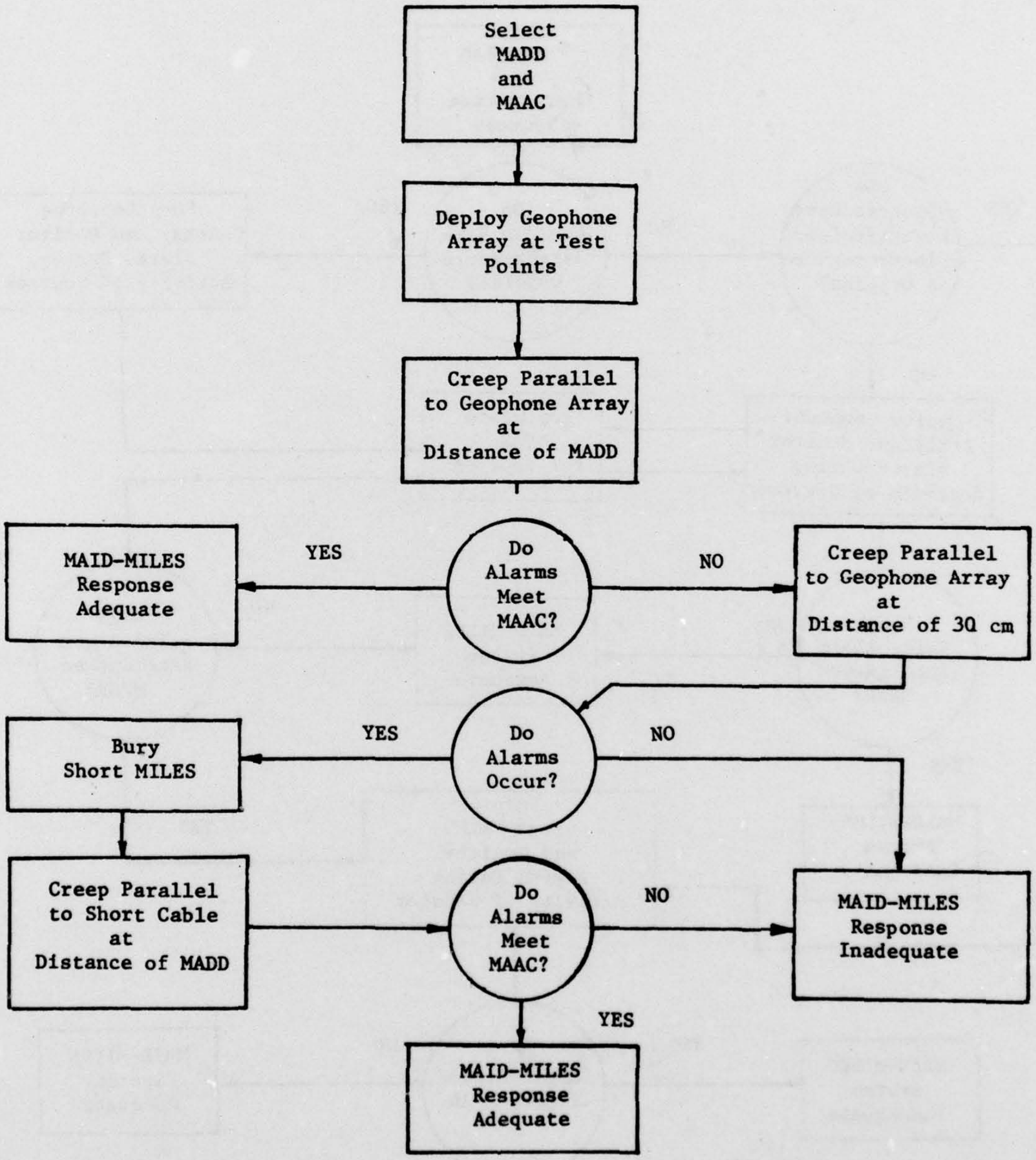


Figure 12. Decision schematic for evaluating detection response of the MAID-MILES system

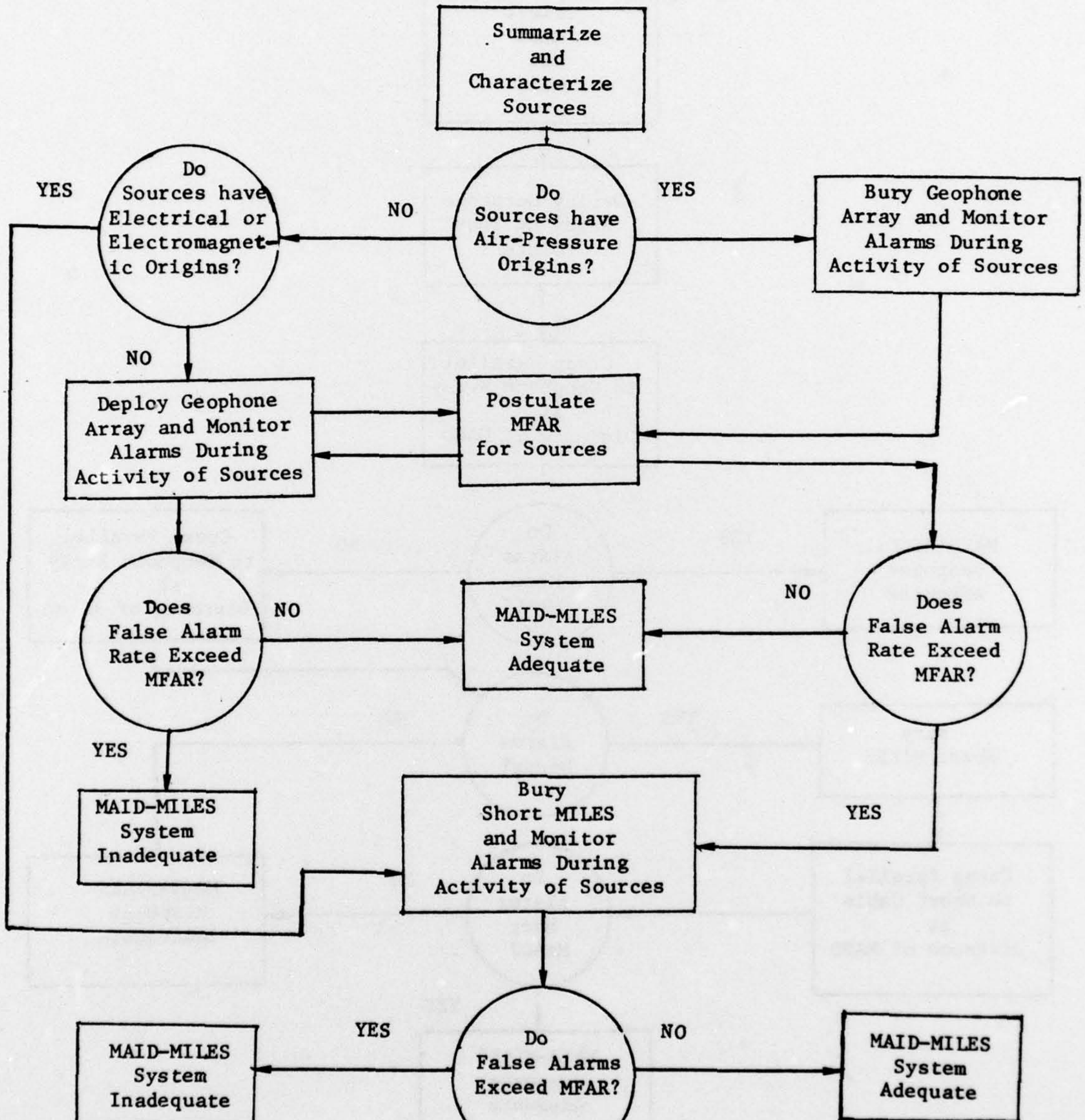


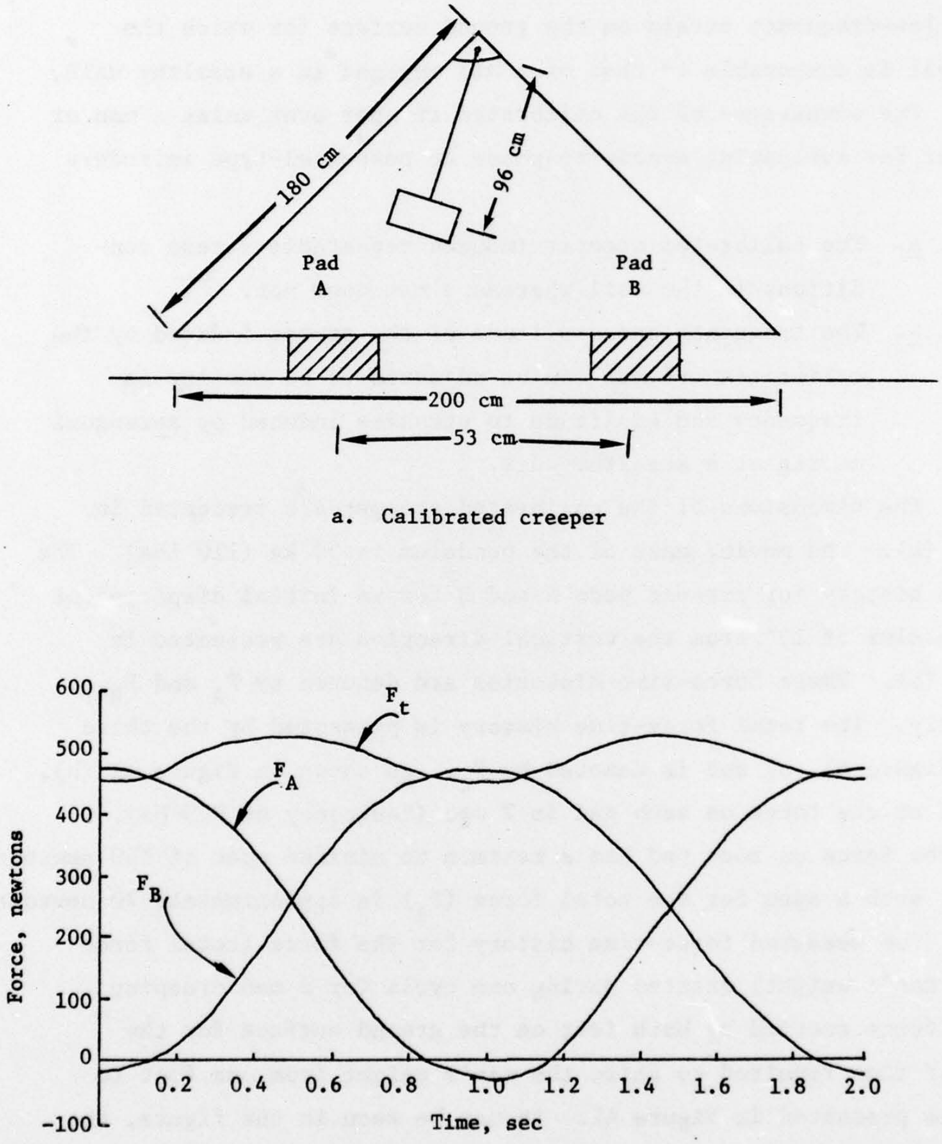
Figure 13. Decision schematic for determining the acceptability of the false alarm rate of the MAID-MILES system

APPENDIX A: DESCRIPTION OF CALIBRATED CREEPER

1. The calibrated creeper is a pendulum device designed to provide a low-frequency stress on the ground surface for which the stress level is comparable to that of a man engaged in a stealthy walk, or creep. The advantages of the calibrated creeper over using a man or drop hammer for evaluating sensor response to personnel-type intruders are:

- a. The calibrated creeper induces repeatable stress conditions in the soil whereas a man does not.
- b. The frequency and amplitude of the stress induced by the calibrated creeper can be adjusted to be similar in frequency and amplitude to stresses induced by personnel moving at a stealthy walk.

2. The dimensions of the calibrated creeper are presented in Figure A1 (a). The moving mass of the pendulum is 50 kg (110 lbs). The force-time history for creeper pads A and B for an initial displacement of the pendulum of 15° from the vertical direction are presented in Figure A1 (b). These force-time histories are denoted by F_A and F_B, respectively. The total force-time history is presented by the third curve in Figure A1 (b) and is denoted by F_t. As shown in Figure A1 (b), the period of the force on each pad is 2 sec (frequency of 0.5 Hz). Although the force on each pad has a maximum to minimum span of 540 newtons (110 lbs), such a span for the total force (F_t) is approximately 70 newtons (15 lbs). The measured force-time history for the force (total force minus the man's weight) exerted during one cycle for a man creeping (i.e. the force exerted by both feet on the ground surface for the duration of time required to shift the man's weight from one foot to another) is presented in Figure A2. As may be seen in the figure, the force ranges from +30 to -40 newtons, a total of 70 newtons with a predominant frequency of between 2 and 3 Hz. The mass of the man was 85 kg (170 lbs).



a. Calibrated creeper

b. Force-time history for creeper pads A and B (F_A and F_B) and total force (F_t)

Figure A1. Description of calibrated creeper and associated force-time histories

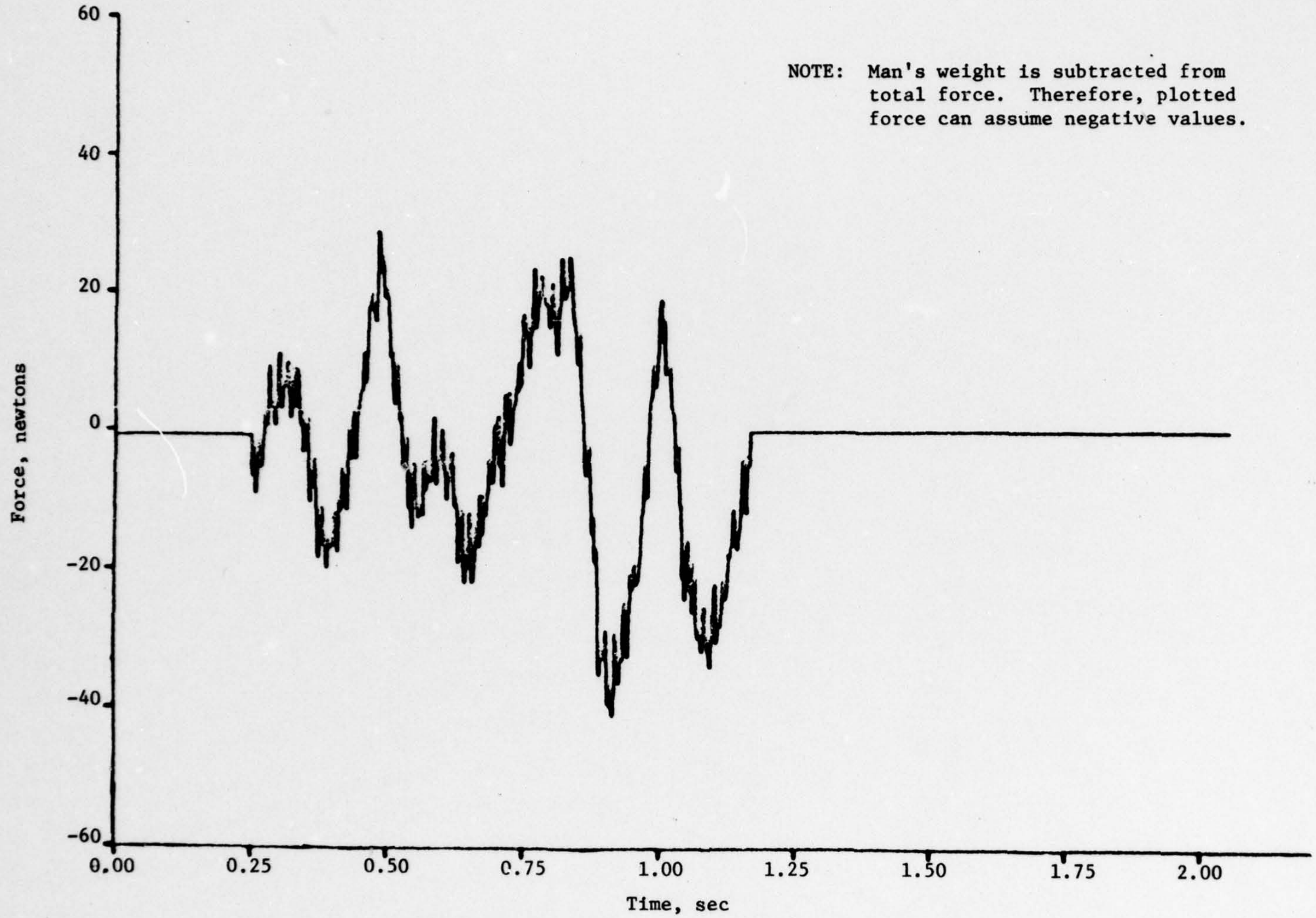


Figure A2. Measured force-time history for a man creeping on sand

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Miller, Charles A
Preinstallation survey guide for MAID-MILES system / by Charles A. Miller. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
32, [19] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; M-78-6)
Prepared for Sandia Laboratories, Albuquerque, New Mexico, under Project No. 4A762730AT42 A4/E3/001.

1. MAID-MILES system. 2. Seismic sensors. 3. Seismic surveys. 4. Site investigations. I. Sandia Laboratories. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; M-78-6.
TA7.W34m no.M-78-6