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TERRAIN CONSIDERATIONS AND DATA BASE DEVELOPMENT FOR THE DESIGN AND TESTING OF DEVICES TO DETECT INTRUDER-INDUCED GROUND MOTION

by

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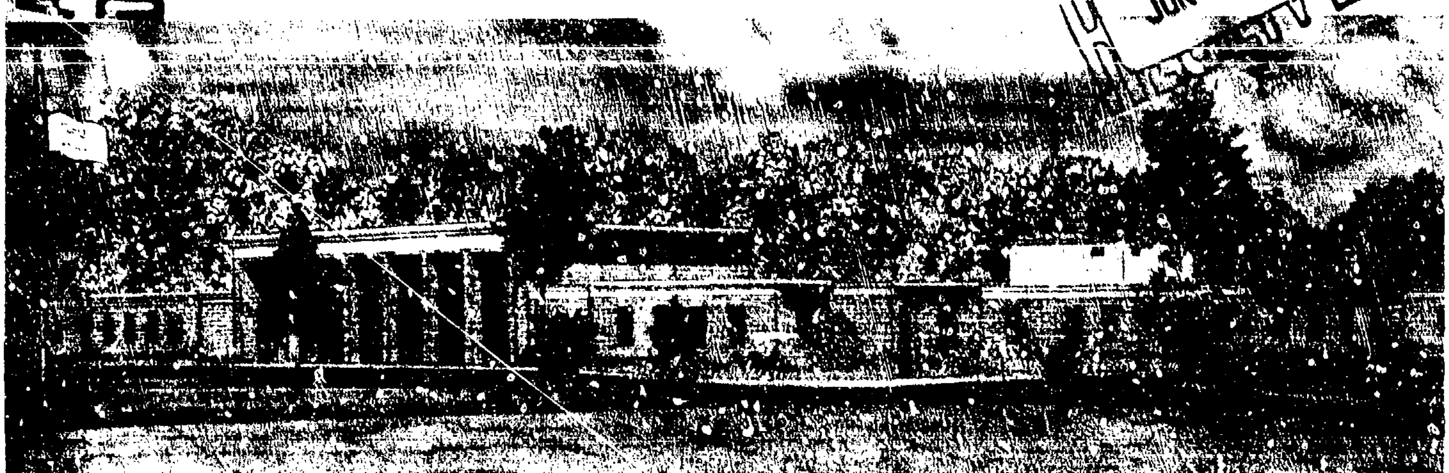

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The purpose of the study reported herein was to develop a readily accessible body of information that defines the ranges of intruder signal characteristics within which seismic sensors for intruder detection, classification, and location must operate. Principal products of the study were:

a. A data base of seismic signatures (recorded on magnetic tape) that contains representation of the range of target types, travel modes, terrains, and

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background noise sources that can realistically be expected to occur for base and installation environments and in operational scenarios.

b. Guidance to users of the data base that will support the needs of sensor designers and evaluators.

Both an experimental and a theoretical approach were taken. The experimental approach consisted of collecting and analyzing the signatures of intruders and background noise sources in a wide range of terrain conditions (as determined from bulk properties describing the compression and shear strength of the media, moisture, density, etc.). The theoretical approach consisted of applying mathematical models of the seismic signature generation and propagation phenomena so as to extend the data base of seismic signatures to include terrain conditions not represented in the data collection portion of the work. The mathematical models were also used to evaluate site documentation procedures and to estimate the frequency of occurrence of groups of terrains for which similar signature characteristics can be expected to occur. The data are analyzed emphasizing those signature characteristics and target-sensor geometries (i.e. target-to-sensor distance, etc.) affecting the operation of sensors currently being deployed or under development.

Most notable conclusions from the study are:

a. The frequency characteristics of signatures of intruders are strong functions of target-to-sensor distances, particularly for distances between 0.5 and 2 metres.

b. The low-frequency characteristics of the near-distance signatures (i.e. those for which the target-to-sensor distances are less than 2 metres) are stable features over the range of terrains represented by the measured data collection. However, the target-to-sensor distance for which the low frequencies predominate becomes smaller as the compression- and shear-wave velocities of the medium increase.

c. For personnel targets at distances exceeding 2 metres, the prominant frequencies of the signatures (i.e. target-to-sensor distances exceeding 2 metres) depend on site properties but are quite independent of the personnel travel modes.

d. The large dependence of the frequency and amplitude on terrain conditions suggests that only the simplest pattern recognition algorithms can be effectively used for detection and background noise suppression unless the signal processors are made adaptive to the local terrain conditions. When such algorithms are adaptive to the terrain, it may still be desirable to employ adaptive digital filtering to reduce background noise prior to implementation of pattern recognition.

e. The estimated frequency of occurrence of terrains having defined ranges in signature characteristics shows that the predominant frequencies of signatures of personnel within 5 metres of the sensor tend to have predominant frequencies of 40 Hz or less (79 percent of the terrains) but amplitudes varying over four orders of magnitude.

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PREFACE

This study was sponsored by the Base and Installation Security System Program Office, Electronic Systems Division, Air Force Systems Command, Hanscom Air Force Base, Massachusetts, under Military Interdepartmental Purchase Request No. 7700016, having the project title, "Terrain Target Analysis."

Information was obtained from the following in preparation of this report:

> Base and Installation Security System Program Management Plan, Jul 1972, Air Force Systems Command, ESD, Hanscom Air Force Base, Massachusetts; and
>
> System Specification For Base and Installation Security System (BISS), BISS-PO, Air Force Systems Command, ESD, Sepc. No. A63714-64715 BISS, Code Identification 50464, 1 Nov 1973. Hanscom Air Force Base, Massachusetts.

This investigation was planned and the report prepared by Dr. Cress. The project manager was Mr. J. R. Lundien. Personnel making contributions to this study were Messrs. P. A. Smith and B. T. Helmuth, who conducted the field data collection, Messrs. E. A. Baylot and M. D. Flohr, who generated the synthetic signatures under the general direction of J. R. Lundien and processed the measured data, and Mr. M. A. Zappi, who analyzed the geologic, physiographic, and soils information for the data collection areas.

The work was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) during the time period March 1976 to August 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). The ESD and ERB are now part of the recently organized Environmental Laboratory of which Dr. John Harrison is Chief.

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

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

Metric (SI) units of measurment in this report can be converted to U. S. customary units as follows:

Multiply	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: $F = 1.8(C) + 32$.

TERRAIN CONSIDERATIONS AND DATA BASE DEVELOPMENT FOR THE DESIGN AND TESTING OF DEVICES TO DETECT INTRUDER-INDUCED GROUND MOTION

PART I: INTRODUCTION

Background

1. The concern of management for the protection of military facilities and materiel has led to increased emphasis on the development of security systems. The reliability of security systems is controlled largely by the performance of the hardware used, particularly the sensors used to detect the presence of intruders. Such sensors must be capable of operating in a variety of environmental conditions, have an acceptably low false or nuisance alarm rate, and have a long operational life with minimal maintenance. The Project Manager, Base and Installation Security System (BISS), as part of his responsibility for the development of integrated security systems has undertaken the task of developing new sensors and improving the deployment and operation of existing sensors.

2. Sensors for intruder detection normally make use of seismic, acoustic, or electromagnetic energy forms. This report addresses factors affecting the performance of seismic sensors.

3. Sensors relying on seismic energy are generally of two types: point sensors and line sensors. Point sensors are normally considered for use in detecting the presence of intruders in a small area having dimensions on the order of 50 m or less (i.e. having a radius on the order of 25 m). Buried line sensors are used for continuous perimeter protection for which the length of the perimeter may be as long as several kilometres. A buried line sensor, referred to as the MILES (Magnetic Intrusion Line Sensor), has already proven to be a key element in the protection of Air Force installations in the U. S. and overseas.

4. Despite the successes of point and line sensors in detecting the presence of intruders, both types have been subject to false alarms

caused by: background noise (both seismically and electromagnetically induced), nuisance alarms (due to animals or other signal sources in the protection zone of the sensor), and variations in intruder-detection performance in different environmental conditions.[1,2] Sensors can be expected to work well only in seismic and background noise environments similar to those used to establish their design and deployment criteria. The designer and subsequent evaluator of a particular sensor system needs to know the relationship of the environments (referred to as terrains) used for design or testing to those that occur worldwide. In order to compare terrains, properties that significantly affect the seismic response of respective terrains must be measured and techniques originated for describing the sensitivity of seismic response to changes in measured properties. Because of the sensitivity of sensor performance to environmental factors, the Waterways Experiment Station (WES) performed the work reported herein to provide information concerning the seismic signature characteristics of intruder-type targets in worldwide environments.

5. WES has previously developed procedures for predicting seismic response to intruder-type sources using quantitative terrain parameters such as seismic compression- and shear-wave velocities, and surface roughness and rigidity.[3,4] In addition, techniques for measuring relevant properties (compression- and shear-wave velocities, surface rigidity, etc.) have also been developed or adapted, as necessary, to provide comprehensive documentation of terrain properties.[5,6]

Purpose

6. The purpose of this study was to develop a readily accessible body of information that defines the range of intruder signal characteristics within which seismic sensors must operate. Principal products desired from this study were:

- a. A data base of seismic signatures (recorded on magnetic tape) that contain representation of the range of target types, travel modes, terrains, and background noise sources that can realistically be expected to occur for base and installation environments and in operational scenarios.

b. Guidance to sensor designers and evaluators for using the data base.

To be useful to the sensor design and evaluation community, this study should: address the problem of describing the range in variation in terrain conditions to be encountered worldwide, provide an approach for relating one terrain to another, provide a description of the characteristics of seismic signatures of intruders for a range of terrains approaching the range in terrains occurring worldwide, and provide information concerning seismic background noise that may mask the seismic signatures of intruders, particularly in background noise environments that occur on military installations and in urban and highly-industrialized areas.

Description of Study

7. To address the objectives of this study, both an experimental and a theoretical approach were taken. The experimental approach consisted of collecting and analyzing the signatures of intruders and background noise sources in a wide range of terrain conditions. The theoretical approach consisted of applying mathematical models of the seismic signature generation and propagation phenomena in order to extend the data base of seismic signatures to include terrain conditions not represented in the data collection portion of the work. Mathematical models were also used to evaluate site documentation procedures and to estimate the frequency of occurrence of groups of terrains for which similar signature characteristics can be expected to occur.

PART II: DATA COLLECTION

Introduction

8. The data collection variables identified for the measured signature collection portion of this study were as follows: target type, target travel mode, target-to-sensor distance, and site condition (terrain and background noise condition). The target type, target travel mode, and target-to-sensor distances were specified in a signature collection plan. The terrain properties to be measured for characterizing the terrain conditions were identified in a site documentation plan. Sites were selected to provide signature data in a wide range of terrain and background conditions. Site documentation and signature data were then obtained at the selected sites.

Signature Collection Plan

Rationale

9. A signature collection plan that explicitly specified the targets, travel modes, travel paths, and sensor configuration was developed prior to the data collection. The rationale for the design of the signature collection plan was based on the following: the definition of the threat confronting Department of Defense (DOD) assets and installations as outlined in the System Specification for Base and Installation Security, past experience of WES personnel in analyzing the factors affecting the performance of devices designed to detect and classify intruder-type targets, and conversations with Base and Installation Security System (BISS) personnel cognizant of the physical constraints and background noise common around high-value military assets. The signature collection plan consisted of the test plan and the test layout. The test plan specified individual targets, combinations of targets, and target travel modes. The test layout specified target paths, sensor types, their orientation, and their spatial distribution.

10. Major considerations in developing the signature collection plan were:

a. The threat to DOD assets and installations is identified as an individual, or group of individuals, who penetrate, or attempt to penetrate, a secured or protected boundary on foot and in an upright, crouched or prone position at speeds between those of a slow crawl and a fast run, by swimming, or by means of conveyance such as a boat, wheeled vehicle, etc.

b. Intruder-type targets against which ground motion sensing devices can be expected to be effective are ground targets (personnel, wheeled and tracked vehicles, etc.). Signatures of other type targets such as aircraft and waterborne craft were collected but regarded as background noise sources.

c. Emphasis was placed on the intruder-type target and travel modes generally most difficult to detect, such as those of intruders engaged in a stealthy walk, or creep.

d. It was desired that vertical and horizontal components of ground motion be measured to provide data for analyzing the response of point sensors that employ vertical sensing geophones, and line sensors that may be sensitive to the vertical component of ground motion, the horizontal component, or both.

e. Measures of the spatial rate of change of signature properties were desired to provide data for evaluating sensor designs that make use of the spatial rate of change of the signature to suppress background noise from distance sources.

f. The direction of incidence of seismic energy to the signature collection site should be measured in anticipation of the development of techniques for spatial detection or classification algorithms.[7]

g. The acoustic energy component should be measured in anticipation of the development of techniques for removing acoustically induced signature components from those seismic signature components arising from forces applied to the ground surface, presumably by an intruder-type target.

h. During portions of the data collection, target-to-sensor distances should be less than 25 m and 5 m or less to evaluate point sensor deployment and line sensor deployment criteria, respectively.

i. Secure areas are commonly surrounded by roads 8-10 m outside the perimeter and, particularly overseas, these roads may be accessible to both civilian and military traffic. For point sensor applications, any target identified as personnel or that is capable of conveying personnel within approximately 25 m can be regarded as an intruder. However, for line sensors, traffic at distances on the order of 8 to 10 m from the perimeter are considered background noise. Therefore, target paths for background noise should be initiated at distances well beyond 25 m and transect within 8 to 10 m from the sensors. An essential consideration in the treatment of background noise is the fact that intruders must be detected during the presence of background noise sources. Therefore, it was considered important that, for selected tests, targets be within the 5 m distance specified for line sensors (and therefore be classified as intruders) at the same time that background noise sources were moving along a path on the order of 8 to 10 m from the sensors.

11. Considerations a, b, and c were used as a basis for defining the targets and travel modes to be represented in the field data collection. Considerations d, e, and f were used to identify the orientation and spatial distribution of the seismic sensors and can be addressed by using three or more geophones placed in a nonlinear manner to form a polygonal array.[7] A microphone was used to obtain the acoustic energy component required in g. Considerations h and i were used as a basis for specifying target paths and target mixes in which one target generated background noise while another target moved through the detection zone of point and line sensors.

Field data collection

12. Test layout. A typical test layout for the data collection is presented on Figure 1. The vertical and two horizontal components of intruder and background noise signatures were sensed by the triaxial geophone at G1. Vertical sensing geophones at G2 and G3 were used to complete the nonlinear array. These sensors were placed 6 to 8 cm beneath the surface. The microphone was placed inside the triangular area defined by the three geophones. The spatial separation of G2 and G3 from G1 was 2 m. The vehicle path was offset 8 m from G1. The personnel path is outlined by the control points A, B, C, and D. That portion of the path C to A to D is perpendicular to the vehicle path. The semi-circular path defined by the path segment A to B to C was used to provide data for estimating the range in variation in personnel signature for a fixed distance from target to sensor.

13. Test plan. The test plan for BISS data collection specified the target types, target mixes, target travel modes, and target paths for signature recording. To address the background noise requirements, tests were conducted in which several targets were moving simultaneously so that one target, referred to as the secondary target, generated background noise for the purpose of masking the signature of a primary target. During such multiple target tests it was necessary to specify the relative positions of the targets involved. A typical test plan for the BISS signature collection is presented in Table 1. Constraints on vehicle and personnel paths due to the location of security fences, protection of vegetation, etc., resulted in some deviation from the typical test plan. These deviations are noted in the field data logs as described in paragraph 4 of Appendix A, Description of Instrumentation and Recorded Data. The tests were sequenced to minimize changes in gain settings on the instrumentation during the conduct of the tests. The target paths are keyed to the test layout (Figure 1).

Site Documentation Plan

Rationale

14. Any sensor system will be subject to degradations in performance in some undesirable environmental conditions. Environmental factors adversely affecting performance of the sensors must be considered in order to rationally address such areas as:

a. Comparisons between the performances of new sensors and signal processors with previous designs. (Does the new design offer improvement in isolated environments or in a general class of environments? If in a general class of environments, how can they be defined and documented?)

b. Establishing deployment criteria. (Should the Miles Cable be buried at 20 cm depths in some soils and 30 cm depths in others? Can specifications be made for defining optimum compaction conditions around line sensors.)

c. Definition of areas unsuitable for the deployment of seismic sensors. (Suppose, based on BISS experience, a particular sensor continually has a high false alarm rate in sites located on deep alluvial soils and other sites located near coastal marshes--are there fundamental properties common to the seismic characteristics of the troublesome sites?)

15. The goal of site documentation is to measure the properties of the environment that affect the generation and propagation of the signatures of both seismic and acoustic signatures. Seismic signatures are normally more sensitive to environmental variations from site to site than acoustic signatures. Because of this and the fact that the purpose of this study supports the operation of seismic sensors, the emphasis in site documentation was placed on the measurement of those properties known to significantly affect the generation and propagation of seismic signatures. Appendix B presents a theoretical discussion of the generation and propagation of seismic signatures and reviews the properties affecting such phenomena. These properties are:

a. Bulk properties (compression-wave velocity, shear-wave velocity, bulk density, soil moisture, soil strength, and depths-to-interfaces of media having significantly different bulk properties).

b. Ground-surface rigidity.

c. Surface roughness.

16. Measurements used by WES for site documentation[6] are summarized below:

Measurement
Compression wave velocity
Shear wave velocity
Bulk density
Soil moisture
Cone index
Plate-load
Surface elevations

Measurements

17. Two categories of measurements used for documenting terrain conditions in terms that can be related to seismic response of an area were: those for documentation of surface and near-surface terrain

factors (restricted to a metre or less from the surface), and those for documenting subsurface terrain factors (primarily seismic velocities and layering). Supplemental site descriptive data such as geologic, physiographic, and meteorologic data were also collected. A brief description of the surface and near-surface measurements and the subsurface measurements follows. More detailed descriptions of these measurements and supplemental site descriptive data are presented in Appendix C and Reference 6.

18. Surface and near-surface terrain factors. Surface geometry, i.e., surface profile along the intruder path, was measured using conventional ground profile (leveling) techniques. Level rod readings were taken with a theodolite. One of the most convenient methods of measuring soil strength was the cone penetrometer (Appendix C). Such readings were taken at depths of 0, 15, and 30 cm. Soil-moisture and density measurements were taken at the same depths as the cone penetrometer readings (0, 15, and 30 cm).

19. Ground surface rigidity was measured using a plate-load test, i.e., a metal plate was pressed against the ground surface with a known force and the resulting deflection of the surface was measured. The dimensions of the plate were selected to be representative of the surface contact area of an intruder. Because of the emphasis of this study on the personnel travel modes--creep, crawl, walk, and run--plate load tests were taken using a plate having dimensions on the order of those of a man's foot (7.5 cm by 30.1 cm). Surface ridigity, as measured by plate-load tests, was sufficiently described by two parameters that depend on whether the soil has a compaction or a plastic nature (Appendix C). For soils that tend to compact, the relevant two parameters are the surface spring constant (K_{sc}) and the maximum soil deflection (Z_{max}) under the plate as estimated by the asymptotic limit of the force-deflection curve for large forces. For plastic conditions, two similar parameters are derived from the force-deflection curve, K_{sp} and F_{max}.

20. Subsurface factors. Data for documentation of subsurface factors were obtained using seismic refraction and vibratory techniques for obtaining the compression- or shear-wave velocities and thicknesses

of layers. The latter method of obtaining shear-wave velocity relies on measurement of the Rayleigh-wave velocity generated by a vibrator, and makes use of the fact that the Rayleigh- and shear-wave velocities are, theoretically, very nearly the same. Refraction and vibratory techniques are discussed more fully in Appendix C and References 5, 6, and 8.

Selection of Data Collection Sites

Rationale

21. To obtain the desired data, the sites selected for signature acquisition must be representative of the range of terrain conditions that can be expected to occur a reasonable percentage of the time. Furthermore, such sites must contain a reasonable range of ambient background noise sources. However, to attempt to define and collect background noise data that could be considered representative of those occurring worldwide would be impractical. Signatures of background noise sources cannot be separated from the terrain environments in which they occur because their signature characteristics are affected by the terrain. However, for purposes of organization, terrain and background noise considerations are discussed separately.

22. Terrain considerations. Properties affecting the generation and propagation of seismic signatures were identified in paragraph 15. Of the listed measurements, the compression-wave velocity was considered to be the most important measurement for purposes of site selection. The reasons for stressing the compression-wave velocity for site selection are:

a. The signature characteristics of intruders are very sensitive to the compression-wave velocity near the surface and to depths as great as 10 m. The sensitivity of the signature characteristics to the compression-wave velocity is conveyed through the correlation of the compression-wave velocity with the shear-wave velocity because it is the shear strength of the medium (hence shear-wave velocity) that largely controls the frequency and amplitude content of the seismic signature of intruders.

b. A number of compression-wave velocity measurements have been obtained throughout the United States and selected foreign countries so that the range in variation in compression-wave velocity in worldwide terrains can be reasonably inferred.

c. The compression-wave velocities for depths exceeding one metre are relatively stable over time for most site conditions. Therefore, site selection based on compression-wave velocities does not have a strong dependence on the immediate meteorological history of a site. Of the listed terrain measurements (paragraph 15), the compression- and shear-wave velocities are generally more relatable to a geographic location than the other measurements. Ground-surface rigidity depends strongly on soil moisture, hence meteorological history. Surface roughness, as it affects the generation of seismic signatures, can be regarded as relatively independent of the geographic location of a site.

23. Terrain data consisting of seismic refraction, seismic vibration, and soils information were assembled from past data collection efforts at WES and are presented in Appendix D. The locations of seismic refraction measurements throughout the U. S. and selected foreign countries are identified in Figure 2. Examination of the top-layer compression wave velocity values (near the surface) in Appendix D shows that they range from 92 m/sec (West Germany, Hessen, site 405) to 3600 m/sec (Alaska, Fairbanks, site 2, refraction line 4). Shear-wave velocities undergo a proportionate range in variation. The range of top- and second-layer compression wave velocities for the terrain data in Appendix D can be summarized by plotting the top-layer compression wave velocity against the second-layer compression wave velocity. Such a plot, is presented in Figure 3 based on data in Appendix D. Not all top- and second-layer velocity conditions in Appendix D are presented in Figure 3. If more than two refraction lines were obtained at a particular site (such as Alaska, Fairbanks, Tank Trail--Appendix D), only those values of top- and second-layer velocity which represent extremes in the top-layer velocities among the refraction lines obtained at the particular site are plotted in Figure 3 (each site is identified as a distinct entry in Appendix D under the column heading Site Identification). For example, five refraction lines were obtained at Alaska,

Fairbanks, Tank Trail. The maximum and minimum top-layer velocities among the five refraction lines occur for refraction line number 5 (2600 m/sec) and refraction line numbers 2 and 3 (both being 750 m/sec). Therefore, the top- and second-layer velocities were plotted in Figure 3 for refraction lines numbers 2 and 5 only. The objective of the terrain considerations for site selection was to select those sites that the measured compression-wave velocities for the selected sites approached the range in variation of the top- and second-layer velocities presented in Figure 3.

24. From the point of view of identifying data collection sites that span a wide range in compression-wave velocities, it was desirable to have some idea of the range of compression-wave velocities and layer depths throughout the United States (since only areas in the continental U. S. were considered for site selection). It was therefore necessary to devise an efficient approach for estimating the compression-wave velocity of terrains based on available information from topographic maps, aerial photography, geologic maps, soils maps, etc. To accomplish this, correlations were made between terrain types and soils information, and the compression-wave velocities, based on past experience of WES personnel in the selection of seismic data acquisition areas. Because of the nature of the information, these correlations had to be very general. The interrelationship between terrain type, predominant top-layer soil characteristics, and the range of compression-wave velocities are shown in Table 2. The soil characteristics associated with the specific terrain types (e.g. low plains, etc.) are representative of the most prevalent conditions commonly found in such types although exceptions occur. For example, in certain physiographic conditions, exposed bedrock areas occur in low plains; however, this is certainly not a prevalent condition. Soil characteristics described in Table 2 are related to the United States Department of Agriculture (USDA) textural classification.

25. Because of the range in compression-wave velocities that can occur for the terrain type and predominant top-layer soils characteristics in Table 2, the final selection of sites, that would successfully

address the terrain considerations, had to be based on measured compression-wave velocities in the selected areas.

26. Background noise considerations. The amount and kinds (types) of background noise sources in an area are the result of the natural conditions or features (meteorological conditions, drainage system, vegetation cover, etc.) found in the area and its cultural features and level of development (the number and classes of roads, degree of urbanization, agricultural practices, etc.). From a statistical point of view, it would be highly desirable to obtain characteristic background noise signatures and mixes of signatures in all worldwide environments of significant areal extent. From a time and cost point of view, this was not practical for this study and emphasis was placed on obtaining background noise data at sites having gross differences in natural and cultural conditions that could be considered to be representative of their range of variation in most Army, Air Force, and Navy installations.

27. The selection of sites for the collection of background noise field data was based on the following considerations:

- a. The sites selected should be representative of background noise environments found in Army, Air Force, and Navy installations. Sites should be located near such military-related background noise sources as airports, housing areas, and training and cantonment areas.
- b. Some of the data collection sites should be located in or near highly developed nonmilitary cultural areas (urban and industrial) adjacent to military installations.
- c. Field data should be collected in areas and environmental conditions where background noise is known to cause false alarms or masking of intruder signatures for presently deployed seismic sensors.
- d. Background noise data should be obtained in natural environments on or near military installations, especially at such times when rain, wind, and other sporadic meteorological conditions are contributing factors.

28. Specific background noise problem areas for intruder sensing devices (i.e. addressing c above) were identified through personal contacts with security personnel at military installations, and through discussions with BISS personnel well versed in the deployment and operation of intruder-detection sensors. The potential background noise

sources at a site are, at best, difficult to identify. However, recent aerial photographs and topographic maps provide a means of identifying the most obvious sources. Because of ease in interpreting particular sources from aerial photograph and topographic maps, the list of sources identified in Table 3 was used to distinguish levels of cultural development and available natural background noise sources.

Area and Site Selection

29. The terrain and background noise considerations in the previous section establish a set of very general criteria for site selection that can be satisfied by a number of areas throughout the United States. The most restrictive consideration was that data be collected where background noise is known to contribute to unsatisfactory performance of presently deployed systems. In view of this flexibility in the selection of data collection areas, a preliminary list of military installations was identified for which BISS personnel and supporting personnel at Sandia Laboratories wanted to obtain security-related information. These installations were:

Malmstrom AFB
Great Falls, Montana

March AFB
Riverside, California

U. S. Naval Weapons Station
Concord, California

U. S. Naval Weapons Station
Seal Beach, California

Sierra Army Depot
Herlong, California

Seneca Army Depot
Seneca, New York

30. Two more installations were added to the preliminary list for consideration. The first of these was Barksdale AFB, Louisiana, which was included because background noise was known to cause false alarms there for the presently deployed seismic sensor system. The other

installation was Fort Hood, Texas, which was included because it was known from previous WES studies to contain sites having a range of different terrain conditions.

31. Based on the terrain and background noise considerations, four military installations were selected for data collection. The four installations, the terrain types (Table 2), predominant background noise source classes, and some potential background noise sources interpreted from topographic maps and aerial photography are summarized in Table 4. Two of the installations are located in low plains, U. S. Naval Weapons Station, Seal Beach, California, and Barksdale AFB, Louisiana. One area is located in high plains, Fort Hood, Texas, and one is located in hills and mountains, March AFB, California. The range in potential background noise sources is considerable. U. S. Naval Weapon Station, Seal Beach, California, is surrounded by considerable industrial and other cultural activity. Barksdale AFB, Louisiana, and March AFB, California, have a mixture of cultural and natural background noise activity with known background noise problems. Fort Hood, Texas, is in a low population density area and is dominated by natural and military-induced background noise sources.

32. The terrain and background noise considerations were incorporated into the final selection of sites (paragraph 25) in the following manner:

- a. A preliminary set of sites was selected at each of the installations based on the availability of near-by background noise sources (within 100 m), the soil types in the area, access, and space available for implementing the field data collection plan.
- b. Compression-wave velocities were measured using seismic refraction equipment at the sites selected in a. Two to four sites were selected at each installation based on the goal of obtaining a range in the compression-wave velocities and the proximity of ambient background noise sources.

33. The selected sites and their respective compression-wave velocities and layer thicknesses are summarized in Table 5. The top-layer velocities are plotted against the second-layer compression wave velocities for the selected sites in Figure 4. Comparison of the

compression-wave velocities in Figure 4 with those of Figure 3 shows that the top- and second-layer compression wave velocities for the selected sites cover a broad range of compression-wave velocities but do not span the range for the assembled terrain data, particularly for the higher compression-wave velocities. Higher compression-wave velocities occur in very rigid terrain conditions, often found in mountainous areas. The difficulty of selecting a set of data collection sites that encompassed the range of variation in the assembled terrain data points out the importance of applying analytical procedures, such as simulation models, to extend the data base to conditions not represented in the data collection program.[3,4] The selected installations and data collection sites are discussed in the following paragraphs. More detailed descriptions are presented in Appendix E.

34. Barksdale AFB, near Shreveport, Louisiana. The reservation is located in the western Gulf Coastal Plain. The principal reason for selecting this installation was the fact that this is a locality where false alarm problems have developed with presently deployed intruder sensing devices. The boundaries of the reservation encompass three distinct physiographic units, i.e., the Red River alluvial plain, Pleistocene stream terraces, and Tertiary uplands of the western Gulf Coastal Plain. Three sites, one in each distinct physiographic unit, were used in the field data collection program. Site 1-A is located in the Red River alluvial plain, site 5 is on a dissected Pleistocene stream terrace, and site 7 is on a gently sloping Tertiary upland. Predominant top-layer soils for all three sites consist of poorly compacted sediments (Table 2). Cultural background noise sources predominate in the western sector of the reservation (near site 1-A). Natural background noise sources are predominant in the eastern sector (near sites 5 and 7).

35. Fort Hood Military Reservation, located in east-central Texas. The reservation is located on a partly dissected, structural high plain, the Lampasas Cut Plain, which is underlain mainly by carbonate (limestone) rocks and which contains remnants of an old plateau. Three sites were selected for the field data collection effort. Site 5-A is located on a partially dissected plain developed on a nodular and marly

limestone. Top-layer soils are loose residual soils containing fragmented rock material (Table 2). Site 8-A is located on high, flat hill (tableland) developed on a Lower Cretaceous limestone sequence. Top-layer soils are weathered and fractured rock. Site 9 is on the alluvial plain of North Nolan Creek. Top-layer soils are poorly compacted. Natural background noise sources, intermittently modified by military training activities, predominate in the vicinity of all three sites.

36. March AFB, near Riverside, California. The reservation is located in the "Perris Plain," a down-faulted block (graben) between the San Jacinto and Santa Ana Mountains. The graben is covered by a deep (395+ m) and irregular alluvial fill which is interspersed with hills and low mountains. Two sites were selected for field data collection. Site 1 is located at the southeast end of the main runway on the alluvial fill and top-layer soils are poorly compacted. Site 2 is on a hill which is underlain by tonalite (quartz diorite). Top-layer soils are loose residual soils containing fragmented rock material. Cultural background noise sources are due to moderate development, primarily air traffic and suburban type sources at these two sites.

37. U. S. Naval Weapons Station, Seal Beach, California. The reservation is located on an emerging coastal plain which has been modified by alluvial deposits of the San Gabriel River, by large-scale faulting, and by landfills. The Seal Beach Fault, part of the Inglewood Fault Zone system, traverses the reservation NW-SE almost parallel to the Pacific Coast Highway and across the southwestern sector of the reservation. South of Westminster Avenue, the terrain is characterized by a tidal marsh and reclaimed lands. Landing Hill, on the west boundary, is a faulted, nonmarine Quaternary terrace deposit. North of Westminster Avenue, the coastal plain has been modified by alluvial deposits of the San Gabriel River. Four sites were selected for field data collection. Site 1 is located along a road in the tidal marsh. Site 2 is on a landfilled area. Site 3 is also on a reclaimed (landfill) area. Site 4 is on the coastal plain modified by alluvial deposits of the San Gabriel River. All four sites have top-layer soils that are poorly compacted sediments. Cultural background noise sources predominate at all four sites.

Data Acquisition

Site documentation measurements

38. The measurements listed in paragraph 16 were organized into surface and near-surface measurements and subsurface measurements. Measurements on the surface consist of surface geometry and plate load tests. In general the surface geometry at each of the sites was visually flat with the vertical relief having the texture of grass clumps or gravel-sized rocks. The surface geometry profiles for the personnel and vehicle paths for each of the sites are retained at WES in the original data files. Each of the sites for which plate-load data were obtained had soils that compacted. Therefore, the descriptive parameters K_{sc} and Z_{max} (Appendix B, paragraph 6) were interpreted from the measured data. Near-surface measurements consisted of bulk density, soil moisture, and cone index. The surface and near-surface measurements are presented in Table 6. Plate-load measurements were not obtained at Seal Beach Naval Weapons Station and March AFB because of equipment operation problems. However, failure to obtain these measurements was not regarded as very significant because analysis of the signature data and plate-load parameters (K_{sc} and Z_{max}) showed that there is not a strong correlation between these parameters and the seismic response of the terrain. This is particularly true for surface conditions which are sufficiently rigid that the intruder does not leave a noticeable rutting depth, or footprint (paragraph 84). The subsurface measurements are presented in Table 7.

Signature acquisition

39. The intruder signature data and background noise data were collected and stored on magnetic tape. An index of the signature data is presented in Appendix F. In Table F1, the data are organized to provide analog tape and test numbers as a function of installation, site, target type, travel mode, and sensor type. A total of 507 tests were recorded during data collection. Background noise sources explicitly noted during the test are also summarized. Personnel speeds varied among individuals, but measured ranges for the various travel modes

for all the tests are tabulated below:

Travel Mode	Range of Speeds, m/sec
Creeping	0.20-0.40
Crawling	0.50-1.0
Walking	1.20-1.6
Running	3.50-5.0

More precise estimates of speed can be derived for each test by tracing the location of the primary target as a function of time using the time-location markers recorded on the event channel of the data tape (Appendix A, Figure A1).

40. The data recording system consisted of a Lockheed Electronic Corporation Model 4107 7-channel tape recorder which can record in the direct and frequency modulated (FM) mode. All signatures were recorded at tape speeds of 1-7/8 in./sec.* For direct recording, the frequency response of the recorder for a tape speed of 1-7.8 in./sec covered the frequency range from 100 Hz to 6000 Hz. For FM recording, the frequency response of the recorder for a tape speed of 1-7/8 in./sec was 0 to 625 Hz. Since most seismic information is below 600 Hz, because of the limits on geophone response and the large attenuation of the propagating seismic signal for frequencies in the hundreds of Hz, the FM recording of geophone signals is acceptable. However, some acoustic signatures were recorded directly, particularly background noise signatures of aircraft, because such acoustic signatures contain substantial energy with frequencies in the thousands of Hz. A more detailed description of the instrumentation, data collection procedures, and field data logs is presented in Appendix A.

41. All measured intruder-signature data were duplicated and provided to the BISS program office. The data were duplicated onto 14-track 1 in.-tape at 1-7/8 in./sec. The recording and duplicating were done using the Inter-Range Instrumentation Group (IRIG) standard with an FM center frequency of 3.375 KHz and with 40 percent deviation on the

* A table of factors for converting metric (SI) units of measurement to U. S. customary units is presented on page 5.

tape representing 1.441 zero to peak volts. As for the Lockheed recorded data, the FM data on the duplicated tapes was band limited between 0 and 625 Hz. The 7 channels of signature data recorded on the Lockheed recorder were duplicated onto the first 7 channels of the 14-track tape in their respective order. The voice channel (recorded direct on edgetrack of the original tapes) was FM recorded on channel 8 and direct recorded on channel 9 of the duplicated tapes.

PART III: DATA ANALYSIS

Introduction

42. In the previous part, the two kinds of data, site documentation and signature data, were described. This part presents an analysis of these data. The analysis was based on the relationship of the data to current efforts to improve the design, deployment, and testing of point and line sensors.

43. A number of sensors can be used to sense ground motion. These devices respond with differing sensitivities (i.e. have different voltage outputs generated by the same spatial distribution of particle motions in the ground). However, in general, they respond in a manner that is proportional to the magnitude of the particle velocities either horizontally or vertically, in the immediate area of the sensor. Furthermore, the mechanical system consisting of the sensor and the coupling of the medium to the sensor is usually sufficiently linear, in a mathematical sense, that a frequency of motion of the medium around the sensor induces a signature for which the same frequency predominates. This is indisputably true for the point-type transducers employing the geophones or piezo-ceramic crystals and has been demonstrated for line-type sensors, such as the MILES.[9,10] It is these response characteristics of the sensors (i.e. that the amplitude and the frequency responses are directly relatable to the ground motion in the immediate area of the sensor) that forms the basis for translating the time and frequency-domain characteristics of the intruder-induced ground motion to the signature characteristics induced in point and line sensors.

44. Current design efforts for ground-motion sensors emphasize improved signal processing techniques. The potential for such improvements has been enhanced by recent technological advances in the manufacture of the electronic components emp[illegible]ng digital processing techniques which are essential for logic design i[illegible]rovements. Two areas of development for signal processing for point and line sensors have been

in the areas of pattern recognition[1] and adaptive digital filtering.[11]

45. Pattern recognition improvements rely on the development of statistically-based algorithms for target detection and classification.[7] Features that characterize selected aspects of the signature (e.g. number of zero crossings of the voltage, amplitude, etc.) are extracted from the signatures of a number of targets and background noise sources in a range of environmental conditions. These features are combined mathematically to produce decision index values with which, hopefully, intruders can be detected and assigned to classes (such as personnel or wheeled vehicles) and background noise sources can be rejected.

46. In order for pattern recognition techniques to be successful, several constraints must be placed on the distribution of feature values used to make the class decisions. For a given class of targets in a given terrain, the distribution of feature values induced by changes in such variables as target type (within a class), target-to-sensor distance, and different target travel modes (walking, running, vehicle speed, etc.) must be sufficiently limited to prevent extensive overlap with the distributions of the feature values, induced by such changes, for targets in other classes. If the pattern recognition algorithms are not adaptive to the particular terrain or sets of similar terrains in which they are employed, the distribution in feature values (for a given class of targets) induced by the changes in the variables discussed above, must be sufficiently limited for <u>all terrains</u> to prevent extensive overlap with the distributions of the feature values, induced by the same changes in the variables, for targets in other classes.

47. Since the values of the features are directly related to frequency and amplitude characteristics of the signatures, the considerations discussed above can be transferred to the frequency domain of the signatures. For pattern recognition algorithms adaptive to the terrain, the frequency domain characteristics in the frequency bands of sensitivity of the features and target-to-sensor distances for operation of the sensor must be independent of target-type (i.e. different individuals or kinds of vehicles), target-to-sensor distance, and target travel mode (man-creeping, -walking, vehicle speed, etc.). For example, for a

given target type, such as personnel, the frequency domain characteristics of the signature should be reasonably independent of target-to-sensor distance, and whether the man is creeping, crawling, walking, or running. If the pattern recognition algorithm is not adapted to the terrain environment, the frequency domain characteristics of the signatures in the frequency region of sensitivity of the features must be reasonably independent of the terrain.

48. A second area of development in signal processing is adaptive digital filtering.[11] Adaptive digital filtering relies on the correlation properties of signatures do distinguish correlated signatures, presumably from background noise sources, from transient signatures associated with intruder-type sources. In particular, the propagating seismic signatures (as opposed to locally acoustically coupled signatures, generally at frequencies on the order of 10 Hz or higher) from distant background noise sources tend to be correlated over time for several seconds or more, even for impulsive sources, because of the continuous change in the velocity of propagation of the wave form with frequency (i.e. dispersion) and the attenuation of selected frequencies by viscous damping. The wave forms from such sources also tend to be correlated over space for distances on the order of the time of correlation of the signatures multiplied by the velocity of propagation. Adaptive digital filtering can be used in two modes, depending on whether the time correlation or spatial correlation properties of the signature are being exploited. The time correlation mode requires only the signal output from a single sensor. The spatial correlation mode exploits the signatures from two or more spatially separated sensors. In order for the time correlation mode to be successful, the signature characteristics of background noise sources must be sufficiently correlated over time so that the adaptive digital filter can anticipate, several seconds in advance, the signature characteristics of the background noise source. Subtraction of its anticipated background signature from the measured signature serves to enhance transient signatures, presumably of intruders. Therefore, the intruder signatures must be sufficiently random in the frequency region used for detection so that the adaptive

digital filtering algorithm does not subtract out successive portions of its signature as well. In order for the spatial correlation to be successful, the background noise can be removed by subtracting the signatures of pairs of sensors.

49. From the deployment point of view, several questions must be answered before a sensor is systematically deployed. Among these questions are:

a. In what kinds of terrain will the sensor be sufficiently sensitive so as to detect the target within the prescribed detection zone?

b. Can two or more sensors be placed within the detection zone to enhance the combined sensor performance so that detection requirements are met?

c. In what kinds of terrain will background noise sources generate false alarms?

d. Will the ground motion induced by the intruders be within the frequency and amplitude regions required for the signal processor to achieve proper classification?

e. How deep should the sensor be buried?

50. Questions a and b are concerned with the amplitude and frequency dependence of target signatures as a function of target-to-sensor distance and target travel mode. Questions c and d are concerned with the amplitude and frequency dependence of target signatures as a function of terrain condition. Question e is particularly relevant to the deployment of line sensors and is concerned with the amplitude and frequency dependence of target signatures as a function of target-to-sensor distance, travel mode, and terrain conditions.

51. Sensors should be tested in the range of environments, intruder-sensor configurations, and intruder travel modes for which the sensors are expected to operate. For evaluation of sensors, the range of environments can best be defined in terms of the terrain properties that most severely affect the frequency and amplitude characteristics of intruder signatures. Therefore, the designer of a test program for such sensors must also be aware of the sensitivity of the intruder signature characteristics to such variables as the target type, target travel mode, target-to-sensor distance, and terrain condition in much

the same way as the designer and deployer of the sensors.

52. The previous discussion illustrates that deployment and testing considerations dictate that the signatures be analyzed in both the frequency and time domain for such variables as target type, target travel mode, target-to-sensor distance, and terrain condition. In addition, the correlation properties of the signatures need to be addressed in support of adaptive digital filtering (paragraph 48).

Signature Data

53. Although it would be desirable to analyze the signature characteristics for each target type and a range of target-to-sensor distances, time constraints dictated that the analysis for this study be restricted to the most difficult target to detect, i.e. personnel signatures (see consideration c, paragraph 10) and selected target-to-sensor distances. The analysis of signature data is partitioned into analyses of the variance induced by each of the variables listed in the previous paragraph. Analyses of signatures for other target types represented in the data collection could be carried out in a manner similar to the treatment for personnel signatures. Plots of signature characteristics describing the frequency distribution of the measured signatures as a function of the data collection variables are presented in the format of Figures 5a and 5b. Three curves are presented in each figure. The three curves denote maximum, mean, and minimum amplitudes and were derived in the following manner:

a. Between six and twelve time segments of the signatures (depending on the availability of appropriate segments of the data), each of 0.68 seconds in length, were selected for which the target was in the proper target-to-sensor distance (for example, 0-0.5 m and 0.5-2 m for Figures 5a and 5b, respectively).

b. The time segments were digitized at a rate of 1500 samples per second and converted to the frequency domain by application of the fast Fourier transform so that each segment had an amplitude value for each frequency.

c. The maxima, means, and minima were obtained using the amplitude values at each frequency (six to twelve of

> them, one for each time segment). The maxima, means, and minima for the appropriate target-to-sensor distances are presented in the top, middle, and lower curves, respectively, for each frequency-domain plot.

In order to preserve detail and to exploit automatic plotting and scaling routines, some of the multiple-plot figures and plates discussed in the subsequent sections have different vertical scales (for example, Figure 5a and 5b have different vertical scales). Such instances are noted on the figures.

54. For purposes of characterizing signatures of intruders, data from five sites were selected. The sites were Barksdale, site 1A; Fort Hood, sites 5A, 8A, and 9; and Seal Beach, site 3. These sites were selected because they spanned the range of all terrain conditions used in the test program. It was convenient to organize the discussion of sites according to the increasing top-layer shear wave velocities. For the five sites for which the signature were analyzed, the order of increasing top-layer shear wave velocities is Seal Beach (site 3), Barksdale (site 1A), Fort Hood (sites 9, 5A, and 8A). When it is convenient to use abbreviations, these five sites are identified respectively by S-3, B-1A, H-9, H-5A, and H-8A.

Target-to-sensor distance

55. Figure 5 illustrates the dependence of the signature characteristics on the target-to-sensor distance for the vertical component of a signature obtained from a man creeping on a rigid (high compression and shear wave velocity) terrain condition, site 8A at Fort Hood. Both Figures 5a and 5b show the frequency domains for the vertical component of the particle velocity of the ground for man-creeping signatures within the distance regions indicated (0-0.5 m and 0.5-2 m, respectively). As can be seen in the figures, the predominant frequencies of the signature shift from less than 10 Hz for target-to-sensor distances less than 0.5 m to approximately 80 Hz for target-to-sensor distances exceeding 0.5 m.

56. Theoretical considerations can be used to explain the dependence of the signature characteristics discussed in the previous paragraph on target-to-sensor distance. The low-frequency signature

characteristics (i.e. less than 10 Hz) for small target-to-sensor distances (less than 0.5 m) can be attributed to quasi-static deflection of the elastic surface of the medium by the weight of the target. Although the data are not presented in this report, elastic theory predicts that the displacements of the medium induced by a quasi-static (low frequency) surface stress will decrease very rapidly with increasing target-to-sensor distance.[12] Elastic theory also predicts that the rate of decrease in medium displacements with target-to-sensor distance depends on the burial depth of the sensor, and for burial depths under consideration for BISS sensor applications (i.e. less than 61 cm, or 24 in.), the displacements (vertical or radial) reach maxima for target-to-sensor distances less than 0.5 m. Such displacements asymptotically approach zero for target-to-sensor distances on the order of 2 m. Elastic theory also predicts that, in addition to the quasi-static displacements, higher frequency displacements (i.e. exceeding 10 Hz for commonly occurring terrains) induced by the stress of the target on the surface will propagate outward from the source. Because these propagating displacements do not attenuate as severely with target-to-sensor distance as do the quasi-static displacements, they tend to dominate the signature characteristics at target-to-sensor distances exceeding 2 m (i.e. where the quasi-static displacements approach zero). Since the propagating displacements consist of higher frequency motions than do the quasi-static displacements, the dominant frequencies of the signature of the targets shift from low frequencies for target-to-sensor distances less than 0.5 m, to higher frequencies for target-to-sensor distances exceeding 2 m. A transition zone occurs between the target-to-sensor distances of 0.5 m to 2 m in which the two displacement types (quasi-static and propagating) compete for the dominant frequency characteristics of the signature. As will be discussed in paragraphs 64 and 65, the predominant frequencies of the propagating signatures measured in this study vary from 12 Hz to 80 Hz, depending on the terrain properties of the site.

57. Although the analyzed signatures in Figure 5 were induced by personnel targets, the predominant frequencies of the signatures depend

on target-to-sensor distance in a manner that can be related to elastic theory (paragraph 56). This relationship with elastic theory provides a basis for projecting the same dependence of the predominant frequencies on target-to-sensor distance to surface targets and travel modes other than man-creeping. Such projection will be used as a basis for generalizing the results of the analysis of personnel signatures to other target types. In view of the dichotomous nature of the frequency domain characteristics of target signatures as a function of target-to-sensor distance, it is convenient to partition the discussion of the signature characteristics into two signature types: those for which the low frequencies predominate (below 10 Hz) and those for which the higher frequencies predominate (above 10 Hz). Those for which the low frequencies predominate are referred to as near-distance signatures. Those for which the higher frequencies predominate are referred to as intermediate-distance signatures. A third type referred to as far-distance signatures would be the logical extension of near- and intermediate-distance signatures. However, within the context of this study, far-distance signatures could be considered to be on the order of several hundred metres. Such large distances are not of direct interest to BISS security requirements.

58. The strong dependence of the frequency domain characteristics of the signature on target-to-sensor distances is particularly applicable to the design considerations for pattern recognition and adaptive digital filtering for line sensors. For example, one appropriate goal for pattern recognition and adaptive digital filtering could be to extend the detection distance of line sensors beyond that for current signal processing techniques, which exploit only the low frequency characteristics of the near-distance signatures. To extend the detection distance beyond several metres, the potential signal processing designs must be sensitive to the higher frequency characteristics of the intermediate-distance signatures. However, previous investigations[7,13] have shown that the frequency characteristics of signatures of vehicles at distances of 25 to 200 m are similar to those of intermediate-distance signatures of personnel. Hence, vehicle traffic could become a more significant source of background noise for signal processors

using the higher frequencies associated with the intermediate-distance signatures than for those using only the low frequencies (less than 10 Hz). Adaptive digital-filtering techniques based on the correlation between signatures from two parallel-deployed line sensors, placed several metres apart, would likely be conducive to rejection of such background noise from sources at distances on the order of 10 m or more.

59. As noted in paragraphs 55 and 56, the predominant frequencies of the signature are sensitive to changes in target-to-sensor distance, particularly for distances on the order of 2 m. The transition zone between distances for which the low frequencies predominate compared to those for which the higher frequencies predominate is on the order of 1.5 m in width (i.e. between 0.5 and 2 m, paragraph 56). The fact that the transition zone is quite narrow is supportive of adaptive digital filtering techniques applied to the signature output of a single line sensor. Certain targets such as wheeled vehicles can generate repetitive (hence time-correlated signatures) for which adaptive filtering techniques may tend to subtract out the signature (paragraph 48). However, as the target approaches the sensor, the predominant frequencies of the signature change distinctly from high frequencies of intermediate-distance signatures. This change induces a transient into processed signatures that has frequencies of the near-distance signatures. This transient can be processed to indicate the presence of the intruder.

Terrain condition

60. The discussion of the variability of signature characteristics with terrain condition is partitioned according to the target-to-sensor distance. Near-distance signatures (paragraph 57) are discussed first for man-creeping signatures. Man-creeping signatures (rather than -crawling, -walking, or -running) were selected because they represent the lowest signal level relative to the personnel travel modes. For the intermediate distance signatures, man-walking signatures were analyzed. In this section, no direct comparisons are made between the near-distance and intermediate-distance signatures so that the analytical limitation imposed by presenting man-creeping signatures for the near-distance signatures and man-walking signatures for the

intermediate-distance signatures should not be very significant. However, should such comparisons be desirable, theoretical considerations discussed in paragraph 57 suggest that frequency characteristics of the signatures are more severely affected by whether the induced signature is attributable to quasi-static or propagational effects than by the target or travel mode. Therefore, frequency-domain comparisons between the man-creeping, near-distance and the man-walking, intermediate-distance signatures should be valid.

61. Near-distance signatures. Figure 6 presents the frequency-domain plots (maximum, mean, and minimum amplitudes) for the vertical component of the particle velocity for man-creeping signatures. Figure 6 shows that the low frequency characteristics of the near-distance signatures is a stable feature over the range of terrain conditions represented by the five data collection sites. The target-to-sensor distance for which the low frequencies predominate are 0- to 2-m for the three lower shear wave velocity sites: S-3, B-1A, and H-9. For H-5A, the minimum amplitude curve for the 0-2 m distances is very small (less than 1×10^{-5} cm/sec) indicating that, at least for some of the signature segments, the low frequencies are not very dominant. Therefore, the maximum distance for the near-distance signatures at H-5A is probably somewhat less than 2 m. For H-8A, the low frequency characteristic of the near-distance signatures did not dominate until the target-to-sensor distance was less than 0.5 m (Figures 5a, 5b, and 6e). In each instance presented in Figure 6, the maximum and mean frequency-domain curves have considerably higher amplitudes for the low frequencies than for the higher frequencies. The amplitudes tend to decrease as the shear wave velocity increases (i.e. the mean amplitudes for Seal Beach, site 3, for the low frequencies are around 0.2×10^{-3} cm/sec, whereas they are on the order of 0.05×10^{-3} cm/sec for Fort Hood, site 8A).

62. The average amplitudes of the vertical and horizontal component (in the direction from the target to the sensor) of man-creeping signatures can be compared in Figures 7a and 7b. Average amplitudes for both unfiltered and low-pass filtered signatures are presented. Filter cut-offs were 5 Hz and 10 Hz with filter roll-off of 24 db per octave.

The sites have been placed in the order of decreasing top-layer shear wave velocity. For both the vertical and horizontal components, the amplitudes tend to increase as the shear wave velocity decreases, with the exception of the horizontal component for Barksdale AFB, site 1A and Fort Hood, site 9. It should be noted that the top-layer shear wave velocities at sites 1A at Barksdale AFB and site 9 at Fort Hood are very similar, being 120 m/sec and 122 m/sec, respectively. Therefore, such sites could be expected to have overlapping signature amplitudes, which is, in fact, what occurs when comparing Figures 7a and 7b. The amplitudes of the vertical component tend to exceed those of the horizontal component, particularly for the sites having the higher shear wave velocities (H-5A and H-8A). The changes in amplitude with target-to-sensor distance for the vertical and horizontal components of the man-creeping signatures were estimated by dividing the unfiltered average amplitudes for the footfall 0.5 m from the sensor by the average amplitudes for the footfall at the sensor. The resulting ratios are presented in Figure 7c. In each instance, ratios for the vertical component exceed those for the horizontal component, indicating that the rate of change in amplitude with distance for the horizontal component generally exceeds that for the vertical component for the near-distance signatures. The rate of change in amplitude with distance is greater for more rigid sites (as indicated by smaller ratios for sites 5A and 8A) than for less rigid sites. Stability of the low frequency characteristic for near-distance signatures over the range of terrain conditions represented by the five data collection sites (paragraph 61) makes this characteristic a reliable feature for detection of intruders. However, target-to-sensor distance over which low-frequency characteristics predominate become less as the shear wave velocity of the media increases.

63. Intermediate-distance signatures. The analysis of the terrain induced variance for intermediate distance signatures is based on the amplitude and frequency characteristics plotted in Figures 8-14. Figure 8 presents the range in amplitudes of the signatures for man-walking signatures for each of the five sites for a fixed source-to-sensor distance of 6 m. The amplitudes vary from a minimum of 0.15×10^{-3} cm/sec for Fort Hood, site 8A, to 20×10^{-3} cm/sec for Seal Beach, site 3.

For each site except Seal Beach, site 3, the range in variation is approximately an order of magnitude (factor of 10). However, at Seal Beach, site 3, the signatures for one footstep impulse tended to be more similar to those of another footstep impulse so that the total range in variation was less than for the other sites. This probably occurred because the surface was sufficiently soft so that the predominant signal generation mechanism was the compaction of the soil as the foot impacted the ground. Such a signal generation mechanism would not seem to be particularly susceptible to erratic differences in the transfer of weight from one foot to another.

64. For the frequency-domain characteristics for man-walking signatures, Figures 9a to 9e are discussed. The predominant frequencies for man-walking signatures for a target-to-sensor distance of 6 m vary from around 12 Hz (Seal Beach, site 3) to 80 Hz (Fort Hood, site 8A). Although the predominant frequencies appear to increase with increasing shear wave velocity, one should be careful in making this interpretation without considering layering effects as well. The three Fort Hood sites, 5A, 8A, and 9, represent terrain conditions having large changes in shear wave velocity with depth. It is the magnitude of the change in shear wave velocity with depth, particularly for a slow shear wave velocity medium over a faster second layer velocity medium, rather than the absolute values of the shear wave velocities of both media, that leads to the selective coupling of frequencies of the stresses on the surface by a target so as to favor the higher frequencies, as will be discussed in paragraph 100.

65. The strong dependence of the amplitude and frequency characteristics of the intermediate-distance signatures on terrain conditions illustrated in Figure 9 is important to the design of both point and line sensors and to the selection of test sites for evaluating such sensors. To be used most effectively, features responsive to the shape of the frequency domain of the signatures must be used in pattern recognition algorithms that are adapted to the terrain conditions in which the sensors are deployed. For pattern recognition algorithms that are not adapted to the local terrain condition (i.e. that are employed in a range of terrain conditions) only the simplest features can be usefully

employed, namely features that distinguish only between the frequency of near-distance signatures (below 10 Hz) and intermediate-distance signatures (10 to 100 Hz or more) without regard to the shape of the amplitude distribution in the frequency domain.

Travel modes

66. Personnel travel modes consisted of creeping, crawling, walking, and running. The near-distance signatures for man-creeping have been discussed previously. Figure 15 presents the frequency-domain characteristics for man-creeping, -crawling, -walking, and -running for the denoted distances for Fort Hood, site 8A. The range of target-to-sensor distances for man-creeping is 0.5-2 m; however, the target-to-sensor distance is 6 m for the other travel modes. The amplitudes differ as could be expected. The peaks of the mean amplitude curves for the 6-m distance targets and travel modes (man-crawling, -walking, and -running) vary from 0.01×10^{-3} cm/sec for man-crawling signatures to 0.03×10^{-3} cm/sec for man-running signatures. The man-creeping signatures are plotted for only the 0.5-2 m distance because signal amplitudes were not great enough to record at the 6 m distance. However, the predominant frequencies of the signatures are approximately the same for each travel mode, including the man-creeping signatures, although the target-to-sensor distance is smaller in this instance. The invariance in the predominant frequencies as a function of the travel mode, such as that occurring at site 8A, occurred at the other sites also (Figures 10-14). Although the frequency domain characteristics of the stresses induced at the surface by the various travel modes differ among one another, the frequency response of the terrain is so selective that the resulting intermediate-distance signatures for each travel mode have essentially the same predominant frequencies.

67. The invariance of the predominant frequencies with travel mode suggests that pattern recognition algorithms using frequency sensitive features adapted to local site conditions could be used to extend the detection distance and classification potential of point and line sensors. Such algorithms should be able to operate independently of the intruder travel mode. Features sensitive to the frequency region of

the intermediate-distance signatures are also particularly responsive to background noise signatures. To reduce the contribution of the latter to the signatures processed for intruder detection, it is probably desirable to make use of two sensors in such a way that the background noise can be continuously subtracted by adaptive digital filtering using the spatial correlation mode (paragraph 48). Pattern recognition employing features responsive to the higher frequencies (i.e. greater than 10 Hz) could then be applied to the resulting signatures (those for which the background noise has been removed, hopefully, using adaptive digital filtering).

Intruder

68. A cursory examination of the signature characteristics induced by two different intruders (obtained from repetitive tests using different personnel such as tests 1 and 2 of Table 1) was made for the three Fort Hood sites (5A, 8A, and 9). As noted in paragraph 66, the frequency domain characteristics of the walking, crawling, and running signatures were dominated by the local site characteristics. That is, the predominant frequencies at a site were quite independent of the stresses induced by the personnel travel modes. Although the data are not presented in this report, the frequency-domain characteristics of signatures of different intruders were similar. However, the amplitudes of the signatures were sensitive to differences in the stresses of one intruder relative to those of another intruder as will be discussed using the data presented in Figure 16. Figure 16 presents the average peak amplitude for repetive tests using two different intruders for the three sites at Fort Hood. Three travel modes are represented: walking, running, and crawling. Intruder 1 weighed 825 newtons (185 lb) and Intruder 2 weighed 690 newtons (155 lb). Although the man-running and man-crawling signatures are consistently larger for the heavier intruder (Intruder 1), the opposite occurs for the man-walking signatures. In this instance the average amplitudes for the lighter intruder (Intruder 1) are greater than for those of the heavier intruder. The average amplitude for the man-crawling signatures differs more between the two intruders than for the other travel modes. This suggests that, when

testing sensors in scenarios in which the intruders are walking, running, or crawling, somewhat more care should be taken in the design of the man-crawling tests to insure that different crawling "styles" are represented.

Site Documentation Data

69. As noted previously, the rationale for site documentation is to measure those properties of the terrain that affect its seismic response. Past studies by WES have shown that the shear wave velocities and layer depths strongly affect the seismic response of the terrain.[3,4] Since the top layer compression wave velocity is quite strongly correlated to the top layer shear wave velocity, the compression wave velocity is also quite strongly related to the seismic response.

70. This section presents the results of a study of the relationship between other measurements (plate load, density, moisture content, cone index - paragraph 16) and the seismic response of the terrain to see if the relative importance of the terrain properties could be demonstrated such that economies in site documentation efforts could be effected. The surface elevations (paragraph 16) will not be discussed because the roughnesses at the data collection sites were not sufficiently different so as to induce distinct differences in the motion characteristics for each of the personnel travel modes. Therefore, it was not considered reasonable to attribute differences in signature characteristics for the selected sites to the surface roughness.

71. The measurements of terrain properties other than the shear and compression wave velocities and layer depths can be qualitatively correlated to the seismic response of the terrain either through the correlation of these measurements to the shear and compression wave velocities of the media, which in turn are related to the seismic response, or through an independent relationship between properties of the media and its surface and the seismic response. The method of analysis used to qualitatively identify strong correlations between the measurements and seismic response consisted of ordering the sites for

each measurement according to increase or decrease of the measured values for each measurement. This ordering was compared with the ordering of sites in the previous section, i.e. ordering based on shear wave velocity. The latter ordering resulted in having the presented data in the order of increasing or decreasing values of the amplitude or dominant frequency characteristics. An exception to the ordered increase or decrease in signature characteristics occurred for Barksdale, site 1A and Fort Hood, site 9 (paragraph 62). These sites were considered interchangeable in the ordering used for discussion of the relationship of the measurements to seismic response. The ordering used for comparison is referred to as the reference ordering, and is:

Seal Beach, site 3
Barksdale, site 1A } interchangeable
Fort Hood, site 9 }
Fort Hood, site 5A
Fort Hood, site 8A

Since the frequency and amplitude characteristics of the signatures for these sites varied considerably, it seemed reasonable to assume that a measurement strongly correlated to the seismic response would undergo distinct changes from site-to-site that paralleled changes in signature characteristics.

72. The subsequent analysis is subject to several limitations. First, the number of sites represented is small. However, distinct differences in their signature characteristics occur so that it is reasonable to expect that a measurement that affects seismic response to the extent of changing the amplitude by an order of magnitude, or the frequency content by tens of Hertz across the range of terrain environments represented in the data collection, would induce an ordering of sites that agrees well with the reference ordering. Secondly, the measurements considered for analysis are surface, or near-surface measurements. Past experience and theoretical modeling have shown that seismic response is affected by terrain properties to depths as deep as ten metres. However, the top layer seismic properties and layer depth are particularly important.

Plate load

73. The plate-load measurement is described by the surface spring constant K_{sc} and the asymptotic value of the rutting depth for large forces, Z_{max}. Examination of Table 2 shows that the order of sites for increasing values of K_{sc} and Z_{max} is:

K_{sc}	Z_{max}
Seal Beach, site 3	Barksdale, site 1A
Fort Hood, site 8A	Fort Hood, site 5A
Fort Hood, site 9	Fort Hood, site 8A
Fort Hood, site 5A	Fort Hood, site 9
Barksdale, site 1A	Seal Beach, site 3

The ordering of the sites for K_{sc} and Z_{max} are not the same as that of the reference ordering. However, Seal Beach, site 3, represents an extreme case for these orderings as well as for the reference ordering. Therefore, the plate-load measurements are not considered as strongly correlated to the seismic response across the range of site conditions considered as are the seismic velocities. However, there is probably a stronger correlation between plate-load measurements and seismic response among soft-surface sites for which K_{sc} is on the order of 10^6 n/m^2 and Z_{max} is on the order of 0.10 m (i.e. conditions similar to those of Seal Beach, site 3) than for more rigid-surface sites (such as the other four).

Density

74. Wet soil densities (Table 6) were selected because they represent the in situ density of the medium. The average of the wet densities presented for each site in Table 6 were selected for analysis. The order of sites for increasing average wet densities is:

Fort Hood, site 5A
Seal Beach, site 3
Fort Hood, site 9
Barksdale, site 1A

Wet density was not obtainable in the field for Fort Hood, site 8A because of rock. The above order of sites does not agree with the reference order and therefore the wet density was not judged as being strongly correlated to the seismic response.

Moisture content

75. The order of sites for increasing average moisture content (percent) derived from Table 6 is:

Fort Hood, site 8A
Fort Hood, site 5A
Fort Hood, site 9
Barksdale, site 1A
Seal Beach, site 3

This ordering indicates a qualitative correlation between the soil moisture and seismic response. It also points out the necessity for being cautious when interpreting correlations involving several variables and limited data. Sites 8A and 5A at Fort Hood contain much rock (Table 6) and therefore tend to have lower moisture content than the clay soils at Fort Hood, site 9, or Barksdale, site 1A. The soil at Seal Beach, site 3 had a very high moisture content. As noted previously, the seismic velocities, particularly the shear wave velocities, strongly affect the seismic response and the shear wave velocities are generally high for media containing rock and low for water-saturated soils. The qualitative correlation of the low moisture content to seismic response for sites 5A and 8A is induced by the relationship of the measured values to the rock content of the media. Obviously, a low moisture content does not imply a rock-type medium. For high values of moisture content, the shear strength of the medium tends to decrease with increasing moisture content so that a correlation between seismic response and moisture content can be expected. The moisture content could be strongly related to the seismic response of frozen soils. However, such conditions were not represented in the measured data. Therefore, moisture content was not considered strongly correlated to seismic response for nonfrozen ground conditions and for soils that had low to intermediate moisture content (below 25 percent for most soils).

Cone index

76. The order of sites for increasing average cone index is:

Seal Beach, site 3

Barksdale, site 1A

Fort Hood, site 9

Fort Hood, site 8A

Fort Hood, site 5A

This ordering agrees well with the reference ordering except for the more rigid sites, Fort Hood, sites 5A and 8A. Comparison of the top layer shear wave velocities (Table 7) with the cone index data (Table 6) indicates that large differences in top layer shear wave velocities are related to the cone index values. For example, the top layer shear wave velocities of sites 2 and 3 at Seal Beach are low (75 m/sec). In both instances, the cone index values are low (71 and 51, respectively). The cone index readings are quite high (400 or more) for the higher shear wave velocity sites (exceeding 200 m/sec) -- sites 5A and 8A at Fort Hood and sites 1 and 2 at March AFB. It is generally difficult to obtain accurate measurements of shear wave velocity near the surface, particularly within the top 15 cm (Appendix C). Cone index can provide a means of documenting near-surface shear strength properties where measurements of the shear wave velocity cannot be easily made. Cone index readings were considered to be correlated to seismic response, particularly for less rigid media (i.e. those for which the cone index readings are less than 500).

Documentation of Site Conditions

77. Proper consideration of site conditions is an important part of the BISS activity especially in the evaluation and the selection of new sensor systems, the identification of areas unsuitable for the deployment of existing systems, and establishment of deployment criteria at a site prior to sensor installation. Because the BISS sensor deployment requirements are directed toward the protection of fixed (permanent) installations, efficient on-site measurements can be made prior to the specification of sensor types and deployment criteria.

78. In the past, site documentation procedures for measurement of

seismic response have been directed toward battlefield sensor systems and have been concerned with documenting site conditions for signature propagating distances on the order of 10 m or more. Although such distances are of interest to BISS requirements, in the subsequent discussion additional emphasis has been placed on site documentation for line sensors. To adequately describe the seismic response for such distances, near-surface and subsurface properties within a few metres of the source are particularly important.

79. As stated previously, the shear- and compression-wave velocities and layer depths have been shown to be essential measurements for describing seismic response. Surface roughness, plate-load test results, soil moisture and density, and cone index are of somewhat lesser importance. This section presents recommendations and supporting discussion of site documentation requirements as it pertains to the design and testing of ground-motion sensing devices for BISS.

Seismic velocity measurements

80. It is recommended that the shear wave velocity be obtained via the measurement of the Rayleigh-wave velocity using the vibrator technique.[8] The depth for which the vibrator technique characterizes the shear strength of a soil depends on the frequency of the vibrator. That is, for shallow depths (for example, 1 m or less), the frequencies that characterize the medium are greater than for those frequencies that characterize the medium several metres under the surface. For propagating wave forms, such as background noise or man-walking signatures at ranges exceeding several metres from the source, the medium characteristics are important several metres under the surface. Therefore, low-frequency characteristics should be measured (i.e. frequencies of 25 Hz or less). For the "low-frequency" quasi-static displacements, such as those occurring for ranges of 2 m or less from the footfall of an intruder, the shear strength of the soil is important for very shallow soil depths (i.e. less than half a metre). For most media, vibrator frequencies of several hundred Hz are needed to characterize the soil at such shallow depths. Therefore, Rayleigh-wave measurements should be obtained over frequencies ranging from less than 25 Hz to 400 Hz.

81. Compression-wave velocity measurements should be obtained using refraction techniques (Appendix C). However, two sets of refraction lines should be run, one set using 2-3 m spacing of geophones, the other using a spacing of geophones of 0.25 m to obtain layering information near the surface.

Other measurements

82. Based on the previous analysis (paragraphs 69-76), the cone index appears to provide the best qualitative correlation of measurement values to seismic response across the range of terrains considered relative to the other measurements. The cone index can provide a measurement of the shear strength properties of the medium near the surface (within 30 cm), a region where measurements of shear-wave velocities are difficult to obtain. Both hand-held and mechanical cones are available. Hand-held cones can be easily transported to soft surfaces where it is difficult to take a vehicle mounted mechanical cone. The cone penetrometer used for measuring cone index and the measurement procedure are described in Appendix C.

83. The other near-surface measurements were not as well correlated to the seismic response across the range of seismic environments considered as were the seismic velocities and cone index (with the exception of the soil moisture which provided anomalous correlation as discussed in paragraph 75). Despite the fact that the density and soil moisture are not as strongly related to the seismic response of the terrain as the compression and shear wave velocity and cone index, these measurements are easily taken and should be obtained as prescribed in Appendix C.

84. Surface rigidity measurements should be prescribed when time and equipment constraints are not too demanding. Availability of equipment or access of a vehicle to particular terrain conditions may prohibit the measurement of surface rigidity using vehicle-mounted plate-load test equipment. Because of the lack of correlation of surface rigidity to seismic response on the more rigid sites (i.e. sites having cone index values that exceed considerably those of Seal Beach, site 3, say 150), failure to obtain surface rigidity measurements should not be

very limiting. For sites having nonrigid surfaces, such as Seal Beach, site 3, it is generally not possible to obtain surface rigidity measurements because of the difficulty of moving the equipment to the area.

PART IV: SIGNATURE SIMULATION RESULTS

Introduction

85. As noted in the discussion of the compression-wave velocities of the selected sites (paragraph 33), the top- and second-layer compression-wave velocities covered a broad range of conditions but did not span the range of those occurring in the terrain data (Appendix D). Therefore, a theoretical approach was taken to expand the data base of seismic signatures by using WES seismic simulation models to generate synthetic signature data. In addition to extending the data base to seismic conditions not represented in the experimental data base, the theoretical approach provided a means for evaluating the sensitivity of the seismic response to the terrain properties, particularly the shear-wave velocities of the media and layer depths.

86. In the previous part, the seismic signatures were shown to have a dichotomous nature dependent on the target-to-sensor distance. For target-to-sensor distances within some prescribed distance on the order of 2 m (depending on site), the personnel signatures were dominated by low frequencies (less than 5 Hz, paragraph 55). Such signatures were referred to as near-distance signatures. For target-to-sensor distances exceeding the prescribed distance, the predominant frequencies were much greater (from 12 to 80 Hz, depending on site, paragraph 64). These signatures were referred to as intermediate distance signatures. The low frequency components of the near-distance signatures do not propagate outward and are the result of the deflection of the elastic surface by the weight of the target. On the other hand, the intermediate-distance signatures propagate outward with moderate loss in amplitude and shifts in frequency (generally to lower frequencies) that are generally detectable tens and even hundreds of metres from target (depending on whether the target is personnel or vehicle). The theoretical approach used in this study emphasized the wave propagation nature[3] and as such is applicable to intermediate distance signatures. A follow-on study of the Miles cable response will include a theoretical

analysis of the near-distance phenomenon.

87. This part describes model validation, the synthetic data base, and a discussion of the range in variation found in the signatures. For the model validation section, signature characteristics of predicted and measured signatures were compared for the five sites selected for analysis in the data analysis part. For the synthetic data base section, a matrix of terrain conditions approaching the range of those occurring in the assembled terrain data was defined and predicted signatures were generated for these matrix elements. The data base consisting of the synthetic and measured signature data was then analyzed to describe the range in variation in signature characteristics that would likely occur in worldwide terrain conditions.

Model validation

88. Models simulating the generation and propagation of seismic signatures have been shown to provide reasonable predictions for the frequency and amplitude characteristics of seismic signatures of military targets.[2,13,14] However, the accuracy requirements for such simulations depend on the application. Previous uses of the simulated signatures have emphasized target-to-sensor distances on the order of 75 m or more, and as such, have exploited signatures having distinctly different frequency distributions from those of the closer distances of primary interest to BISS, 25 m or less (paragraph 3). For distances of 25 m or less, significantly higher frequency components occur in the signatures than for those of further distances. The higher frequencies are attenuated more strongly with distance by viscous damping than are the lower frequencies (Appendix B). Before applying the simulation models to the closer target-to-sensor distances (i.e. on the order of 25 m or less), it was felt that additional model validation work was needed.

89. As for the data analysis part, emphasis was placed on the personnel signatures, particularly man-walking signatures. Predictions of man-walking signatures were made for target-to-sensor distances of 6 m. The terrain data used for these predictions were those measured at the sites: plate-load and seismic velocity data (Tables 5 and 6,

respectively). Because of the sensitivity of signature characteristics to shear-wave velocities and layer depths, the layer depths were chosen to be those associated with shear-wave velocity change. The compression-wave velocity for each layer was selected to be the measured value that predominated through most of that layer. Under these guidelines, the following shear- and compression-wave velocities and layer depths were used for predictions of signatures:

Installation	Site	Layer No.	Layer Depth, m	Velocity, m/sec Shear	Compression
Barksdale AFB	1A	1	0.0-4.0	120	353
		2	4.0+	170	1700
Fort Hood	5A	1	0.0-1.8	203	780
		2	1.8+	381	1950
	8A	1	0.0-2.1	253	1410
		2	2.1+	427	2825
	9	1	0.0-3.8	122	300
		2	3.8+	203	1675
Seal Beach Naval Weapons Station	3	1	0.0-3.0	75	497
		2	3.0+	125	965

90. The adequacy of prediction models to calculate reasonable signatures was studied by comparing the frequency and amplitude characteristics of the measured and predicted man-walking signatures. The frequency domain characteristics of the measured and predicted signatures were compared by identifying the 20 Hz region for which the average amplitude of the signature (measured or predicted) was the largest relative to the remaining frequencies. A 20 Hz region was selected because the energy in the frequency domain of most personnel signatures is concentrated within a bandwidth on the order of 20 Hz or greater as may be seen in Figures 10 to 14. The central value of the 20-Hz bandwidth is identified as the center frequency (CF). The average amplitude for the 20 Hz region represented by the CF, referred to as the AACF, is also used to characterize the frequency domains of the signatures.

91. The model validation task was accomplished with some feedback from the data analysis part. The purpose of the feedback of information from the data analysis part was to allow improvements in the signature

prediction models where an apparent need was observed. Initial results of comparisons of the amplitudes of the measured and predicted signatures indicated that the predicted signatures were generally larger in amplitude than the measured signatures. The initial comparisons of the predominant frequencies of the measured and predicted signatures were favorable. In order to obtain better correlation, the amplitudes of the predicted signatures were reduced by a factor of 0.3 through modification of the forcing function (Appendix B). Although such a factor may seem large, the amplitudes of signatures of individual footstep impulses may vary at a site over a factor of ten between the largest and smallest amplitude signatures (Figure 8). A conservative approach for predicting signature amplitudes is consistent with BISS requirements for personnel detection for low signal levels.

92. The CFs for the measured and predicted man-walking signatures are compared in Figure 17. As may be seen in the figure, the agreement is good for the lower frequencies (S-3, B-1A, H-9) and fairly good at the higher frequencies sites (H-5A, H-8A). The predicted signature amplitudes after empirical adjustment of the amplitudes in the time domain (paragraph 91), are compared with the range in variation of the measured amplitudes in Figure 18. From Figure 18 one can see that the predicted amplitude after empirical adjustment falls within the range in variation of the measured amplitudes for each of the five sites.

<u>Synthetic data base</u>

93. As noted previously, under many terrain conditions the compression- and shear-wave velocities and layer depths determine the resulting signature characteristics for a given target in a given terrain environment. However, the relationship between the compression- and shear-wave properties of a terrain and the signature characteristics is complex. In order to relate particular terrain properties to signature characteristics, a number of terrain conditions were defined in terms of the seismic properties: compression- and shear-wave velocities and layer thicknesses, bulk density and surface rigidity. Each terrain condition is referred to as a terrain matrix element. The group of these elements constitute the terrain matrix. Examination of the top- and

second-layer compression wave velocities for measured terrain data as presented in Figure 3 and in Appendix D shows that top-layer compression wave velocities vary from 92 m/sec to 3600 m/sec (paragraph 23). Therefore, elements of the terrain matrix were selected so as to extend over such a range of velocities. A second problem, however, was that of determining the number of layers to be included in the matrix and the size of the changes in the compression- and shear-wave velocities and layer thicknesses between adjacent terrain matrix elements. In order to reasonably limit the number of terrain matrix elements, only single- and two-layer terrain conditions were represented.

94. The terrain matrix is presented in Table 8. The compression-wave velocities for the top layer vary from 150 m/sec to 2300 m/sec. This range spans the major portion of the conditions represented in the assembled terrain data in Appendix D. The second-layer compression wave velocites are also spanned by the terrain matrix. They range from 300 m/sec to 5000 m/sec. The signature characteristics for the personnel travel modes are not strongly correlated to the surface spring constants (paragraph 73). To reduce the complexity of the matrix of generated signatures, only two surface spring constant conditions were represented in the matrix of predictions. For top-layer shear wave velocities of 75 m/sec, the surface spring constant was selected to be 1×10^{-6} n/m^2 and Z_{max} was 0.1 m. For the remaining matrix elements, the surface spring constant was selected to be 1×10^{-8} n/m^2 and Z_{max} was 0.005 m.

95. Intermediate-distance signatures were predicted for the vertical and radial components of the ground motion for the personnel travel modes of creeping, walking, and running for each of the 144 matrix elements. The signatures of man-creeping were predicted for a target-to-sensor distance of 2 m whereas those of man-crawling, walking, and running were predicted for target-to-sensor distances of 5 m and 15 m. Man-creeping signatures were not predicted at the 5- and 15-m distances because the signature amplitudes would have been too small to reasonably expect detection. In addition, signatures of an M35 vehicle for a target-to-sensor distance of 75 m were generated for the elements in the terrain matrix as a guide to background noise signature characteristics

in various seismic environments. A description of the data tapes, identification lines for the data, data format, and the time and frequency domain information are given in Appendix G.

Variations in Signature Characteristics

96. The purpose of this part is to use the measured and synthetic data to provide information concerning the range in signatures characteristics that can be expected to occur in a wide range of environments. In the model validation section two parameters are defined for characterizing the frequency domains of the signatures: center frequency and average amplitude at the center frequency. These parameters are used here to describe the range in variation in signature characteristics. For the 6 m distance, man-walking signature data, the bandwidth selected for computation of the CF (paragraph 90) was 20 Hz because the energy in frequency domain of such signatures was concentrated within a bandwidth of 20 Hz or greater. For the M35 at 75 m, the higher frequencies in the signatures are attenuated by the longer propagation distance (75 m versus 6 m) with the result that the energy in the frequency domain is concentrated within a bandwidth narrower than for that of the man-walking signatures. Therefore, a 10 Hz average was used for the computation of the CF for the M35 signatures.

97. To study the range in variation in signature characteristics that can reasonably be expected to occur worldwide, man-walking and background noise signatures were selected. Man-walking signatures were selected, rather than signatures for the other personnel travel modes, in order to limit the number of signatures for which the analysis was made and to be consistent with the emphasis on such signatures in the previous part. Table 9 shows, for each matrix element (Table 8), the calculated CF and AACF for man walking and a background noise signature (M35 truck moving at 32 km/hr). Predictions were made for target-to-sensor distances of 5 and 15 m for the man-walking target and 75 m for the background noise source.

98. The predicted seismic signatures from the background noise

source (M35) tend to be lower in frequency than those for man walking because the background noise source is more distant than the man-walking target. In general, this would be true for most background noise sources because the seismic signature is attenuated with propagation distance more severely at the higher frequencies than the lower frequencies due to viscous damping (Appendix B). An exception to this "low frequency" characteristic of background noise is that due to acoustically-coupled seismic energy (such as from aircraft, engine firing of vehicles, etc). Measurable amounts of acoustically-coupled seismic energy appears to couple to the surface very near the sensor so that high frequencies (above 50 Hz) may be present in the signature. However, as will be shown from analysis of the predicted signatures data, much of the background noise in an area (due to vehicle traffic) contains frequencies below 30 Hz.

99. To illustrate the range in variation of the CFs and AACFs, these values are plotted in Figure 19 for each of the 144 matrix elements for man-walking signatures for the 5-m target-to-sensor distance. The AACFs vary over five orders of magnitude (from 10^{-8} to 10^{-3} cm/sec). The CFs vary from 10 Hz to 180 Hz. Since the matrix elements were derived using the terrain data in Appendix D, the ranges of variation in Figure 19 are representative of those that can occur in most terrain environments for target-to-sensor distances of 5 m.

100. As stated earlier, examination of the CFs in Table 9 for the man-walking and selected background noise signatures shows that the CFs of the signatures of the sample background source (propagating a distance of 75 m) tend to be lower than those of the man-walking for the 5- and 15-m cases. Careful study of Tables 8 and 9 also shows that the shift in the predominant frequencies of the signatures are due primarily to the layering of the media having distinctly different shear-wave velocities. For example, the CF of the predominant frequencies for the man-walking signature with a target-to-sensor distance of 5 m for matrix element 17 (having a 0.25 m top layer) is 127 Hz. For matrix element 18 (having a 1.5 m top layer) the frequency drops to 25 Hz for the 5 m distance. The high frequencies attenuate very rapidly with range,

however, so that at a range of 15 m the CF for matrix element 17 is 13 Hz and 25 Hz for matrix element 18. Physically, the large frequency dependence on layering of media having large differences in their respective shear-wave velocities can be attributed to the fact that the particle motion for a Rayleigh-wave with a prescribed frequency is constrained to be within approximately a wave length of the surface. Although the top layer of a soil may be "soft" and therefore suggestive of good coupling of energy to the media, only those waves that can travel in the top layer can be efficiently coupled into it. Such waves must have a wavelength on the order of the top layer depth or less (i.e. since small wavelengths imply high frequencies, only frequencies above a prescribed frequency cutoff can travel efficiently in the top layer). Waves having wavelengths longer than the top-layer depth do not couple efficiently to the media because their existence requires that the more rigid second layer be vibrationally excited. Such waves have low frequencies relative to the efficiently coupled waves traveling in the top layer. As a result of these factors, the signature characteristics that are coupled to the media for an intruder traveling over a material having a shallow top layer will tend to have considerably higher frequencies than the signature characteristics for an intruder traveling over a deeper top layer. For example, the higher values of the CFs at Fort Hood, sites 5a and 8a (Figure 17) are the result of the shear wave layering phenomena having large discontinuities in the shear-wave velocities rather than the fact that the top-layer shear wave velocities are higher at these sites than the other sites for which signature data were analyzed.

101. Near-distance signatures for man-creeping were discussed in paragraphs 60 through 62. Two components of particle velocity were examined, vertical and radial. One of the most favorable aspects of the near-distance signatures is the fact that, for distances of 0.5 m or less, the low frequency component of the signature (15 Hz or less) dominates the frequency domain irrespective of site condition (among those signatures analyzed). The target-to-sensor distance dependence of this low frequency component confines its use for detection to target to

target-to-sensor distances of several metres or less, depending on site conditions. A favorable aspect of the measured near-distance signatures is that the variation in amplitude for both the vertical and radial components (unfilterd) is less than an order of magnitude from site to site for the 0.5 m target-to-sensor distance signatures (see Figure 7). This range in amplitude variation contrasts with the similar measured range in variation of several orders of magnitude at the same sites for the intermediate-distance intruder signatures (Figure 8). The decreased range in variation for the near-distance signatures, which are dominated by the low frequencies, makes sense from a theoretical point of view.

[illegible] displacements at each site for quasi-static conditions, such as those occurring at the low frequencies typical of the near-distance signatures, are proportional to the shear moduli of the respective media. The shear moduli are proportional, in turn, to the square of the respective shear wave velocites. For the five sites for which the signatures were analyzed, the shear wave velocities (Table 4) near the surface varied from 75 m/sec to 253 m/sec. The square of the ratios of the maximum and minimum shear-wave velocities (3.37) is 11.35, or, approximately an order of magnitude.

PART V: DISTRIBUTION OF TERRAINS

Introduction

102. The previous part illustrates that there can exist a large range of variation in signatures from intruders of interest to BISS. The result of this variation is that the signature characteristic for two different intruder classes e.g. personnel and wheeled vehicles, will probably assume similar values in particular sets of terrain environments. This makes the design of logics that can consistently discriminate them more difficult. The design problem, however, would be considerably diminished if the design was based on a limited number of terrains. For this reason, it is of interest to determine how often terrains associated with signatures having particular characteristics occur. Although it appears impractical to define with certainty the frequency of occurrence of terrains that exhibit similar seismic responses, a crude estimate can be made using the data summarized in Appendix D as if it were proportional to conditions found worldwide.

103 The objectives of the analysis of the distribution of terrains were to estimate the frequency of occurrence: (a) terrains having defined ranges in their measured properties as such properties are related to those of the terrain matrix elements (Table 8) and (b) terrains for which the seismic response to intruder and background noise sources were similar. This part contains discussions of the assumed population for estimating the distribution of terrains, the distribution of terrains based on their measured properties, and the distribution of terrains based on their predicted seismic response to intruder and background noise sources.

Assumed Population

104. Appendix D contains compression and shear wave velocity and the corresponding layer depth data for 568 individual sampling points (seismic refraction or vibratory lines) from diverse locations in the

United States, mid-Pacific, the Panama Canal Zone, and West Germany. Of these, 418 could be collapsed to one and two layer cases that could be directly associated with similar conditions in the terrain matrix (Table 8). These were used to estimate the proportion of the environments represented by each terrain matrix element. There were 150 data sampling points that could not be collapsed to one or two layer cases or were two layer cases with a faster top-layer velocity medium over a slower second-layer velocity medium that could not be suitably associated with the terrain matrix. It would have been desirable to include these data in the analysis; however, the effort would have been considerable and it is doubtful that their inclusion would have significantly improved the overall estimate Therefore, in the interest of expediency, the 150 sampling points were omitted from this analysis. In many instances several refraction or vibratory lines in Appendix D have been taken in the same area, displaced only several hundred metres from one another. To avoid the obvious biasing that could occur if each of the lines were treated as an independent sample, a subset of the entire set, referred to as the reduced set, was selected based on a requirement that no more than three refraction or vibration lines could be selected from the same geographical area (such as Fort Carson, Colorado). In the event that three lines were selected from the same geographical area, the three were selected on the basis that the extremes in the top-layer shear wave velocities were represented as well as a refraction line that, insofar as possible, represented a top-layer shear wave condition near the average of the two extreme top-layer shear wave velocities. The reduced set, obtained in this manner, contained data from 151 sampling points.

Distribution of Terrain Properties

105. The estimate of the frequency of occurrence of terrains having defined ranges of measured properties was based on the reduced and entire data sets (paragraph 103) in Appendix D. To obtain the desired element, the terrain data (Appendix D) were assigned to similar terrain matrix elements in the following manner:

a. Assignments were made on the basis of the shear wave velocity and the associated layer thickness. For one and two layer cases, the terrain conditions were assigned to the closest element in the terrain matrix (i.e. if a terrain condition had a top layer shear wave velocity of 140 m/sec, a layer depth of 3.5 m, and a second layer shear wave velocity of 230 m/sec, it would be assigned to terrain matrix element 37, Table 8, having a top-layer shear wave velocity of 135 m/sec, a layer depth of 4 m, and a second layer velocity of 200 m/sec).

b. Three layer cases were collapsed to two layer cases if the second layer extended below 7 m or if the first or third layer velocities were sufficiently close to the second layer velocity such that two layers could be combined. For the latter consideration, the criterion was that the first (or third layer) was combined with the second layer if the velocity of the first (or third) layer was assigned to the same velocity represented in the terrain matrix as was the second layer. The 7-m layer depth was selected based on the sensitivity of the propagating signatures to layer thicknesses. That is, comparisons of predicted signatures for one, two, and three layer cases indicate that they are not very sensitive to changes in layer thicknesses exceeding 4 m, particularly for top-layer shear wave velocities below 400 m/sec (however, they are very sensitive to shallow layers less than two metres or so). For cases where the third layer exceeds 7 m, one of the upper layers must be 3.5 m thick or thicker, and as such will tend to dominate the signature characteristics.

The percent occurrence was obtained by dividing the number of assignments to each terrain matrix element by the number of samples in the reduced and entire data sets (151 and 418, respectively).

106. The percent occurrence for the terrain matrix elements for the reduced and entire data sets are presented in the last two columns of Table 9. Because of the manner in which the reduced and entire data sets were assigned to the terrain matrix elements, the ranges in seismic velocities represented by each percent occurrence are defined by the midway point between the seismic velocities and layer depths of matrix elements having adjacent values for these quantities. For example, the percent of occurrence for matrix element number 1 represents the top-layer compression wave velocity range from 0 to 245 m/sec (i.e. 245 m/sec is midway between the compression wave velocity for matrix element

number 1,150 m/sec, and that of the matrix elements having adjacent values for the top-layer compression wave velocities, 340 m/sec).

107. The percent occurrences can be used to estimate the frequency of occurrence of terrain environments having defined ranges of compression or shear wave velocity by summing the percent occurrence for all of the terrain matrix elements within the defined ranges of compression or shear wave velocity or layer thickness. For example, the frequency of occurrence of terrains for which the top-layer compression wave velocity is less than 245 m/sec (i.e. midway between adjacent compression wave velocities represented in the terrain matrix-150 and 340 m/sec) can be obtained by summing the percent occurrence for matrix elements 1 through 32 (see Table 8). The resulting sum is 11.22 percent.

108. Such estimates of the frequency of occurrence of ranges of seismic velocities and layer depths can be used as a basis for such things as selection of test areas, optimization of deployment procedures, or evaluation of sensor performance. For example, practical considerations constrain the number and representation of test areas that can be applied to sensor evaluation. However, a strong consideration for sensor evaluation should be that the selected test areas be representative of ranges of commonly occurring shear and compression wave velocities. Deployment considerations, such as depth of burial of line sensors, can be optimized so as to be applicable to the broadest sets of terrain conditions.

109. Several assumptions have been made in the process of obtaining the estimates of the distribution of terrain properties. Of these, the assumptions related to the shear wave velocities are the most significant because of the sensitivity of the seismic response to this parameter. The discussion in the previous paragraphs describing the estimates of the distribution of signature characteristics should be interpreted within the following assumptions and limitations:

<u>a</u>. In instances where shear wave velocities were not measured, the shear wave velocity has been defined to be a fixed ratio of the compression wave velocity, 0.4 for soils and 0.55 for rock.

b. Very little frozen ground data is represented in the terrain data in Appendix D, even through the frozen ground condition represents a significant portion of seismic conditions in worldwide environments.

c. Compression wave velocities are sensitive to water tables whereas the shear wave velocities are not. Most of the shear wave velocities in Appendix D are estimated based on compression wave data.

Distribution of Seismic Response

110. The approach for estimating the frequency of occurrence of terrains having a defined seismic response consisted first of identifying groups of terrain matrix elements for which the associated signatures had CFs and AACFs in specified ranges. For personnel, the 5 m distance, man-walking signatures were selected. The groups were defined by ranges in the CF having 20 Hz intervals (0-20 Hz, 20-40 Hz,...) and order of magnitude changes in the AACF (10^{-8}-10^{-7} cm/sec, 10^{-7}-10^{-6} cm/sec,...). The terrain matrix elements in each group can be obtained from Table 8. For example, the terrain matrix elements in the respective CF and AACF intervals of 0-20 Hz and 10^{-4}-10^{-3} cm/sec are 1, 2, 3, 4, 7, 8, 11, 12, 15, 16, 19, 20, 23, 24, 27, 28, 31, and 32. The frequency of occurrence for the group is then estimated by summing the percent occurrences for each terrain matrix element in the group. In the example, the sum for the appropriate matrix elements is 3.30 percent for the reduced data set. The groups and frequency of occurrence are presented in Figure 20 for the 5 m distance, man-walking signatures.

111. In an analogous manner, the groups and frequency of occurrence can be derived for the background noise signatures (M35 at 75 m). However, as stated in paragraph 96, the groups were defined to have a 10 Hz bandwidth rather than 20 Hz in order to be consistent with the 10 Hz averaging window used for determination of the CF for the background noise source. The results are presented in Figure 21.

112. The range in variation in the signature characteristics for 5 m distance, man-walking signatures (Figure 19) is considerable. Figure 20 shows that the CFs for most of the terrain conditions are less

than 40 Hz (79 percent of the reduced set of the terrain data have associated signatures for which the CFs are less than 40 Hz). Although the AACFs are concentrated in the amplitude region 10^{-5}-10^{-4} cm/sec and CF values less than 40 Hz (53.2 percent of the reduced set of terrains have been assigned to this region), the AACFs are quite widely distributed from 10^{-7} cm/sec to 10^{-3} cm/sec. For testing of point and line sensors, particularly those employing signal processors utilizing frequency information as high as 40 Hz, it would be desirable to select four test areas that, at a minimum, spanned the range from the group defined by (0-20 Hz, 10^{-7}-10^{-6} cm/sec) to 20-40 Hz, 10^{-4}-10^{-3} cm/sec). For example, examination of Table 9 shows that four such terrain conditions, and their associated group (defined within the parentheses) would be matrix element 96 (0-20 Hz, 10^{-7}-10^{-6} cm/sec, matrix element 63 (0-20 Hz, 10^{-6}-10^{-5} cm/sec), matrix element 18 (20-40 Hz, 10^{-4}-10^{-3} cm/sec). The shear and compressional wave velocities for these matrix elements can be obtained from Table 8.

113. The predominant frequencies for the background noise source (M35 at 75 m) tend to be lower than those of the personnel signatures as may be seen by comparing the frequency of occurrence for equivalent frequency ranges in Figures 20 and 21. Therefore, the higher frequencies associated with the personnel signatures at the closer distances can be exploited for detection, provided adaptive digital filtering or an alternate technique is applied to reduce the background noise from distant sources, particularly acoustic sources.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

114. A data base consisting of measured and synthetic signature data spanning a wide range of terrains, target types, travel modes, and background noise sources has been collected, or generated, and provided to the BISS-PO (paragraphs 41 and 95).

115. The measured and synthetic signature data have been analyzed to provide guidance to users. Most notable conclusions are:

- a. The frequency characteristics of signatures of intruders are strong functions of target-to-sensor distances, particularly for distances between 0.5 and 2 m (paragraph 55).
- b. The low-frequency characteristics of the near-distance signatures are stable features over the range of terrains represented by the measured data collection (paragraph 62). However, the target-to-sensor distance for which the low frequencies predominate becomes smaller as the compression- and shear-wave velocities of the medium increase.
- c. For personnel signatures, the predominant frequencies of intermediate-distance signatures depend on site properties (paragraph 64) but are quite independent of the personnel travel modes (paragraph 66).
- d. The large dependence of the frequency and amplitude on terrain conditions suggests that only the simplest pattern recognition algorithms can be effectively used for detection and background noise suppression unless the signal processors are made adaptive to the local terrain conditions (paragraph 65). When such algorithms are adaptive to the terrain, it may still be desirable to employ adaptive digital filtering to reduce background noise prior to implementation of the pattern recognition algorithms (paragraph 57).
- e. The estimated frequency of occurrence of terrains having defined ranges in signature characteristics shows that the predominant frequencies of close distance (5 m), personnel signatures tend to have predominant frequencies of 40 Hz or less (79 percent of the terrains) but amplitudes varying over four orders of magnitude.
- f. The range in variation in amplitude for the same terrain for near-distance man-creeping signatures is less than for that of intermediate-distance signatures (paragraph 101).

Recommendations

116. As a result of this study, the following recommendations are made:

<u>a</u>. Test sites for evaluating sensor performance be selected on the basis of the frequency of occurrence of terrains having defined ranges in shear- and compression-wave velocities and in seismic response (paragraph 113).

<u>b</u>. Site documentation at test sites and areas having poor sensor performance be done in accordance with the procedures recommended in paragraphs 77 through 84.

<u>c</u>. The application of adaptive digital filtering using parallel-deployed line sensors be investigated for the purpose of reducing background noise (paragraph 57). Such an investigation should include evaluations of both the economics of deploying parallel line sensors and the performance of the devices.

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* Bibliographic material for the classified reference will be furnished to qualified agencies upon request.

Table 1

Typical Test Plan for BISS Signature Collection

Test No.	Target Primary (number)/Secondary (number)	Travel Mode Primary/Secondary	Target Paths
1	Personnel (1)/NA	Walking/NA	1
2	Personnel (1)/NA	Walking/NA	1
3	Personnel (3)/NA	Walking/NA	1 (personnel two metres apart)
4	Personnel (1)/NA	Crawling/NA	1
5	Personnel (1)/NA	Crawling/NA	1
6	Personnel (3)/NA	Crawling/NA	1 (personnel two metres apart)
7	Personnel (1)/NA	Running/NA	1
8	Personnel (1)/NA	Running/NA	1
9	Personnel (3)/NA	Running/NA	1 (personnel two metres apart)
10	Personnel (1)/NA	Creeping	1
11	Personnel (1)/NA	Creeping	1
12	Personnel (3)/NA	Creeping/NA	1 (personnel two metres apart)
13	1/4-ton vehicle (1)/NA	8 kph/NA	2
14	1/4-ton vehicle (1)/NA	32 kph/NA	2
15	1/4-ton vehicle (1)/personnel (1)	32 kph/walking	3
16	1/4-ton vehicle (1)/personnel (1)	32 kph/creeping	4
17	2-1/2-ton vehicle (1)/NA	8 kph/NA	2
18	2-1/2-ton vehicle (1)/NA	32 kph/NA	2
19	2-1/2-ton vehicle (1)/personnel (1)	32 kph/walking	3
20	2-1/2-ton vehicle (1)/personnel (1)	32 kph/creeping	4
21	M113 APC (1)/NA	8 kph/NA	2
22	M113 APC (1)/NA	32 kph/NA	2
23	M60 tank (1)/NA	8 kph/NA	2
24	M60 tank (1)/NA	32 kph/NA	2

* Target paths (see Figure 1): (1) Start at A, move around semicircle past B to C, then move out to D; (2) Start vehicle at E and proceed to F; (3) Personnel intruder starts at A when vehicle is at the closest point of approach to the sensors, proceeds around the semicircle past B to C; test stops when personnel intruder reaches C; (4) Personnel intruder starts at C when vehicle is at closest point of approach to sensors; test stops when personnel intruder crosses semicircle (at A).

Table 2

Range of Compression Wave Velocities Occurring in Different Terrain Types

Terrain Types	Compressional (P) Wave Velocity Characteristics: Predominant Top-Layer Soil Characteristics	Average Velocities m/sec*
Low plains (coastal and alluvial)	Poorly compacted sediments (sands, silts, clays)	150 - 600
	Compacted sediments (sands, silts, clays) and gravels	400 - 1200
	Water saturated sediments (sands, silts, clays)	600 - 1800
High plains (tablelands and plateaus)	Poorly compacted soils (sands, silts, clays)	200 - 700
	Cemented residual soils (sands, silts, clays)	800 - 3000
	Loose residual soils containing fragmented rock material	300 - 1100
	Weathered or fractured rock	300 - 3000
	Unweathered solid rock	1800 - 5800
Hills and mountains	Compacted soils (sands, silts, clays)	400 - 1200
	Loose residual soils (sands, silts)	200 - 700
	Loose residual soils containing fragmented rock material	300 - 1100
	Weathered or fractured rock	300 - 3000
	Unweathered solid rock	1800 - 5800

* Subject to change as a function of moisture content. Compression wave velocity of water will range from 1400 to 1700 m/sec depending on temperature and salt content.

Table 3

Cultural and Natural Background Noise Sources

Cultural		Natural	
1.	Urban areas	1N.*	Rain
2.	Villages	2N.	Sleet
3.	Railroads	3N.	Hail
4.	Airports	4N.	Ice (glaciers, etc.)
5.	Amusements areas (race tracks, etc.)	5N.	Wind
6.	Waterways (canals, etc.)	6N.	Intermittent streams
7.	Interstate highways	7N.	Streams and rivers
8.	Principal highways	8N.	Shorelines (coast and lakes)
9.	Secondary roads	9N.	Waterfalls
10.	Dry weather road or trail	10N.	Thunder
11.	Mines (underground and open pit)	11N.	Volcanoes and earth tremors
12.	Factories and mills	12N.	Rock cracking
13.	Generating stations	13N.	Animal noise
14.	Agricultural areas	14N.	Storms (sand)
15.	Construction operations	15N.	Forests or woodlands
16.	Above ground transmission lines	16N.	Brush and grasslands
17.	Transmission towers (microwave)		
18.	Pipelines		
19.	Lock or dam		
20.	Campsite (recreation)		
21.	Wells (oil and gas)		
22.	Wells (water)		
23.	Windmills and water mills		
24.	Drawbridges and tunnels		
25.	Impact areas and firing ranges		
26.	Cantonments or training areas		
27.	Schools and institutions		
28.	Logging activities		
29.	Pumping stations		
30.	Isolated house or building		
31.	Industrial and test areas		
32.	Trainways and aerial cableways		

Note: Revised from Table 25, Reference 20.
* N denotes natural on list.

Table 4

Terrain Types and Some Background Noise Source Characteristics for Selected Areas

Installation	Terrain Type	Predominant Background Noise Source Classes	Potential Background* Noise Sources
Barksdale AFB, LA	Low Plains	Cultural	Railroads Airport Interstate highway Oil and gas wells Forests and woodlands Rain and thunder Animal noise
Fort Hood, TX	High Plains	Mixed cultural and natural	Mines (quarry) Pipeline Brush and grassland Wind
March AFB, CA	Hills and mountains	Mixed cultural and natural	Airport Windmills Railroads Interstate highway Agricultural areas Water wells Brush and grasslands Wind
U. S. Naval Weapons Station, Seal Beach, CA	Low Plains	Cultural	Waterways and canals Principal highways Oil and gas wells Industrial areas Railroads Shoreline (tide, wave-action) Wind

* Identification of natural-class transient sources (wind, rain and thunder, animal noise, etc) is based on likely occurrences at these areas because of meteorological and natural conditions.

Table 5

Seismic Compression Wave Velocities for Data Collection Sites

Installation	Site No.	Compression Wave Layer No.	Layer Depth, m	Velocity m/sec
Barksdale AFB, LA	1A	1	0.0-4.4	353
		2	4.4+	1700
	5	1	0.0-1.2	367
		2	1.2+	533
	7	1	0.0-1.5	357
		2	1.5+	595
Fort Hood, TX	5A	1	0.0-2.0	780
		2	2.0+	1950
	8A	1	0.0-1.9	1410
		2	1.9+	2825
	9	1	0.0-3.1	300
		2	3.1+	1675
March AFB, CA	1	1	0.0-0.9	270
		2	0.9	695
	2	1	0.0-1.0	590
		2	1.0+	1030
U. S. Naval Weapons Station, Seal Beach, CA	1	1	0.0-1.3	220
		2	1.3+	1400
	2	1	0.0-3.5	300
		2	3.5+	1200
	3	1	0.0-1.1	165
		2	1.1-3.0	497
		3	3.0+	965
	4	1	0.0-0.4	200
		2	0.4-2.5	265
		3	2.5+	600

Table 6

Summary of Surface and Near-Surface Measurements for Data Collection Sites

Installation	Site	Surface* $K_{S,C}$ $(n.m^2)$	Surface* Z_{max} (m)	Near Surface Depth, cm From	Near Surface Depth, cm To	Near Surface Density, g/cm3 Wet	Near Surface Density, g/cm3 Dry	Moisture Content %	Cone** Index
Barksdale AFB, LA	1A	1.01×10^8	0.0065	0.0	7.5	1.85	1.57	18.0	280
				15.0	22.5	1.88	1.57	19.6	240
				30.0	37.5	1.91	1.59	20.3	220
	5	6.2×10^7	0.0054	0.0	7.5	1.71	1.45	17.9	395
				15.0	22.5	1.85	1.53	21.4	362
				30.0	37.5	1.84	1.53	20.2	388
	7	3.[illegible] × 10^7	0.0090	0.0	7.5	1.81	1.55	17.0	335
				15.0	22.5	1.95	1.67	17.4	344
				30.0	37.5	1.89	1.58	20.3	337
Fort Hood, TX	5A	1.74×10^7	0.0045	0.0	7.5	1.61	1.47	9.7	1125
				15.0	22.5	Rock	Rock	14.4	**
				30.0	37.5	Rock	Rock	14.1	**
	8A	1.53×10^7	0.0110	0.0	7.5	Rock	Rock	14.1	851
				15.0	22.5	Rock	Rock	5.0	**
				30.0	37.5	Rock	Rock	**	**
	9	1.67×10^7	0.0130	0.0	7.5	1.69	1.45	17.1	414
				15.0	22.5	1.76	1.44	22.3	458
				30.0	37.5	1.80	1.46	22.8	394
March AFB, Riverside, CA	1			0.0	7.5	1.92	1.81	6.2	430
				15.0	22.5	1.99	1.86	6.6	368
				30.0	37.5	1.81	1.68	7.4	750
	2			0.0	7.5	1.85	1.76	5.4	**
				15.0	22.5	2.17	2.07	7.5	**
				30.0	37.5	Rock	Rock	6.5	**
Naval Weapons Station Seal Beach, CA	1			0.0	7.5	1.69	1.52	11.5	454
				15.0	22.5	2.07	1.78	16.2	750
				30.0	37.5	2.01	1.70	18.2	**
	2			0.0	7.5	1.58	1.32	19.4	71
				15.0	22.5	1.83	1.54	18.7	204
				30.0	37.5	1.81	1.48	23.4	257
	3	1.08×10^6	0.102	0.0	7.5	1.84	1.34	37.9	51
				15.0	22.5	1.75	1.20	46.8	47
				30.0	37.5	1.26	0.78	60.8	39
	4			0.0	7.5	1.82	1.59	14.5	345
				15.0	22.5	1.75	1.50	16.8	417
				30.0	37.5	1.73	1.47	17.6	389

* Field measurements of the surface rigidity using plate load tests were not taken at March AFB or Seal Beach Naval Weapons Station. Estimates of surface rigidity were made for Seal Beach site 3 on the basis of rutting depth and weight for man-walking.
** Data were not taken because soil was too hard for appropriate measurements.

Table 7

Summary of Subsurface Site Documentation Data for Selected Sites *

Installation	Site No.	Compression Wave Layer No.	Compression Wave Layer Depth, m	Compression Wave Velocity m/sec	Shear Wave Layer No.	Shear Wave Layer Depth, m	Shear Wave Velocity m/sec
Barksdale AFB	1A	1	0.0-4.4	353	1	0.0-4.0	120
		2	4.4+	1700	2	4.0+	170
	5	1	0.0-1.41	352	1	0.0-3.8	125
		2	1.41+	525	2	3.8+	150
	7	1	0.0-1.5	357	1	0.0-4.6	115
		2	1.5+	595	2	4.6+	280
Fort Hood	5A	1	0.0-2.0	780	1	0.0-1.8	203
		2	2.0+	1950	2	1.8+	381
	8A	1	0.0-1.9	1410	1	0.0-2.1	253
		2	1.9+	2825	2	2.1+	427
	9	1	0.0-3.1	300	1	0.0-3.8	122
		2	3.1+	1675	2	3.8+	203
March AFB	1	1	0.0-0.9	270	1	0.0-3.1	210
		2	0.9	695	2	3.1+	260
	2	1	0.0-1.0	590	1	0.0-6.25	280
		2	1.0+	1030	2	6.25+	450
Seal Beach Naval Weapons Station	1	1	0.0-1.3	220	1	0.0-10.0+	93
		2	1.3+	1400			
	2	1	0.0-0.90	200	1	0.0-2.2	75
		2	0.90-3.95	397	2	2.2+	145
		3	3.95+	1000			
	3	1	0.0-1.1	165	1	0.0-3.0	75
		2	1.1-3.0	497	2	3.0+	125
		3	3.0+	965			
	4	1	0.0-0.4	200	1	0.0-10.0+	125
		2	0.4-2.5	265			
		3	2.5+	600			

* Seismic velocities selected for measurements were nearest to walk path. Layer depths measured to approximately 10 m depth.

Table 8

Terrain Matrix

Characteristics of Top Layer/Foundation Material

Terrain Matrix Element	Compression-Wave Velocity m/sec	Shear-Wave Velocity m/sec	Bulk Density g/cm^3	First Layer Thickness m
1	150/300	75/125	1.60/1.70	0.25
2	150/300	75/125	1.60/1.70	1.50
3	150/300	75/125	1.60/1.70	2.25
4	150/300	75/125	1.60/1.70	4.00
5	150/340	75/135	1.60/1.70	0.25
6	150/340	75/135	1.60/1.70	1.50
7	150/340	75/135	1.60/1.70	2.25
8	150/340	75/135	1.60/1.70	4.00
9	150/500	75/200	1.60/1.80	0.25
10	150/500	75/200	1.60/1.80	1.50
11	150/500	75/200	1.60/1.80	2.25
12	150/500	75/200	1.60/1.80	4.00
13	150/680	75/275	1.60/2.00	0.25
14	150/680	75/275	1.60/2.00	1.50
15	150/680	75/275	1.60/2.00	2.25
16	150/680	75/275	1.60/2.00	4.00
17	150/1450	75/400	1.60/2.05	0.25
18	150/1450	75/400	1.60/2.05	1.50
19	150/1450	75/400	1.60/2.05	2.25
20	150/1450	75/400	1.60/2.05	4.00
21	150/2000	75/550	1.60/1.80	0.25
22	150/2000	75/550	1.60/1.80	1.50
23	150/2000	75/550	1.60/1.80	2.25
24	150/2000	75/550	1.60/1.80	4.00
25	150/2000	75/750	1.60/2.10	0.25
26	150/2000	75/750	1.60/2.10	1.50
27	150/2000	75/750	1.60/2.10	2.25
28	150/2000	75/750	1.60/2.10	4.00
29	150/5000	75/1500	1.60/2.50	0.25
30	150/5000	75/1500	1.60/2.50	1.50

(Continued)

Table 8 (Continued)

Terrain Matrix Element	Compression-Wave Velocity m/sec	Shear-Wave Velocity m/sec	Bulk Density g/cm^3	First Layer Thickness m
31	150/5000	75/1500	1.60/2.50	2.25
32	150/5000	75/1500	1.60/2.50	4.00
33	340	135	1.70	10.00
34	340/500	135/200	1.70/1.80	0.25
35	340/500	135/200	1.70/1.80	1.50
36	340/500	135/200	1.70/1.80	2.25
37	340/500	135/200	1.70/1.80	4.00
38	340/680	135/275	1.70/2.00	0.25
39	340/680	135/275	1.70/2.00	1.50
40	340/680	135/275	1.70/2.00	2.25
41	340/680	135/275	1.70/2.00	4.00
42	340/1450	135/400	1.70/2.05	0.25
43	340/1450	135/400	1.70/2.05	1.50
44	340/1450	135/400	1.70/2.05	2.25
45	340/1450	135/400	1.70/2.05	4.00
46	340/2000	135/550	1.70/1.80	0.25
47	340/2000	135/550	1.70/1.80	1.50
48	340/2000	135/550	1.70/1.80	2.25
49	340/2000	135/550	1.70/1.80	4.00
50	340/2000	135/750	1.70/2.10	0.25
51	340/2000	135/750	1.70/2.10	1.50
52	340/2000	135/750	1.70/2.10	2.25
53	340/2000	135/750	1.70/2.10	4.00
54	340/2750	135/1100	1.70/2.30	0.25
55	340/2750	135/1100	1.70/2.30	1.50
56	340/2750	135/1100	1.70/2.30	2.25
57	340/2750	135/1100	1.70/2.30	4.00
58	500	200	1.80	10.00
59	500/680	200/275	1.80/2.00	0.25
60	500/680	200/275	1.80/2.00	1.50
61	500/680	200/275	1.80/2.00	2.25
62	500/680	200/275	1.80/2.00	4.00
63	500/1450	200/400	1.80/2.05	0.25
64	500/1450	200/400	1.80/2.05	1.50

(Continued)

Table 8 (Continued)

Terrain Matrix Element	Compression-Wave Velocity m/sec	Shear-Wave Velocity m/sec	Bulk Density g/cm^3	First Layer Thickness m
65	500/1450	200/400	1.80/2.05	2.25
66	500/1450	200/400	1.80/2.05	4.00
67	500/2000	200/500	1.80/1.80	0.25
68	500/2000	200/500	1.80/1.80	1.50
69	500/2000	200/500	1.80/1.80	2.25
70	500/2000	200/500	1.80/1.80	4.00
71	500/2000	200/750	1.80/2.10	0.25
72	500/2000	200/750	1.80/1.80	1.50
73	500/2000	200/750	1.80/1.80	2.25
74	500/2000	200/750	1.80/1.80	4.00
75	500/2750	200/1100	1.80/2.30	0.25
76	500/2750	200/1100	1.80/2.30	1.50
77	500/2750	200/1100	1.80/2.30	2.25
78	500/2750	200/1100	1.80/2.30	4.00
79	655	260	1.70	10.00
80	655/1450	260/400	1.70/2.05	0.25
81	655/1450	260/400	1.70/2.05	1.50
82	655/1450	260/400	1.70/2.05	2.25
83	655/1450	260/400	1.70/2.05	4.00
84	655/2000	260/550	1.70/1.80	0.25
85	655/2000	260/550	1.70/1.80	1.50
86	655/2000	260/550	1.70/1.80	2.25
87	655/2000	260/550	1.70/1.80	4.00
88	655/2000	260/750	1.70/2.00	0.25
89	655/2000	260/750	1.70/2.00	1.50
90	655/2000	260/750	1.70/2.00	2.25
91	655/2000	260/750	1.70/2.00	4.00
92	655/2750	260/1100	1.70/2.30	0.25
93	655/2750	260/1100	1.70/2.30	1.50
94	655/2750	260/1100	1.80/2.30	2.25
95	655/2750	260/1100	1.80/2.30	4.00
96	655/4875	260/2500	1.70/2.50	0.25
97	655/4875	260/2500	1.70/2.50	1.50
98	655/4875	260/2500	1.70/2.50	2.25
99	655/4875	260/2500	1.70/2.50	4.00

(Continued)

Table 8 (Continued)

Terrain Matrix Element	Compression-Wave Velocity m/sec	Shear-Wave Velocity m/sec	Bulk Density g/cm^3	First Layer Thickness m
100	655/5000	260/1500	1.70/2.50	0.25
101	655/5000	260/1500	1.70/2.50	1.50
102	655/5000	260/1500	1.70/2.50	2.25
103	655/5000	260/1500	1.70/2.50	4.00
104	1435	400	1.90	10.00
105	1450/2000	400/550	1.90/1.80	0.25
106	1450/2000	400/550	1.90/1.80	1.50
107	1450/2000	400/550	1.90/1.80	2.25
108	1450/2000	400/550	1.90/1.80	4.00
109	1450/2000	400/750	1.90/2.10	0.25
110	1450/2000	400/750	1.90/2.10	1.50
111	1450/2000	400/750	1.90/2.10	2.25
112	1450/2000	400/750	1.90/2.10	4.00
113	1450/5000	400/1500	1.90/2.50	0.25
114	1450/5000	400/1500	1.90/2.50	1.50
115	1450/5000	400/1500	1.90/2.50	2.25
116	1450/5000	400/1500	1.90/2.50	4.00
117	2000	550	1.80	10.00
118	2000/2750	550/1100	1.80/2.30	0.25
119	2000/2750	550/1100	1.80/2.30	1.50
120	2000/2750	550/1100	1.80/2.30	2.25
121	2000/2750	550/1100	1.80/2.30	4.00
122	2000/4875	550/2500	1.80/2.50	0.25
123	2000/4875	550/2500	1.80/2.50	1.50
124	2000/4875	550/2500	1.80/2.50	2.25
125	2000/4875	550/2500	1.80/2.50	4.00
126	2000/5000	550/1500	1.80/2.50	0.25
127	2000/5000	550/1500	1.80/2.50	1.50
128	2000/5000	550/1500	1.80/2.50	2.25
129	2000/5000	550/1500	1.80/2.50	4.00
130	2000/2000	750/550	2.10/1.80	0.25
131	2000/2000	750/550	2.10/1.80	1.50
132	2000/2000	750/550	2.10/1.80	2.25
133	2000/2000	750/550	2.10/1.80	4.00

(Continued)

Table 8 (Concluded)

Terrain Matrix Element	Compression-Wave Velocity m/sec	Shear-Wave Velocity m/sec	Bulk Density g/cm^3	First Layer Thickness m
134	2000	750	2.10	10.00
135	2000/5000	750/1500	2.10/2.50	0.25
136	2000/5000	750/1500	2.10/2.50	1.50
137	2000/5000	750/1500	2.10/2.50	2.25
138	2000/5000	750/1500	2.10/2.50	4.00
139	2400	900	2.10	10.00
140	3200	1200	2.40	10.00
141	2800/4875	1000/2500	2.00/2.50	0.25
142	2800/4875	1000/2500	2.00/2.50	1.50
143	2800/4875	1000/2500	2.00/2.50	2.25
144	2800/4875	1000/2500	2.00/2.50	4.00

(Sheet 5 of 5)

Table 9

Signature Characteristics and Estimate Frequency of Occurrence for Selected Intruder and Background Noise Signatures

Terrain Matrix Element	Signature Characteristics* — Man Walking — 5 m Distance: CF, Hz	AACF, cm/sec	15 m Distance: CF, Hz	AACF, cm/sec	Selected Background Noise**: CF, hz	AACF, cm/sec	Frequency Occurrence, %† — Reduced	Entire
1	16	1.05×10^{-4}	15	4.78×10^{-5}	7	6.31×10^{-4}	0.66	0.24
2	19	3.95×10^{-4}	19	1.50×10^{-4}	7	8.36×10^{-4}	-	-
3	15	4.39×10^{-4}	15	1.80×10^{-4}	7	1.17×10^{-3}	-	-
4	12	4.49×10^{-4}	12	1.93×10^{-4}	7	1.94×10^{-3}	-	-
5	18	8.34×10^{-5}	16	3.82×10^{-5}	7	4.74×10^{-4}	1.32	0.72
6	21	4.04×10^{-4}	21	1.46×10^{-4}	7	6.71×10^{-4}	0.66	0.24
7	15	4.36×10^{-4}	15	1.75×10^{-4}	7	1.01×10^{-3}	-	-
8	12	4.46×10^{-4}	1[illegible]	1.91×10^{-4}	7	1.87×10^{-3}	-	-
9	15	5.41×10^{-5}	15	2.81×10^{-5}	7	1.15×10^{-3}	1.32	1.44
10	22	3.72×10^{-4}	20	1.35×10^{-4}	7	1.78×10^{-3}	-	-
11	16	5.35 [illegible]	16	2.22×10^{-4}	7	2.96×10^{-3}	-	-
12	16	6.57×10^{-4}	12	2.99×10^{-4}	9	5.75×10^{-3}	1.32	0.48
13	15	1.92×10^{-5}	13	1.00×10^{-5}	7	2.68×10^{-4}	1.32	1.44
1	26	3.29×10^{-4}	23	1.[illegible]0 $\times 10^{-4}$	7	8.46×10^{-4}	-	0.24

(Continued)

* For definitions of CF and AACF see paragraphs 90 and 96 of the text.
** Selected background noise signature is that of an M35 moving 32 km/hr over a cross-country path.
† Dashes indicate that no assignments were made from the terrain data.

(Sheet 1 of 10)

Table 9 (Continued)

Terrain Matrix Element	Signature Characteristics: Man Walking, 5 m Distance, CF, Hz	5 m Distance, AACF, cm/sec	15 m Distance, CF, Hz	15 m Distance, AACF, cm/sec	Selected Background Noise, CF, Hz	Selected Background Noise, AACF, cm/sec	Frequency of Occurrence, %: Reduced	Entire
15	18	4.30×10^{-4}	16	1.65×10^{-4}	7	1.23×10^{-3}	-	-
16	12	4.54×10^{-4}	12	1.95×10^{-4}	7	2.99×10^{-3}	-	-
17	127	1.17×10^{-5}	13	4.83×10^{-6}	6	1.20×10^{-4}	0.66	0.48
18	26	3.34×10^{-4}	25	1.08×10^{-4}	7	5.61×10^{-4}	-	0.24
19	18	4.11×10^{-4}	18	1.54×10^{-4}	16	8.19×10^{-4}	0.66	0.48
20	12	4.46×10^{-4}	12	1.91×10^{-4}	7	2.56×10^{-3}	-	-
21	133	1.02×10^{-5}	13	3.59×10^{-6}	6	1.24×10^{-4}	-	0.96
22	26	3.31×10^{-4}	25	1.06×10^{-4}	7	5.31×10^{-4}	0.66	0.72
23	18	4.05×10^{-4}	18	1.52×10^{-4}	16	8.31×10^{-4}	-	0.24
24	12	4.15×10^{-4}	12	1.79×10^{-4}	7	2.62×10^{-3}	-	-
25	130	1.20×10^{-5}	13	2.74×10^{-4}	6	1.21×10^{-4}	0.66	0.24
26	26	3.27×10^{-4}	25	1.05×10^{-4}	6	5.91×10^{-4}	1.32	0.48
27	18	3.76×10^{-4}	18	1.41×10^{-4}	7	8.75×10^{-4}	0.66	0.24
28	12	4.38×10^{-4}	12	1.88×10^{-4}	7	2.85×10^{-3}	-	-
29	129	1.10×10^{-5}	13	2.32×10^{-6}	6	1.53×10^{-4}	-	-
30	26	3.24×10^{-4}	25	1.03×10^{-4}	6	7.50×10^{-4}	-	-

(Continued)

Table 9 (Continued)

Terrain Matrix Element	Signature Characteristics: Man Walking, 5 m Distance, CF, Hz	Man Walking, 5 m Distance, AACF, cm/sec	Man Walking, 15 m Distance, CF, Hz	Man Walking, 15 m Distance, AACF, cm/sec	Selected Background Noise, CF, Hz	Selected Background Noise, AACF, cm/sec	Frequency of Occurrence, %, Reduced	Frequency of Occurrence, %, Entire
31	18	3.95×10^{-4}	18	1.49×10^{-4}	6	1.15×10^{-3}	-	-
32	12	4.39×10^{-4}	12	1.88×10^{-4}	7	3.27×10^{-3}	-	-
33	19	6.90×10^{-5}	18	3.02×10^{-5}	7	2.89×10^{-4}	5.96	[illegible]
34	21	2.01×10^{-5}	21	9.38×10^{-6}	7	2.60×10^{-4}	0.66	0.43
35	37	4.20×10^{-5}	35	1.56×10^{-5}	7	2.97×10^{-4}	1.99	[illegible]
36	23	6.42×10^{-5}	23	2.74×10^{-5}	7	3.27×10^{-4}	1.99	[illegible]
37	19	6.13×10^{-5}	18	2.68×10^{-5}	7	4.74×10^{-4}	1.99	[illegible]
38	21	8.50×10^{-6}	21	4.18×10^{-6}	7	7.76×10^{-5}	0.66	[illegible]
39	40	3.85×10^{-5}	38	1.46×10^{-5}	7	1.06×10^{-4}	2.65	[illegible]
40	26	6.62×10^{-5}	25	2.83×10^{-5}	23	1.34×10^{-4}	1.32	2.63
41	18	8.18×10^{-5}	18	3.65×10^{-5}	16	4.92×10^{-4}	1.32	1.20
42	15	1.31×10^{-5}	15	7.02×10^{-6}	13	2.04×10^{-4}	0.66	1.91
43	41	3.35×10^{-5}	40	1.33×10^{-5}	16	2.17×10^{-4}	1.32	1.20
44	29	5.90×10^{-5}	28	2.50×10^{-5}	25	1.31×10^{-4}	-	2.15
45	18	8.15×10^{-5}	18	3.70×10^{-5}	16	6.20×10^{-4}	1.32	1.44
46	21	2.54×10^{-6}	21	1.36×10^{-6}	9	1.00×10^{-4}	0.66	0.72

(Continued)

(Sheet 3 of 10)

Table 9 (Continued)

Terrain Matrix Element	Signature Characteristics: Man Walking, 5 m Distance, CF, Hz		Man Walking, 15 m Distance, CF, Hz		Selected Background Noise, CF, Hz		Frequency of Occurrence, %	
	CF, Hz	AACF, cm/sec	CF, Hz	AACF, cm/sec	CF, Hz	AACF, cm/sec	Reduced	Entire
47	41	3.10×10^{-5}	41	1.22×10^{-5}	7	1.71×10^{-4}	3.31	1.91
48	31	5.79×10^{-5}	29	2.41×10^{-5}	6	2.26×10^{-4}	0.66	2.15
49	18	8.86×10^{-5}	18	4.03×10^{-5}	16	6.82×10^{-4}	3.31	4.55
50	21	1.19×10^{-6}	21	6.48×10^{-7}	7	5.07×10^{-5}	0.66	0.72
51	43	2.94×10^{-5}	41	1.16×10^{-5}	9	4.05×10^{-4}	3.31	2.63
52	32	5.69×10^{-5}	29	2.34×10^{-5}	9	4.29×10^{-4}	2.65	2.15
53	18	9.05×10^{-5}	18	4.10×10^{-5}	16	6.98×10^{-4}	0.66	3.11
54	37	1.52×10^{-6}	37	8.22×10^{-7}	7	5.22×10^{-5}	-	-
55	42	2.86×10^{-5}	41	1.13×10^{-5}	7	2.08×10^{-4}	0.66	0.72
56	32	5.64×10^{-5}	29	2.30×10^{-5}	7	4.77×10^{-4}	-	0.24
57	19	9.14×10^{-5}	18	4.14×10^{-5}	9	1.28×10^{-4}	-	0.96
58	22	1.15×10^{-5}	21	5.29×10^{-6}	16	6.11×10^{-5}	1.99	1.20
59	21	9.00×10^{-6}	21	4.45×10^{-6}	7	1.38×10^{-4}	0.66	0.96
60	21	9.82×10^{-6}	21	4.83×10^{-6}	7	1.61×10^{-4}	-	2.65
61	37	1.67×10^{-5}	37	7.09×10^{-6}	7	1.82×10^{-4}	1.99	1.20
62	22	2.76×10^{-5}	21	1.31×10^{-5}	7	2.27×10^{-4}	1.99	1.67

(Continued)

Table 9 (Continued)

Terrain Matrix Element	Signature Characteristics: Man Walking, 5 m Distance, CF, Hz	AACF, cm/sec	15 m Distance, CF, Hz	AACF, cm/sec	Selected Background Noise, CF, Hz	AACF, cm/sec	Frequency of Occurrence, %, Reduced	Entire
63	22	2.99×10^{-6}	22	1.54×10^{-6}	16	2.69×10^{-5}	0.66	0.72
64	60	9.45×10^{-6}	59	3.52×10^{-6}	16	3.67×10^{-5}	0.66	0.96
65	40	1.84×10^{-5}	38	7.99×10^{-6}	16	4.65×10^{-5}	-	1.44
66	22	3.45×10^{-5}	22	1.66×10^{-5}	16	1.22×10^{-4}	-	0.96
67	34	5.86×10^{-6}	34	2.99×10^{-6}	32	5.28×10^{-5}	0.66	0.48
68	62	8.65×10^{-6}	60	3.28×10^{-6}	51	8.50×10^{-6}	1.99	1.67
69	40	1.74×10^{-5}	40	7.65×10^{-6}	35	4.82×10^{-5}	1.99	1.44
70	23	3.60×10^{-5}	23	1.73×10^{-5}	23	1.25×10^{-4}	0.66	0.72
71	19	1.44×10^{-6}	19	7.92×10^{-7}	9	4.40×10^{-5}	-	-
72	63	7.83×10^{-6}	62	3.06×10^{-6}	9	1.70×10^{-4}	0.66	0.48
73	41	1.58×10^{-5}	41	6.98×10^{-6}	9	1.92×10^{-4}	1.32	0.72
74	25	3.55×10^{-5}	23	1.71×10^{-5}	9	2.57×10^{-4}	1.32	2.15
75	18	4.90×10^{-7}	18	2.74×10^{-7}	6	2.18×10^{-5}	-	-
76	63	7.43×10^{-6}	62	2.93×10^{-6}	6	6.26×10^{-5}	-	-
77	42	1.48×10^{-5}	41	6.50×10^{-6}	7	1.04×10^{-4}	0.66	0.72
78	25	3.40×10^{-5}	25	1.62×10^{-5}	7	1.99×10^{-4}	1.32	0.96
79	22	9.45×10^{-6}	22	4.57×10^{-6}	16	5.74×10^{-5}	5.30	2.87

(Continued)

Table 9 (Continued)

Terrain Matrix Element	Signature Characteristics: Man Walking, 5 m Distance, CF, Hz	AACF, cm/sec	15 m Dist, CF, Hz	AACF, cm/sec	Selected Background Noise, CF, Hz	AACF, cm/sec	Frequency of Occurrence, %: Reduced	Entire
80	22	3.25×10^{-6}	21	1.68×10^{-6}	16	3.19×10^{-5}	-	-
81	82	3.95×10^{-6}	21	1.94×10^{-6}	7	4.07×10^{-5}	0.66	0.96
82	57	6.48×10^{-6}	40	2.83×10^{-6}	7	4.72×10^{-5}	-	0.24
83	26	1.33×10^{-5}	25	6.53×10^{-6}	16	6.87×10^{-5}	2.65	0.96
84	22	1.34×10^{-6}	22	7.09×10^{-7}	16	1.23×10^{-5}	-	0.24
85	82	4.17×10^{-6}	81	1.51×10^{-6}	16	1.81×10^{-5}	0.66	2.15
86	57	7.23×10^{-6}	57	2.96×10^{-6}	45	2.30×10^{-5}	-	0.24
87	29	1.44×10^{-5}	29	7.02×10^{-6}	25	5.64×10^{-5}	2.65	1.20
88	31	3.49×10^{-6}	31	1.85×10^{-6}	31	3.83×10^{-5}	-	-
89	100	3.92×10^{-6}	82	1.39×10^{-6}	78	1.92×10^{-5}	0.66	0.72
90	59	7.10×10^{-6}	59	2.90×10^{-6}	48	2.13×10^{-5}	0.66	0.48
91	32	1.41×10^{-5}	31	6.74×10^{-6}	31	6.43×10^{-5}	0.66	0.48
92	18	5.19×10^{-6}	18	2.89×10^{-6}	9	2.98×10^{-5}	-	-
93	100	3.92×10^{-6}	83	1.35×10^{-6}	10	8.19×10^{-5}	-	0.24
94	60	7.07×10^{-6}	59	2.91×10^{-6}	10	1.61×10^{-4}	1.32	0.96
95	34	1.42×10^{-6}	32	6.72×10^{-6}	10	2.02×10^{-4}	1.99	0.96

(Continued)

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Table 9 (Continued)

Terrain Matrix Element	Signature Characteristics: Man Walking, 5 m Distance		Man Walking, 15 m Distance		Selected Background Noise		Frequency of Occurrence, %	
	CF, Hz	AACF, cm/sec	CF, Hz	AACF, cm/sec	CF, Hz	AACF, cm/sec	Reduced	Entire
96	19	1.93×10^{-7}	19	1.10×10^{-7}	7	1.37×10^{-5}	-	-
97	101	3.92×10^{-6}	83	1.32×10^{-6}	7	6.28×10^{-5}	-	-
98	60	7.01×10^{-6}	59	2.88×10^{-6}	7	1.24×10^{-4}	-	0.24
99	34	1.42×10^{-5}	34	6.68×10^{-6}	9	2.68×10^{-4}	-	0.24
100	19	2.25×10^{-7}	19	1.27×10^{-7}	7	1.06×10^{-5}	-	-
101	100	3.92×10^{-6}	83	1.33×10^{-6}	7	4.58×10^{-5}	-	-
102	60	7.02×10^{-6}	59	2.89×10^{-6}	7	7.92×10^{-5}	-	-
103	34	1.42×10^{-5}	34	6.72×10^{-6}	9	1.93×10^{-4}	-	0.24
104	23	1.96×10^{-6}	23	1.00×10^{-6}	16	1.30×10^{-5}	3.31	1.20
105	22	1.84×10^{-6}	22	9.77×10^{-7}	7	3.68×10^{-5}	-	0.24
106	22	1.99×10^{-6}	21	1.06×10^{-6}	7	5.55×10^{-5}	-	-
107	22	2.15×10^{-6}	21	1.14×10^{-6}	7	4.48×10^{-5}	0.66	0.24
108	22	3.04×10^{-6}	22	1.60×10^{-6}	7	1.60×10^{-4}	0.66	0.24
109	22	5.84×10^{-7}	22	3.17×10^{-7}	16	6.48×10^{-6}	-	-
110	127	9.70×10^{-7}	22	3.67×10^{-7}	16	7.71×10^{-6}	1.99	0.96
111	83	1.46×10^{-6}	82	6.20×10^{-7}	16	1.27×10^{-5}	0.66	0.72

(Continued)

Table 9 (Continued)

Terrain Matrix Element	Signature Characteristics: Man Walking, 5 m Distance: CF, Hz	AACF, cm/sec	Man Walking, 15 m Distance: CF, Hz	AACF, cm/sec	Selected Background Noise: CF, Hz	AACF, cm/sec	Frequency of Occurrence, %: Reduced	Entire
112	41	2.80×10^{-6}	41	1.40×10^{-6}	44	1.55×10^{-5}	-	-
113	129	1.75×10^{-8}	10	8.54×10^{-9}	89	5.49×10^{-7}	-	-
114	135	9.07×10^{-7}	13	3.48×10^{-7}	117	9.34×10^{-6}	0.66	0.24
115	100	1.52×10^{-6}	86	6.27×10^{-7}	82	1.94×10^{-5}	-	0.24
116	56	2.61×10^{-6}	54	1.22×10^{-6}	45	1.90×10^{-5}	-	-
117	37	7.56×10^{-7}	37	3.83×10^{-7}	16	4.76×10^{-6}	1.99	0.96
118	21	7.54×10^{-7}	21	4.19×10^{-7}	16	2.03×10^{-6}	-	-
119	177	4.06×10^{-7}	18	1.47×10^{-7}	16	2.54×10^{-6}	-	-
120	125	6.20×10^{-7}	12	2.54×10^{-7}	117	6.71×10^{-6}	0.66	0.72
121	62	1.08×10^{-6}	62	5.37×10^{-7}	78	9.29×10^{-6}	-	0.24
122	57	1.90×10^{-7}	57	1.05×10^{-7}	6	6.40×10^{-8}	-	-
123	179	3.73×10^{-7}	78	1.52×10^{-7}	7	5.91×10^{-9}	-	-
124	129	6.46×10^{-7}	13	2.71×10^{-7}	117	1.02×10^{-5}	-	-
125	67	9.84×10^{-7}	66	4.89×10^{-7}	7	1.82×10^{-9}	0.66	2.87
126	38	4.30×10^{-8}	37	2.36×10^{-8}	89	1.00×10^{-6}	-	-
127	179	3.92×10^{-7}	18	1.50×10^{-7}	168	1.65×10^{-6}	0.66	0.24

(Continued)

Table 9 (Continued)

Terrain Matrix Element	Signature Characteristics: Man Walking, 5 m Distance, CF, Hz	AACF, cm/sec	15 m Distance, CF, Hz	AACF, cm/sec	Selected Background Noise, CF, Hz	AACF, cm/sec	Frequency of Occurrence, %: Reduced	Entire
128	126	6.51×10^{-7}	12	2.72×10^{-7}	117	9.20×10^{-6}	-	-
129	64	1.10×10^{-6}	63	5.49×10^{-7}	78	1.11×10^{-5}	0.66	0.24
130	23	1.17×10^{-6}	22	6.18×10^{-7}	16	1.02×10^{-5}	-	-
131	23	1.17×10^{-6}	23	6.21×10^{-7}	16	9.68×10^{-6}	-	-
132	23	1.09×10^{-6}	22	5.80×10^{-7}	16	9.27×10^{-6}	-	-
133	22	8.23×10^{-7}	22	4.39×10^{-7}	16	7.78×10^{-6}	-	-
134	38	2.53×10^{-7}	38	1.32×10^{-7}	89	2.60×10^{-6}	-	0.24
135	37	4.43×10^{-8}	37	2.44×10^{-8}	89	1.03×10^{-6}	-	-
136	179	6.87×10^{-8}	37	3.47×10^{-8}	89	1.22×10^{-5}	-	-
137	154	2.34×10^{-7}	15	1.01×10^{-7}	117	2.33×10^{-6}	-	-
138	85	3.62×10^{-7}	85	1.78×10^{-7}	88	9.57×10^{-6}	-	-
139	38	1.37×10^{-7}	38	7.30×10^{-8}	89	2.29×10^{-6}	-	0.24
140	101	4.21×10^{-8}	38	2.12×10^{-8}	89	1.21×10^{-6}	1.32	0.48
141	37	9.16×10^{-9}	37	5.14×10^{-9}	37	8.08×10^{-8}	-	-
142	37	1.34×10^{-8}	37	7.52×10^{-9}	9	1.49×10^{-8}	-	0.24

(Continued)

Table 9 (Concluded)

Terrain Matrix Element	Signature Characteristics: Man Walking: 5 m Distance: CF, Hz	AACF, cm/sec	15 m Distance: CF, Hz	AACF, cm/sec	Selected Background Noise: CF, Hz	AACF, cm/sec	Frequency of Occurrence, %: Reduced	Entire
143	179	2.30×10^{-8}	19	1.12×10^{-8}	89	6.32×10^{-7}	0.66	0.48
144	125	1.84×10^{-7}	12	8.87×10^{-8}	9	5.19×10^{-9}	0.66	0.48

(Sheet 10 of 10)

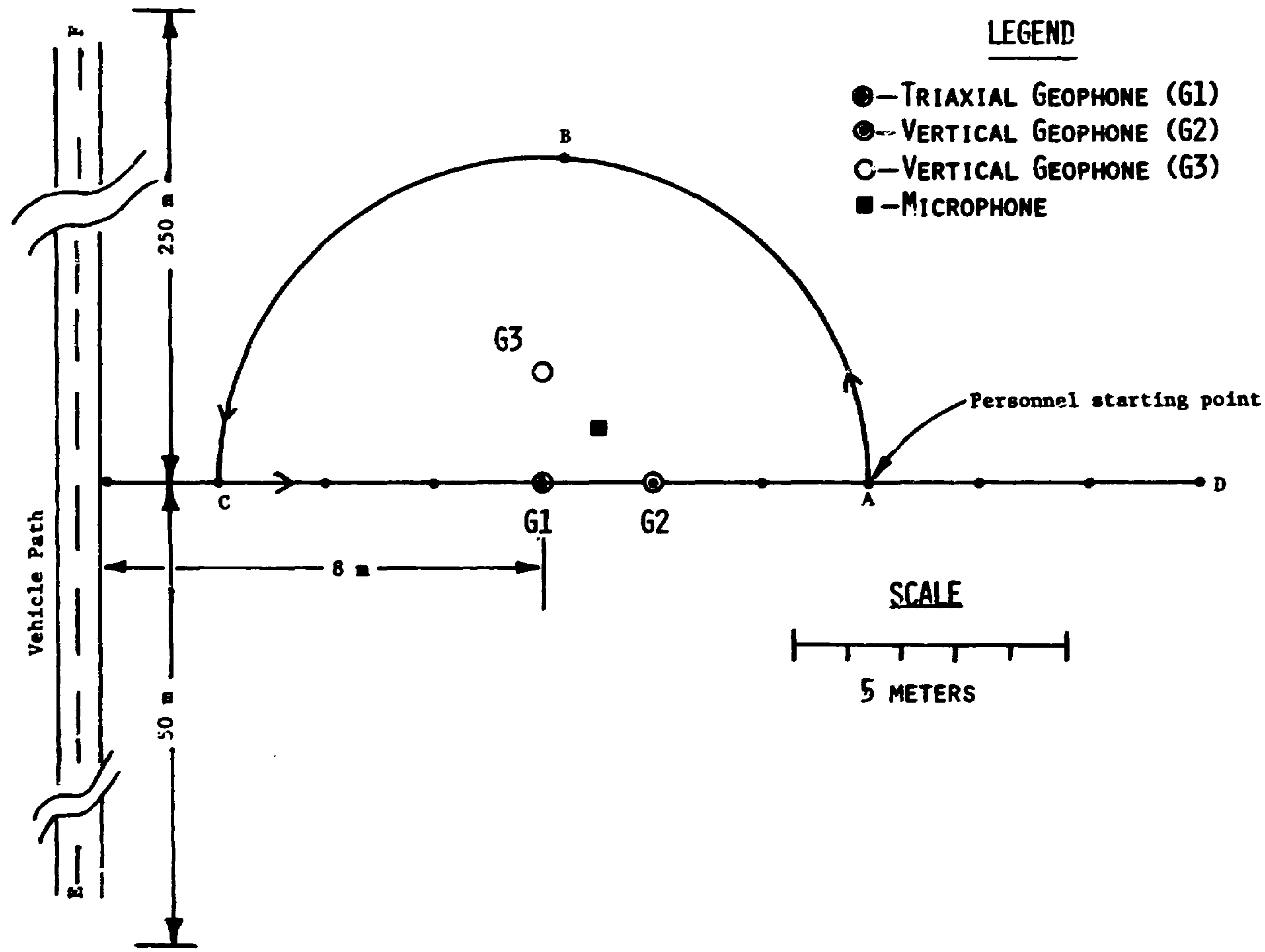


Figure 1. Typical test layout for BISS data collection

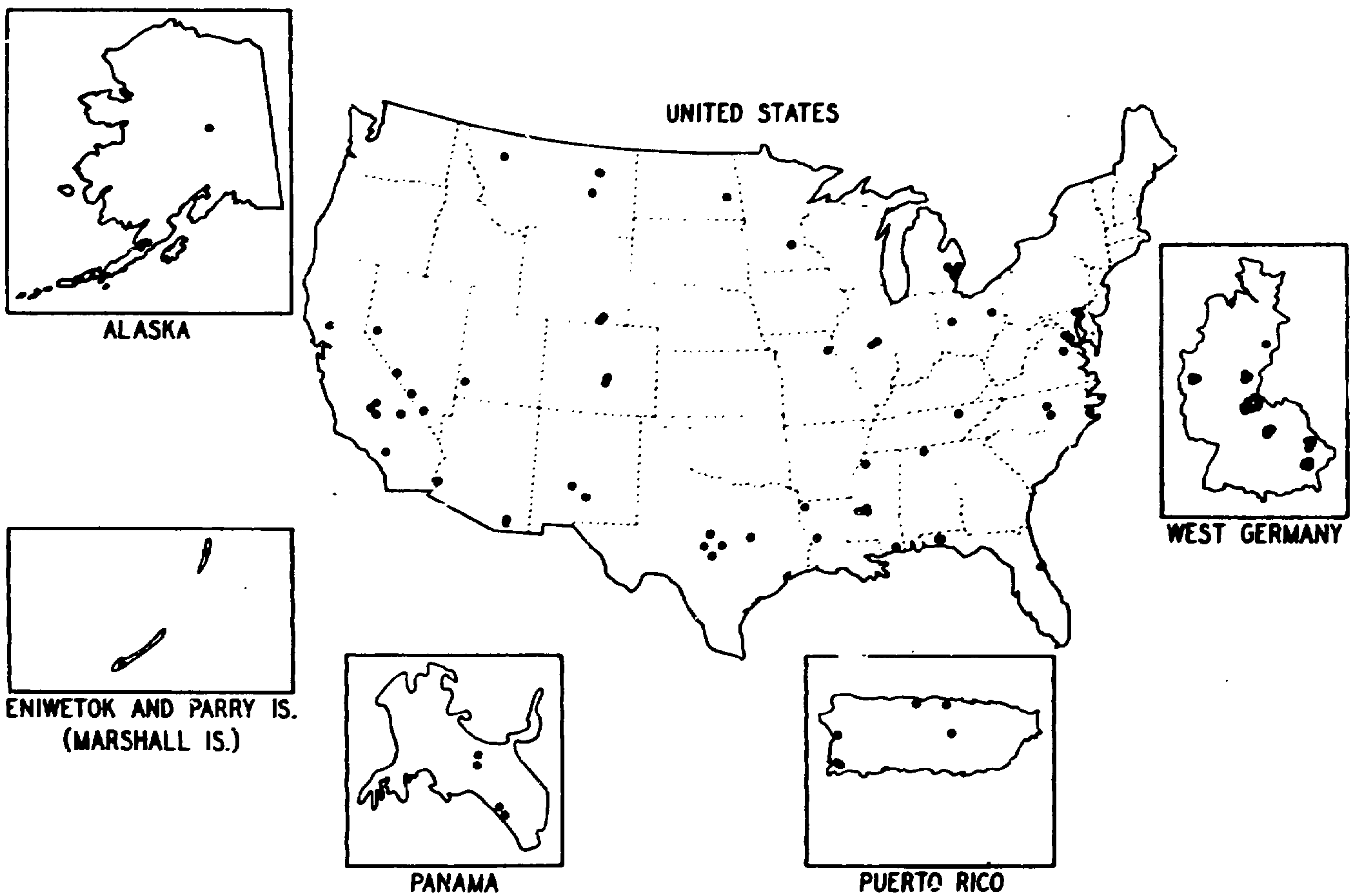


Figure 2. Locations of seismic refraction measurements

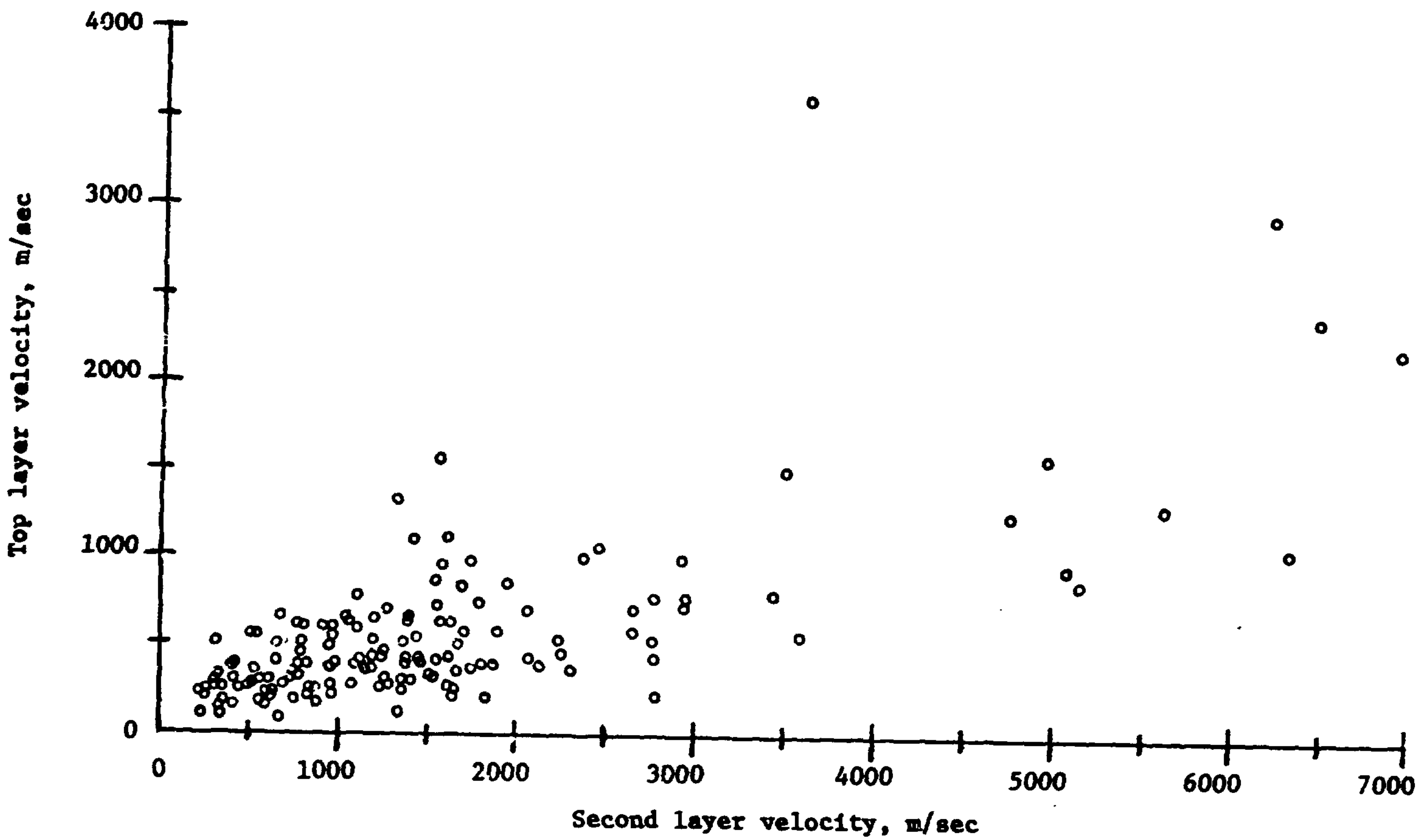


Figure 3. Top-layer versus second-layer compression wave velocities for terrain data

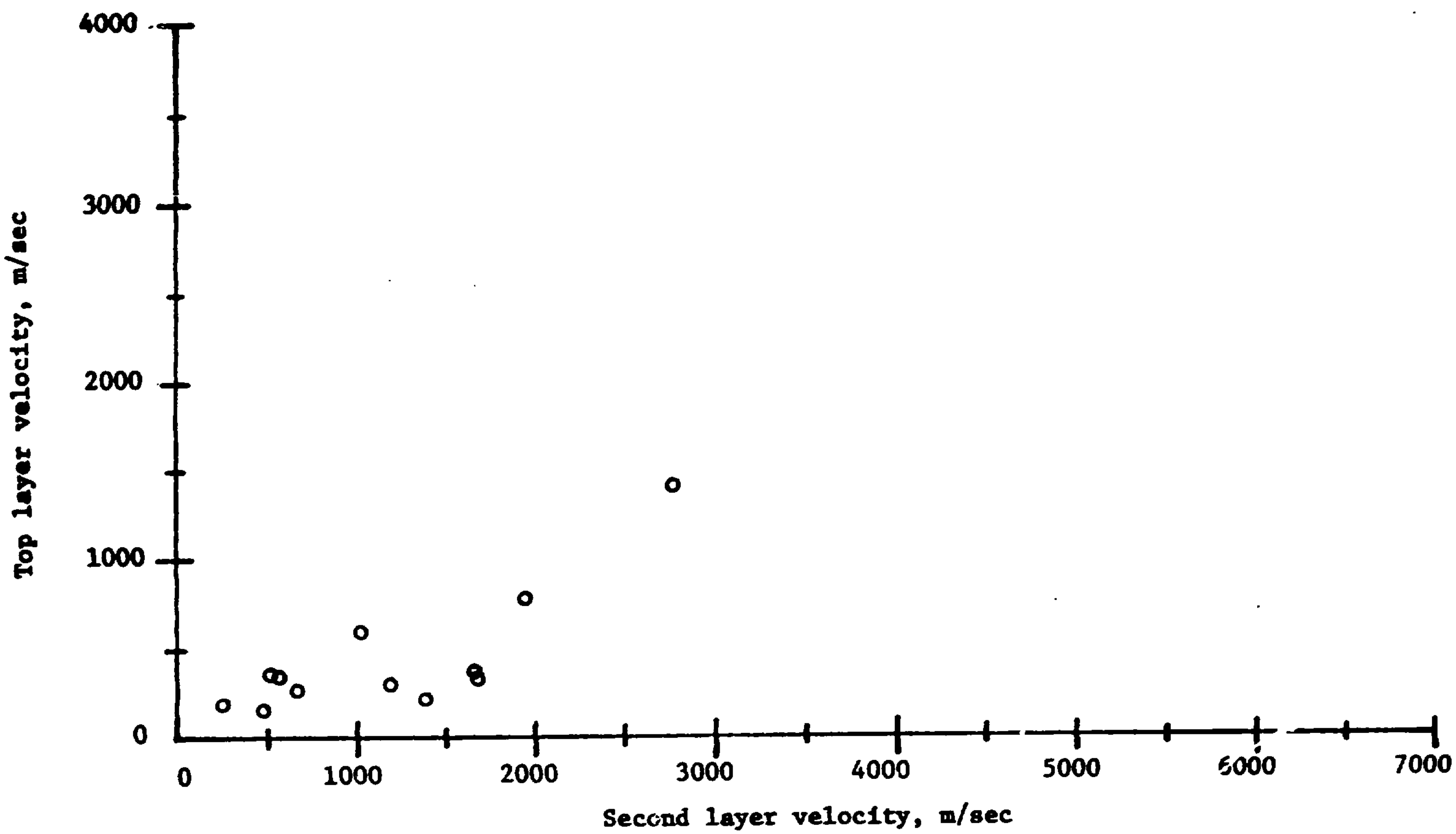


Figure 4. Top- and second-layer compression wave velocities for selected sites

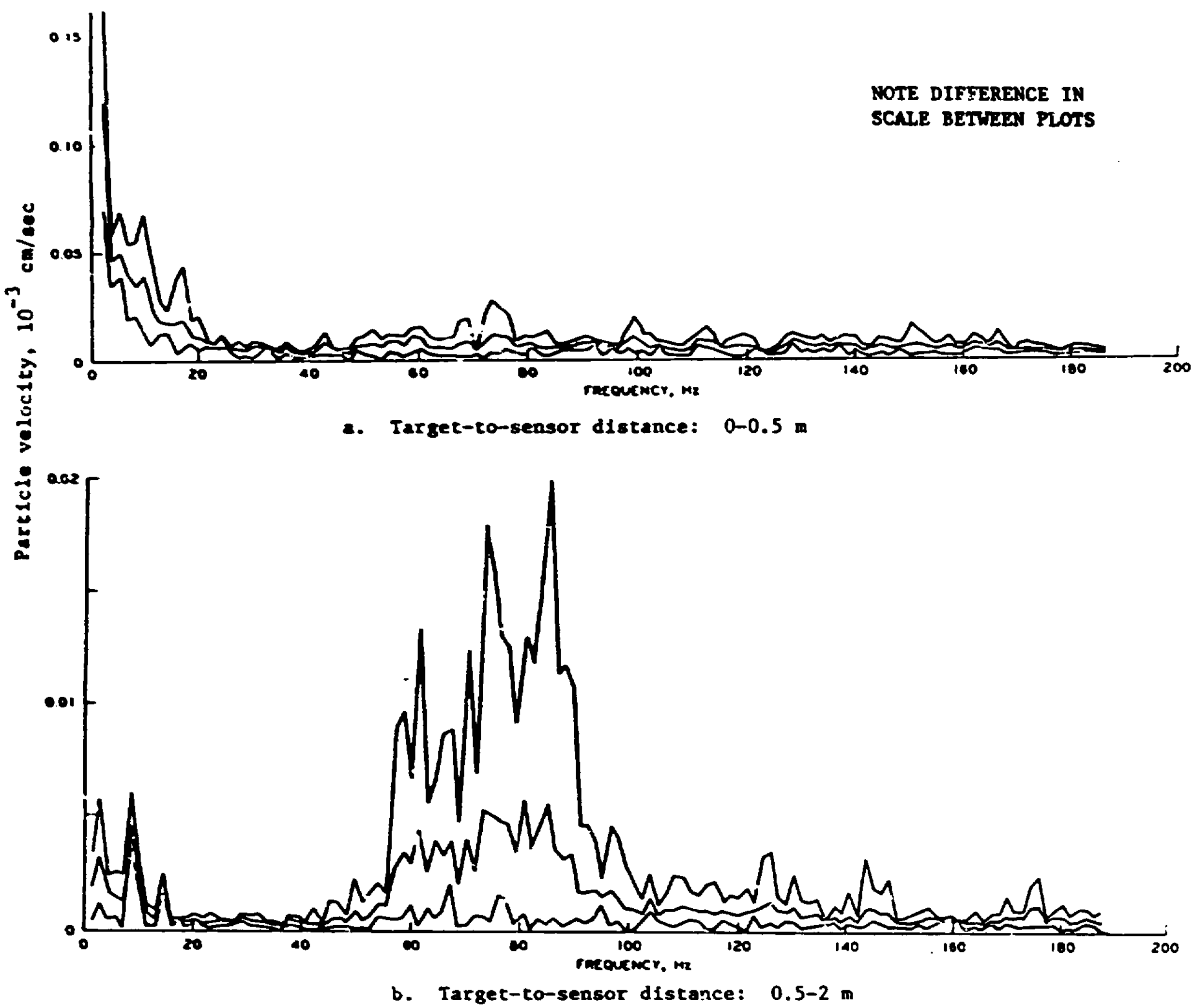
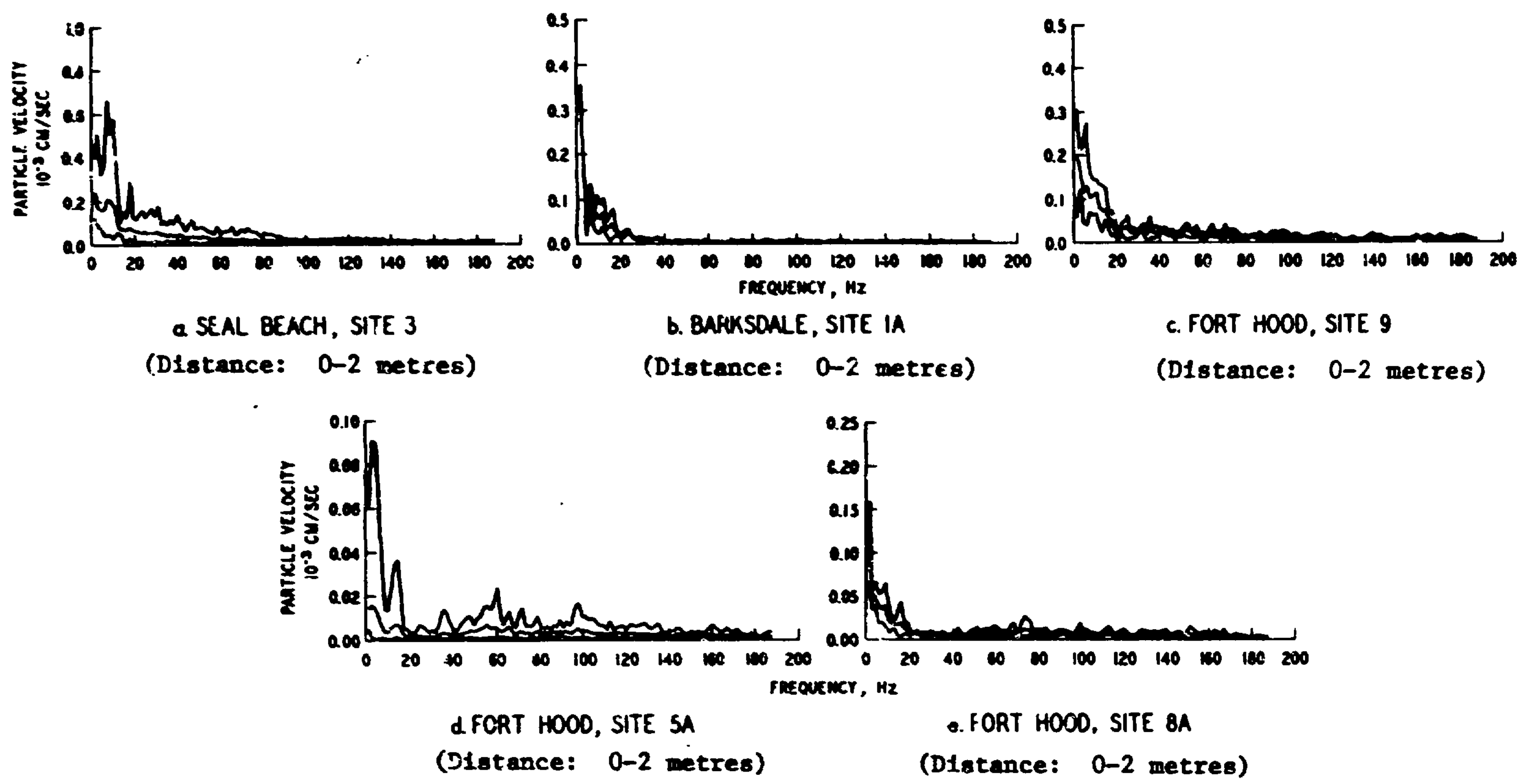


Figure 5. Example of the change in the frequency domain characteristics with target-to-sensor distance for man-creeping signatures (Fort Hood, site 8A)

NOTE DIFFERENCE IN
SCALE AMONG PLOTS



a. SEAL BEACH, SITE 3
(Distance: 0–2 metres)

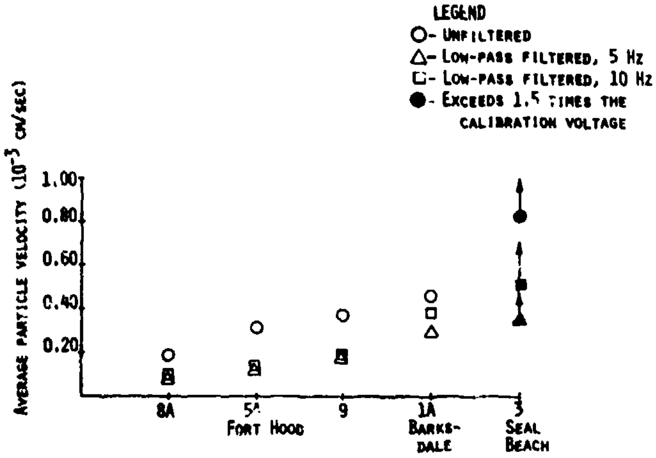
b. BARKSDALE, SITE 1A
(Distance: 0–2 metres)

c. FORT HOOD, SITE 9
(Distance: 0–2 metres)

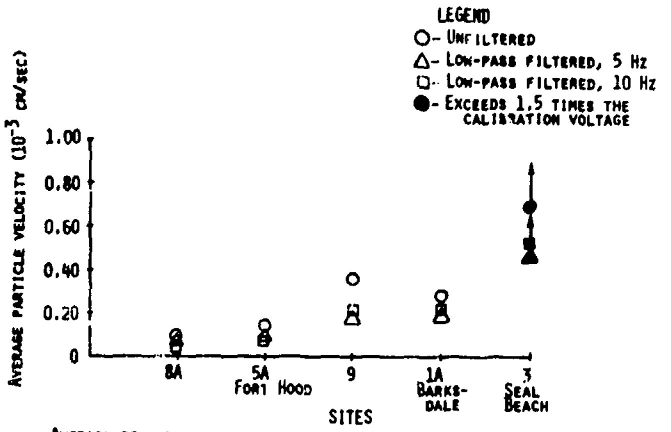
d. FORT HOOD, SITE 5A
(Distance: 0–2 metres)

e. FORT HOOD, SITE 8A
(Distance: 0–2 metres)

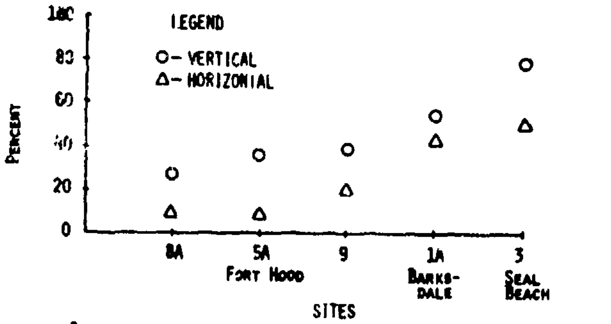
Figure 6. Frequency domain characteristics for man-creeping signatures



AVERAGE PEAK PARTICLE VELOCITY FOR VERTICAL COMPONENT OF MAN-CREEPING SIGNATURES FOR FOOTFALL 0.5 M REMOVED FROM SENSOR LOCATION



AVERAGE PEAK PARTICLE VELOCITY FOR HORIZONTAL COMPONENT OF MAN-CREEPING SIGNATURES FOR FOOTFALL 0.5 M REMOVED FROM SENSOR LOCATION



RATIO OF AVERAGE PEAK AMPLITUDE FOR FOOTFALL 0.5 M FROM SENSOR TO THE AVERAGE PEAK AMPLITUDE FOR FOOTFALL AT THE SENSOR

Figure 7. Average amplitude and amplitude ratios for near-distance, man-creeping signatures

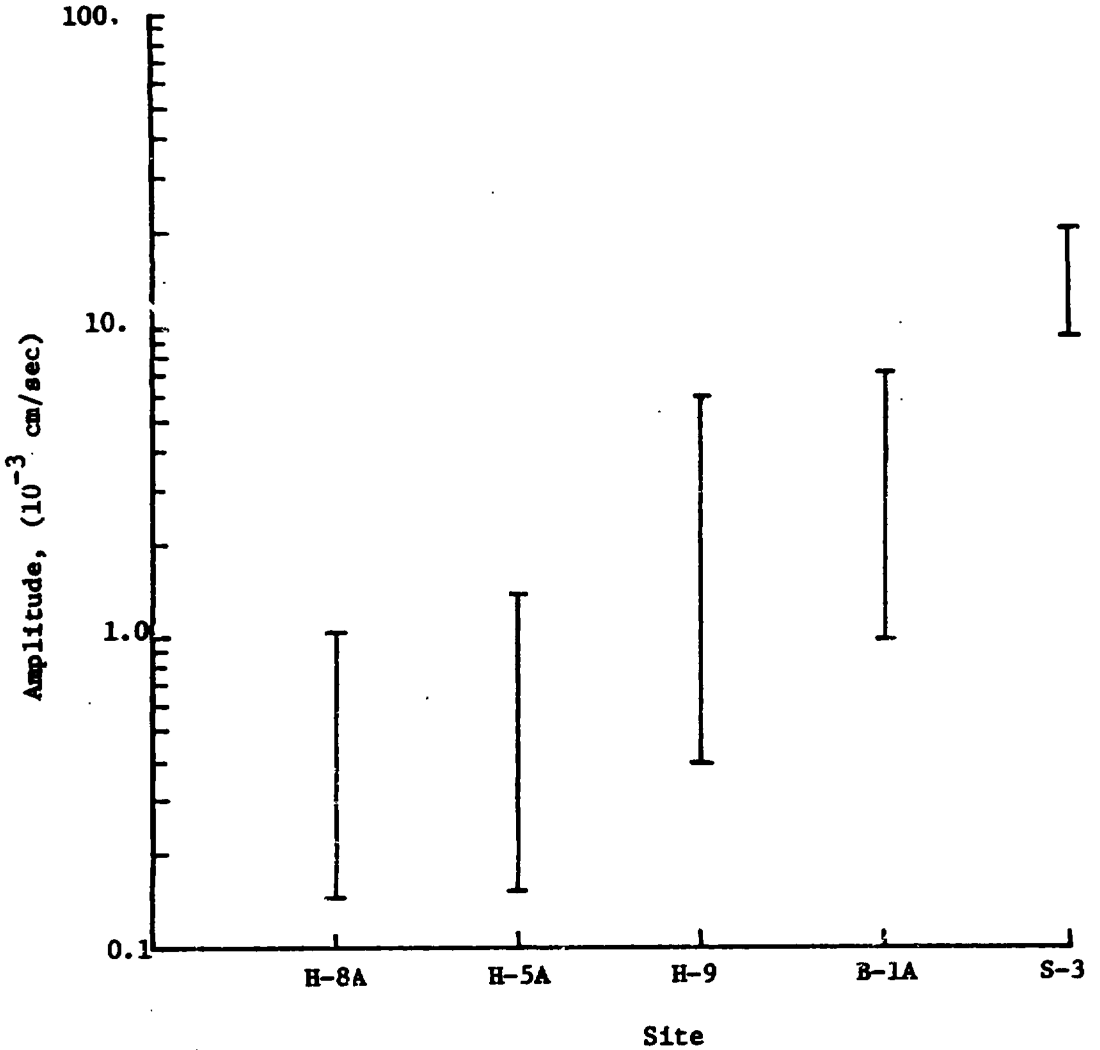


Figure 8. Measured Range of Amplitudes of Man-walking Signatures For Source-to-Sensor Distance of 6 m

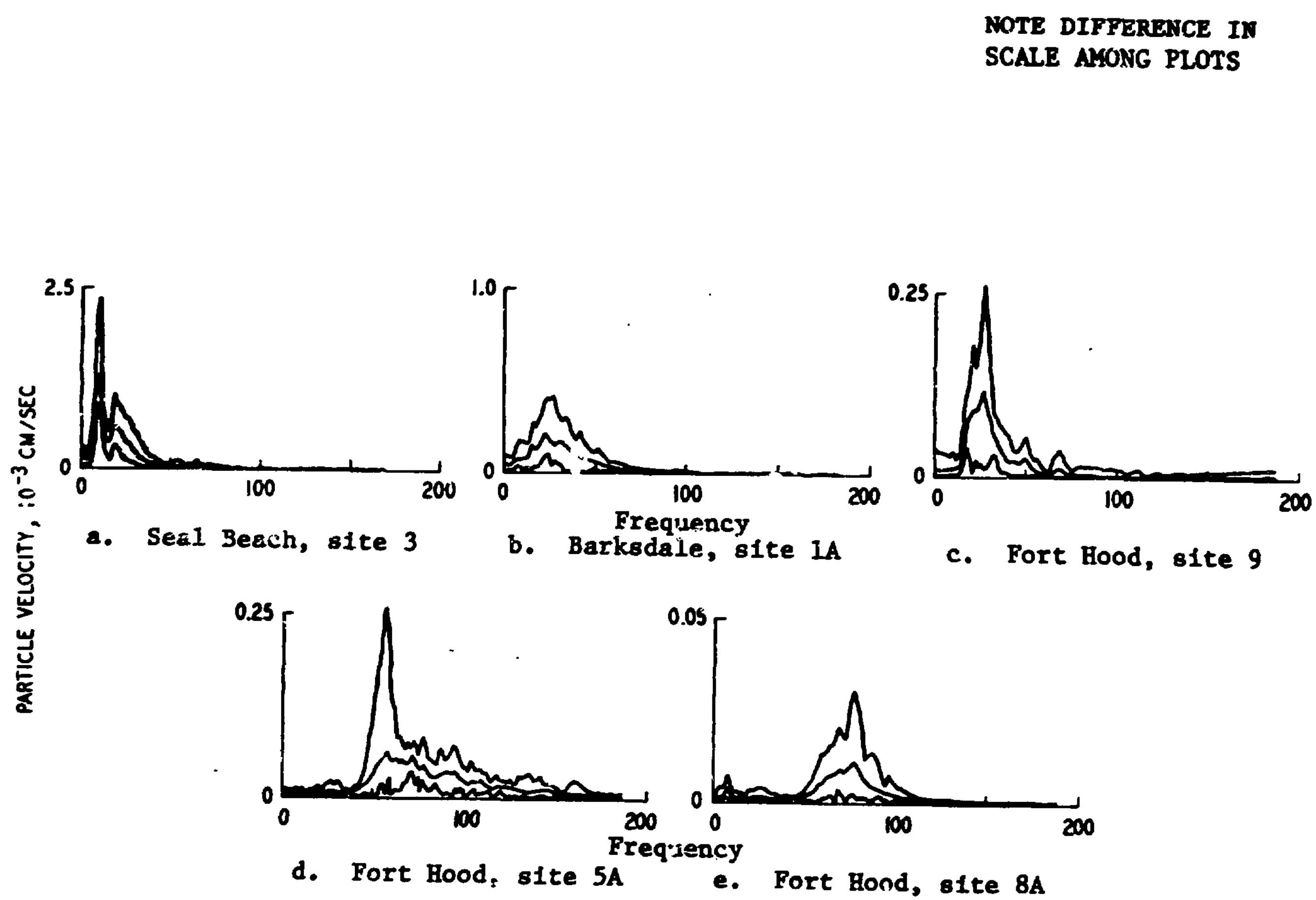


Figure 9. Frequency-domains of man-walking signatures (target-to-sensor distance = 6 m)

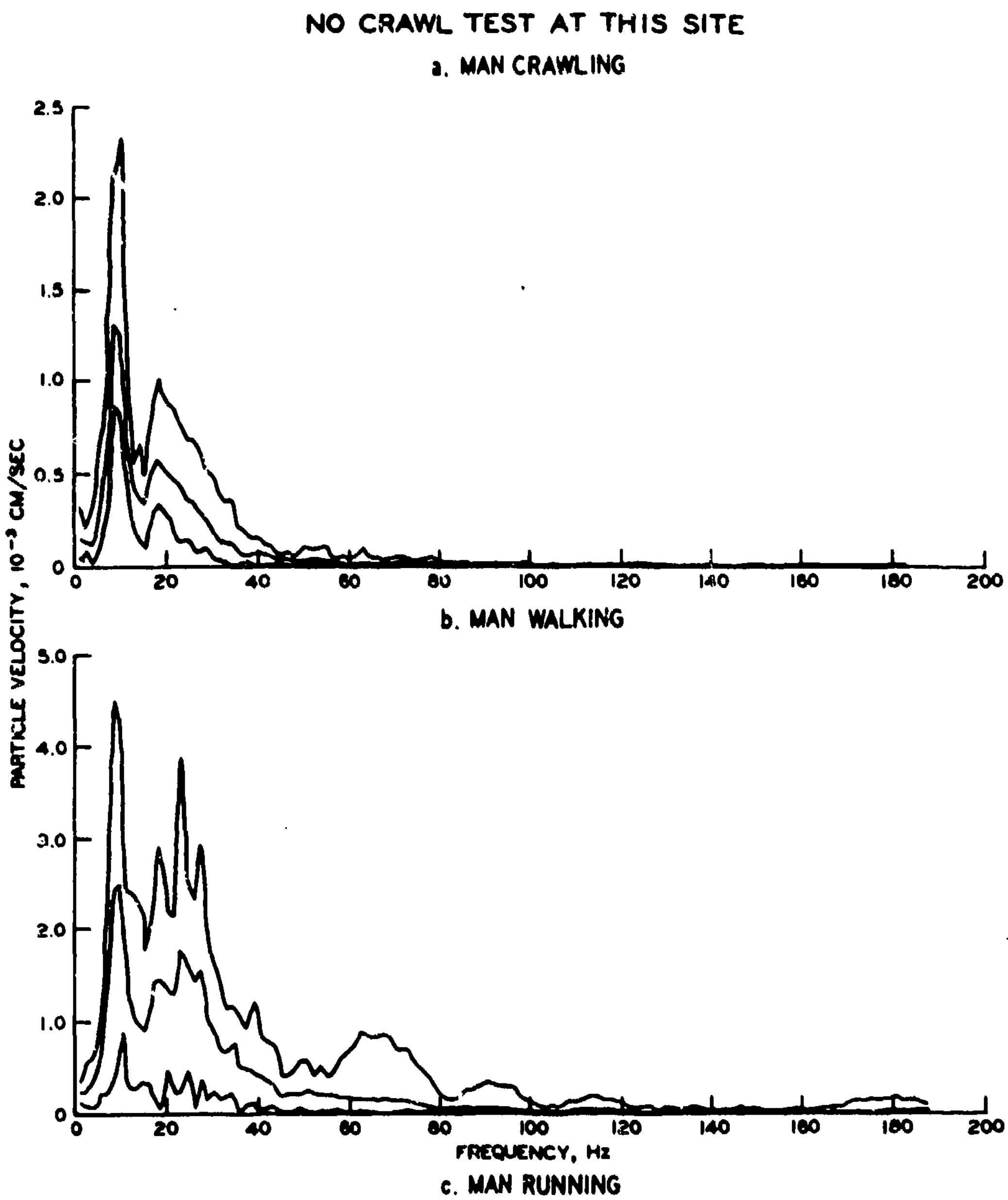


Figure 10. Frequency-domain characteristics of personnel signatures for Seal Beach, site 3 (target-to-sensor distance = 6 m)

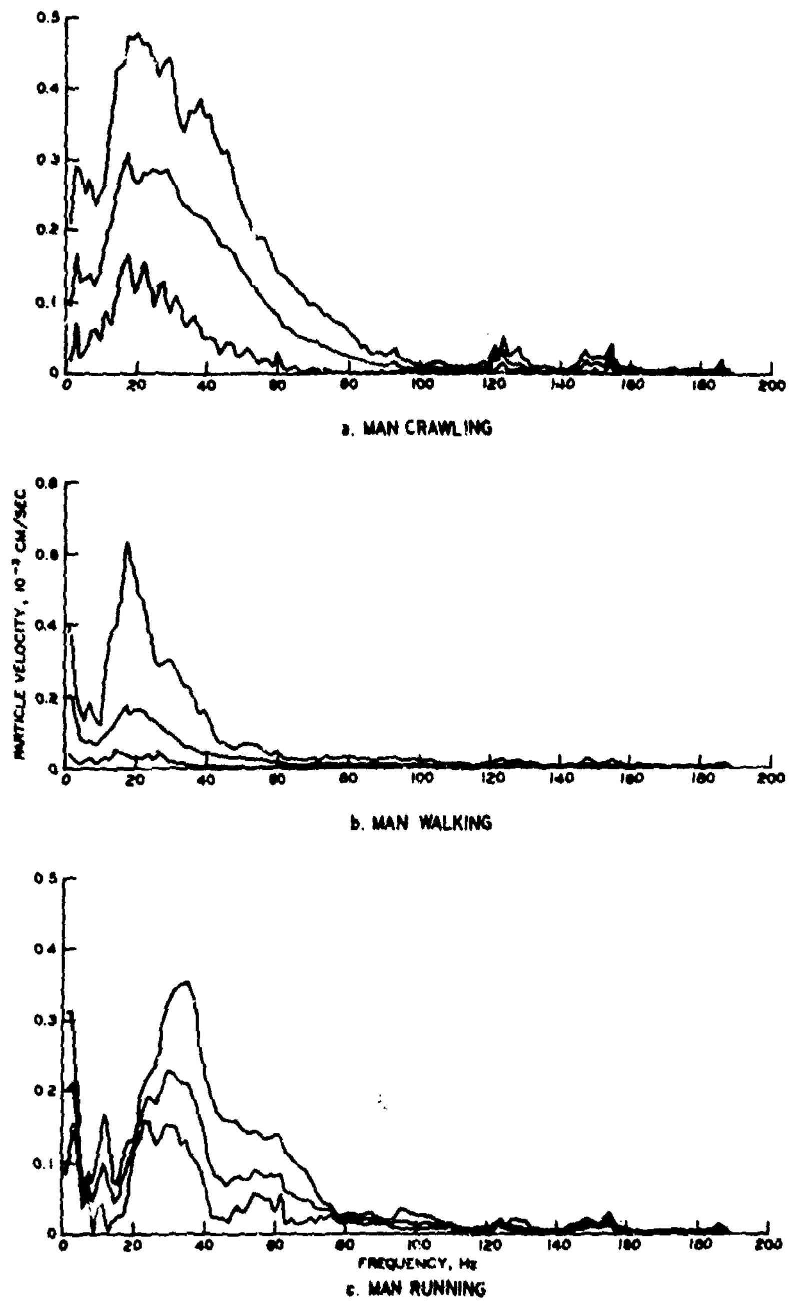


Figure 11. Frequency-domain characteristics of personnel signatures for Barksdale AFB, site 1A (target to sensor distance = 6 m)

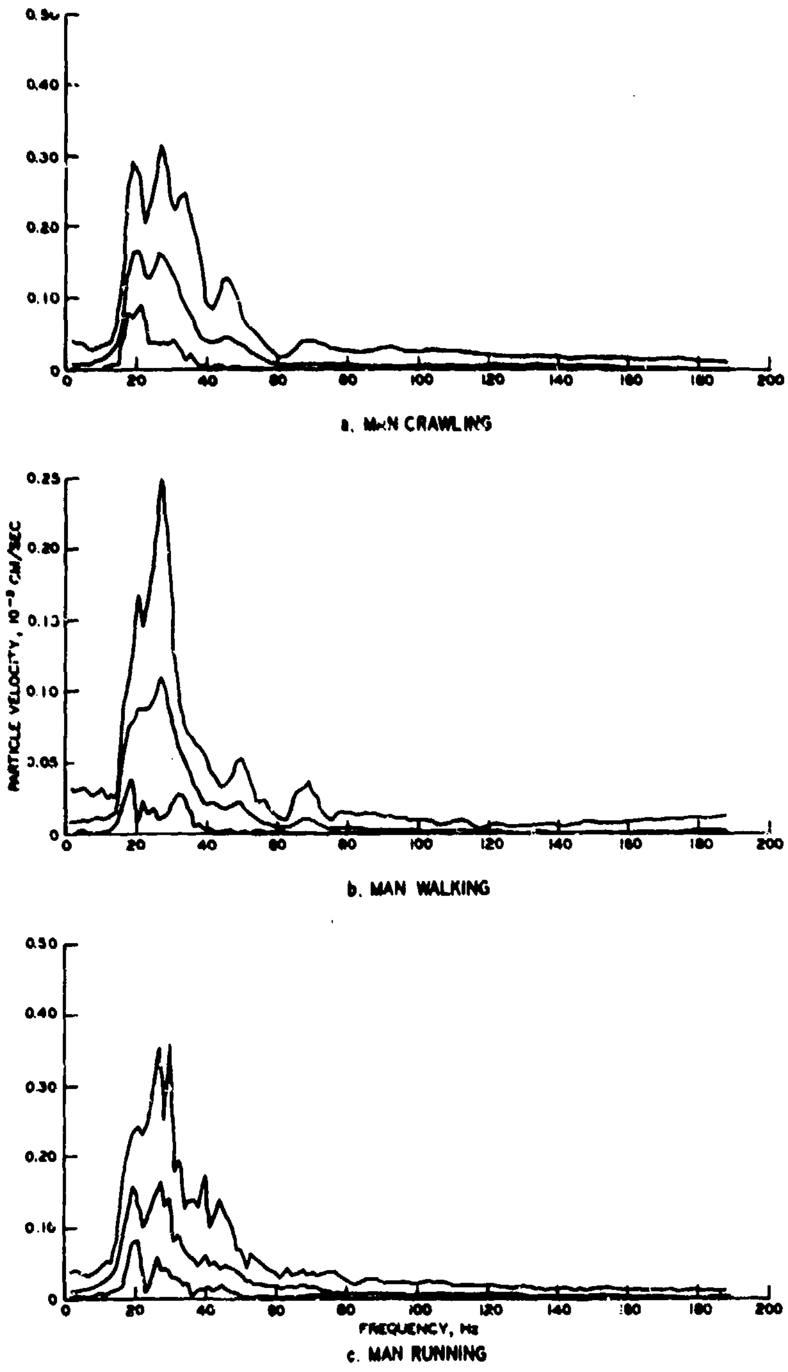


Figure 12. Frequency-domain characteristics of personnel signatures for Fort Hood, site 9 (target-to-sensor distance ≈ 6 m)

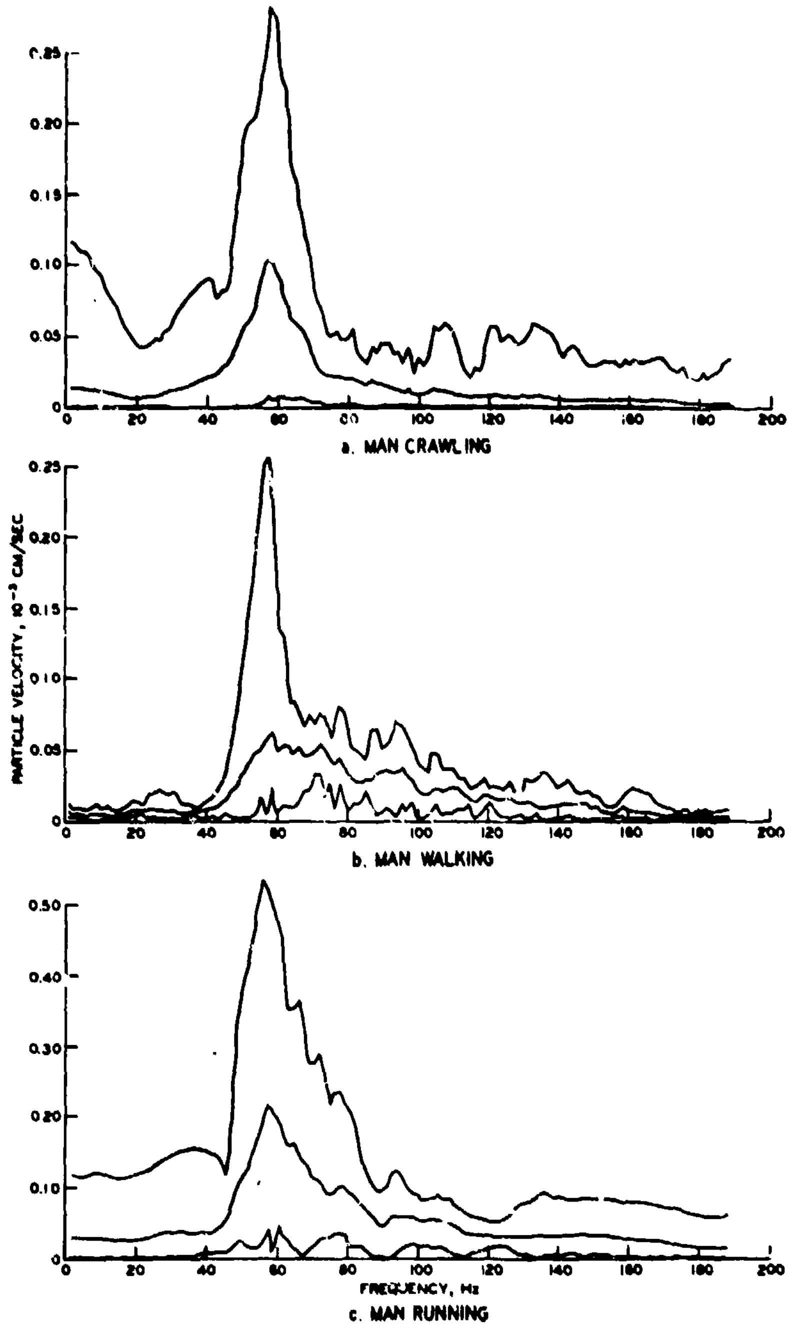


Figure 13. Frequency-domain characteristics of personnel signatures for Fort Hood, site 5A (target-to-sensor distance = 6 m)

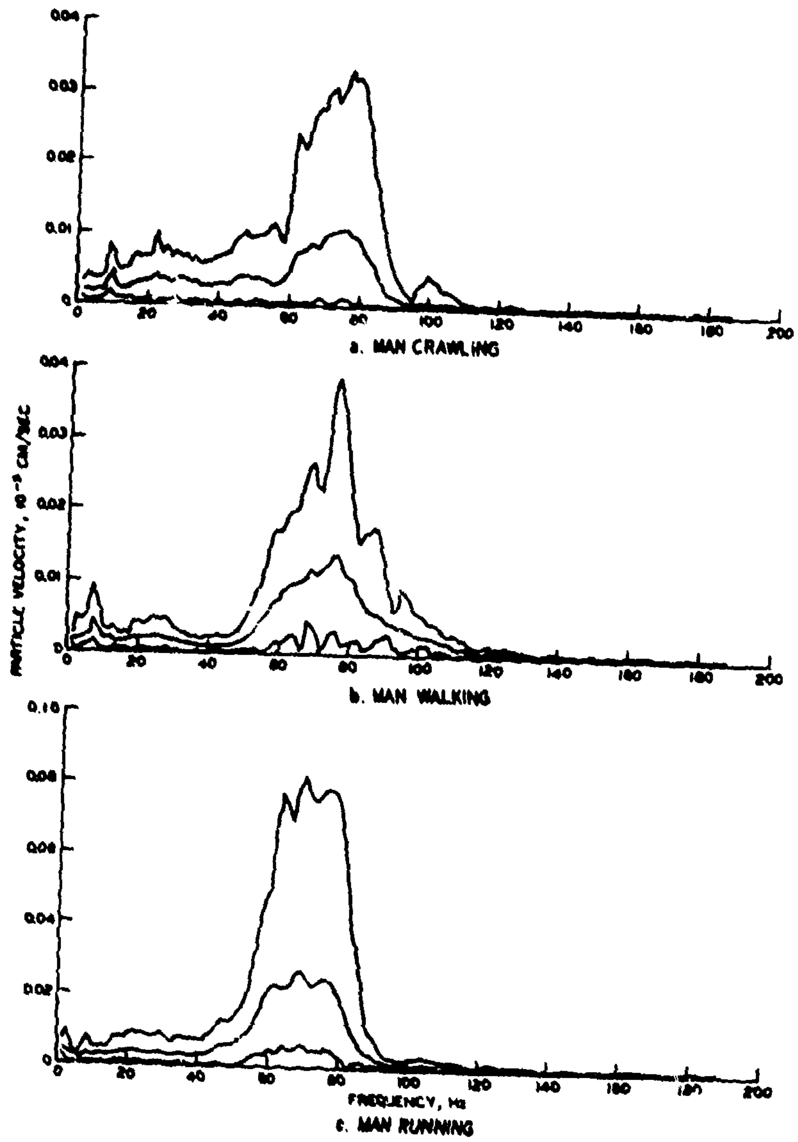


Figure 14. Frequency-domain characteristics of personnel signatures for Fort Hood, site 8A (target-to-sensor distance = 6 m)

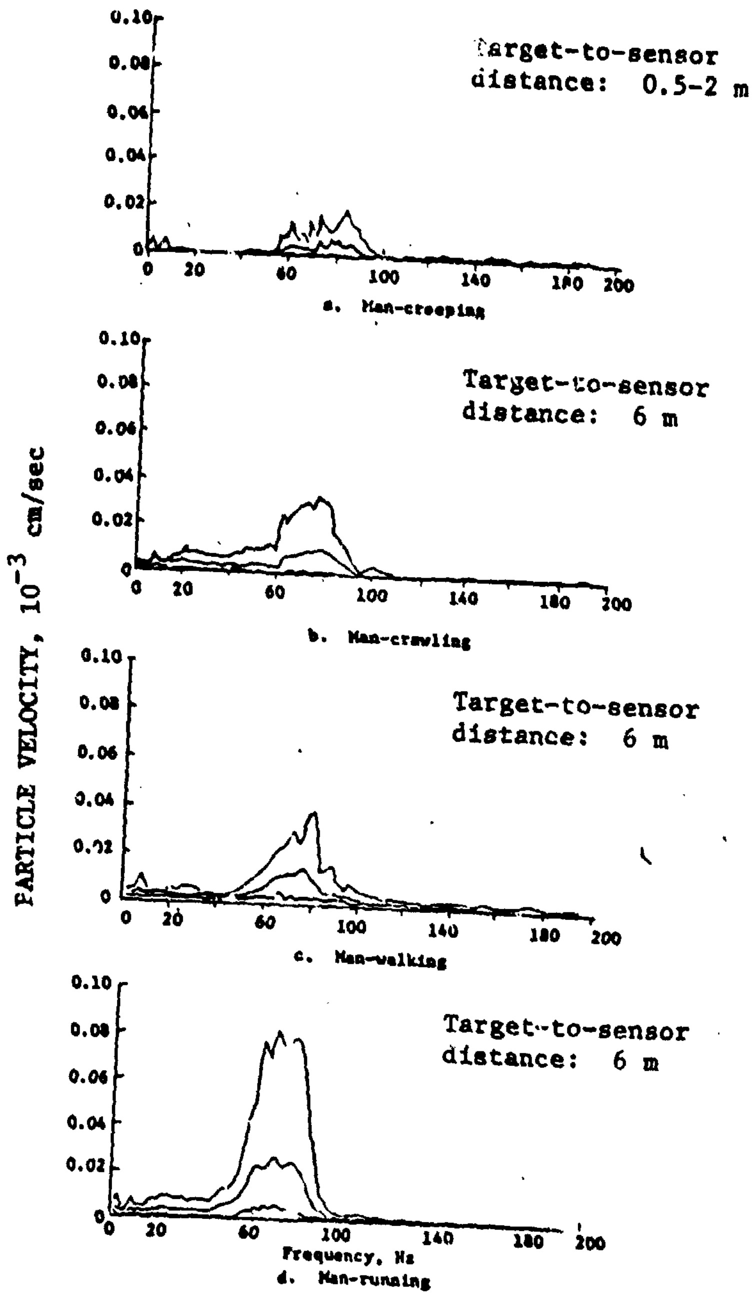


Figure 15. Frequency-domains of personnel signatures for Fort Hood, site 8A

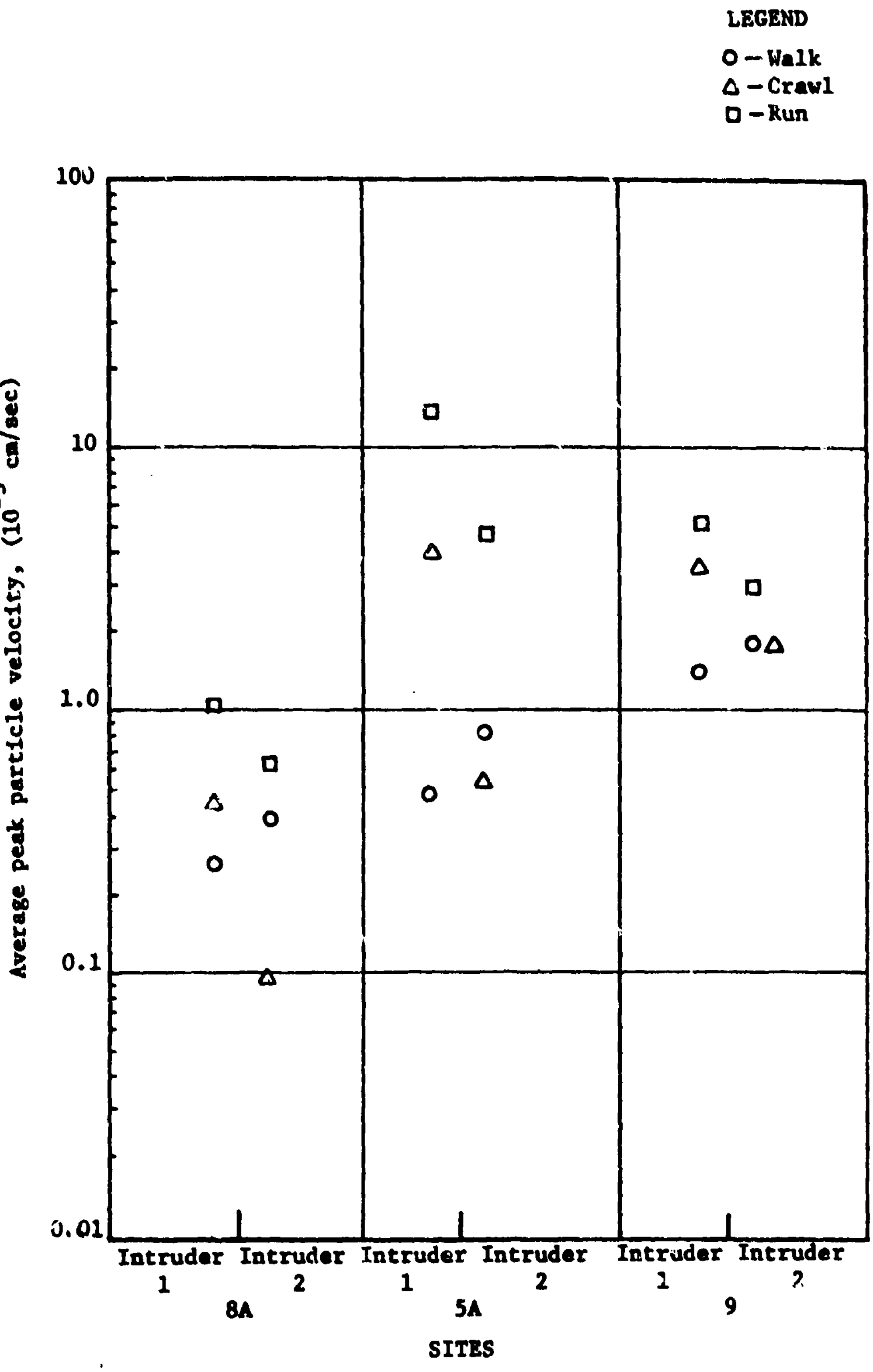


Figure 16. Average peak particle velocity of signatures of two intruders walking, crawling, and running for the three Fort Hood sites

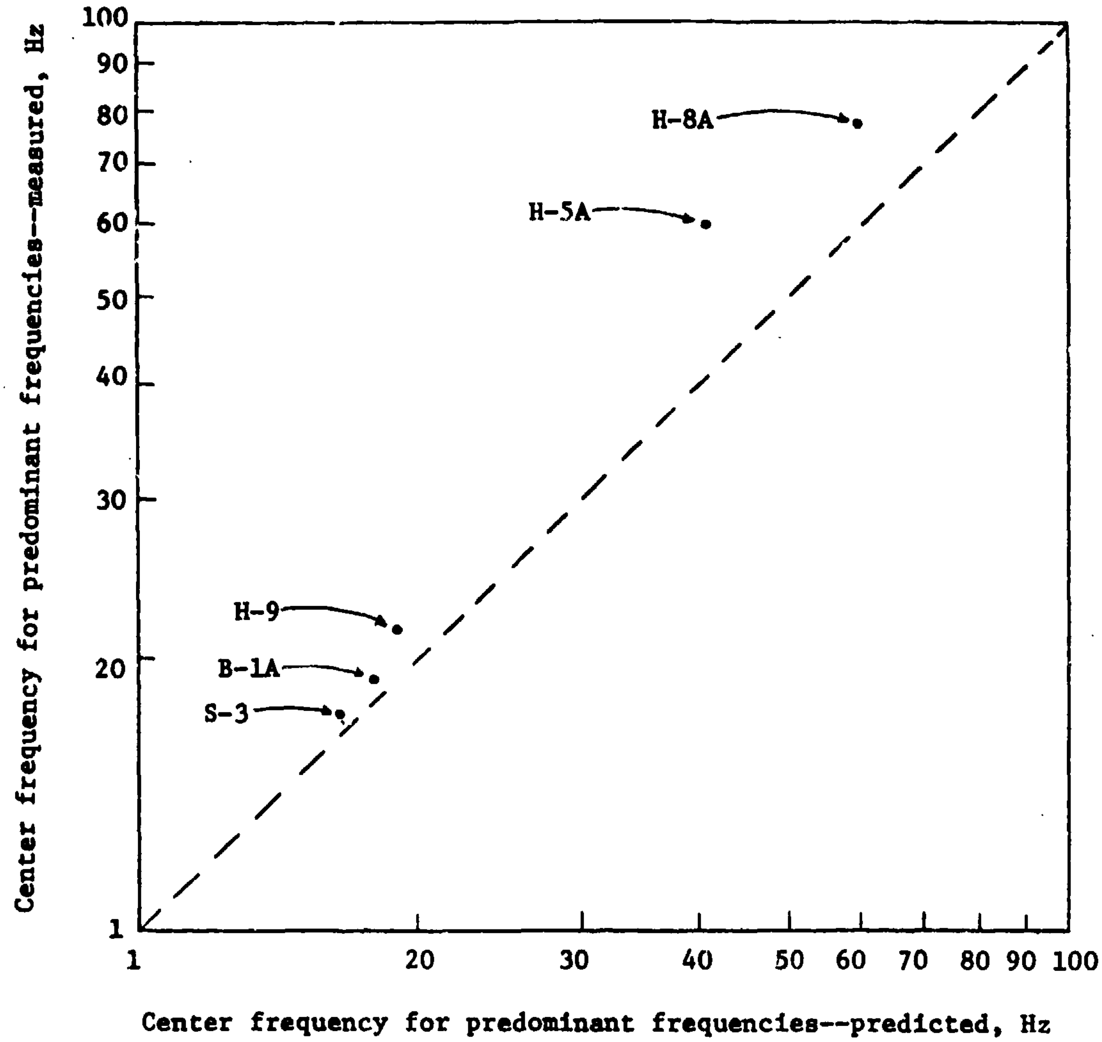


Figure 17. Comparison of predicted and measured center frequencies for predominant frequencies of vertical component of particle velocity for footsteps

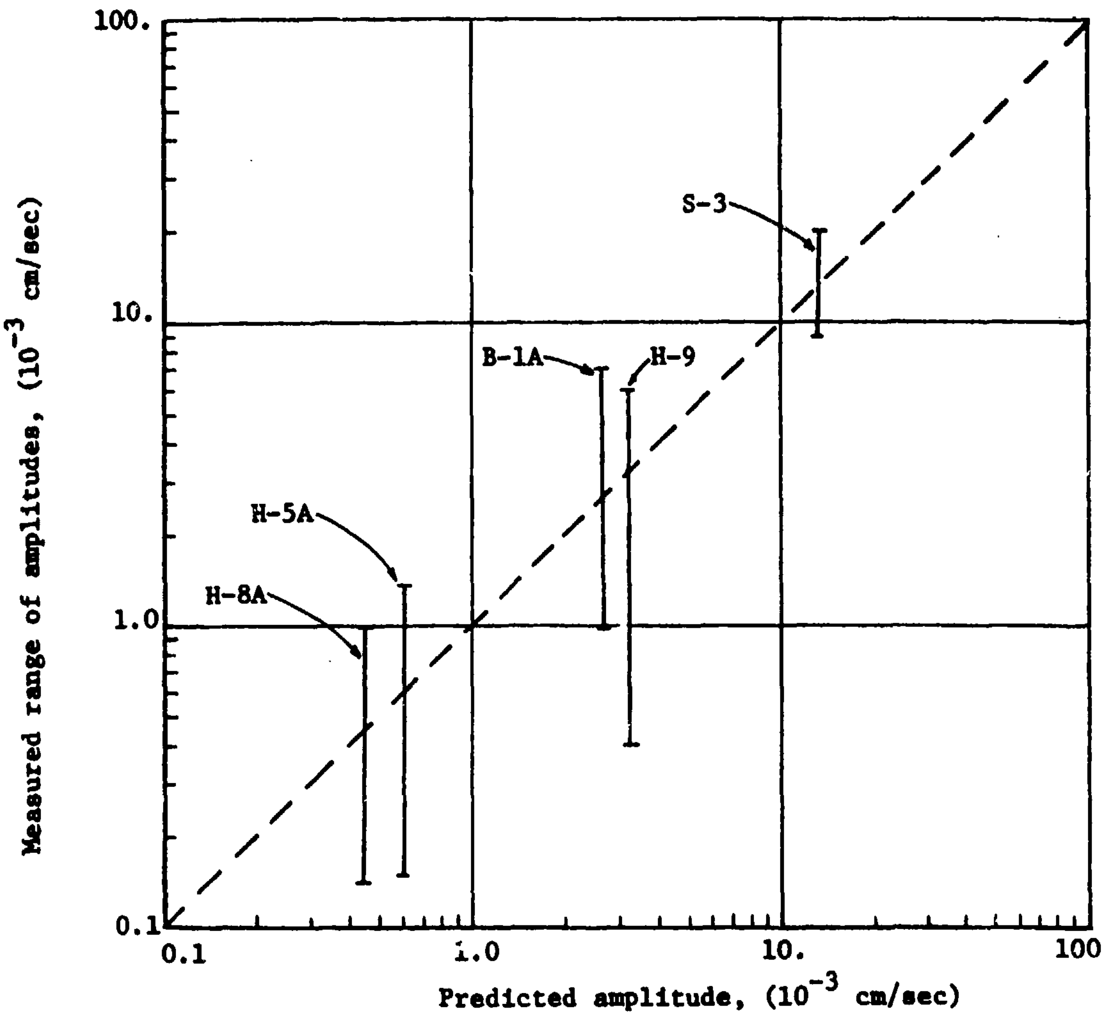


Figure 18. Comparison of predicted amplitudes of vertical components of particle velocity and the measured range of amplitudes for footsteps

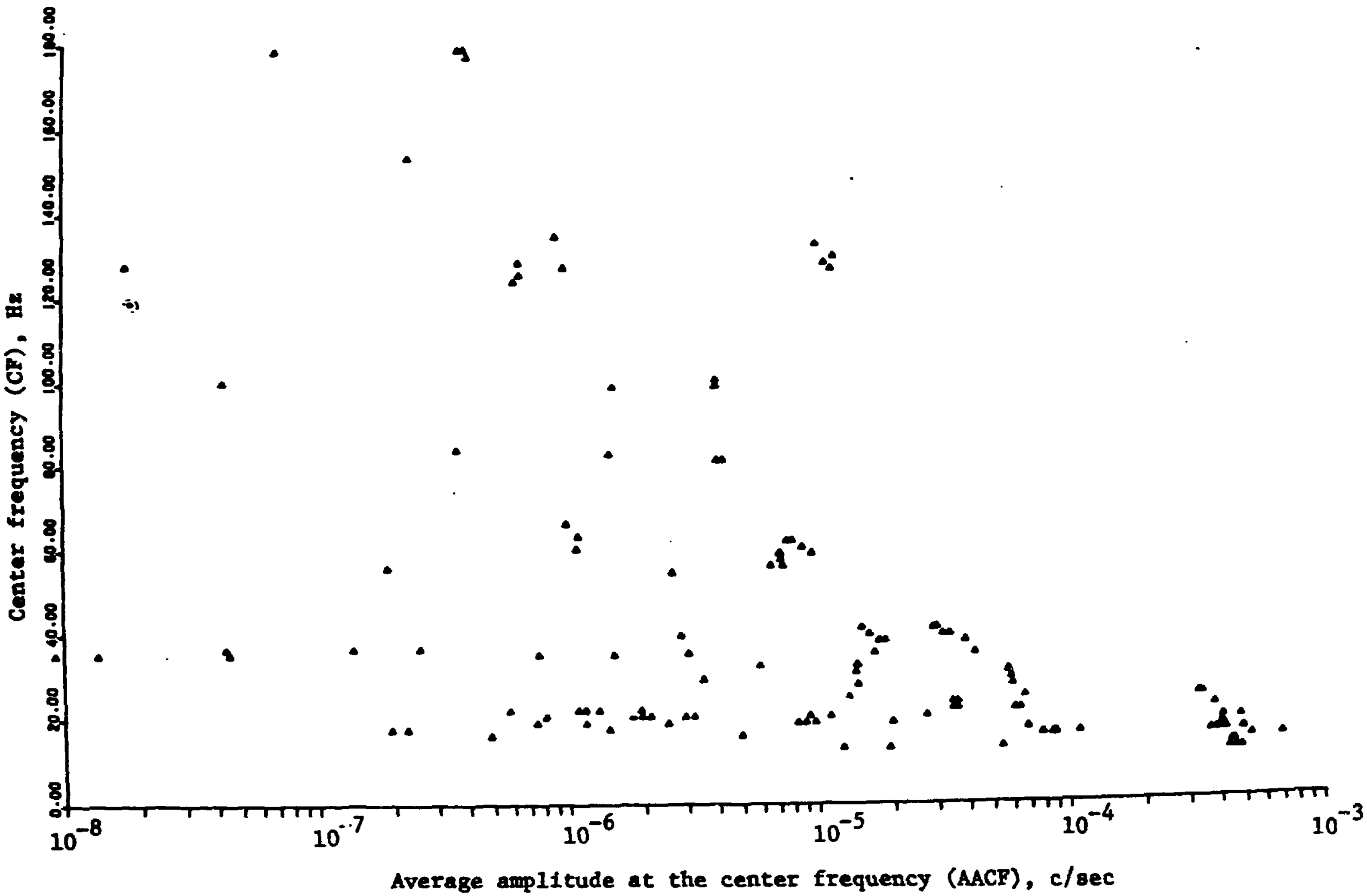


Figure 19. Distribution of CFs and AACFs for man-walking signatures represented in the terrain matrix for a target-to-sensor distance of 5 m

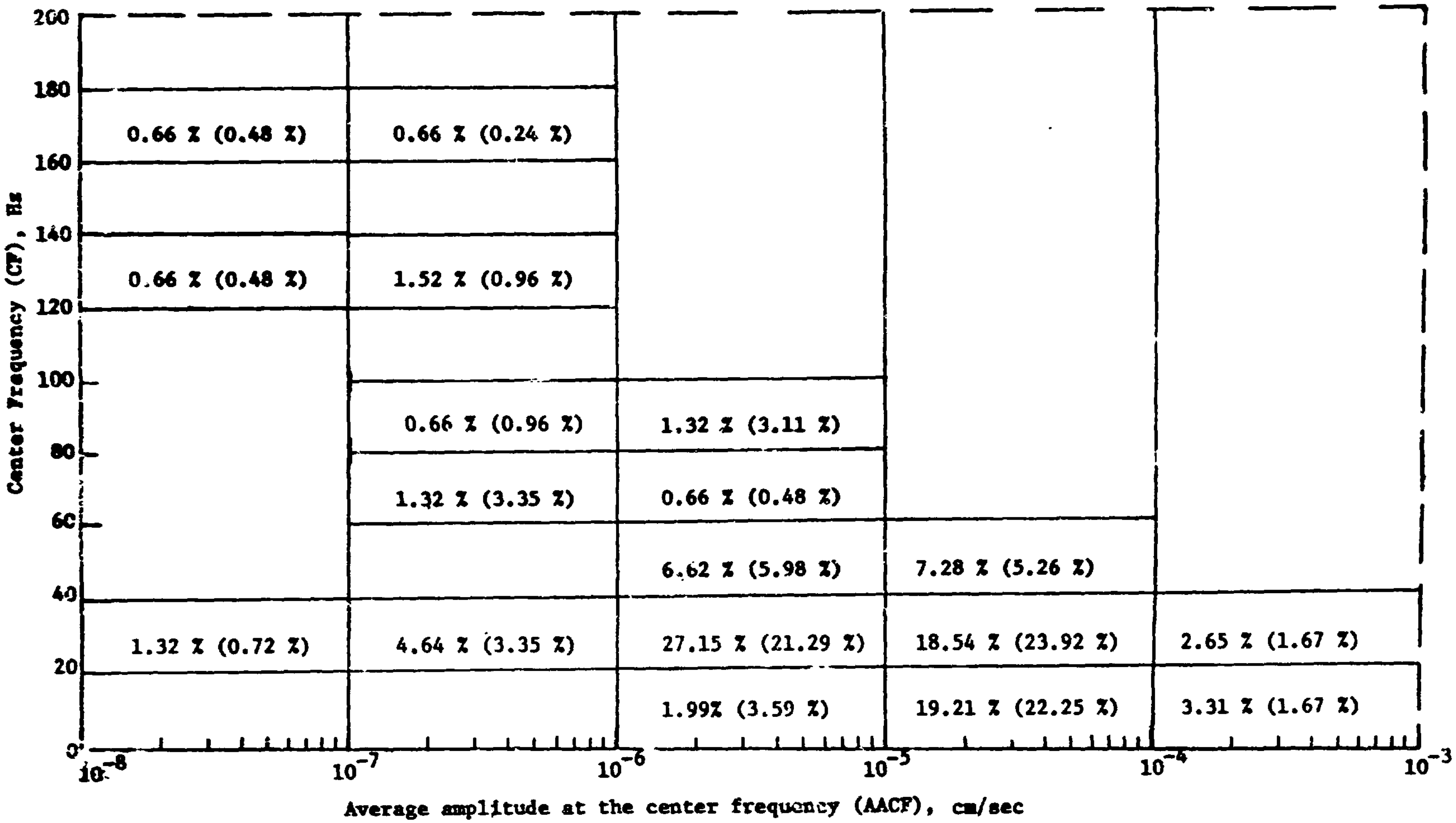


Figure 20. Groups and frequency of occurrence for man-walking signatures at the 5-m distance (percents in parentheses are for entire set)

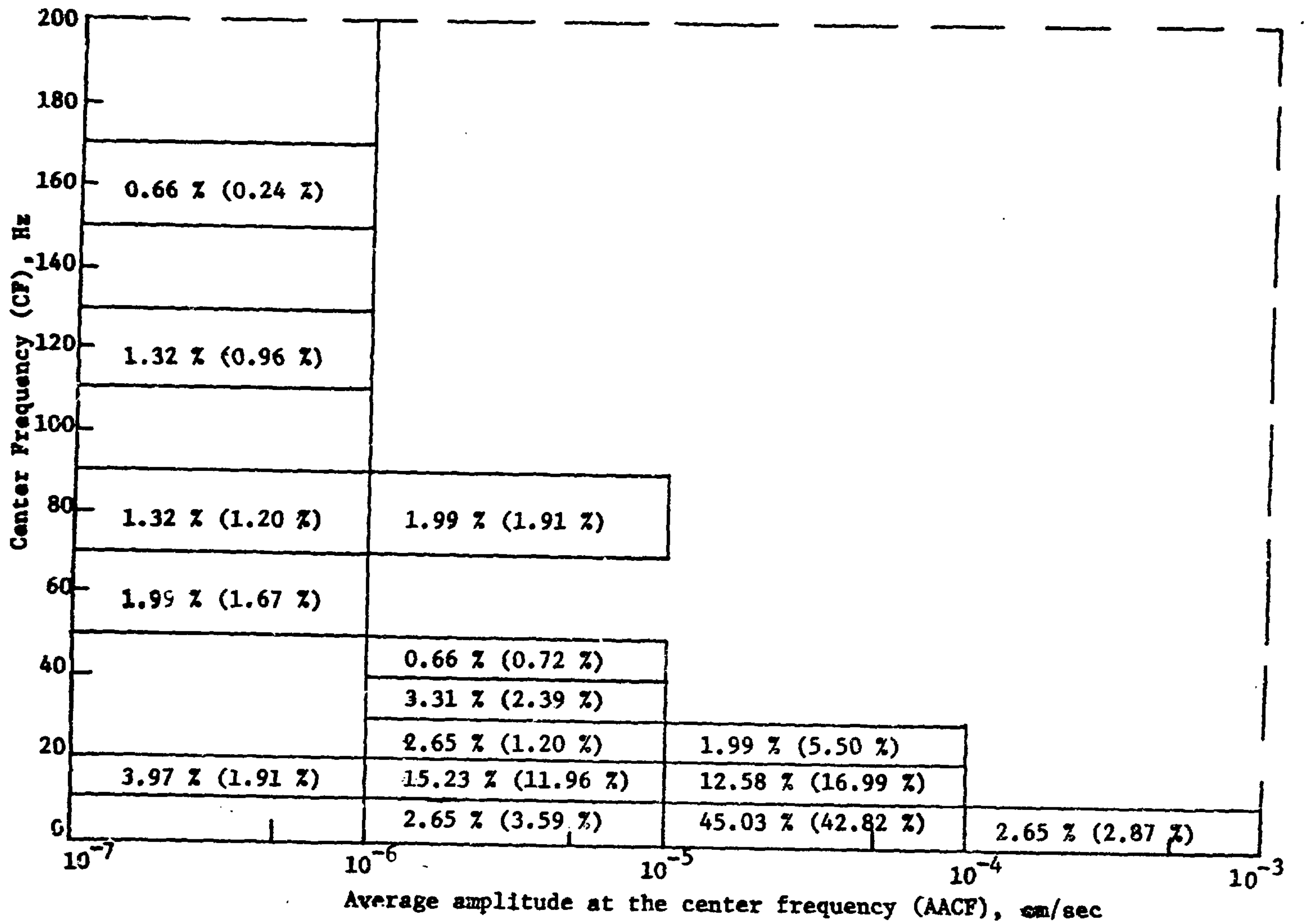


Figure 21. Groups and frequency of occurrence for sample background noise signature, M35, 32 kph, 75-m source to sensor distance (percents in parentheses are entire set)

APPENDIX A: DESCRIPTION OF INSTRUMENTATION AND RECORDED DATA

1. This appendix presents a description of the recording instrumentation and the documentation of the recorded data. The description of the instrumentation includes the data recording equipment, sensors, and associated frequency response. The description of the documentation of the recorded data presents an explanation of the field data logs.

Instrumentation

2. Figure A1 presents a block diagram of the major components of the WES analog data recording system. The WES uses a small battery-powered (d-c) analog recording system. The battery powered system eliminates noise that can be caused by the trailer-mounted generators used to power a-c systems. The major components of the WES analog recording system are given in the following subparagraphs:

- a. Seismic signatures were sensed with Model L4-3D triaxial geophones. The L4-3D geophone is encased in a waterproof housing. It has a 1-Hz natural frequency and is damped at 70 percent of critical. There are three geophones, each aligned along one of the Cartesian axes.
- b. Acoustic signatures were sensed with a type 4921 outdoor microphone unit manufactured by Brüel and Kjaer Instruments. The microphone is a condenser type and permits sound measurements to be conducted in hostile environmental conditions. It uses a quartz-coated, 1.27 cm (1/2 in.) condenser. The preamplifier is housed in an atmosphere of silica gel to reduce moisture problems. The amplifier has a rotary switch with five 10 db gain steps and a continuously variable 10 db potentiometer so that a total amplification of 60 db can be achieved. The frequency response has a high-pass filter characteristic that is essentially flat from 50 to 20000 Hz and is 4 db down at 20 Hz. The sensitivity is 0.001 volts per microbar. The unit has a rain cover and windscreen. The dynamic range is 46 db to 160 db relative to 0.0002 microbars.

c. An FM magnetic tape recorder, Lockheed Model 417, which records and reproduces seven channels of data at 1-7/8, 3-3/4, and 7-1/2 in./sec, giving frequency responses of DC to 625 Hz, DC to 1250 Hz, and DC to 2500 Hz, respectively, on 1/2-in. tape was used. Data were recorded at 1-7/8 in./sec, since the 625-Hz upper limit is adequate for this type of data. Acoustic recordings of vehicle and background noise data were recorded in the FM mode with the exception of aircraft signatures. Aircraft signatures were recorded whenever possible, in the direct recording mode so as to allow reproduction of frequencies between 100 and 6250 Hz. The dynamic range of the tape recorder is 37 db for the FM mode at a tape speed of 1-7/8 in./sec. The dyanamic range for the direct mode at that speed is 35 db. The center frequency for the FM signal is 3375 Hz.

d. A Model 887AB, Fluke Company, digital voltmeter having self-contained batteries was used to monitor the calibration voltages.

e. A Tektronix Model 422 portable oscilloscope was used to monitor the transducer output, the amplifier output to tape recorder, and the tape recorder output.

f. An electronic counter, Hewlett-Packard 5300, with its associated power supply was used to align the tape recorder.

g. WES-designed amplifiers using cascaded operational amplifiers produce voltage gains of 0.1 to 1000 and are used to amplify low-amplitude signals.

h. An oscillograph, Century Model 444, was used to make a permanent paper record in the field from the magnetic tape recorder.

Portions of the previously described equipment were housed in two racks, shock-mounted in fiberglass operating cases made by Environmental Container Systems, which have front and back covers and, when in place, form a shipping container. The other pieces of equipment also have fiberglass transit cases, which protect the units with 2-in.-thick polyurethane.

This equipment will operate from four lead-acid automobile batteries for 20 hr before recharging of batteries is necessary. All this equipment can be installed in a small van for field use and transportation. In its present form, this equipment has been shipped by airfreight to various locations throughout the world and has been used successfully in tests conducted thereafter.

Recorded data

3. The main text presented a description of the typical data collection scenario (test layout, Figure 1 and test plan, Table 1). However, deviations from the typical scenario occurred because:

a. Intruder type targets, such as tracked vehicles, were not always available or the test areas were not suitable for vehicle runs because of security and environmental considerations.

b. The Miles cable was added to the sensor configuration when possible (Barksdale AFB, Site 1A and March AFB, Site 1) with the result that one geophone sensor had to be removed from the recording configuration in order that the total number of the recorded signatures did not exceed six channels (one channel was used as a time-event channel, leaving six available channels on the seven track recorder).

c. The walk path was altered after the first data collection effort (Barksdale AFB, Louisiana; Sites 1A, 5, and 7) to conform with the description in Figure 1. The semicircular path was added to aid in the analysis of the variation in signature amplitudes for a given travel mode independent of intruder-to-sensor distance.

4. Because of the deviations from the typical data collection plan and test layout, the data logs should be consulted for specific information concerning data collection at a site. Figure A2 presents an example of the field data logs. The header information presents the area (Barksdale AFB), site number (Site 5), test type (man running), date of test (15 June 1976), calibration number (4), tests for which calibration number 4 is used (Tests 29-34), analog tape number (LEC-78), and the instrumentation operators (Reynolds and Savage). The tape

channels are identified in the first column with the symbols FM and DIR identifying the particular recording mode, frequency modulated or direct. The event marker in this instance is on channel 6. A d-c voltage (approximately one volt) is placed on the tape channel whenever the target passes an event marker stake. The voice channel is placed on edgetrack. The second column, tranducer location, identifies the sensors and their identification numbers when appropriate (1, 2, and 3 corresponds to G1, G2, and G3 in Figure 1). Each site has a figure in the data logs similar to Figure 1 in the main text that describes the sensor locations, sensor identification numbers, and target paths. For the geophones, the particular component of ground motion being recorded (vertical, radial, transverse) is identified in the transducer-location column.

5. The next four columns, calibrate value, calibrate step, gain, and sensitivity are all related. The geophone channels will be discussed first. An a-c voltage (20 Hz) is placed on the tape. The root-mean-square (rms) of this voltage is approximately 1 volt. Since the output voltage from the sensor is amplified by some factor (gain in column 5), the applied a-c voltage corresponds to an equivalent voltage level out of the sensor equal to the voltage applied to the tape divided by the gain. The equivalent voltage level out of the sensor (that would result in the a-c voltage applied to the tape for the given gain setting) is referred to as the a-c calibrate step. The rms value of this voltage is given in column 4. The a-c calibrate step corresponds to a velocity of the ground motion (in cm/sec) that is obtained by dividing the sensitivity (column 6) into the a-c calibrate step. The value of the rms of the a-c calibrate step is referred to as the calibrate value and is presented in column 4.

6. A mechanical calibration device is used to calibrate the microphone channel. A 90 db acoustic sound pressure level (ralative to 0.0002 microbars of pressure) generated by a vibrating diaphram is recorded on the acoustic channel (channel 7). The gain setting on the microphone amplifier during recording was 30 db as noted by the arrow in Figure A2. The specific amplifier and sensor serial numbers for recording are presented in columns 7 and 8.

7. During recording of test 29, the microphone gain setting was raised by 10 db from 30 db to 40 db (circled in Figure A2) so that acoustic signal levels lower than those of the mechanical calibration signal [90 db sound pressure level (SPL) relative to 0.0002 microbars] could be recorded. This 10 db change in the gain level means that a voltage level of an acoustic signal equal to the voltage recorded on the tape for calibration (i.e. the voltage recorded from the 90 db SPL) is equivalent to 80 db SPL. That is, the gain was increased by 10 db so as to record signal levels 10 db smaller than the 90 db SPL used during calibration. Therefore, the value of the gain on the acoustic channel during calibration and during the particular test of interest should be obtained from the data logs so as to compute the SPL for the particular test by subtracting the increase in gain (or adding the decrease in gain) from the 90 db SPL used for calibration.

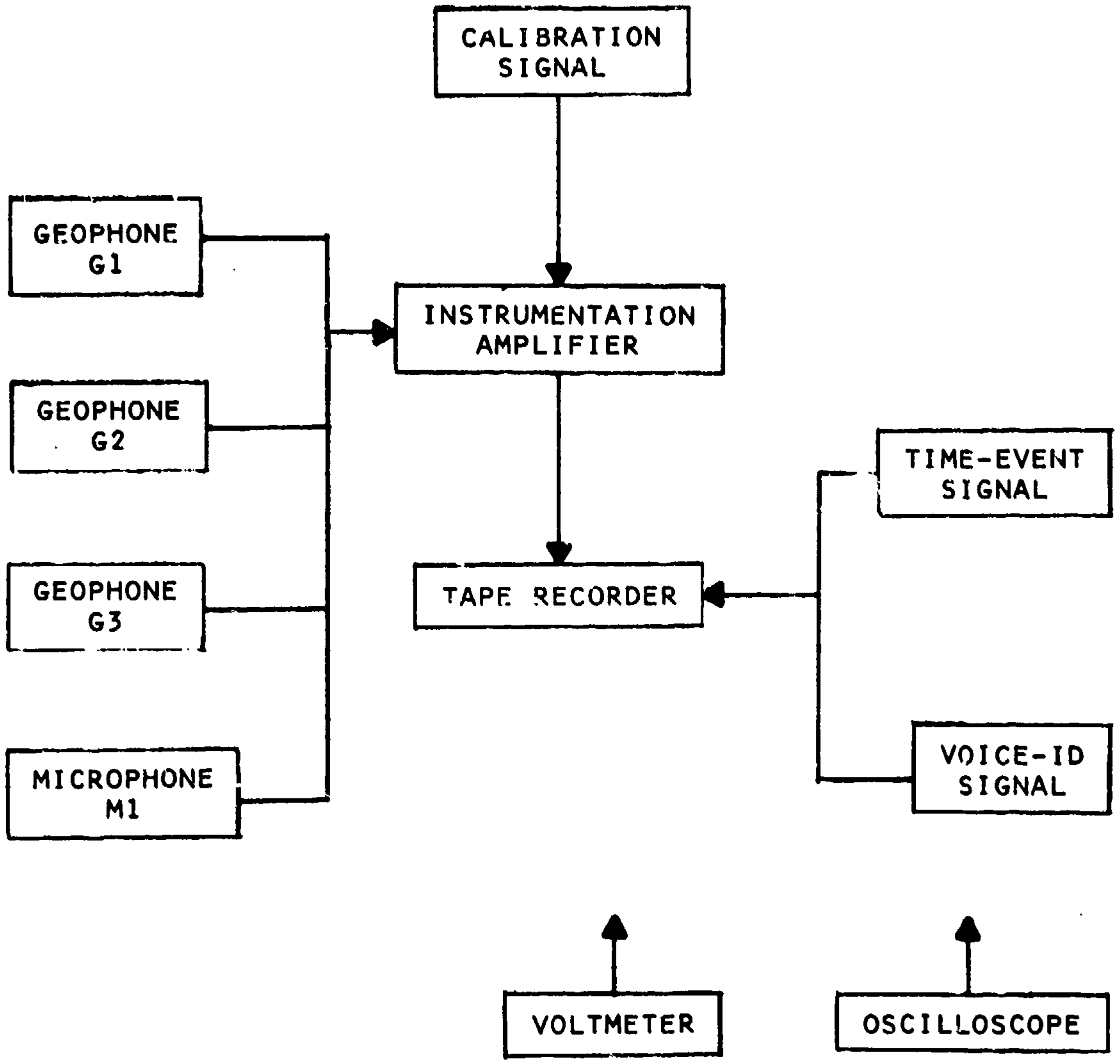


Figure A1. Block diagram of major components of analog-recording system used in BISS data collection

DATA ACQUISITION LOG

LOCATION Site 5 TYPE TEST Man Run DATE 15 June 76

CAL NO. 4 TEST NOS. 29-34 TAPE REEL NO. LEC-78

Barksdale AFB., LA OPERATOR Reynolds-Savage

Tape Chan	Transducer Location	Calibrate RMS Value CM-SEC	Calibrate AC Step/Volts RMS	Gain	Sensitivity V/CM/SEC	Amplifier Channel SER. NO.	Transducer S/N Type
1FM	1-vertical	0.057	0.135	8	2.36	4	L4-3D/126
2FM	1-radial	0.059	0.1405	8	2.36	3	L4-3D/126
3FM	1-transverse	0.056	0.1324	8	2.36	2	L4-3D/126
4FM	2-vertical	0.046	0.1086	10	2.36	10	L4-3D/1
5FM	3-vertical	0.058	0.137	8	2.36	6	L4-3D/127
6FM	Event mk.						
7DIR	Microphone	90d/b SPL		30d/b at CAL			B&K/506181
8							
9							
	Voice on Edge Track						
11							
12							
13							
14							

REMARKS: Radial axis pointed at road on all L4-30 geophones. B&K microphone is sitting on a 6 in. piece of foam rubber that is 3 ft square. We are using TD com stand which places mike 3 ft above ground.

Test No.	Time	Day	Hr	Min	Sec	Footage	Remarks
CAL 4			16	45			1 min zero levels 1 min CAL signal (100 Hz) 1 min zero levels
29			16	55			Billy Helmuth Runs from - 10 M to + 20 M; event marks AL SM interval except - 5M. B&K mike gain set at 40 db
30			16	56			Helmuth Run + 20 m - 10 M Event marks at each 5 M B&K mike gain set at 40 db

Figure A2. Field data logs

APPENDIX B: OVERVIEW OF THEORETICAL MODELS OF SIGNATURE GENERATION AND PROPAGATION

1. The considerations in the generation and propagation of microseismic signatures are shown in Figure B1. The medium in which the microseismic waves propagate is assumed to be composed of layers of homogenous, viscoelastic material. The source of the seismic energy is a force or stress applied to the surface of the medium referred to as the forcing function which causes a corresponding motion in the medium. The source is not restricted to any one form as long as a stress signal is available. In practical applications it can be a footstep, a vehicle (wheeled or tracked), or background noise (e.g. wind-blown vegetation). Once the energy is coupled into the medium, it propagates away from the source in various modes. These modes can be interpreted as shear waves, compression waves, or the multiple modes of Rayleigh waves. In most cases for intrusion detection devices, the shear, compression, and higher-order Rayleigh wave modes are small with respect to amplitude in comparison with the fundamental Rayleigh wave and can be neglected. However, when these other modes are not negligible, their effect must be added, in turn, for a wave prediction. As the waves propagate away from the source, their amplitudes decrease as computed with the transmission coefficients. The decrease in amplitude is caused by geometric attenuation (i.e. the energy is spread over an expanding area as the signal phase fronts advance over greater distances) and viscous damping (i.e. losses due to radiation and friction between soil particles). Effects of topographic features can be estimated through computation of macrogeometry coefficients. Losses from topographic features are due to energy refraction, reflection, and wave conversion (e.g. a Rayleigh wave encountering a discontinuity can become a source of new Rayleigh waves and body waves with different transmission coefficients). At the desired range, the vertical and radial components of particle motion (i.e. displacement, velocity, and acceleration) can be predicted. The prediction equation for particle motion as a function of range and time is shown below.

$$A_{\ell p}(r,t) = \sum_{n} (\omega_n e^{i\pi/2})^{p-1} D_n e^{i\omega_n t} \sum_{m} S_{m,n} B_{m,n\ell} H^{(1)}_{(\ell-1)}(K_{m,n} r)$$

where

A = particle motion

ℓ = signal component

p = particle motion number

r = range

t = time

n = frequency number

ω = circular frequency

D = Fourier coefficients for source forcing function

m = mode number

S = surface macrogeometry coefficients

B = source coupling coefficients

H = transmission coefficients

K = wave number

2. Compression wave velocity, shear wave velocity, mass density, and layer thickness are used in the computation of the wave numbers and source coupling coefficients for Rayleigh waves. The computations are all made in the frequency domain, and the signal prediction is converted to the time domain via an inverse Fourier transform.

3. The source coupling coefficients and the transmission coefficients for a given range can be combined to form the site transfer function. Source coupling coefficients have low values at low frequencies and high values at high frequencies. This frequency response is similar to that of a high-pass electronic filter. The transmission coefficients at any given range have high values at low frequencies and low values at high frequencies. This frequency response varies with range and is similar to that of a low-pass electronic filter. The site transfer function is the product of the source coupling coefficient and the transmission coefficient at each frequency. The site transfer function usually has a peaked response similar to that of a band-pass electronic filter. The frequencies around which the peak is located are the predominant frequencies of the site for sources having a broad band of frequencies

represented in the forcing function. However, the frequency domains of the forcing function of most sources tends to decrease with increasing frequency above 10 Hz. As a result the predominant frequencies of most signatures at a site tend to be less than the dominant frequencies in the frequency domain of the site transfer function. Predominant frequencies vary with the target-to-sensor distance. Any source of input signals with a component at or near the predominant frequencies will be enhanced over other frequency components. The relationship between the forcing function of a source, and the site transfer function and the resulting frequency characteristics of the signature are illustrated in Figure B2.

4. Forcing functions for men-walking, -creeping, -crawling, and -running have been developed using a simplified model in which the mass of the man is transferred from one support (a foot, hand, or elbow) to another at a rate descriptive of the particular travel mode (walking, running, crawling, or creeping). The computation of the forcing function is based on the dynamics resulting from the mass of the person being transferred to a surface modeled as a spring damper system. The equation used to compute the forcing function is

$$M_e \ddot{y} + C_s \dot{y} + \phi (y) = F \qquad (1)$$

where

M_e = effective mass of man and soil

y = vertical displacement

C_s = damping constant

$\phi(y)$ = spring force exerted by ground surface

F = applied force from man's weight

$\dot{y}$ and $\ddot{y}$ in equation (1) denote first and second derivatives with respect to time. It should be noted that M_e is a function of time and in turn is dependent on the rate of transfer of mass from one support to another. This rate of transfer is referred to as the loading rate.

5. The ground surface nearly always has two spring forces: that of the spring force exerted on an increasing load under compression

conditions, and that of the spring force that acts on a decreasing load during rebound conditions. Normally the rebound spring constant (i.e. shape of the force-deflection curve) is much higher than the compression spring constant (the compression spring constant is often referred to as the coefficient of subgrade reaction k_s, in the literature dealing with pavement design).[16] The compression spring constant can have one of several shapes: (a) it can be linear; (b) it can increase as the vertical deflection y increases (compaction or strain-hardened condition); or (c) it can decrease as the vertical deflection y increases (fluidization or plastic condition). These cases are illustrated in a highly generalized form in Figure B3.

6. Simplified functions are fitted to the curves in Figure B3 such that:

a. For compaction conditions:

$$\phi(y) = \frac{K_{sc}\, y}{1 - \dfrac{y^2}{Z^2_{max}}}$$

b. For plastic conditions:

$$\phi(y) = \frac{K_{sp}\, y}{1 + \dfrac{y^2}{Z^2_{max}}}$$

where

K_{sc} = spring constant for the linear approximation of the force-deflection curve for compaction condition

K_{sp} = spring constant for the linear approximation of the force-deflection curve for the plastic condition.

Z_{max} = deflection at maximum bearing strength. For compaction condition, Z_{max} is the deflection asymptote for y under high loads; for plastic condition, Z_{max} is the deflected beyond which the material appears to collapse under a force asymptote F_{max}.

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* Raised numbers refer to similarly numbered items in "References" at end of main text.

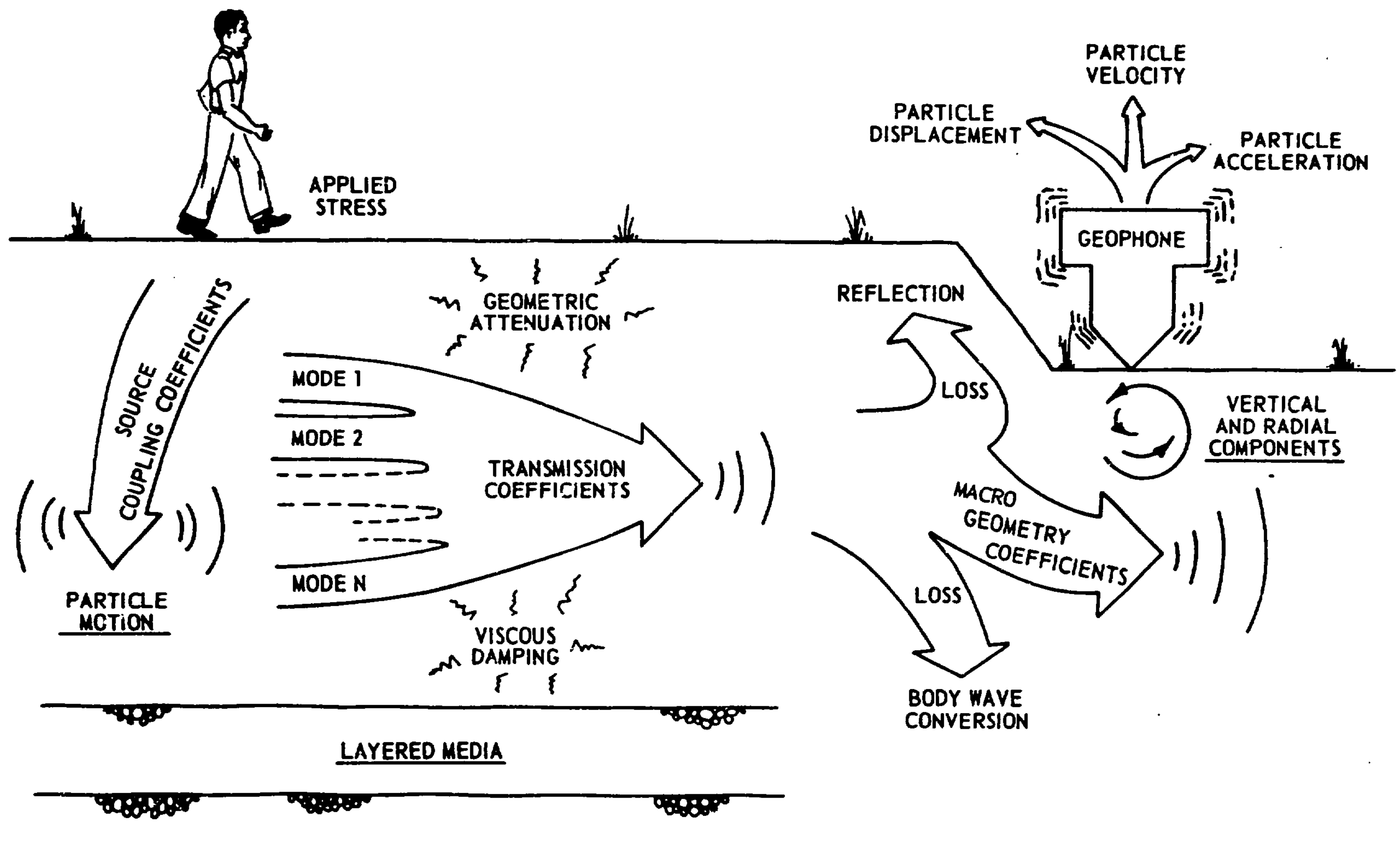


Figure B1. Seismic wave propagation

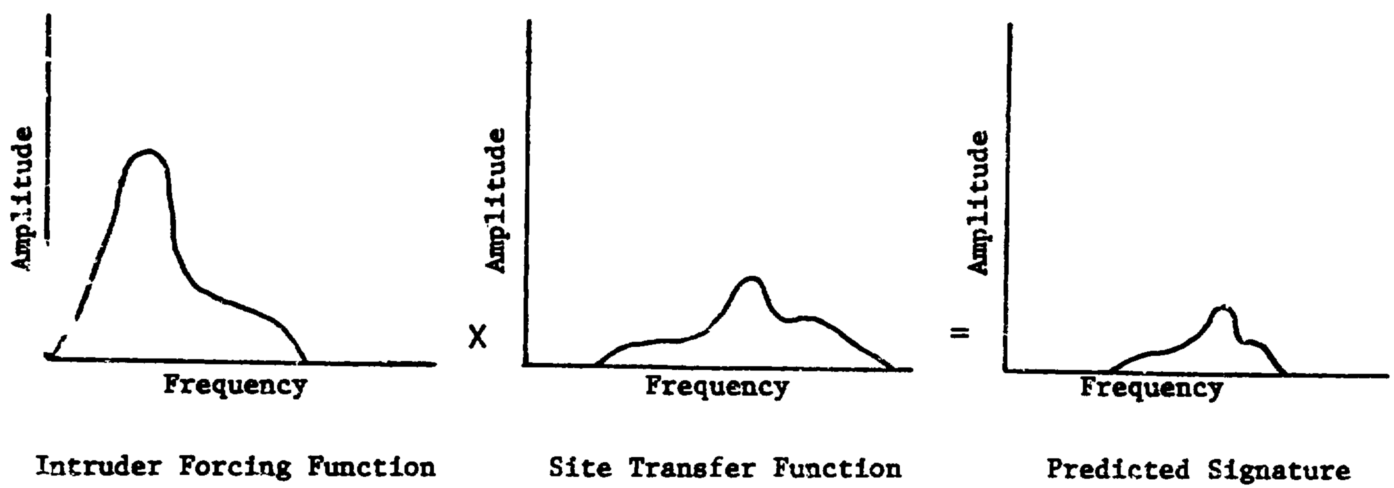


Figure B2. Relationship between frequency domains of Intruder Forcing Function, Site Transfer Function, and the Predicted Signature

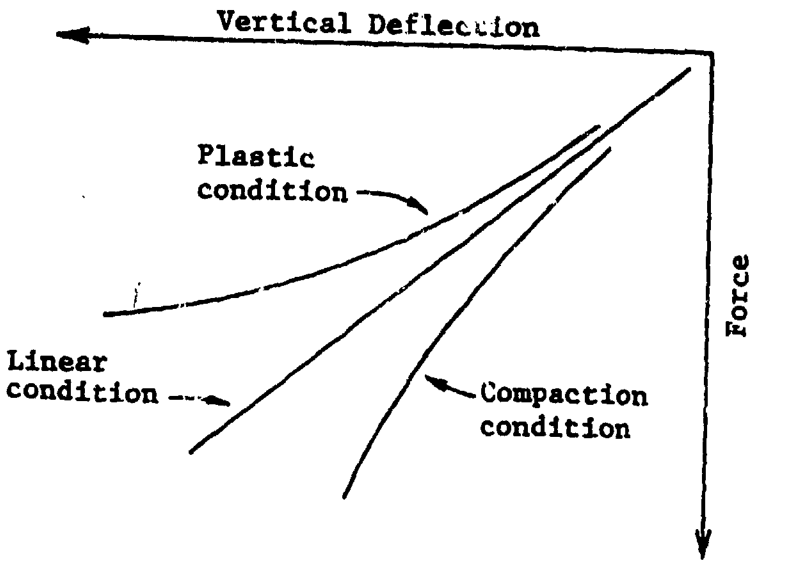


Figure B3. Force-deflection characteristics for nonlinear spring $\phi(y)$

APPENDIX C: SITE DOCUMENTATION PROCEDURES

Surface and near-surface terrain factors

1. The geometry and rigidity of the surface over which the intruder travels control the amount of seismic energy generated and coupled to the substrate. For this reason, the surface microgeometry surveys, cone index readings, and plate-load tests are made along the personnel paths and or vehicle trails. Major surface irregularities can modify the propagating surface wave; therefore, the ground surface geometry between the intruder and sensor must also be defined.

2. Surface geometry. Surface microgeometry profiles are measured with a good-quality surveying level or theodolite. Rod readings accurate to at least 1 cm are taken at all major breaks in the walk line or roadway to define the long-wavelength irregularities. This is particularly true for geophone-type sensors (as opposed to line sensors). When vehicle signatures are involved, several samples (three or four samples 3 m long per 100 m of roadway) of surface profiles are obtained with rod readings made every 25 cm. Finally, several samples (three or four samples 50 cm long per 100 m of roadway) are obtained with rod readings every 5 cm. The sample points are selected to characterize the kind and distribution of surface roughness in the roadway. The surveys at the three levels of generalization (i.e. rod readings at major breaks in the roadway and at 25 and 5 cm) are superimposed to reconstruct (statistically) the surface roughness of the trail or roadway. In addition, photographs of the ground surface are always obtained.

3. Soil strength. Of the several techniques available (e.g. plate load tests, determination of California Bearing Ratio, measurement of cone penetration resistance, etc.), the measurement of reference cone penetration resistance as obtained with the standard soil trafficability cone (Chapters 2 and 9 of Reference 17) is the most convenient method for describing soil strength for seismic signatures studies. The cone penetrometer is an instrument used to obtain an index of in situ shear strength of soil. It consists of a 30-deg cone with a 0.5- or 0.2-sq in. base area mounted on one end of a shaft. The shaft has circumferential

bands indicating depth of penetration. At the top of the shaft is mounted a dial indicator within a proving ring, which indicates the force applied axially to the penetrometer. The instrument is forced vertically into the soil while records are made of the dial reading for various sinkage depths. For seismic signatures studies, cone index are measured to a depth of 30 cm with measurements at 0-, 15-, and 30-cm depths. At least 15 cone penetration readings should be made (and averaged) for each area where cone penetration resistance measurements are desired.

4. The cone penetrometer has been modified by WES so that the cone can be inserted into the ground mechanically. A low-speed reversible electric motor is mounted on a frame that is attached to the front bumpter of a military truck. The motor is used to apply the axial force on the cone. The force is measured by a load cell, and the vertical distance traveled is measured mechanically. Mechanical cone penetrometers should be used, if available. This instrument has three advantages over the standard trafficability cone penetrometer:

- a. A more constant force is applied to the cone.
- b. Higher cone index values can be obtained with the mechanical cone penetrometer than with the standard trafficability cone penetrometer.
- c. The mechanically driven penetrometer can supply an analog signal on both cone index value and depth of penetration, which can be recorded graphically as the test progresses.

5. If the walk line or roadway is quite rigid, cone penetration readings cannot be obtained. A description of the walk line or road surface is very important and in such instances, includes a description of the type and condition of the surface, i.e. concrete, bituminous pavement, brick, stone, crushed rock or coral, waterbound macadam, gravel, natural or stabilized soil, shell, cinders, disintegrated granite, etc.

6. Soil moisture and density. Where cone penetrometer readings can be obtained, soil samples for the determination of soil moisture and density are taken at each cone penetration point at the surface (0- to 5-cm layer) and at depths of 15 and 30 cm.

Subsurface factors

7. The subsurface factors between the target and geophones that affect the propagating wave are wet density, shear and compression wave velocities, and thicknesses of each layer. Two methods of obtaining the seismic velocity will be discussed, refraction seismic survey and the vibratory techniques. Standard refraction seismic surveys are conducted (at selected sampling locations at the data collection site depending on the diversity of subsurface conditions) to obtain compression and shear wave velocities and layering to a depth of 10 m. Shear wave velocities and layer depths can also be obtained using vibratory techniques. The compression and shear wave velocity and refraction layer thicknesses of the materials over which the intruder traverses provide a good indication of how the mechanically applied energy will couple to the ground; therefore, these parameters should be measured. To obtain a measure of the compression and shear wave velocities and thicknesses of the refraction layers, a refraction seismic survey[18] must be conducted at each test site. Several portable seismographs are commercially available. WES uses a WES-modified GeoSpace Corporation GT-2B, 12-channel portable seismograph.[15] This seismic instrument is designed to record, on film or direct-write oscillograph, shallow refracted data from 1 to 12 inputs, depending on the number of desired recording traces. The X-25 Model L-1 geophone and a double-ended portable spread cable with HS-20 polarized takeouts at 24-ft intervals are used in conjunction with the GT-2B seismograph recorder. The GT-2B recorder has been modified, so that an oscillograph (Centruy wide-band 444) trace can be seen while testing is in process. Any seismic refraction equipment similar to the above-mentioned items should yield the desired information. To obtain additional definition of the near-surface compression wave velocity and refraction layers, the spacing between geophones is small (i.e. approximately 25 cm). Otherwise, techniques for conducting the survey are similar to more conventional refraction seismic survey techniques (Reference 17). The vibratory technique relies on the theoretical relationship between the Rayleigh and shear wave velocities to obtain the shear wave velocity. For reasonable values of Poisson's ratio (between 0.1 and 0.5), the

shear wave velocity is within 10 percent of the Rayleigh wave velocity. A variable frequency vibrator is used to induce ground motion at the surface of the medium. The resulting ground motion is predominantly Rayleigh waves. The velocity of the Rayleigh waves is then measured using geophones properly spaced along the line of wave propagation. WES field teams use a Ling Model MKV50, 50 lb maximum force vibrator built to WES specifications so as to operate as an inertial mass system. The vibrator induces frequencies into the medium ranging from 25 to 400 Hz.

Supplemental site descriptive data

8. Geologic, vegetation, and meteorologic data on a site can be quite useful in extrapolating the test results from one site to other areas. These descriptions are prepared with the aid of personnel (Soil Conservation Service staff, etc.) familiar with the area. The information includes a statement on geology, name and description of the physiographic and landform unit, site topographic position, estimates of depth to the water table, land use, soil parent material, and description of the soil profile.[19] Also, vegetation formation is identified and listed. A formation is a major vegetational unit; for instance, deciduous forest, boreal forest, or grassland. Additional data, such as plant species and their respecitve densities can be identified or qualitatively measured through photographs of the data collection sites.

APPENDIX D: TERRAIN DATA

Table D1

Seismic Refraction and Soils Data

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line*	Geographic Coordinates Latitude/Longitude**	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec†	Depth m	USCS Classification	General††
							United States						
Alabama	Decatur Brown's Ferry Nuclear Plant	1	1	344530 N/870733 W	1	0.00–3.28	661	1	0.00–3.28	265	0.00–1.22	--	Lean clay
					2	3.28–9.53	1402	2	3.28–9.53	561	1.22–1.83	--	Silty sand
					3	9.53+	5182	3	9.53+	2073	1.83–2.51	--	Silt
											2.51–3.73	--	Lean clay
											3.73–4.42	--	Sandy gravel and clayey chert
											4.42–4.88	--	Clayey chert
											4.88–6.25	--	Chert
											6.25–7.85	--	Clayey chert
											7.85–8.53	--	Chert and clayey chert
			2		1	0.00–2.90	631	1	0.00–2.90	252	0.00–1.83	--	Lean clay
					2	2.90–9.91	1570	2	2.90–9.91	658	1.83–3.51	--	Clayey chert
					3	9.91+	5182	3	9.91+	2073	3.51–3.66	--	Cherty clay
											3.66–8.38	--	Clayey chert
											8.38–9.91	--	Cherty clay
											9.91–10.52	--	Fat clay
											10.52–10.82	--	Cherty clay
											10.82–11.13	--	Refusal
	Redstone Arsenal	--	1	3441-- N/8640-- W	1	0.00–3.66	457	1	0.00–0.85	251‡	0.00–0.61	CL	Silty sand, tan
					2	3.66–12.50	1097	2	0.85–1.89	227‡	0.61–4.57	CL	Firm clay, red
					3	12.50+	5182	3	1.89–4.91	237‡	4.67–10.97	CH	Firm clay, yellow
								4	4.91–10.70	297‡	10.97–12.80	CL	Clay and boulders
								5	10.70+	--	12.80+	--	Limestone
Alaska	Fairbanks gravel road	1	1	6451-- N/14720-- W	1	0.00–2.30	530	1	0.00–2.30	212	--	--	Frozen soil
					2	2.30+	2760	2	2.30+	1104	--	--	
			2		1	0.00–2.25	825	1	0.00–2.25	330	--	--	
					2	2.25+	1635	2	2.25+	654	--	--	
			3		1	0.00–1.80	675	1	0.00–1.80	270	--	--	
					2	1.80+	1390	2	1.80+	556	--	--	
	Fairbanks tank trail	1	1	6451-- N/14720-- W	1	0.00+	1940	1	0.00+	776	--	--	
			2		1	0.00–1.30	750	1	0.00–1.30	300	--	--	
					2	1.30–7.00	1370	2	1.30–7.00	548	--	--	
					3	7.00+	2600	3	7.00+	1064	--	--	
			3		1	0.00–1.30	750	1	0.00–1.30	300	--	--	
					2	1.30–7.25	1470	2	1.30–7.25	588	--	--	
					3	7.25+	3050	3	7.25+	1220	--	--	

(Continued)

* Specific line location is available.
** Degrees, minutes, seconds, e.g. 344530 N = 34°45'30" N; dashes indicate incomplete coordinates.
† Shear-wave velocity is computed from compression-wave velocity, unless otherwise noted.
†† Soil descriptions are listed as found in the literature. No attempt has been made to relate general description to USCS terms.
‡ Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Alaska (Cont'd)	Fairbanks tank trail (Cont'd)	1	4	645100 N/1473650 W	1	0.00-1.35	2500	1	0.00-1.35	1000	—	—	Frozen soil
					2	1.35+	4540	2	1.35+	1816	—	—	
			5		1	0.00-2.30	2600	1	0.00-2.30	1040	—	—	
					2	2.30+	4650	2	2.30+	1860	—	—	
	Fairbanks gravel road	2	1	645045 N/1473430 W	1	0.00-1.10	620	1	0.00-1.10	248	—	—	
					2	1.10+	2380	2	1.10+	952	—	—	
			2		1	0.00-1.50	580	1	0.00-1.50	232	—	—	
					2	1.50+	1180	2	1.50+	472	—	—	
			3		1	0.00-1.15	1000	1	0.00-1.15	400	—	—	
					2	1.15+	2140	2	1.15+	856	—	—	
			4		1	0.00+	3600	1	0.00+	1440	—	—	
	Fairbanks paved road	3	1	645250 N/1473950 W	1	0.00-2.85	760	1	0.00-2.85	304	—	—	
					2	2.85+	2840	2	2.85+	1136	—	—	
			2		1	0.00-2.40	810	1	0.00-2.40	324	—	—	
					2	2.40+	2880	2	2.40+	1152	—	—	
			3		1	0.00-2.65	780	1	0.00-2.65	312	—	—	
					2	2.65+	2780	2	2.65+	1112	—	—	
			4		1	0.00-2.85	1240	1	0.00-2.85	496	—	—	
					2	2.85+	2320	2	2.85+	928	—	—	
			5		1	0.00-1.00	600	1	0.00-1.00	240	—	—	
					2	1.00+	1400	2	1.00+	560	—	—	
Arizona	Ft. Huachuca Blue Site	—	1	313539 N/1101625 W	1	0.00-1.55	435	1	0.00-1.55	174		(No soils data)	
					2	1.55+	745	2	1.55+	298			
			2		1	0.00-0.65	365	1	0.00-0.65	146			
					2	0.65-3.15	530	2	0.65-3.15	212			
					3	3.15+	780	3	3.15+	317			
	Ft. Huachuca (dry season)	335	1	313545 N/1101503 W	1	0.00-0.70	403	1	0.00-0.70	185*	0.00-0.70	SC	—
					2	0.70-2.70	635	2	0.70-2.70	282*	0.40-2.70	GC	—
					3	2.70+	975	3	2.70+	390	2.70	—	—
		336	1	313532 N/1101542 W	1	0.00-0.65	330	1	0.00-0.65	129*	0.00-0.65	SC	—
					2	0.65-2.00	600	2	0.65-2.00	285*	0.65-2.00	CL	—
					3	2.00+	775	3	2.00+	310	2.00+	—	—
		337	1	313549 N/1101515 W	1	0.00-1.10	523	1	0.00-1.10	179*	0.00-1.10	SC	—
					2	1.10-3.70	690	2	1.10-3.70	256*	1.10-3.70	SC	—
					3	3.70+	885	3	3.70+	354	3.70+	—	—

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Arizona (Cont'd)	Ft. Huachuca (dry season) (Cont'd)	338	1	313549 N/1101540 W	1	0.00–0.75	500	1	0.00–0.75	207*	0.00–0.75	SC	—
					2	0.75+	840	2	0.75+	266*	0.75+	SC	—
		339	1	313535 N/1101516 W	1	0.00–1.40	403	1	0.60–1.40	168*	0.00–1.40	SC	—
					2	1.40+	883	2	1.40+	322*	1.40+	SC	—
		340	1	313513 N/1101542 W	1	0.00–0.50	250	1	0.00–0.50	165*	0.00–0.50	SC	—
					2	0.50–2.80	700	2	0.50–2.80	363*	0.50–2.80	SC	—
					3	2.80+	830	3	2.80+	481	2.80+	—	—
		341	1	313521 N/1101530 W	1	0.00–1.15	365	1	0.00–1.15	204*	0.00–1.15	SC	—
					2	1.15+	818	2	1.15+	323*	1.15+	—	—
		342	1	313— N/1101— W	1	0.00–1.10	353	1	0.00–1.10	176*	0.00–1.10	SC	—
					2	1.10+	820	2	1.10+	369*	1.10+	—	—
		347	1	313813 N/1101640 W	1	0.00–0.65	230	1	0.00–0.65	125*	0.00–0.65	SM	—
					2	0.65+	763	2	0.65+	352*	0.65+	—	—
		348	1	313500 N/1101520 W	1	0.00–0.90	345	1	0.00–0.90	165*	0.00–0.90	SC	—
					2	0.90–3.60	588	2	0.90–3.60	337*	0.90–3.60	—	—
					3	3.60+	800	3	3.60+	464	3.60+	—	—
		349	1	313510 N/1101527 W	1	0.00–0.50	250	1	0.00–0.50	138*	0.00–0.50	SC	—
					2	0.50–4.45	595	2	0.50–4.45	371*	0.50–4.45	—	—
					3	4.45+	890	3	4.45+	—	4.45+	—	—
		410	1	313957 N/1101412 W	1	0.00–1.85	373	1	0.00–1.85	121*	0.00–1.85	CL	—
					2	1.85+	730	2	1.85+	312*	1.85+	—	—
		411	1	313819 N/1101231 W	1	0.00–2.34	358	1	0.00–2.35	167*	0.00–2.35	CL	—
					2	2.35–5.70	622	2	2.35–5.70	272*	2.35–5.70	—	—
					3	5.70+	995	3	5.70+	577	5.70+	—	—
		412	1	313636 N/1101815 W	1	0.00–2.80	360	1	0.00–2.80	151*	0.00–2.80	—	—
					2	2.30+	1130	2	2.80+	413*	2.80+	—	—
		413	1	320947 N/1105106 W	1	0.00–3.35	357	1	0.00–3.35	116*	0.00–3.35	CH	—
					2	3.35+	1550	2	3.35+	435*	3.35+	—	—
	Ft. Huachuca Red Site	—	1	313547 N/1101646 W	1	0.00–1.00	385	1	0.00–1.00	154		(No soils data)	
					2	1.00–5.70	690	2	1.00–5.70	276			
					3	5.70+	1085	3	5.70+	434			
			2		1	0.00–0.60	370	1	0.00–0.60	148			
					2	0.60–3.05	500	2	0.60–3.05	200			
					3	3.05+	920	3	3.05+	368			
	Ft. Huachuca (wet season)	335	1	313545 N/1101503 W	1	0.00–2.30	465	1	0.00–2.30	166*	0.00–2.30	SC	—
					2	2.30+	855	2	2.30+	294*	2.30+	GC	—

(Continued)

* Measured value.

Table D1 (Continued)

Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Compression Wave Layer No.	Compression Wave Layer Depth, m	Compression Wave Velocity m/sec	Shear Wave Layer No.	Shear Wave Layer Depth, m	Shear Wave Velocity m/sec	Soil Description Depth m	Soil Description USCS Classification	Soil Description General
					United States (Continued)								
Arizona (Cont'd)	Ft. Huachuca (wet season) (cont'd)	336	1	313532 N/1101542 W	1	0.00–0.80	325	1	0.00–0.80	152*	0.00–0.80	SC	—
					2	0.80+	748	2	0.80+	245*	0.80+	CL	—
		337	1	313549 N/1101515 W	1	0.00–1.15	455	1	0.00–1.15	139*	0.00–1.15	SC	—
					2	1.15–3.40	685	2	1.15–3.40	283*	1.15–3.40	SC	—
					3	3.40+	855	3	3.40+	—	3.40+	—	—
		338	1	313549 N/1101540 W	1	0.00–0.95	375	1	0.00–0.95	156*	0.00–0.95	SC	—
					2	0.95+	900	2	0.95+	253*	0.95+	SC	—
		339	1	313535 N/1101516 W	1	0.00–1.50	435	1	0.00–1.50	137*	0.00–1.50	SC	—
					2	1.50+	820	2	1.50+	340*	1.50+	SC	—
		340	1	313513 N/1101542 W	1	0.00–0.55	210	1	0.00–0.55	161*	0.00–0.55	SC	—
					2	0.55–2.95	650	2	0.55–2.95	333*	0.55–2.95	SC	—
					3	2.95+	728	3	2.95+	—	2.95+	—	—
		341	1	313521 N/1101530 W	1	0.00–1.00	370	1	0.00–1.00	172*	0.00–1.00	SL	—
					2	1.00+	723	2	1.00+	304*	1.00+	—	—
		342	1	313--- N/1101--- W	1	0.00–0.95	380	1	0.00–0.95	143*	0.00–0.95	SL	—
					2	0.95+	870	2	0.95+	346*	0.95+	—	—
		345	1	313--- N/1101--- W	1	0.00–1.20	420	1	0.00–1.20	168	(No Soils Data)		
					2	1.20–7.10	665	2	1.20–7.10	386			
					3	7.10+	990	3	7.10+	574			
		347	1	313813 N/1101540 W	1	0.00–0.55	215	1	0.00–0.55	147*	0.00–0.55	SM	—
					2	0.55+	805	2	0.55+	333*	0.55+	—	—
		348	1	313500 N/1101520 W	1	0.00–0.80	350	1	0.00–0.80	182*	0.00–0.80	SC	—
					2	0.80–4.50	583	2	0.80–4.50	301*	0.80–4.50	—	—
					3	4.50+	815	3	4.50+	—	4.50+	—	—
		349	1	313510 N/1101527 W	1	0.00–0.75	230	1	0.00–0.75	149*	0.00–0.75	SC	—
					2	0.75–5.70	625	2	0.75–5.70	340*	0.75–5.70	—	—
					3	5.70+	945	3	5.70+	—	5.70+	—	—
	Ft. Huachuca White Site	—	1	313557 N/1101636 W	1	0.00–1.25	420	1	0.00–1.25	168	(No Soils Data)		
					2	1.25–4.00	615	2	1.25–4.00	246			
					3	4.00+	840	3	4.00	336			
			2		1	0.00–1.15	460	1	0.00–1.15	184			
					2	1.15–5.05	610	2	1.15–5.05	244			
					3	5.05+	855	3	5.05+	342			
			3		1	0.00–1.30	450	1	0.00–1.30	180			
					2	1.30–5.95	630	2	1.30–5.95	252			
					3	5.95+	960	3	5.95+	384			

(Continued)

* Measured value.

(Sheet 4 of 47)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Arizona (Cont'd)	Yuma	330	1	325448 N/1141904 W	1 2	0.00-1.20 1.20+	253 778	1 2	0.00-1.20 1.20+	250* 311		(No soils data)	
		331	1	325400 N/1142414 W	1 2	0.00-0.30 0.30+	245 365	1 2	0.00-0.30 0.30+	100* 146			
		332	1	325600 N/1142500 W	1 2	0.00-2.25 2.25+	326 745	1 2	0.00-2.25 2.25+	125* 298			
		333	1	325107 N/1142710 W	1 2	0.00-1.50 1.50+	185 1738	1 2	0.00-1.50 1.50+	115* 695			
California	Camp Pendleton Gentle Slope	--	1	3551-- N/11801-- W	1 2	0.00-2.78 2.78+	355 510	1 2	0.00-2.76 2.78+	142 204	0.00-0.58 0.00-0.58	CL CL	-- --
			2		1 2	0.00-0.96 0.96+	360 535	1 2	0.00-0.[illegible] 0.96+	144 214			
	Camp Pendleton Hillside Site	--	1		1 2	0.00-4.50 4.50+	369 1240	1 2	0.00-4.50 4.50+	146 496	0.00-0.58	CL	--
			2		1 2	0.00-4.19 4.19+	360 1005	1 2	0.00-4.19 4.19+	144 402	0.00-0.58	CL	--
	Camp Pendleton Ocean Beach	--	1	332415 N/1172515 W	1 2	0.00-1.19 1.19+	364 1216	1 2	0.00-1.19 1.19+	145 486	0.00-0.23 0.23-0.58	SM SP	-- --
			2		1 2	0.00-1.35 1.35+	370 1215	1 2	0.00-1.35 1.35+	148 486	0.00-0.23 0.23-0.58	SM SP	-- --
	Camp Pendleton Parking Area	--	1	3539-- N/11737-- W	1 2 3	0.00-1.63 1.63-5.30 5.30+	350 630 1595	1 2 3	0.00-1.63 1.63-5.30 5.30+	140 252 638		(No soils data)	
			2		1 2 3	0.00-1.42 1.42-5.79 5.79+	350 675 1925	1 2 3	0.00-1.42 1.42-5.79 5.79	140 270 770			
	Camp Pendleton Ravine	--	1	3551-- N/11801-- W	1	0.00+	342	1	0.00+	137	0.00-0.36	--	Light brownish-gray, loamy, fine sand
			2		1	0.00+	350	1	0.00+	140	0.00-0.97 0.97-1.22 1.22+	-- -- --	Sandy clay Loamy coarse sand Decomposed sand-stone
	China Lake Chimney Peak	--	1	355101 N/1180153	1 2	0.00-2.10 2.10+	529 1151	1 2	0.00-2.10 2.10+	212 460	0.00-0.23 0.23-0.58	SM CL	-- --
			2		1 2	0.00-2.00 2.00+	464 1147	1 2	0.00-2.00 2.00+	162 459	0.00-0.23 0.23-0.58	SM CL	-- --

(Continued)

* Measured value.

Table D1 (Continued)

Location: Subdivision	Location: Site Identification	Location: Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Compression Wave: Layer Depth, m	Compression Wave: Velocity m/sec	Shear Wave: Layer No.	Shear Wave: Layer Depth, m	Shear Wave: Velocity m/sec	Soil Description: Depth	Soil Description: USCS Classification	Soil Description: General
							United States (continued)						
California (Cont'd)	China Lake Coso Mountain	—	1	[illegible]036 N/1174317 W	1	0.00-1.25	571	1	0.00-1.25	228	0.00-0.23	SM	—
					2	1.25+	1386	2	1.25+	554			—
			2		1	0.00-1.40	375	1	0.00-1.40	150	0.00-0.23	SM	—
					2	1.40-5.30	800	2	1.40-5.30	320			—
					3	5.30+	1080	3	5.30+	432			—
	China Lake Nurse Stable Road	—	1	3542-- N/11825-- W	1	0.00-2.35	404	1	0.00-2.35	162	0.00-0.58	SP	—
					2	2.35+	1073	2	2.35+	429			—
			2		1	0.00-2.55	423	1	0.00-2.55	169	0.00-0.58	SP	—
					2	2.55+	1433	2	2.55+	573			—
	China Lake, K-2 Hillside "Rock Hill"	—	1	354428 N/1173227 W	1	0.00-1.05	1000	1	0.00-1.04	400	0.00-0.23	SM	—
					2	1.05+	2386	2	1.05+	954	0.23+		Rock
			2		1	0.00-1.20	705	1	0.00-1.20	282	0.00-0.23	SM	—
					2	1.20+	2071	2	1.20+	828	0.23+		—
	China Lake, K-2 Road	—	1	354435 N/1173300 W	1	0.00-0.71	800	1	0.00-0.71	300	0.00-0.11	SP	Gravel road
					2	0.71+	1190	2	0.71+	476	0.11-0.23	SM	—
			2		1	0.00-1.15	666	1	0.00-1.15	266	0.00-0.11	SP	Gravel road
					2	1.15+	1900	2	1.15+	760	0.11-0.23	SM	—
	China Lake, K-2 Sand	—	1	354440 N/1173252 W	1	0.00-1.15	399	1	0.00.1.15	160	0.00-0.23	SP	—
					2	1.15+	1257	2	1.15+	503	0.23-0.58	SM	—
			2		1	0.00-1.35	399	1	0.00-1.35	160	0.00-0.23	SP	—
					2	1.35+	1387	2	1.35+	555	0.23-0.58	SM	—
	China Lake, K-2 Sand/Rock	—	1	354433 N/1173304 W	1	0.00-1.25	434	1	0.00-1.25	173	0.00-0.23	SP	—
					2	1.25-6.10	1450	2	1.25-6.10	580	0.23-0.58	GM	—
					3	6.10+	3000	3	6.10+	1200			
			2		1	0.00-1.40	600	1	0.00-1.40	240	0.00-0.23	SP	—
					2	1.40+	1898	2	1.40+	760	0.23-0.58	GM	—
	China Lake, Kennedy Meadows	—	1	360303 N/1180751 W	1	0.00-1.40	387	1	0.00-1.40	155	0.00-0.23	SM	—
					2	1.40+	2304	2	1.40+	922	0.50-0.58	GP	—
	China Lake Kern River Site	1	1	355136 N/1182657 W	1	0.00-1.05	863	1	0.00-1.05	345	0.00-0.08	SP	—
						1.05+	1964	2	1.05+	786			
			2		1	0.00-0.90	1067	1	0.00-0.90	427	0.00-0.08	SP	Rocky area, unable to obtain soil samples
					2	0.90+	2467	2	0.90+	987			
	China Lake-Lake Isabella	1	1	354220 N/1182430 W	1	0.00-4.75	346	1	0.00-4.75	138	0.00-0.08	OL	—
					2	4.75+	1983	2	4.75	793	0.08-0.23	SM	—
											0.23-0.58	ML	—

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
United States (Continued)													
California (Cont'd)	China Lake Lake Isabella (Cont'd)	1	2	354220 N/1182530 W	1	0.00-3.50	323	1	0.00-3.50	129	0.00-0.08	OL	--
					2	3.50+	1370	2	3.50+	548	0.08-0.23	SM	--
											0.23-0.58	ML	--
		3	1	354140 N/1182544 W	1	0.00-1.55	469	1	0.00-1.55	188	(No soils data)		
					2	1.55+	1424	2	1.55+	570			
			2		1	0.00-2.45	545	1	0.00-2.45	218			
					2	2.45+	2223	2	2.45+	889			
		4	1	354141 N/1182546 W	1	0.00-3.50	397	1	0.00-3.30	159			
					2	3.30-10.50	2141	2	3.30-10.50	856			
					3	10.50+	3050	3	10.50+	1220			
			2		1	0.00-5.54	444	1	0.00-5.54	178			
					2	5.54+	2511	2	5.54	1004			
	China Lake Magazine Exposed Rock	--	1	354203 N/1173600 W	1	0.00-1.45	1500	1	0.00-1.45	600	0.00-0.08	CL	--
					2	1.45+	3500	2	1.45+	1400			
			2		1	0.00-1.75	1000	1	0.00-1.75	400	0.00-0.08	CL	--
					2	1.75	3428	2	1.75+	1371.2			
	China Lake Mirror Lake	--	1	353834 N/1173800 W	1	0.00-8.03	339	1	0.00-8.03	135.6	(No soils data)		
					2	8.03+	1960	2	8.03+	792			
			2		1	0.00-3.62	310	1	0.00-3.62	124			
					2	3.62-7.80	570	2	3.62-7.80	228			
					3	7.80+	1000	3	7.80+	400			
	China Lake Paxton Ranch Brush	--	1	354808 N/1173704 W	1	0.00-2.25	372	1	0.00-2.25	149	0.00-0.09	CH	--
					2	2.25+	1610	2	2.25+	644	0.09-0.23	OL	--
			2		1	0.00-2.35	377	1	0.00-2.35	151	0.23-0.38	OH	--
					2	2.35+	1735	2	2.35+	604	0.38-0.58	CH	--
	China Lake Paxton Ranch Lake Bed	--	1	354807 W/1173707 W	1	0.00-2.55	363	1	0.00-2.55	145	0.67-0.80	--	Dark gray clay
					2	2.55+	1725	2	2.55+	690	0.80-0.82	--	Dark sand
											0.82-1.04	--	Dark gray clay
											1.04	--	Water table
			2		1	0.00-2.55	400	1	0.00-2.55	160	0.00-0.15	--	Clay
					2	2.55+	1875	2	2.55+	750	0.15-0.17	--	Sand
											0.17-0.67	--	Clay mixed with gypsum crystals
	China Lake Paxton Ranch Meadows	--	1	354808 N/1173708 W	1	0.00-2.30	389	1	0.00-230	156	0.00-0.23	OL	--
					2	2.30+	1787	2	2.30+	715	0.23-0.53	OH	--
			2		1	0.00-2.75	462	1	0.00-2.75	185	0.00-0.23	OL	--
					2	2.75+	2266	2	2.75+	905	0.23-0.58	OH	--

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
California (Cont'd)	China Lake Towerio	—	1	354640 N/1173455 W	1	0.00-2.72	400	1	0.00-2.72	160	0.00-0.08	SM	Very loose sand
					2	2.72+	849	2	2.72+	260	0.15-0.58	SP	Very loose sand
			2		1	0.00-3.00	419	1	0.00-3.00	168	0.06-0.08	SM	--
					2	3.00+	724	2	3.00+	289	0.15-0.58	SP	--
	China Lake Tower Road	—	1	354436 N/1173500 W	1	0.00-6.95	350	1	0.00-6.95	140	0.00-0.58	SP-SM	--
					2	6.95+	1378	2	6.95+	551			
			2		1	0.00-7.06	395	1	0.00-7.06	158	0.00-0.58	SP-SM	--
					2	7.06+	1180	2	7.06+	472			
	China Lake Wilson Mesa Area 1a	—	1	354547 N/1173537 W	1	0.00-1.83	229	1	0.00-1.83	133	0.00-1.83	—	Overburden
					2	1.83-10.06	1036	2	1.83-10.06	601	1.83-10.06	—	Weathered rock
					3	10.06+	3290	3	10.06+	1856	10.06+	—	Unweathered rock (granite)
	Cima Dome	—	1	352030 N/1173230 W	1	0.00-0.30	152	1	0.00-0.30	88	0.00-0.30	—	Overburden
					2	0.30-6.10	1524	2	0.30-6.10	884	0.30-6.10	—	Weathered rock
					3	6.10+	4267	3	6.10+	2475	6.10+	—	Unweathered rock
	Ft. Irwin Granite Mountain	—	1	353030 N/1164030 W	1	0.00-0.91	75	1	0.00-0.91	177	0.00-0.91	—	Overburden
					2	0.91+	[illegible]	2	0.91+	495	0.91+	—	Weathered rock
			2		1	0.00-0.30	178	1	0.00-0.30	103	0.00-0.30	—	Overburden
					2	0.30-4.27	945	2	0.30-4.27	548	0.30-4.27	—	Weathered rock
					3	4.27+	3048	3	4.27+	1768	4.27+	—	Unweathered rock
	Ft. Irwin Paradise Range	—	1	353000 N/1164000 W	1	0.00-3.96	381	1	0.00-3.96	221	0.00-3.96	—	Overburden
					2	3.96+	2476	2	3.96+	1436	3.96+	—	Unweathered rock
			2		1	0.00-0.61	204	1	0.00-0.61	118	0.00-0.61	—	Overburden
					2	0.61+	1143	2	0.61+	663	0.61+	—	Weathered rock
	March AFB	—	1	353209 N/1171442 W	1	0.00-0.88	270	1	0.00-3.10	210*	—	—	--
					2	0.88+	695	2	3.10+	260*	—	—	--
			2	335209 N/1171442 W	1	0.00-0.95	590	1	0.00-6.25	280*	—	—	--
					2	0.95+	1030	2	6.25+	450*	—	—	--
	Marysville Dam and Spillway	—	1	3916-- N/12125-- W	1	0.00-1.52	442	1	0.00-1.52	256	0.00-1.07	—	Clay and sand
					2	1.52-12.04	1557	2	1.52-12.04	926	1.07-5.33	--	Decomposed metavolcanics, soft to moderately soft
					3	12.04+	5593	3	12.04+	3244	5.33-17.68	--	Metavolcanics, moderately soft and moderately hard
											17.68-22.56	—	Metavolcanics, soft to moderately soft
											22.56+	--	Rock, moderately hard

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
California (Cont'd)	Maryville Dam and Spillway (Cont'd)	4	2	3916-- N/12125-- W	1	0.00-1.68	488	1	0.00-1.68	283	0.00-2.74	--	Sandy gravel
					2	1.68-3.96	844	2	1.68-3.96	513	2.74-6.40	--	Decomposed diorite, soft
					3	3.96-11.58	1600	3	3.96-11.58	928	6.40-15.70	--	Diorite, moderately hard
					4	11.58+	4923	4	11.58+	2855	15.70-17.68	--	Metavolcanics, moderately hard
											17.68-18.29	--	Fault zone, rock is soft
											18.29+	--	Metavolcanics, moderately hard
			3		1	0.00-1.68	442	1	0.00-1.68	256		(No soils data)	
					2	1.68-8.08	930	2	1.68-8.08	539			
					3	8.08+	4389	3	8.08+	12546			
			4		1	0.00-0.61	411	1	0.00-0.61	164	0.00-1.37	--	Sandy clay
					2	0.61-4.11	930	2	0.61-4.11	372	1.37-11.58	--	Decomposed metavolcanics, soft
					3	4.11-12.50	2301	3	4.11-12.50	1335	11.58-12.50	--	Metavolcanics, soft to moderately hard
					4	12.50+	5227	4	12.50+	3032	14.94-26.21	--	Rock, soft to moderately soft
											26.21+		Fault zone, rock, soft to very soft
			5		1	0.00-0.91	366	1	0.00-0.91	146	0.00-0.61	--	Clay and silty sand
					2	0.91-2.44	838	2	0.91-2.44	335	0.61-6.71	--	Decomposed metavolcanics, soft
					3	2.44-13.26	1600	3	2.44-13.26	928	6.71-15.70	--	Metavolcanics, soft to moderately hard
					4	13.26+	5852	4	13.26+	3394	15.70+		Rock, moderately soft to hard
			6		1	0.00-0.91	411	1	0.00-0.91	164		(No soils data)	
					2	0.91-7.32	1311	2	0.91-7.32	760			
					3	7.32+	5212	3	7.32+	3023			
			7		1	0.00-1.83	442	1	0.00-1.83	177			
					2	1.83-9.14	1128	2	1.83-9.14	654			
					3	9.14+	4938	3	9.14+	2864			
			8		1	0.00-0.91	335	1	0.00-0.91	134	0.00-2.13	--	Sandy gravel and clayey sand
					2	0.91-14.94	1600	2	0.91-14.94	928	2.13-6.20	--	Decomposed diorite, soft; decomposed metavolcanic, soft to moderately soft

(Continued)

Table D1 (Continued)

Location: Subdivision	Location: Site Identification	Location: Site No.	Location: Refraction Line	Location: Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Compression Wave: Layer Depth, m	Compression Wave: Velocity m/sec	Shear Wave: Layer No.	Shear Wave: Layer Depth, m	Shear Wave: Velocity m/sec	Soil Description: Depth m	Soil Description: USCS Classification	Soil Description: General
					United States (Continued)								
California (Cont'd)	Marysville Dam and Spillway (Cont'd)	—	8	3916-- N/12125-- W	3	14.94+	5837	3	14.94+	3385	6.20-15.44	—	Diorite moderately hard; metavolcanics moderately soft to moderately hard
											15.44-19.20	—	Metavolcanics, moderately hard
											19.20+	—	Fault zone, rock is soft and metavolcanics, moderately hard
			9		1	0.00-1.07	411	1	0.00-1.07	164	0.00-1.83	—	Silty sand
					2	1.07-6.40	1250	2	1.07-6.40	500	1.83-9.60	—	Decomposed metavolcanics, soft
					3	6.40-10.97	2789	3	6.40-10.97	1619	9.60-14.02	—	Metavolcanics, moderately soft to moderately hard
					4	10.97+	5563	4	10.97+	3226	14.02+	—	Metavolcanics moderately hard to very hard
	Mentone Damsite	G-1	1	3358-- N/11732-- W	1	0.00-6.10	610	1	0.00-6.10	244		(No soils data)	
					2	6.10-42.67	975	2	6.10-42.67	390			
					3	42.67+	2195	3	42.67+	878			
		G-2	1		1	0.00-3.66	610	1	0.00-3.66	244			
					2	3.66-29.87	1036	2	3.66-29.87	415			
					3	29.87-72.24	1570	3	29.87-72.24	628			
					4	72.24+	2819	4	72.24+	1126			
		G-3	1		1	0.00-4.11	610	1	0.00-4.11	244			
					2	4.11-50.90	914	2	4.11-50.90	366			
					3	50.90+	2316	3	50.90+	927			
	Prado Dam Section AA	1	1	3357-- N/11801-- W	1	0.00-1.30	259	1	0.00-1.52	107*	—	—	Silty sand, very loose to medium dense; gravelly sand-silty gravelly sand, medium dense to dense
					2	1.30-3.73	457	2	1.52-3.58	152*			
					3	3.73-4.30	1067	3	3.58-4.72	175*			
					4	4.86+	1722	4	4.72+	213*			
	Pedro Dam Section BB	2	1		1	0.00-2.44	259	1	0.00-2.29	107*	—	—	Surface-clay, soft to stiff; silty sand, medium dense to very loose; gravelly sand-silty gravelly sand, medium dense to dense
					2	2.44-3.89	457	2	2.29-3.81	152*			
					3	3.89-4.72	1067	3	3.81-4.27	175*			
					4	4.72+	1722	4	4.27+	213*			

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
California (Cont'd)	Prado Dam Section CC	3	1	3357-- N/11801-- W	1	0.00-1.52	259	1	0.00-0.76	107*	--	--	Surface-silty sand; silty gravelly sand-gravely sand, medium to dense
					2	1.52-2.74	457	2	0.76-1.45	152*			
					3	2.74-3.81	1067	3	1.45-2.13	175*			
					4	3.81+	1722	4	2.13-2.82	213*			
								5	2.82+	290*			
	San Francisco	--	1	375015 N/1222930 W	1	0.00-2.44	320	1	0.00-2.44	128	0.00-3.05	--	Sandy clay and clayey silt
					2	2.44-36.58	1396	2	2.44-36.58	799	3.05-8.53	--	Graywacke, soft to medium
					3	36.58+	3642	3	3658	1457	8.53-24.38	--	Graywacke, moderately soft to hard with shale streaks
											24.38-38.40	--	Graywacke, hard, streaks of shale and clay seams
											38.40+	--	Shale, moderately soft; chert, very hard
	Seal Beach	1	1	334434 N/1180-14 W	1	0.00-1.30	220	1	0.00+	93*		(No soils data)	
					2	1.30	1400						
		2	1	334438 N/1180325 W	1	0.00-0.90	200	1	0.00-2.20	75*			
					2	0.90-3.95	397	2	2.20+	145*			
					3	3.95+	1000						
		3	1	334412 N/1180444 W	1	0.00-1.10	165	1	0.00-3.00	75*	--	Marsh	
					2	1.10-3.04	497	2	3.00+	125*			
					3	3.04+	965						
		4	1	364621 N/1180304 W	1	0.00-0.40	200	1	0.00+	125*		(No soils data)	
					2	0.40-2.50	265						
					3	2.50+	600						
Colorado	Ft. Carson Array Area No. 1	--	1	383124 N/1044539 W	1	0.00-1.15	320	1	0.00-1.15	128			
					2	1.15-4.45	1180	2	1.15-4.45	472			
					3	4.45+	2350	3	4.45+	940			
			2		1	0.00-1.00	370	1	0.00-1.00	148			
					2	1.00-3.40	1000	2	1.00-3.40	400			
					3	3.40+	2020	3	3.40+	808			

(Continued)

* Measured value.

Table D1 (Continued)

Subdivision	Site Identification	Site No.	Ref. [illegible]tion Line	[illegible] Coordinates Latitude/Longitude	Compression Wave Layer No.	Compression Wave Layer Depth, m	Compression Wave Velocity m/sec	Shear Wave Layer No.	Shear Wave Layer Depth, m	Shear Wave Velocity m/sec	Soil Description Depth m	Soil Description USCS Classification	Soil Description General
						United States (Continued)							
Colorado (Cont'd)	F. [illegible]rson [illegible] Area No. [illegible]	—	1	[illegible]3120 N/1044538 W	1	0.00-1.45	315	1	0.00-1.45	126		(No soils data)	
					2	1.45-8.85	640	2	1.45-8.85	256			
					3	8.85+	2400	3	8.85+	960			
			2	3[illegible] N/1045228 W	1	0.00-2.40	375	1	0.00-2.40	150			
					2	2.40-9.40	640	2	2.40-9.40	256			
					3	9.40+	2200	3	9.40+	880			
			3	382650 N/1045227 W	1	0.00-3.40	440	1	0.00-3.40	176			
					2	3.40+	835	2	3.40+	334			
			4	382650 N/1045227 W	1	0.00-3.75	445	1	0.00-3.75	178			
					2	3.75+	840	2	3.75+	336			
	Ft. Carson Firing Point No. 213	—	1	383116 N/1044627 W	1	0.00-1.80	400	1	0.00-1.80	160			
					2	1.80-3.20	1810	2	1.80-3.20	724			
					3	3.20+	2000	3	3.20+	800			
	Ft. Carson Firing Point No. 214	—	1	383100 N/1044632 W	1	0.00-2.20	425	1	0.00-2.20	170			
					2	2.20-5.20	1350	2	2.20-5.20	540			
					3	5.20+	2390	3	5.20+	956			
	Ft. Carson Firing Point No. 215	—	1	382945 N/1044620 W	1	0.00-1.40	400	1	0.00-1.40	160			
					2	1.40-3.05	785	2	1.40-3.05	314			
					3	3.05+	3000	3	3.05+	1200			
	Ft. Carson Mortar Point No. 7	—	1	383215 N/1044606 W	1	0.00-1.00	600	1	0.00-1.00	240			
					2	1.00-6.80	825	2	1.00-6.80	330			
					3	6.80+	2050	3	6.80+	820			
	Ft. Carson Soil Sampling Area No. 1	—	1	383124 N/1044537 W	1	0.00-1.45	525	1	0.00-1.45	210			
					2	1.45-3.35	1040	2	1.45-3.35	416			
					3	3.35+	1500	3	3.35+	600			
	Ft. Carson Soil Sampling Area No. 2	—	1	382554 N/1044330 W	1	0.00-2.05	500	1	0.00-2.05	200			
					2	2.05-5.55	2650	2	2.05-5.55	1060			
					3	5.55+	3300	3	5.55+	1320			
	Ft. Carson Soil Sampling Area No. 3	—	1	382635 N/1045140 W	1	0.00-1.60	750	1	0.00-1.60	300			
					2	1.60-6.00	1800	2	1.60-6.00	720			
					3	6.00+	2800	3	6.00+	1120			
	Ft. Carson Vehicle Test Area	—	1	382642 N/1045245 W	1	0.00-1.95	415	1	0.00-1.95	166			
					2	1.95-10.45	1670	2	1.95-10.45	668			
					3	10.45+	2850	3	10.45+	1140			
			2		1	0.00-1.85	395	1	0.00-1.85	158			
					2	1.85-6.50	1460	2	1.85-6.50	584			
					3	6.50+	2650	3	6.50+	1060			
			3		1	0.00-4.25	400	1	0.00-4.25	160			
					2	4.25+	2500	2	4.25+	1008			

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Florida	Cape Kennedy North Saturn Site	--	1	2824-- N/8038-- W	1	0.00-2.50	311	1	0.00-0.64	63#	0.00-12.19	SP	Marine sand, medium dense
					2	2.50+	1676	2	0.64-2.29	136#			
								3	2.29-5.24	231#			
	Cape Kennedy TAA-2A	--	1	2843-- N/8038-- W	1	0.00-1.80	335	1	0.00-0.82	131#	0.00-7.62	SP	Marine sand, medium dense
					2	1.80+	1524	2	0.82-2.59	158#			
								3	2.59-5.24	210#			
	Eglin Field	--	1	3022-- N/8628-- W	1	0.00+	318	1	0.00-0.21	85#	0.00-4.57	SP-SM	Marine silty sand
								2	0.21-1.01	103#			
								3	1.01-2.83	137#			
	Gator Mine Test Eglin AFB	--	1	3022-- N/8628-- W	1	0.00-3.60	210	1	0.00-3.60	84	0.00-0.08	SP	--
					2	3.60-11.50	440	2	3.60-11.50	176	0.23-0.30	SP-SM	--
					3	11.50+	1400	3	11.50+	560	1.00-1.08	SP	
			2		1	0.00-3.60	200	1	0.00-3.60	80	0.00-0.08	SP	--
					2	3.60-11.80	440	2	3.60-11.80	176	0.15-0.65	SP-SM	--
					3	11.80+	1400	3	11.80+	560	0.65-1.08	SP	--
Illinois	Chicago Westchester	--	1	3358-- N/11732-- W	1	0.00-1.22	229	1	0.00-1.22	92	0.00-5.03	--	Sandy clay; clay
					2	1.22-5.33	640	2	1.22-5.33	256	5.03-10.36	--	Sandy clay; silty sand; gravelly clay
					3	5.33-22.71	1707	3	5.33-22.71	683	10.36-11.28	--	Sandy silt; silty clay
					4	22.71+	5791	4	22.71+	2316	11.28-12.95	--	Cobbles, clay, sand, gravel
											12.95-14.94	--	Sandy clay, silty sand
											14.94-17.98	--	Clayey gravel; gravel
											17.98-18.75	--	Rock; sandy silt
											18.75-20.42	--	Gravel
											20.42-21.34	--	Silty gravel
											21.34-24.38	--	Cobbles and boulders
											24.38-25.91	--	Silty sand
											25.91+	--	Rock
			2	415140 N/375110 W	1	0.00-4.11	320	1	0.00-4.11	128	0.00-0.61	--	Sandy clay
					2	4.11-27.13	1768	2	4.11-27.13	707	0.61-4.88	--	Clay
					3	27.13+	5715	3	27.13+	2286	4.88-7.10	--	Silty sand
											7.10-8.53	--	Gravelly clay
											8.53-10.36	--	Sandy clay
											10.36-11.58	--	Silty clay
											11.58-12.19	--	Clay
											12.19-13.11	--	Sand and gravel
											13.11-15.24	--	Sandy clay
											15.24-16.15	--	Gravel
											16.15-17.68	--	Clayey gravel
											17.68-19.51	--	Sandy silt
											19.51-20.42	--	Gravel
											20.42-21.34	--	Silty gravel
											21.34-24.38	--	Cobbles and boulders
											24.38-25.91	--	Silty sand
											25.91+	--	Rock

(Continued)

Measured value.

Table D1 (Continued)

Location: Subdivision	Location: Site Identification	Location: Site No.	Location: Refraction Line	Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Compression Wave: Layer Depth, m	Compression Wave: Velocity m/sec	Shear Wave: Layer No.	Shear Wave: Layer Depth, m	Shear Wave: Velocity m/sec	Soil Description: Depth m	Soil Description: USCS Classification	Soil Description: General
						United States (Continued)							
Illinois (Cont'd)	Decatur, Oakley Dam Site	1	1	394842 N/885445 W	1	0.00-4.30	549	1	0.00-4.30	219	0.00-4.30	--	Weathered clay
					2	4.30-23.90	1722	2	4.30-23.90	689	4.30-23.90	--	Sand and clay
					3	23.90+	3658	3	23.90+	1463	23.90+	--	Shale and limestone
			2		1	0.00-3.66	549	1	0.00-3.66	219	0.00-3.66	--	Weathered clay
					2	3.66-33.50	1417	2	3.66-33.50	432	3.66-33.50	--	Clay
					3	33.50+	3658	3	33.50+	1463	33.50+	--	Shale and limestone
			3		1	0.00-4.30	549	1	0.00-4.30	219	0.00-4.30	--	Weathered clay
					2	4.30-7.60	1417	2	4.30-7.60	432	4.30-7.60	--	Clay
					3	7.60-24.40	2134	3	7.60-24.40	650	7.60-24.40	--	Sand and clay
					4	24.40+	3658	4	24.40+	1463	24.40+	--	Shale and limestone
		2	1		1	0.00-4.27	594	1	0.00-4.27	238	0.00-4.27	--	Weathered clay
					2	4.27-33.22	1722	2	4.27-33.22	689	4.27-33.22	--	Clay and sand
					3	33.22+	3505	3	33.22+	1402	33.22+	--	Shale and limestone
		3	1		1	0.00-3.66	518	1	0.00-3.66	207	0.00-3.66	--	Weathered clay
					2	3.66-41.91	1676	2	3.66-41.91	671	3.66-41.91	--	Sand and clay
					3	41.91+	4572	3	41.91+	1829	41.91+	--	Shale and limestone
		4	1		1	0.00-5.49	488	1	0.00-5.49	195	0.00-5.49	--	Weathered clay
					2	5.49-30.02	1631	2	5.49-30.02	652	5.49-30.02	--	Sand and clay
					3	30.02+	4724	3	30.02+	1890	30.02+	--	Shale and limestone
		5	1		1	0.00-3.66	518	1	0.00-3.66	207	0.00-3.66	--	Weathered clay
					2	3.66-9.14	1036	2	3.66-9.14	415	3.66-9.14	--	Sand
					3	9.14-26.20	1372	3	9.14-26.20	549	9.14-26.20	--	Clay
					4	26.20+	4267	4	26.20+	1707	26.20+	--	Limestone
			2		1	0.00-4.57	472	1	0.00-4.57	189	0.00-4.57	--	Weathered clay
					2	4.57-28.70	1935	2	4.57-28.70	774	4.57-28.70	--	Clay-glacial till
					3	28.70+	4267	3	28.70+	1707	28.70+	--	Limestone
			3		1	0.00-2.44	472	1	0.00-2.44	189	0.00-2.44	--	Weathered clay
					2	2.44-45.10	1935	2	2.44-45.10	774	2.44-45.10	--	Glacial-till clay
					3	45.10+	4267	3	45.10+	1707	45.10+	--	Limestone
Louisiana	Barksdale AFB	1A	1	323111 N/934100 W	1	0.00-4.40	353	1	0.00-4.00	130*		(No soils data)	
					2	4.40+	1700	2	4.30+	170*			
			2		1	0.00-4.40	357	1	0.00-4.40	143			
					2	4.40+	1432	2	4.40+	573			
		1B	1	323120 N/934104 W	1	0.00-4.45	363	1	0.00-4.45	145			
					2	4.45+	1375	2	4.45+	550			
			2		1	0.00-4.45	342	1	0.00-4.45	137			
					2	4.45+	2100	2	4.45+	840			

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Louisiana (Cont'd)	Barksdale AFB (Cont'd)	10	1	323115 N/934048 W	1	0.00-4.00	350	1	0.00-4.00	140		(no soils data)	
					2	4.00+	1500	2	4.00+	600			
			2		1	0.00-4.00	338	1	0.00-4.00	135			
					2	4.00+	1600	2	4.00+	720			
		3	1	323015 N/933851 W	1	0.00-3.20	382	1	0.00-3.20	153			
					2	3.20+	1373	2	3.20+	549			
			2		1	0.00-3.90	348	1	0.00-3.90	139			
					2	3.90+	1967	2	3.90+	787			
			3		1	0.00-3.40	338	1	0.00-3.40	135			
					2	3.40+	1625	2	3.40+	650			
		5	1	323116 N/933543 W	1	0.00-0.92	381	1	0.00-3.80	125*			
					2	0.92+	540	2	3.80+	150*			
			2		1	0.00-1.41	352	1	0.00-1.41	141			
					2	1.41+	525	2	1.41+	210			
			3		1	0.00-2.65	380	1	0.00-2.65	152			
					2	2.65+	610	2	2.65+	244			
		6	1	323125 N/933250 W	1	0.00-2.70	450	1	0.00-2.70	180			
					2	2.70+	765	2	2.70+	306			
			2		1	0.00-3.90	450	1	0.00-3.90	180			
					2	3.90+	833	2	3.90+	333			
		7	1	323026 N/933237 W	1	0.00-0.93	500	1	0.00-0.93	200			
					2	0.93+	829	2	0.93+	331			
			2		1	0.00-1.55	357	1	0.00-4.60	115*			
					2	1.55-7.10	595	2	4.60+	284*			
					3	7.10+	1250						
			3		1	0.00-0.82	364	1	0.00-0.82	145			
					2	0.82-4.46	485	2	0.82-4.46	194			
					3	4.46+	900	3	4.46+	360			
		8	1	322918 N/933405 W	1	0.00+	368	1	0.00+	147			
		9	1	322819 N/933620 W	1	0.00-5.60	350	1	0.00-5.60	140			
					2	5.60+	1660	2	5.60+	664			
			2		1	0.00-5.30	355	1	0.00-5.30	142			
					2	5.30+	1640	2	5.30+	656			
			3		1	0.00-5.20	353	1	0.00-5.20	141			
					2	5.20+	1400	2	5.20+	560			

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Louisiana (Cont'd)	Ft. Polk	2	1	3119-- N/9313-- W	1	0.00-1.50	415	1	0.00-1.50	166	0.00-1.00	—	Sandy silt
					2	1.50-11.30	790	2	1.50-11.30	316	1.00-3.50	—	Clayey sand
					3	11.30+	1500	3	11.30+	600	3.50-8.10	—	Sandy silt
											8.10-12.80	—	Clayey sand
											12.80-14.10	—	Siltstone
			2		1	0.00-0.60	410	1	0.00-0.60	164	0.00-1.00	—	Sandy silt
					2	0.60-10.00	720	2	0.60-10.00	286	1.00-3.50	—	Clayey sand
					3	10.00+	1300	3	10.00+	600	3.50-8.10	—	Sandy silt
											8.10-12.80	—	Clayey sand
											12.80-14.10	—	Siltstone
		3	1		1	0.00-1.40	385	1	0.00-1.40	154	0.00-3.00	—	Sandy clay
					2	1.40-7.20	850	2	1.40-7.20	340	3.00-4.40	—	Sand
					3	7.20+	1725	3	7.20+	690	4.40-7.10	—	Clay, sand, silt
											7.10-12.10	—	Clayey silt
			2		1	0.00-1.05	405	1	0.00-1.05	162	0.00-3.00	—	Sandy clay
					2	1.05-7.70	995	2	1.05-7.70	398	3.00-4.40	—	Sand
					3	7.70+	1740	3	7.70+	696	4.40-7.10	—	Clay, sand, silt
											7.10-12.10	—	Clayey silt
		4	1		1	0.00-1.85	425	1	0.00-1.85	170	0.00-1.80	—	Clayey silt
					2	1.85+	1565	2	1.85+	626	1.80-3.20	—	Silty clay
											3.20-7.00	—	Sand
											7.00-10.00	—	Sandy silt
Maryland	Aberdeen Proving Grounds	1	1	392808 N/760400 W	1	0.00-1.30	240	1	0.00-1.30	96	0.00-0.38	ML	—
					2	1.30+	1460	2	1.30+	584	0.38-0.82	CL-ML	—
			2		1	0.00-1.20	300	1	0.00-1.20	124			
					2	1.20+	1420	2	1.20+	568			
		3	1	393600 N/761534 W	1	0.00-1.10	220	1	0.00-1.10	88	0.00-0.10	ML	—
					2	1.10-2.90	840	2	1.10-2.90	336	0.10-0.40	MH	—
					3	2.90+	2200	3	2.90+	880	0.40-0.75	ML	—
											0.75+	CL	—
		5	1	393550 N/761525 W	1	0.00-5.40	440	1	0.00-5.40	176	0.00-0.33	ML	—
					2	5.40+	1400	2	5.40+	560	0.33+	SM	—
Michigan	Allen	—	1	4240-- N/8315-- W	1	0.00-0.61	305	1	0.00-0.61	122		(No soils data)	
					2	0.61-44.00	975	2	0.61-44.00	390			
					3	44.00-119.00	2134	3	44.00-119.00	854			
					4	119.00+	3430	4	119.00+	1372			
	Auburn Heights	—	1	4238-- N/8315-- W	1	0.00-0.76	229	1	0.00-0.76	92	0.00-2.44	CL	Clay
					2	0.76-14.90	601	2	0.76-14.90	240	2.44-3.35	SC-CW	Gravelly clay
					3	14.90-103.00	1600	3	14.90-103.00	640	3.35-4.57	CL	Silty clay
					4	103.00+	3810	4	103.00+	1524	4.57-9.45	SP	Fine sand
											9.45-14.30	SM	Sandy silt
											14.30-21.50	SC-GW	Sandy gravelly clay
											21.50+	SP	Sand

(Continued

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Michigan (Cont'd)	Detroit Detroit Arsenal	1	1	4222-- N/8303-- W	1	0.00-1.20	253	1	0.00-2.16	129	0.00-3.05	CL	Silty clay, stiff
					2	1.20+	1676	2	2.16-8.35	267	3.05-10.67	CL	Sandy clay
								3	8.35-26.10	259	10.67-13.11	CH	Fat clay
											13.11-17.37	CL	Slightly sandy clay, soft
											17.37+	CH	Slightly sandy clay, stiff
		2	1		1	0.00-0.90	335	1	0.00-2.13	160	0.00-3.05	CL	Silty clay, stiff
					2	0.90+	1554	2	2.13-6.10	369	3.05-9.75	CL	Sandy clay, subfirm
								3	6.10-14.00	272	9.75-13.72	CL	Sandy clay
											13.72+	CH	Slightly sandy clay, medium soft
	Lake Orion	--	1	4238-- N/8315-- W	1	0.00-1.52	305	1	0.00-1.52	122	0.00-2.00	--	Sandy clay and cobbles
					2	1.52-29.10	1661	2	1.52-29.10	644	2.00-2.70	--	Clay
					3	29.10-70.00	2560	3	29.10-70.00	1024	2.70-4.90	--	Sandy clay and gravel
					4	70.00+	3048	4	70.00+	1219	4.90-5.50	--	Clay
											5.50-9.30	--	Sandy clay and gravel
											9.30-12.50	--	Gravelly silt sand
											12.50-15.10	--	Clayey sandy gravel
											15.10-16.50	--	Gravelly clayey sand
											16.50-22.30	--	Silty sand and gravel
											22.30-28.30	--	Silty clay
											28.30+	--	Gravel, silt, clay
	Milford (GMPG)	1	1	4235-- N/8337-- W	1	0.00-0.13	2000	1	0.00-0.13	1004*	0.00-0.05	--	Asphalt
					2	0.13+	2320	2	0.13-0.30	749*	0.05-0.50	SM	--
								3	0.30-0.80	356*	0.50-1.00	SM	--
								4	0.80-2.15	248*	1.00-1.50	SW-SM	--
								5	2.15-3.47	212*	1.50+	--	--
			2		1	0.00-0.13	1575	1	0.00-0.12	960*	0.00-0.05	--	Asphalt
								2	0.12-0.62	436*	0.05-0.50	SM	--
								3	0.62-1.37	233*	0.50-1.00	SM-SC	--
								4	1.37-2.22	221*	1.00-1.75	SM	--
								5	2.22-3.36	232*			
			3		1	0.00-0.13	2280	1	0.00-0.13	790*	0.00-0.05	--	Asphalt
					2	0.13+	2280	2	0.13-0.48	439*	0.05-0.50	SP	--
								3	0.48-0.87	268*	0.50-1.75	SM-SC	--
								4	0.87-3.32	256*			
			4		1	0.00-0.30	530	1	0.00-0.30	212	(No soils data)		
					2	0.30+	1275	2	0.30+	510			
			5		1	0.00-0.13	2000	1	0.00-0.11	858*	0.00-0.05	--	Asphalt
					2	0.13+	2095	2	0.11-0.17	690*	0.05-0.50	SM	--
								3	0.17-0.60	336*	0.50-1.00	SP	--
								4	0.60-1.02	206*	1.00-1.50	F	--
								5	1.02-3.60	203*	1.50-2.25	SP	--

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Michigan (Cont'd)	Milford (GMPG) (Cont'd)	—	6	4235-- N/8337-- W	1	0.00-0.18	375	1	0.00-0.18	150		(No soils data)	
					2	0.18+	1150	2	0.18+	460			
			7		1	0.00-0.30	290	1	0.00-0.25	158*	0.00-0.65	SP-SM	—
					2	0.30-4.00	525	2	0.25-1.34	165*	0.65-0.90	SM	—
					3	4.00+	1665	3	1.34-3.50	176*			
			8		1	0.00-4.00	490	1	0.00-0.15	300*	0.00-0.05	SM-SC	—
					2	4.00+	1885	2	0.15-0.76	240*	0.05-0.50	SM	—
								3	0.76-2.00	200*	0.50-1.00	SM	—
								4	2.00+	219*	1.00-1.50	SW-SM	—
			9		1	0.00-1.20	450	1	0.00-1.13	175*	0.00-0.05	SM	—
					2	1.20-5.00	815	2	1.13-2.44	240*	0.05-0.50	SP	—
					3	5.00+	1695	3	2.44+	247*	0.50-1.00	SM-SC	—
											1.00-1.75	SM-SC	—
			10		1	0.00-1.10	380	1	0.00-1.11	129*		(No soils data)	
					2	1.10-3.90	630	2	1.11-2.15	163*			
					3	3.90+	1600	3	2.15+	187*			
		2	1		1	0.00-5.40	630	1	0.00-0.41	254*	(Surface)	GM-GC	—
					2	5.40+	1540	2	0.41-1.07	227*			
								3	1.07-2.29	207*			
								4	2.29+	209*			
			2		1	0.00-4.20	660	1	0.00-0.42	316*		(No soils data)	
					2	4.20+	1580	2	0.42-1.31	266*			
								3	1.31-2.79	254*			
			3		1	0.00-4.20	655	1	0.00-0.41	257*			
					2	4.20+	1480	2	0.41+	231*			
			4		1	0.00-0.15	350	1	0.00-0.33	183*			
					2	0.15-5.20	565	2	0.33+	201*			
					3	5.20+	1565						
			5		1	0.00-5.10	530	1	0.00-0.64	159*			
					2	5.10+	1600	2	0.64+	190*			
	Rochester	1	1	4241-- N/8309-- W	1	0.00-1.83	305	1	0.00-1.83	122	0.00-0.91	—	Lean clay
					2	1.83-10.70	1722	2	1.83-10.70	681	0.91-7.00	—	Fat clay
					3	10.70-82.80	1966	3	10.70-82.80	786	7.00-11.00	—	Sandy-silty clay
					4	82.80+	3810	4	82.80+	1524	11.00-14.60	—	Sandy-silty clay and cobbles
											14.60-25.60	—	Sandy-silty clay and gravel
											25.60-34.10	—	Fat clay
											34.10+	—	Silty sand to sandy silt

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Minnesota	Honeywell Proving Grounds, St. Francis	--	1	4525-- N/9330-- W	1 2	0.00-8.90 8.90+	343 1800	1 2	0.00-2.00 2.00-4.60	130 276	--	--	No soils data
Mississippi	Big Black Site (February 1970)	--	1	321140 N/901015 W	1	0.00+	311	1	0.00+	124	(No soils data)		
			2		1	0.00+	326	1	0.00+	130			
			3		1	0.00+	325	1	0.00+	130			
			4		1	0.00+	325	1	0.00+	130			
			5		1	0.00+	312	1	0.00+	125			
			6		1	0.00+	319	1	0.00+	127			
			7		1	0.00+	320	1	0.00+	128			
			8		1 2	0.00-7.32 7.32+	323 1524	1 2	0.00-7.32 7.32+	129 610			
			9		1 2 3	0.00-4.33 4.33-5.94 5.94+	294 530 1366	1 2 3	0.00-4.33 4.33-5.94 5.94+	118 212 546			
	Big Black Site (September 1970)	1	1	321140 N/901015 W	1 2	0.00-6.25 6.25+	335 1463	1 2	0.00-6.25 6.25+	134 585			
		2	2		1 2	0.00-7.16 7.16+	335 1356	1 2	0.00-7.16 7.16+	134 542			
	Biloxi, Keesler AFB	1	1	3026-- N/8824-- W	1 2	0.00-4.30 4.30+	328 1524	1 2 3	0.00-0.61 0.61-2.16 2.16-4.21	99* 129* 168*			
	Country gravel	1	1	3215-- N/9015-- W	1 2	0.00-12.85 12.85+	540 1200	1 2	0.00-12.85 12.85+	216 480			
	Ewell gravel pit	1	1		1 2 3	0.00-1.45 -- --	310 510 990	1 2 3	0.00-1.45 -- --	124 204 3[illegible]6			
	Gill's Place	1	1	321820 N/902055 W	1	0.00+	1560	1	0.00+	624			
			2		1 2	0.00-3.75 3.75+	1370 1915	1 2	0.00-3.75 3.75+	548 766			
	Highway 61 N Bypass	2	1	322304 N/904937 W	1	0.00+	314	1	0.00-8.66	158*	0.00+	--	Loess
			2		1	0.00+	320	1	0.00-4.75	152*	0.00+	--	Loess
		3	1	322325 N/904936 W	1	0.00+	320	1	0.00-8.38	160*	0.00+	--	Loess

(Continued)

* Measured value.

Table D1 (Continued)

Location: Subdivision	Location: Site Identification	Location: Site No.	Location: Refraction Line	Location: Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Compression Wave: Layer Depth, m	Compression Wave: Velocity m/sec	Shear Wave: Layer No.	Shear Wave: Layer Depth, m	Shear Wave: Velocity m/sec	Soil Description: Depth m	Soil Description: USCS Classification	Soil Description: General
						United States (Continued)							
Mississippi (Cont'd)	Highway 61 E Bypass (Cont'd)		2	322325 N/904936 W	1	0.00+	326	1	0.00-3.17	144*	0.00+	—	Loess
	Sardis Dam	1	1	3423-- N/9045-- W	1	0.00-4.11	305	1	0.00-4.11	122	0.00-3.20	CL	Clay
					2	4.11+	1631	2	4.11+	652	3.20-12.50	SP-SM	Sand
											12.50-16.46	CH	Clay
											16.46+	SP-SM	Sand
	Vicksburg (April 1967 Tests)		1	321810 N/905136 W	1	0.00-3.35	320	1	0.00-15.54	229*	0.00-5.49	CL	Silty clay
					2	3.35-36.88	1676	2	15.54-27.74	607*	5.49-9.14	ML	Clayey silt
					3	36.88-39.01	3048	3	27.74-33.83	890*	9.14-14.33	ML	Soft silt
								4	33.83-36.88	1308*	14.33-36.88	CL	Firm clay
								5	36.88-39.01	939*	21.03-21.64	SM	Sandy silt, soft
											21.64-29.57	CL	Firm shaley clay
											29.57-36.58	SP	Cemented sand
											36.58-37.80	CL	Sandy clay
											37.80-38.10	—	Limestone
											38.10-38.40	SP	Cemented sand
											38.40-39.32	—	Limestone
	Vicksburg Gravel Pit	1	1	3218-- N/9021-- W	1	0.00-0.40	530	1	0.00-0.40	212		(No soils data)	
					2	0.40-5.30	660	2	0.40-5.30	264			
					3	5.30+	1240	3	5.30+	496			
	Vicksburg Poorhouse Site	--	1	321823 N/905114 W	1	0.00-4.30	260	1	0.00-4.30	104		—	Loess
					2	4.30+	1530	2	4.30+	612		—	Loess
		—	2		1	0.00-0.50	255	1	0.00-0.50	102	—	—	Loess
					2	0.50-6.20	320	2	0.50-6.20	128	—	—	Loess
					3	6.20+	1380	3	6.20+	552	—	—	Loess
	Vicksburg West Test Area	—	1	321810 N/905136 W	1	0.00-3.96	305	1	0.00-2.01	146*	0.00-2.44	CL	Silty clay, medium
					2	3.96+	1524	2	2.01-12.80	196*	2.44-6.10	CL	Silty clay, soft
								3	12.80-28.30	248*	6.10-9.14	ML	Clayey silt
											9.14-14.32	MH	Silt, soft
											14.32-21.03	CL	Clay, firm
											21.03-21.64	MH	Sandy silt, soft
											21.64-29.57	CL	Shaley clay
											29.57-38.40	--	Cemented sand
											38.40+	—	Limestone
Missouri	Hannibal, Clarence Cannon Dam and Reservoir	—	1	3923-- N/9150-- W	1	0.00-4.72	410	1	0.00-4.72	164	0.00-4.72	—	Silt and clay
					2	4.72-17.68	2134	2	4.72-17.68	853	4.72-17.68	—	Clay, sand, and gravel
					3	17.68-40.08	3612	3	17.68-40.08	1445	17.68-40.08	—	Shale
					4	40.08+	6096	4	40.08+	2438	40.08+	—	Limestone

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Missouri (Cont'd)	Hannibal, Clarence Cannon Dam and Reservoir (Cont'd)		2	3923-- N/9150-- W	1	0.00-5.64	472	1	0.00-5.64	189	0.00-5.64	--	Silt and clay
					2	5.64-20.42	2088	2	5.64-20.42	835	5.64-20.42	--	Clay, sand, and gravel
					3	20.42-48.16	3612	3	20.42-48.16	1445	20.42-48.16	--	Shale
					4	48.16+	6507	4	48.16+	2603	48.16+	--	Limestone
			3		1	0.00-5.94	425	1	0.00-5.94	170	0.00-5.94	--	Silt and clay
					2	5.94-16.15	2164	2	5.94-16.15	866	5.94-16.15	--	Clay, sand, and gravel
					3	16.15-43.43	3353	3	16.15-43.43	1341	16.15-43.43	--	Shale
					4	43.43+	7315	5	43.43+	2926	43.43+	--	Limestone
			4		1	0.00-3.81	387	1	0.00-3.81	155	0.00-3.81	--	Silt and clay
					2	3.81-22.86	1341	2	3.81-22.86	536	3.81-22.86	--	Clay, sand, and gravel
					3	22.86-26.37	3658	3	22.86-26.37	1463	22.86-26.37	--	Shale
					4	26.37+	6248	4	26.37+	2499	26.37+	--	Limestone
			5		1	0.00-3.12	394	1	0.00-3.12	159	0.00-3.12	--	Silt and clay
					2	3.12-10.97	1006	2	3.12-10.97	402	3.12-10.97	--	Sand and gravel
					3	10.97-29.57	2377	3	10.97-29.57	951	10.97-29.57	--	Shale
					4	29.57+	5486	4	29.57+	2195	29.57+	--	Limestone
			6		1	0.00-4.88	411	1	0.00-4.88	165	0.00-4.88	--	Silt and clay
					2	4.88-9.91	1478	2	4.88-9.91	591	4.88-9.91	--	Sand and gravel
					3	9.91-29.11	2088	3	9.91-29.11	835	9.91-29.11	--	Shale
					4	29.11+	5791	4	29.11+	2316	29.11+	--	Limestone
			7		1	0.00-4.72	355	1	0.00-4.72	142	0.00-4.72	--	Silt and clay
					2	4.72-15.39	1951	2	4.72-15.39	780	4.72-15.39	--	Sand and gravel
					3	15.39-40.39	3353	3	15.39-40.39	1341	15.39-40.39	--	Shale
					4	40.39+	6706	4	40.39+	2682	40.39+		Limestone
			8		1	0.00-3.96	328	1	0.00-3.96	131	0.00-3.96	--	Silt and clay
					2	3.96-10.67	1542	2	3.96-10.67	610	3.96-10.67	--	Sand gravel
					3	10.67-31.39	2591	3	10.97-31.39	1063	10.67-31.39	--	Shale
					4	31.39+	5486	4	31.39+	2195	31.39+	--	Limestone
			9	3923-- N/9151-- W	1	0.00-3.51	405	1	0.00-3.51	162	0.00-3.51	--	Silt and clay
					2	3.51-13.41	1697	2	3.51-13.41	439	3.51-13.41	--	Sand and gravel
					3	13.41-33.22	2972	3	13.41-33.22	1189	13.41-33.22	--	Shale
					4	33.22+	5288	4	33.22+	2115	33.22+	--	Limestone
			10		1	0.00-5.18	422	1	0.00-5.18	169	0.00-5.18	--	Silt and clay
					2	5.18-18.29	2088	2	5.18-18.29	835	5.18-18.29	--	Sand and gravel
					3	18.29-38.71	3338	3	18.29-38.71	1335	18.29-38.71	--	Shale
					4	38.71+	6096	4	38.71+	2438	38.71+	--	Limestone
			11,12		1	0.00-4.95	465	1	0.00-4.95	186	0.00-4.95	--	Silt and clay
					2	4.95-18.29	1448	2	4.95-18.29	579	4.95-18.29	--	Sand and gravel
					3	18.29-34.59	3383	3	18.29-34.59	1353	18.29-34.59	--	Limestone
					4	34.59+	5639	4	34.59+	2256	34.59+		

(Continued)

(Sheet 21 of 47)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Montana	Conrad	PAR	1	4753-- N/10645-- W	1	0.00-4.57	320	1	0.00-4.42	220*	0.00-5.03	--	Sandy clay
					2	4.57-11.89	777	2	4.42-11.73	243*	5.03-5.49	--	Silty sand, dense
					3	11.89-26.52	1585	3	11.73-18.29	280*	5.49-6.40	--	Sandy clay, hard
					4	26.52+	2758	4	18.29+	--	6.40-13.42	--	Sand compact with loose zones
											13.42-16.76	--	Sandy clay, very stiff
											16.76+	--	Shale with siltstone, gypsum, and clay seams
			2		1	0.00-4.57	305	1	0.00-4.72	259*	(Same as Refraction line 1 above)		
					2	4.57-9.30	777	2	4.72-7.82	300*			
					3	9.30-22.86	1433	3	7.82-19.81	286*			
					4	22.86+	2505	4	19.81	--			
	Fallon, Mineral Mountain	--	1	3818-- N/11853-- W	1	0.00-0.30	152	1	0.00-0.30	88*	0.00-0.30	--	Overburden
					2	0.30-10.67	1143	2	0.30-10.67	663*	0.30-10.67	--	Weathered rock
					3	10.67+	2637	3	10.67+	1529*	10.67+	--	Unweathered rock (granitic)
	Fallon, Rivaria Mesa	--	1		1	0.00+	914	1	0.00+	530*	--	--	Weathered rock (welded tuff)
	Fallon, Sand Springs Mountains	--	1	3920-- N/11840-- W	1	0.00-0.30	191	1	0.00-0.30	110*	0.00-0.30	--	Overburden
					2	0.30-12.19	1204	2	0.30-12.19	698*	0.30-12.19	--	Weathered rock
					3	12.19+	2652	3	12.19+	1538*	12.19+	--	Unweathered rock (granitic)
			2		1	0.00-0.91	191	1	0.00-0.91	110*	0.00-0.91	--	Overburden
					2	0.91+	1143	2	0.91+	663*	0.91+	--	Weathered rock granitic
	Fallon, Three Peaks	--	1		1	0.00-0.61	156	1	0.00-0.61	91*	0.00-0.61	--	Overburden
					2	0.61-22.25	1021	2	0.61-22.25	592*	0.61-22.25	--	Weathered rock
					3	22.25+	3277	3	22.25+	1900*	22.25+	--	Unweathered rock
			2		1	0.00-0.61	171	1	0.00-0.61	99*	0.00-0.61	--	Overburden
					2	0.61-13.11	914	2	0.61-13.11	530*	0.61-13.11	--	Weathered rock
					3	13.11+	3277	3	13.11+	1900*	13.11+	--	Unweathered rock
	Ft. Peck, Pre-Gondola I	ALPHA	1	475546 N/1063515 W	1	0.00-2.79	445	1	0.00-2.79	258	0.00-2.79	--	Highly weathered bedrock
					2	2.79-4.42	1097	2	2.79-4.42	636	2.79-4.42	--	Moderately weathered bedrock
					3	4.42+	1829	3	4.42+	1061	4.42+	--	Unweathered bedrock
			2		1	0.00-2.18	312	1	0.00-2.18	181	0.00-2.18	--	Highly weathered bedrock
					2	2.18-3.55	949	2	2.18-3.55	550	2.18-3.55	--	Moderately weathered bedrock
					3	3.55+	1829	3	3.55+	1061	3.55+	--	Unweathered bedrock

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Montana (Cont'd)	Ft. Peck, Pre-Gondola I (Cont'd)	BRAVO	1	475546 N/1063825 W	1	0.00-2.44	373	1	0.00-2.44	217	0.00-2.44	--	Highly weathered bedrock
					2	2.44+	1737	2	2.44+	1008	2.44+	--	Unweathered bedrock
					1	0.00-2.50	366	1	0.00-2.50	212	0.00-2.50	--	Highly weathered bedrock
					2	2.50+	1859	2	2.50+	1078	2.50+	--	Unweathered bedrock
		Charlie	1	475553 N/1063830 W	1	0.00-1.68	335	1	0.00-1.68	194	0.00-1.68	--	Highly weathered bedrock
					2	1.68-4.11	640	2	1.68-4.11	371	1.68-4.11	--	Moderately weathered bedrock
					3	4.11+	1920	3	4.11+	1114	4.11+	--	Unweathered bedrock
			2		1	0.00-1.52	312	1	0.00-1.52	181	0.00-1.52	--	Highly weathered bedrock
					2	1.52-5.64	838	2	1.52-5.64	486	1.52-5.64	--	Moderately weathered bedrock
					3	5.64+	1829	3	5.64+	1061	5.64+	--	Unweathered bedrock
		Delta	1	475558 N/1063813 W	1	0.00-2.13	551	1	0.00-2.13	203	0.00-2.13	--	Highly weathered bedrock
					2	2.13-3.76	1015	2	2.13-3.76	589	2.13-3.76	--	Moderately weathered bedrock
					3	3.76+	1737	3	3.76+	1008	--	--	Unweathered bedrock
			2		1	0.00-2.13	549	1	0.00-2.13	318	0.00-2.13	--	Highly weathered bedrock
					2	2.13-4.72	930	2	2.13-4.72	539	2.13-4.72	--	Moderately weathered bedrock
					3	4.72+	1859	3	4.72+	1078	4.72+	--	Unweathered bedrock
	Ft. Peck, Pre-Gondola II	--	1	485548 N/1063830 W	1	0.00-4.42	411	1	0.00-4.42	239	0.00-3.05	--	Shale, highly weathered
					2	4.42+	1829	2	4.42+	1061	3.05-5.49	--	Shale, moderately weathered
											5.49-29.26	--	Shale
			2		1	0.00-4.42	437	1	0.00-4.42	254	0.00-2.44	--	Shale, highly weathered
					2	4.42+	1783	2	4.42+	1034	2.44-4.11	--	Shale, moderately weathered
											4.11-26.15	--	Shale
			3		1	0.00-4.87	488	1	0.00-4.87	283	0.00-1.98	--	Shale, highly weathered
					2	4.87+	1829	2	4.87+	1061	1.98-4.42	--	Shale, moderately weathered
											4.42-30.25	--	Shale
	Ft. Peck Seismic Investigation Lower Level	1	1	4800-- N/10625-- W	1	0.00-3.66	351	1	0.00-3.66	140	0.00-4.27	--	Sand
					2	3.66-7.32	732	2	3.66-7.32	293	4.27-6.10	--	Clay
					3	7.32-39.32	1768	3	7.32-39.32	707	6.10-7.62	--	Silt
					4	39.32+	2195	4	39.32+	878	7.62-9.60	--	Sand

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	UBCS Classification	General
					United States (Continued)								
Montana (Cont'd)	Ft. Peck Seismic Investigation Lower Level (Cont'd)	1	1	4800-- N/10625-- W							9.60-10.97	--	Clay
											10.97-15.54	--	Sand
											15.54-22.25	--	Clay
											22.25-26.52	--	Sand
											26.52-28.96	--	Silt
											28.96-30.48	--	Clay
											30.48-36.58	--	Sand
											36.58+	--	Shale
			2		1	0.00-6.40	381	1	0.00-6.40	152	0.00-45.11	--	Sand
					2	6.40-46.63	480	2	6.40-46.63	192	45.11-46.63	--	Clay
					3	46.63+	1768	3	46.63+	707	46.63-48.13	--	Sand
											48.13-50.90	--	Clay
											50.90-59.74	--	Sand
Nevada	Jackass Flats ESTS 2	--	1	3730-- N/11720-- W	1	0.00-4.88	442	1	0.00-4.88	177	(No soils data)		
					2	4.88+	823	2	4.88+	329			
			2		1	0.00-1.83	442	1	0.00-14.63	315‡			
					2	1.83-19.20	671	2	14.63-32.00	449‡			
					3	19.20+	975						
			3		1	0.00-1.83	442	1	0.00-17.98	324‡			
					2	1.83-19.20	671	2	17.98-86.50	468‡			
					3	19.20+	975						
			4		1	0.00-3.66	283	1	0.00-3.66	113			
					2	3.66-12.50	1097	2	3.66-12.50	439			
					3	12.50+	1341	3	12.50+	536			
			5		1	0.00-2.44	283	1	0.00-2.44	113			
					2	2.44-12.80	1097	2	2.44-12.80	439			
					3	12.80+	1707	3	12.80+	683			
			6		1	0.00-2.44	253	1	0.00-2.44	101			
					2	2.44-9.45	853	2	2.44-9.45	341			
					3	9.45+	1676	3	9.45+	670			
			7		1	0.00-2.44	253	1	0.00-2.44	101			
					2	2.44-7.62	853	2	2.44-7.62	341			
					3	7.62+	1676	3	7.62+	670			
			8		1	0.00-9.14	914	1	0.00-0.14	396‡			
					2	9.14+	1372	2	9.14-36.27	519‡			
			9		1	0.00-9.14	1006	1	0.00-9.14	443‡			
					2	9.14+	1372	2	9.14-42.67	570‡			
			10		1	0.00-3.35	305	1	0.00-3.35	122			
					2	3.35+	1372	2	3.35+	549			

(Continued)

‡ Measured value.

Table D1 (Continued)

Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Compression Wave Layer No.	Compression Wave Layer Depth, m	Compression Wave Velocity m/sec	Shear Wave Layer No.	Shear Wave Layer Depth, m	Shear Wave Velocity m/sec	Soil Description Depth m	Soil Description USCS Classification	Soil Description General
						United States (Continued)							
Nevada (Cont'd)	Jackass Flats ESTB 2 (Cont'd)	—	11	3730— N/11720— W	1 2 3	0.00-2.13 2.13-16.76 [illegible]76+	381 610 1280	1 2 3	0.00-2.31 2.31-16.76 16.76+	152 244 512		(No soils data)	
			12		1 2	0.00-2.74 2.74+	277 1057	1 2	0.00-2.74 2.74+	111 427			
	Jackass Flats ESTB 3	—	1		1 2	0.00-1.83 1.83+	510 1067	1 2 3	0.00-1.19 1.19-13.56 13.56-42.67	195* 448* 550*			
			2		1 2	0.00-1.83 1.83+	610 1067	1 2	0.00-1.37 1.37-44.20	223* 520*			
			3		1 2 3	0.00-1.83 1.83-60.05 60.65+	610 1067 2134	1 2	0.00-1.83 1.83-39.01	261* 483*			
			4		1 2 3	0.00-1.52 1.52-72.24 72.24+	762 1113 2530	1 2 3	0.00-1.52 1.52-72.24 72.24+	305 445 1012			
			5		1 2	0.00-1.83 1.83+	610 1493	1 2	0.00-1.83 1.83+	244 597			
			6		1 2	0.00-1.52 1.52+	762 1387	1 2	0.00-1.52 1.52+	305 555			
			7		1 2	0.00-1.83 1.83+	610 1097	1 2	0.00-1.83 1.83+	244 439			
			8		1 2	0.00-1.83 1.83+	427 1128	1 2	0.00-1.83 1.83+	171 451			
			9		1 2	0.00-2.13 2.13+	610 1097	1 2	0.00-2.13 2.13+	244 439			
			10		1 2 3	0.00-2.44 2.44-11.89 11.89+	975 1585	1 2 3	0.00-[illegible] 2.44-11.89 11.89+	390 634			
			11		1 2 3	0.00-3.35 3.35-9.45 9.45+	762 1585	1 2 3	0.00-3.35 3.35-9.45 9.45+	305 634			
			12		1 2 3	0.00-2.74 2.74-10.67 10.67+	762 1585	1 2 3	0.00-2.74 2.74-1067 10.67+	305 634			
	Jackass Flats midway between ESTBS 2 and 3	—	1		1 2	0.00-14.02 14.02+	884	1	0.00-14.02	354			

* Measured value.

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Nevada (Cont'd)	Jackass Flats midway between ESTB 2 and 3 (Cont'd)	--	[illegible]	3730-- N/11720-- W	1	0.00-2.74	436	1	0.00-2.74	174	(No soils data)		
					2	2.74+	1463	2	2.74+	585			
	Mercury Dome Mountain	--	1	3642-- N/11601-- W	1	0.00-7.77	960	1	0.00-7.77	384	0.00-3.05	--	Clayey silt
					2	7.77+	1387	2	7.77+	555	3.05-6.10	--	Vesicular basalt
											6.10-10.97	--	Dense basalt
											10.97-21.95	--	Vesicular basalt
											21.95-28.04	--	Dense basalt
											28.04-35.36	--	Vesicular basalt
											35.36-36.27	--	Dense basalt
											36.27-67.06	--	Vesicular basalt
											67.06+	--	Dense basalt
			2		1	0.00-3.05	747	1	[illegible]	[illegible]	(Same as Refraction Line 1 above)		
					2	3.05-73.46	1554	2	[illegible]	[illegible]			
					3	73.46+	4267	3	[illegible]	[illegible]			
	Mercury, Gold Meadows	--	1		1	0.00-11.89	1113	1	0.00-11.89	[illegible]	0.00-0.61	--	Silty sand
					2	11.89-57.00	1615	2	11.89-57.00	646	0.61-7.92	--	Quartz monzonite
					3	57.00+	3536	3	57.00+	1414	7.92-57.30	--	Gougy clay
											57.30+	--	Quartz monzonite
			2		1	0.00-3.66	671	1	0.00-3.66	262	(Same as Refraction Line 1 above)		
					2	3.66-23.16	1341	2	3.66-23.16	536			
					3	23.16+	3109	3	23.16+	1244			
	Nellis AFB	--	1	3618-- N/11458-- W	1	0.00-1.30	500	1	0.00-1.30	222*	(No soils data)		
					2	1.30-2.90	900	2	1.30-2.90	360*			
					3	2.90+	1330	3	2.90+	650*			
New Mexico	White Sands	28	1	300915 N/1062315 W	1	0.00-1.75	290	1	0.00-1.75	116			
					2	1.75+	1637	2	1.75+	655			
		29	1		1	0.00-6.10	457	1	0.00-6.10	183			
					2	6.10-70.10	1753	2	6.10-70.10	701			
					3	70.10+	2438	3	70.10+	975			
		31	1		1	0.00-2.51	509	1	0.00-2.51	204			
					2	2.51-7.39	933	2	2.51-7.39	373			
					3	7.39+	1713	3	7.39+	685			
		32	1		1	0.00-3.20	521	1	0.00-3.20	208			
					2	3.20-11.05	798	2	3.20-11.05	319			
					3	11.05+	1844	3	11.05+	738			
		39	1		1	0.00-8.46	914	1	0.00-8.46	366			
					2	8.46+	1746	2	8.46+	699			
North Carolina	Ft. Bragg Area I	374	1	350306 N/792003 W	1	0.00-7.70	385	1	0.00-7.70	145*	0.00-7.00	CL	--
					2	7.70+	1500	2	7.70+	600			

(Continued)

* Measured value.

Table D1 (Continued)

	Location				Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
North Carolina (Cont'd)	Ft. Bragg Area 2	375	1	350805 N/792123 W	1 2 3	0.00-1.30 1.30-5.00 5.00+	415 1250 2120	1 2 3	0.00-1.30 1.30-5.00 5.00+	145* 350* 848	0.00-1.30	SC	--
	Ft. Bragg Area 3	379	1	351112 N/791730 W	1 2 3	0.00-3.10 3.10-7.00 7.00+	380 1020 1500	1 2 3	0.00-3.10 3.10-7.00 7.00+	140* 260* 600	0.00-3.10	SC	--
	Ft. Bragg Area 3	380	1	351110 N/791648 W	1 2 3	0.00-2.30 2.30-6.35 6.35+	350 1120 2350	1 2 3	0.00-2.30 2.30-6.35 6.35+	145* 250* 940	0.00-2.30	SC	--
	Ft. Bragg Area 3	381	1	351113 N/791651 W	1 2 3	0.00-2.20 2.20-6.50 6.50+	325 1200 2450	1 2 3	0.00-2.20 2.20-6.50 6.50+	130* 380* 980	0.00-2.20	SC	--
	Ft. Bragg Area 3	382	1	351042 N/791712 W	1 2	0.00-2.90 2.90+	350 665	1 2	0.00-2.90 2.90+	125* 300*	0.00-2.90	SC	--
	Ft. Bragg Area 3	383	1	351112 N/791730 W	1 2 3	0.00-1.40 1.40-4.40 4.40+	360 970 1965	1 2 3	0.00-1.40 1.40-4.40 4.40+	135* 240* 786	0.00-1.40	SP-SM	--
	Ft. Bragg Area 4	377	1	351228 N/791353 W	1 2	0.00-2.55 2.55+	375 1565	1 2	0.00-2.55 2.55+	130* 400*	0.00-2.60	SP-SM	
	Ft. Bragg Area 5	378	1	351004 N/791635 W	1 2	0.00-2.15 2.15+	395 940	1 2	0.00-2.15 2.15+	170* 350*	0.00-2.10	SM	--
	Ft. Bragg Area 6	376	1	350628 N/791622 W	1 2 3	0.00-1.60 1.60-3.85 3.85+	360 600 1125	1 2 3	0.00-1.60 1.60-3.85 3.85+	145* 200* 450	0.00-1.60	SM	--
	Ft. Bragg Area 7	372	1	350720 N/791120 W	1 2	0.00-8.25 8.25+	370 1490	1 2	0.00-8.25 8.25+	170* 450*	0.00-8.20	SC	--
	Ft. Bragg Area 8	373	1	350237 N/791238 W	1 2 3	0.00-3.25 3.25-8.65 8.65+	335 1300 2565	1 2 3	0.00-3.25 3.25-8.65 8.65+	155* 380* 1126	0.00-3.20	SM	--
	Ft. Bragg Area 9	371	1	3502-- N/7912-- W	1 2	0.00-5.40 5.40+	305 625	1 2	0.00-5.40 5.40+	140* 250*			
	Ft. Bragg Area 10	370	1	351050 N/785615 W	1 2 3	0.00-2.05 2.05-5.60 5.60+	295 1015 2700	1 2 3	0.00-2.05 2.05-5.60 5.60+	110* 250* 1080	0.00-2.00	SP	--
North Dakota	Hope	--	1	4714-- N/973-- W	1 2	0.00-3.70 3.70+	366 1646	1 2 3 4 5	0.00-2.43 2.43-3.05 3.05-3.66 3.66-4.79 4.79-5.94	122* 244* 146* 272* 238*	0.00-10.06 10.06-12.19 12.19-28.04	CL ML CL	Stones and boulder with sand pockets

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
North Dakota (Cont'd)	Hope (Cont'd)	--	1	4714-- N/9732-- W				6	5.94-6.40	192#			
								7	6.40-6.80	295#			
								8	6.80-11.20	215#			
Ohio	Belle Fontaine AFB	--	1	402130 N/834530 W	1	0.00-1.04	901	1	0.00-1.04	225#	0.00-24.38	CL	Glacial till, silty clay, silt, and gravel
					2	1.04-3.41	829	2	1.04-3.41	207#			
					3	3.41-11.60	1264	3	3.41-11.60	316#			
	Camp Dennison	--	1	402330 N/812000 W	1	0.00-2.10	441	1	0.00-2.10	251#	0.00-24.88	GP	Glacial outwash, sandy gravel
					2	2.10+	1219	2	2.10-8.29	331#			
								3	8.29-13.40	442#			
								4	13.40-18.30	549#			
	ORDL Floodwall Site	--	1	--				1	0.00-0.37	211#	0.00-1.52	--	Topsoil
								2	0.37-0.94	123#	1.52-11.30	CL	Lean to sandy clay
								3	0.94-2.90	196#	11.30+	GW	Sandy gravel
Tennessee	Oak Ridge	1	1	355930 N/842010 W	1	0.00-7.32	914	1	0.00-7.32	321#	0.00-7.92	--	Lean clay
						7.32+	5121	2	7.32+	1377#	7.92-10.67	--	Fat clay
											10.67-18.59	--	Limestone
		2	1		1	0.00-11.28	884	1	0.00-11.28	242#	0.00-10.69	--	Clay
						11.28+	4466	2	11.28+	434#	10.67-14.32	--	Clay and shale fragments
											14.02-45.72	--	Shale, heavily fractured
Texas	Ft. Hood 1975	1	1	310300 N/974716 W	1	0.00-1.70	340	1	0.00-1.70	136		(No soils data)	
					2	1.70+	2650	2	1.70+	1060			
		5	1	311307 N/975218 W	1	0.00-1.70	430	1	0.00-1.70	170			
					2	1.70+	2100	2	1.70+	840			
		5A	1	311156 N/975322 W	1	0.00-2.00	780	1	0.00-1.80	203			
					2	2.00+	1950	2	1.80+	381			
		6	1	311503 N/975025 W	1	0.00-2.00	340	1	0.00-2.00	135			
					2	2.00+	2580	2	2.00+	1030			
		6A	1	311438 N/975003 W	1	0.00-1.40	230	1	0.00-1.40	92			
					2	1.40+	2470	2	1.40+	1115			
		8A	1	310814 N/973725 W	1	0.00-1.90	1410	1	0.00-2.10	253			
					2	1.90+	2825	2	2.10+	427			
		9	1	310855 N/973533 W	1	0.00-3.10	300	1	0.00-3.80	122			
					2	3.10+	1675	2	3.80+	203			
	Sanguine	BG-CR-10	1	303600 N/981954 W	1	0.00-0.91	396	1	0.00-0.91	159		--	Granite, unweathered, fractured
					2	0.91-5.79	1174	2	0.91-5.79	470			
					3	5.79+	4421	3	5.79+	1768			

(Continued)

\# Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave				Soil Description	
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Texas (Cont'd)	Sanguine (Cont'd)	BG-CR-10	2	303600 N/981954 W	1	0.00-0.91	396	1	0.00-0.91	195		(No soils data)	
					2	0.91-4.19	1174	2	0.91-4.19	470			
					3	4.19+	4421	3	4.19+	1768			
		BG-CR-25	1	305524 N/990908 W	1	0.00-0.61	831	1	0.00-0.61	332	—	—	Granite, weathered, severely decomposed
					2	0.61-1.91	1700	2	0.61-1.91	690			
					3	1.91+	4512	3	1.91+	1805			
			2		1	0.00-0.91	831	1	0.00-0.91	332	0.00-1.68	--	Granite, unweathered, fractured
					2	0.91-3.81	1700	2	0.91-3.81	680			
					3	3.81+	4512	3	3.81+	1805	1.68+	—	
		BG-CR-28	1	304554 N/992128 W	1	0.00-0.69	412	1	0.00-0.69	165	0.00-3.05	--	Silt and sand
					2	0.69-3.66	1212	2	0.69-3.66	485	3.05+	--	Slightly weathered granite
					3	3.66+	4268	3	3.66+	1707			
			2		1	0.00-2.74	412	1	0.00-2.74	165			
					2	2.74-4.72	1212	2	2.74-4.72	485			
					3	4.72+	4268	3	4.72+	1707			
		BG-CR-32	1	304450 N/985724 W	1	0.00-1.07	442	1	0.00-1.07	177	0.00-2.13		Sand, clay, silt, weathered granite
					2	1.07-3.05	1197	2	1.07-3.05	479	2.13-6.40		Severely weathered granite
					3	3.05-16.61	2477	3	3.05-16.61	991	6.40-11.89		Highly fractured granite
					4	16.61+	3213	4	16.61+	2085	11.89-17.98		Moderately hard granite
											17.98+		Highly fractured granite
			2		1	0.00-0.46	442	1	0.00-0.46	177		(No soils data)	
					2	0.46-2.90	1197	2	0.46-2.90	479			
					3	2.90+	2477	3	2.90+	991			
		BG-R-3	1	305205 N/983610 W	1	0.00-0.46	549	1	0.00-0.46	220			
					2	0.46-5.18	1441	2	0.46-5.18	576			
					3	5.18-6.10	3536	3	5.18-6.10	1414			
					4	6.10+	6098	4	6.10+	2439			
			2		1	0.00-0.76	549	1	0.00-0.76	220			
					2	0.76-11.13	1441	2	0.76-11.13	576			
					3	11.13+	6098	3	11.13+	2659			
		BG-R-4	1	30520[illegible] N/983608 W	1	0.00-1.07	541	1	0.00-1.07	216			
					2	1.07-5.79	1227	2	1.07-5.79	491			
					3	5.79-18.75	2012	3	5.79-18.75	805			
					4	18.75+	6646	4	18.75+	2659			
			2		1	0.00-1.14	541	1	0.00-1.14	216			
					2	1.14-5.03	1227	2	1.14-5.03	491			
					3	5.03-20.73	2012	3	5.03-20.73	805			
					4	20.73+	6646	4	20.73+	2659			

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Texas (Cont'd)	Sanguine (Cont'd)	BG-R-11	1	304936 N/982004 W	1	0.00-1.98	381	1	0.00-1.98	152		(No soils data)	
					2	1.98+	1349	2	1.98+	540			
			2		1	0.00-1.75	381	1	0.00-1.75	152			
					2	1.75-16.46	1349	2	1.75-16.46	540			
					3	16.46+	4572	3	16.46+	1829			
		BG-R-13	1	304206 N/1982305 W	1	0.00-0.84	427	1	0.00-0.84	171			
					2**	0.84+	701	2**	0.84+	280			
					2**	0.84+	1021	2**	0.84+	409			
			2		1	0.00-0.53	171	1	0.00-0.53	171			
					2**	0.53+	280	2**	0.53+	280			
					2**	0.53+	409	2**	0.53+	409			
		BG-R-15	1	303612 N/984200 W	1	0.00-1.45	381	1	0.00-1.45	152			
					2	1.45-6.55	1349	2	1.45-6.55	540			
					3	6.55+	2867	3	6.55+	1146			
			2		1	0.00-1.68	381	1	0.00-1.68	152			
					2	1.68-5.64	1349	2	1.68-5.64	540			
					3	5.64+	2866	3	5.64+	1146			
		BG-R-20	1	302618 N/984015 W	1	0.00-0.91	411	1	0.00-0.91	165	0.00-0.46	—	Gravel, sand, silt
					2	0.91-8.46	1898	2	0.91-8.46	759	0.46-2.74	—	Slightly weathered, highly fractured granite
					3	8.46+	5245	3	8.46+	2098	2.74-6.71	—	Granite unweathered, fractured vertically, and horizontally
			2		1	0.00-0.69	411	1	0.00-0.69	165	6.71+	—	Granite nonfractured
					2	0.69-3.05	1898	2	0.69-3.05	759			
					3	3.05+	5244	3	3.05+	2098			
		BG-R-21	1	304615 N/984700 W	1	0.00-1.30	434	1	0.00-1.30	174		(No soils data)	
					2	1.30-12.50	1349	2	1.30-12.50	540			
					3	12.50+	2530	3	12.50+	1012			
			2		1	0.00-0.99	434	1	0.00-0.99	174			
					2	0.99-12.80	1349	2	0.99-12.80	540			
					3	12.80+	2530	3	12.80+	1012			
		BG-R-22	1	305042 N/984700 W	1	0.00-1.14	427	1	0.00-1.14	170			
					2	1.14-5.33	1669	2	1.14-5.33	668			
					3	5.33+	3170	3	5.33+	1269			
			2		1	0.00-0.69	427	1	0.00-0.69	170			
					2	0.69-4.11	1669	2	0.69-4.11	[illegible]			
					3	4.11+	3170	3	4.11+	1268			
		BG-R-23	1	304836 N/985606 W	1	0.00-0.61	396	1	0.00-0.61	159			

** These layers are adjacent, discontinuities occurred.

(Sheet 30 of 47)

Table D1 (Continued)

Location: Subdivision	Location: Site Identification	Location: Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Compression Wave: Layer Depth, m	Compression Wave: Velocity m/sec	Shear Wave: Layer No.	Shear Wave: Layer Depth, m	Shear Wave: Velocity m/sec	Soil Description: Depth m	Soil Description: USCS Classification	Soil Description: General
					United States (Continued)								
Texas (Cont'd)	Sanguine (Cont'd)	BG-R-23	1	304836 N/985606 W	2	0.61-5.26	1418	2	0.61-5.26	567		(No soils data)	
					3	5.26+	4238	3	5.26+	1695			
			2		1	0.00-0.61	396	1	0.00-0.61	159			
					2	0.61-2.59	1418	2	0.61-2.59	567			
					3	2.59+	4238	3	2.59+	1695			
		BG-R-26	1	304945 N/991410 W	1	0.00-0.76	473	1	0.00-0.76	189			
					2	0.76-5.56	1265	2	0.76-5.56	506			
					3	5.56+	3765	3	5.56+	1506			
			2		1	0.00-0.69	473	1	0.00-0.69	189			
					2	0.69-5.49	1265	2	0.69-5.49	506			
					3	5.49+	3765	3	5.49+	1506			
		BG-R-29	1	305100 N/990656 W	1	0.00-1.37	389	1	0.00-1.37	155			
					2	1.37-7.24	2256	2	1.37-7.24	902			
					3	7.24+	4787	3	7.24+	1915			
			2		1	0.00-1.75	389	1	0.00-1.75	155			
					2	1.75-9.75	2256	2	1.75-9.75	902			
					3	9.75+	4787	3	9.75+	1915			
		BG-R-33	1	304230 N/985116 W	1	0.00-0.46	396	1	0.00-0.46	159			
					2	0.46-10.21	1563	2	0.46-10.21	625			
					3	10.21+	3765	3	10.21+	1506			
			2		1	0.00-0.61	396	1	0.00-0.61	159			
					2	0.61-10.06	1563	2	0.61-10.06	540			
					3	10.06+	3765	3	10.06+	1506			
		BG-R-35	1	304345 N/991245 W	1	0.00-1.60	611	1	0.00-1.60	204	0.00-1.37	--	Silt, clay, sand
					2	1.60-5.94	479	2	1.60-5.94	479	1.37-3.35	--	Granite, weathered
					3	5.94+	3308	3	5.94+	1323	3.35+	--	Granite, unweathered, fractured
			2		1	0.00-0.61	511	1	0.00-0.61	204		(No soils data)	
					2	0.61-3.66	1197	2	0.61-3.66	479			
					3	3.66+	3308	3	3.66+	1323			
		BG-R-37	1	303945 N/990015 W	1	0.00-1.98	381	1	0.00-1.98	152			
					2	1.98-12.19	1768	2	1.98-12.19	707			
					3	12.19+	3110	3	12.19+	1244			
			2		1	0.00-2.13	381	1	0.00-2.13	152			
					2	2.13-11.89	1768	2	2.13-11.89	707			
					3	11.89+	3110	3	11.89+	1244			
		BG-R-42	1	304006 N/984554 W	1	0.00-0.76	434	1	0.00-0.76	174			
					2	0.76-5.94	1593	2	0.76-5.94	637			
					3	5.94+	4055	3	5.94+	1622			
			2		1	0.00-0.99	434	1	0.00-0.99	174			
					2	0.99-3.81	1593	2	0.99-3.81	637			
					3	3.81+	4055	3	3.81+	1622			

(Continued)

Table D1 (Continued)

Location: Subdivision	Location: Site Identification	Location: Site No.	Location: Refraction Line	Location: Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Compression Wave: Layer Depth, m	Compression Wave: Velocity m/sec	Shear Wave: Layer No.	Shear Wave: Layer Depth, m	Shear Wave: Velocity m/sec	Soil Description: Depth m	Soil Description: USCS Classification	Soil Description: General
					United States (Continued)								
Utah	Cedar City Operation Mine Shaft	B	1	4050-- N/11050-- W	1	0.00-2.13	511	1	0.00-2.13	296	0.00-2.13	--	Overburden
					2	2.13-8.23	2042	2	2.13-8.23	1184	2.13-8.23	--	Weathered rock
					3	8.23+	2987	3	8.23+	1732	8.23+	--	Unweathered rock
		C	1		1	0.00-3.96	450	1	0.00-3.96	261	0.00-3.96	--	Overburden
					2	3.96+	2635	2	3.96+	1644	3.96+	--	Unweathered rock
		D	1		1	0.00-8.84	869	1	0.00-8.84	504	0.00-8.84	--	Overburden
					2	8.84+	3277	2	8.84+	1900	8.84+	--	Unweathered rock
		E	1		1	0.00-2.74	883	1	0.00-2.74	477	0.00-2.74	--	Overburden
					2	2.74-17.68	1722	2	2.74-17.68	999	2.74-17.68	--	Weathered rock
					3	17.68+	2789	3	17.68+	1618	17.68+	--	Unweathered rock
		1	1	4005-- N/11050-- W	1	0.00-0.61	156	1	0.00-0.61	91	0.00-0.61	--	Overburden
					2	0.61-13.11	1021	2	0.61-13.11	592	0.61-13.11	--	Weathered rock
					3	13.11+	3277	3	13.11+	1900	13.11+	--	Unweathered rock
		2	1		1	0.00-0.61	171	1	0.00-0.61	99	0.00-0.61	--	Overburden
					2	0.61-13.11	914	2	0.61-13.11	530	0.61-13.11	--	Weathered rock
					3	13.11+	3353	3	13.11+	1945	13.11+	--	Unweathered rock
		3	1		1	0.00-0.30	152	1	0.00-0.30	88	0.00-0.30	--	Overburden
					2	0.30-3.05	411	2	0.30-3.05	239	0.30-3.05	--	Weathered rock
					3	3.05+	3170	3	3.05+	1839	3.05+	--	Unweathered rock
		4	1		1	0.00-1.22	267	1	0.00-1.22	155	0.00-1.22	--	Overburden
					2	1.22-6.40	1143	2	1.22-6.40	663	1.22-6.40	--	Weathered rock
					3	6.40+	3658	3	6.40+	2121	6.40+	--	Unweathered rock
		5	1		1	0.00-3.35	366	1	0.00-3.35	212	0.00-3.35	--	Weathered rock
					2	3.35+	2454	2	3.35+	1423	3.35	--	Unweathered rock
		6	1		1	0.00-1.22	229	1	0.00-1.22	133	0.00-1.22	--	Overburden
					2	1.22-6.10	1097	2	1.22-6.10	636	1.22-6.10	--	Weathered rock
					3	6.10+	2972	3	6.10+	1724	6.10+	--	Unweathered rock
	Little Dell Damsite	--	1	405700 N/1115730 W	1	0.00-0.61	335	1	0.00-12.19	244*	0.00-5.49	--	Silty clay
					2	0.61-5.03	480	2	12.19-21.34	427*	5.49-9.75	--	Gravel
					3	5.03-11.28	1494	3	21.34-30.48	701*	9.75-15.24	--	Silty clay with some gravel
					4	11.28+	3048	4	30.48+	1219*	15.24-20.12	--	Sand with cobbles and boulders
											20.12-21.03	--	Sandstone, fractured
											21.03-25.30	--	Siltstone
Virginia	Woolbridge and Ft. Belvoir	Blue Course	1	3845-- N/7710-- W	1	0.00-0.25	275	1	0.00-0.25	110	0.00-0.25	--	Silt and clay, some sand
					2	0.25-8.24	1240	2	0.25-8.24	496	0.25-0.65	--	Silty clay, some sand
					3	8.24+	4700	3	8.24+	1886	0.65-1.00	--	Clay with some sand
			2		1	0.00-0.13	175	1	0.00-0.13	70	(Same as Refraction Line 1 above)		
					2	0.13-0.73	420	2	0.13-0.73	168			
					3	0.73-5.60	1180	3	0.73-5.60	472			

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Virginia (Cont'd)	Woolbridge and Ft. Belvoir (Cont'd)	Blue Course	2	3845-- N/7710-- W	4	5.60+	4820	4	5.60+	1928	(Same as Refraction Line 1 above)		
			3		1	0.00-0.38	240	1	0.00-0.38	96			
					2	0.38-5.10	1600	2	0.38-5.10	640			
					3	5.10+	2700	3	5.10+	1080			
			4		1	0.00-0.63	385	1	0.00-0.63	154			
					2	0.63-6.15	1420	2	0.63-6.15	564			
					3	6.15	3000	3	6.15+	1200			
			5		1	0.00-1.10	440	1	0.00-1.10	176			
					2	1.10-5.00	1110	2	1.10-5.00	440			
					3	5.00+	3100	3	5.00+	1240			
			6		1	0.00-1.35	440	1	0.00-1.35	176			
					2	1.35-6.60	1440	2	1.35-6.60	576			
					3	6.60+	3480	3	6.60+	1392			
			7		1	0.00-0.25	385	1	0.00-0.25	154			
					2	0.25-5.20	1200	2	0.25-5.20	480			
					3	5.20+	4000	3	5.20+	1600			
			8		1	0.00-0.23	385	1	0.00-0.23	154			
					2	0.23-5.25	1100	2	0.23-5.25	440			
					3	5.25+	2920	3	5.25+	1168			
		Green Course	1		1	0.00-0.51	330	1	0.00-0.51	132	0.00-0.40	--	Sandy silt and clay
					2	0.51-6.03	1520	2	0.51-6.03	680	0.40-0.60	--	Sandy silt and clay, moist
					3	6.03+	2940	3	6.03+	1176	0.60-1.00	--	Sandy silt, some clay and gravel
			2		1	0.00-0.51	375	1	0.00-0.51	150	(Same as Refraction Line 1 above)		
					2	0.51-4.73	1285	2	0.51-4.73	514			
					3	4.73+	2100	3	4.73+	840			
			3		1	0.00-0.13	170	1	0.00-0.13	68			
					2	0.13-1.25	580	2	0.13-1.25	232			
					3	1.25-7.35	2020	3	1.25-7.35	808			
					4	7.35+	3460	4	7.35+	1384			
			4		1	0.00-1.75	590	1	0.00-1.75	236			
					2	1.75-5.50	1900	2	1.75-5.50	760			
					3	5.50+	3400	3	5.50+	1360			
			5		1	0.00-1.00	650	1	0.00-1.00	260			
					2	1.00-5.00	1400	2	1.00-5.00	560			
					3	5.00+	3600	3	5.00+	1440			
			6		1	0.00-0.40	375	1	0.00-0.40	150			
					2	0.40-4.20	1630	2	0.40-4.20	625			
					3	4.20+	2190	3	4.20+	876			

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Virginia (Cont'd)	Woolbridge and Ft. Belvoir (Cont'd)	SSCS	1	3845— N/7710— W	1	0.00–0.45	235	1	0.00–0.45	94	—	—	Upper terrace-silt-clay loam soil; lower elevations—Marine clays and marly (calcareous) deposits
					2	0.45+	580	2	0.45+	232			
			2		1	0.00–0.18	130	1	0.00–0.18	52	—	—	Upper terrace-silt-clay loam soil; lower elevations—Marine clays and marly (calcareous) deposits
					2	0.18–0.42	280	2	0.18–0.42	112			
					3	0.42+	575	3	0.42+	230			
			3		1	0.00–1.25	275	1	0.00–1.25	110	—	—	Upper terrace-silt-clay loam soil; lower elevations—Marine clays and marly (calcareous) deposits
					2	1.25+	650	2	1.25+	260	—	—	
			4		1	0.00–0.10	110	1	0.00–0.10	44	—	—	
					2	0.10–0.53	230	2	0.10–0.53	92	—	—	
					3	0.53+	560	3	0.53+	224	—	—	
		White Course	1		1	0.00–0.65	285	1	0.00–0.65	114	0.00–0.50	—	Silt and clay
					2	0.65+	1860	2	0.65+	720	0.50–1.00	—	Silt and clay with sand, moist
			2		1	0.00–0.13	180	1	0.00–0.13	72	(Same as Refraction Line 1 above)		
					2	0.13–0.65	560	2	0.13–0.65	224			
					3	0.65–6.15	1280	3	0.65–6.15	514			
					4	6.15+	3300	4	6.15+	1320			
			3		1	0.00–4.90	790	1	0.00–4.90	316			
					2	4.90+	2950	2	4.90+	1180			
		Yellow Course	1		1	0.00–0.25	290	1	0.00–0.25	116	0.00–0.25		Sandy silt and clay, some gravel
					2	0.25–7.85	970	2	0.25–7.85	388	0.25–0.35		Coarse silt and clay, gravelly
					3	7.85+	3000	3	7.85+	1200	0.35–1.00		Silty clayey sand, medium coarse, with gravel
			2		1	0.00–0.20	250	1	0.00–0.20	100	(Same as Refraction Line 1 above)		
					2	0.20–7.45	820	2	0.20–7.45	328			
					3	7.45+	2590	3	7.45+	1036			
			3		1	0.00–0.13	250	1	0.00–0.13	100			
					2	0.13–5.63	750	2	0.13–5.63	300			
					3	5.63	1820	3	5.63+	728			

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					United States (Continued)								
Virginia (Cont'd)	Woolbridge and Ft. Belvoir (Cont'd)	SSCS	4	3845-- N/7710-- W	1	0.00-4.63	880	1	0.00-4.63	352	(Same as Refraction Line 1 above)		
					2	4.63+	1550	2	4.63+	620			
			5		1	0.00-0.24	250	1	0.00-0.24	100			
					2	0.24-5.50	870	2	0.24-5.50	348			
					3	5.50+	3000	3	5.50+	1200			
Wyoming	Laramie Range	P4-1	1	411755 N/1051920 W	1	0.00-7.32	518	1	0.00-7.32	301	--	--	Surface-outcrops of granite separated by varying thicknesses of residual and/or alluvial soil; bedrock-Sherman granite
					2	7.32+	4724	2	7.32+	2740			
			2		1	0.00-7.32	549	1	0.00-7.32	318	--	--	Surface-outcrops of granite separated by varying thicknesses of residual and/or alluvial soil; bedrock-Sherman granite
					2	7.32+	5121	2	7.32+	2970	(Same as Refraction Line 2 above)		
		P4-1A	1		1	0.00-3.35	488	1	0.00-3.35	283			
					2	3.35+	4526	2	3.35+	2625			
			2		1	0.00-2.74	488	1	0.00-2.74	283			
					2	2.74+	5456	2	2.74+	3164			
		P4-2	1		1	0.00-30.48	2042	1	0.00-30.48	1184			
					2	30.48+	4282	2	30.48+	2484			
			2		1	0.00-3.05	671	1	0.00-3.05	389			
					2	3.05-19.81	2438	2	3.05-1981	1414			
					3	19.81+	4618	3	19.81+	2678			
		P4-2A	1	411000 N/1052011 W	1	0.00-5.18	671	1	0.00-5.18	389			
					2	5.18+	4328	2	5.18+	2510			
			2		1	0.00-9.45	640	1	0.00-9.45	371			
					2	9.45+	4084	2	9.45+	2369			
		P6-1	1	410936 N/1052742 W	1	0.00-10.36	991	1	0.00-10.36	575			
					2	10.36+	5197	2	10.36+	3014			
			2		1	0.00-1.83	457	1	0.00-1.83	265			
					2	1.83-14.63	716	2	1.83-14.63	415			
					3	14.63+	5166	3	14.63+	2996			
		P6-1A	1	410840 N/1052706 W	1	0.00-2.74	1524	1	0.00-2.74	884			
					2	2.74+	4785	2	2.74+	2776			

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	UBCS Classification	General
						United States (Continued)							
Wyoming (Cont'd)	Laramie Range (Cont'd)	F6-2	1	410936 N/1052742	1 2	0.00-6.10 6.10+	1311 4755	1 2	0.00-6.10 6.10+	760 2758	(Same as Refraction Line 2 above)		
			2		1 2	0.00-5.16 5.16+	1311 4964	1 2	0.00-5.16 5.16+	760 2722			
			3		1	0.00-6.40	869	1	0.00-6.40	504	--	--	Surface-outcrops of granite separated by varying thicknesses of residual and/or alluvial soil; bedrock-Sherman granite
					2	6.40+	5243	2	6.40+	3041	(Same as Refraction Line 3 above)		
			4		1 2	0.00-6.40 6.40+	808 5364	1 2	0.00-6.40 6.40+	468 3111			
			5		1 2	0.00-6.10 6.10+	914 4435	1 2	0.00-6.10 6.10+	520 2572			
			6		1 2	0.00-5.18 5.18+	1097 4481	1 2	0.00-5.18 5.18+	636 2599			
			7		1 2	0.00-6.40 6.40+	[illegible] [illegible]	1 2	0.00-6.40 6.40+	689 2351			
			8		1 2	0.00-6.10 6.10+	[illegible] 4724	1 2	0.00-6.10 6.10+	928 2740			
			9		1 2	0.00-4.88 4.88+	1052 3962	1 2	0.00-4.88 4.88+	610 2298			
			10		1 2	0.00-4.57 4.57+	672 3505	1 2	0.00-4.57 4.57+	369 2033			
			11		1 2	0.00-5.49 5.49+	869 4282	1 2	0.00-5.49 5.49+	[illegible] 2484			
			12		1 2	0.00-4.88 4.88+	1646 4465	1 2	0.00-4.88 4.88+	955 2590			
			13		1 2	0.00-6.10 6.10+	1189 4563	1 2	0.00-6.10 6.10+	689 2705			
			14		1 2	0.00-13.11 13.11+	1646 4328	1 2	0.00-13.11 13.11+	945 2510			
			15		1 2	0.00-4.57 4.57+	853 3810	1 2	0.00-4.57 4.57+	495 2210			
			16		1 2	0.00-4.57 4.57+	[illegible] 4176	1 2	0.00-4.57 4.57+	592 2422			

(Continued)

Table D1 (Continued)

Location: Subdivision	Location: Site Identification	Location: Site No.	Location: Refraction Line	Location: Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Compression Wave: Layer Depth, m	Compression Wave: Velocity m/sec	Shear Wave: Layer No.	Shear Wave: Layer Depth, m	Shear Wave: Velocity m/sec	Soil Description: Depth m	Soil Description: USCS Classification	Soil Description: General
						United States (Concluded)							
Wyoming (Cont'd)	Laramie Range (Cont'd)	P6-2	17	410936 N/1052742 W	1	0.00-6.10	1036	1	0.00-6.10	601	(Same as Refraction Line 3 above)		
					2	6.10+	4435	2	6.10+	2572			
			18		1	0.00-4.88	869	1	0.00-4.88	504			
					2	4.88+	4526	2	4.88+	2625			
			19		1	0.00-7.62	1189	1	0.00-7.62	689	—	—	Surface-outcrops of granite separated by varying thicknesses of residual and/or alluvial soil; bedrock-Sherman granite
					2	7.62+	3993	2	7.62+	2316	(Same as Refraction Line 19 above)		
			20		1	0.00-5.49	1006	1	0.00-5.49	583			
					2	5.49+	3917	2	5.49+	2272			
			21		1	0.00-6.40	1311	1	0.00-6.40	760			
					2	6.40+	4518	2	6.40+	2678			
			22		1	0.00-6.10	1097	1	0.00-6.10	636			
					2	6.10+	3414	2	6.10+	1980			
			23		1	0.00-6.40	1067	1	0.00-6.40	619			
					2	6.40+	3886	2	6.40+	2254			
			24		1	0.00-7.01	1173	1	0.00-7.01	681			
					2	7.01+	4176	2	7.01+	2422			
		P6-2A	1	410840 N/1052706 W	1	0.00-4.88	792	1	0.00-4.88	460			
					2	4.88+	4374	2	4.88+	2537			
			2		1	0.00-4.27	914	1	0.00-4.27	530			
					2	4.27+	4359	2	4.27+	2526			
		P6-3	1		1	0.00-9.75	792	1	0.00-9.75	460			
					2	9.75+	5121	2	9.75+	2970			
			2		1	0.00-9.45	701	1	0.00-9.45	407			
					2	9.45+	5182	2	9.45+	3005			
		P6-3A	1		1	0.00-5.49	899	1	0.00-5.49	522			
					2	5.49+	3871	2	5.49+	2245			
			2		1	0.00-5.18	1189	1	0.00-5.18	689			
					2	5.18+	4130	2	5.18+	2395			
		P6-4A	1		1	0.00-2.13	777	1	0.00-2.13	451			
					2	2.13-17.98	1402	2	2.13-17.98	813			
					3	17.98+	5700	3	17.98	3306			
			2		1	0.00-5.79	610	1	0.00-5.79	354			
					2	5.79+	3520	2	5.79+	2042			

(Continued)

Table D1 (Continued)

Location: Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Layer Depth, m	Velocity m/sec	Shear Wave: Layer No.	Layer Depth, m	Velocity m/sec	Soil Description: Depth m	USCS Classification	General
						Marshall Islands							
Mid-Pacific	Eniwetok Atoll C-Band	—	1	1120-- N/16220-- E	1	0.00-1.52	305	1	0.00-1.40	144*	(No soils data)		
					2	1.52+	1615	2	1.40-8.69	1320*			
			2		1	0.00-1.83	335	1	0.00-0.91	160*	0.00-2.13	—	Medium size coral sand, containing shells and occasional cobbles and boulders
					2	1.83+	1524	2	0.91-1.37	177*	2.13+	—	Coral ledge underlain with material similar to surface, containing occasional coral heads
								3	1.37-9.14	351*			
			3		1	0.00-1.52	290	1	0.00-1.13	155*	(Same as Refraction Line 2 above)		
					2	1.52+	1524	2	1.13-7.32	320*			
								3	7.32-8.02	479*			
	Eniwetok Atoll Reser	—	1		1	0.00-1.22	278	1	0.00-0.61	93*	0.00-2.13	—	Compact gravelly sand with cobbles
					2	1.22+	2438	2	0.61-6.10	386*	2.13+	—	Coral ledge underlain with materials similar to surface, containing occasional coral heads
								3	6.10-16.15	420*			
			2		1	0.00-1.22	381	1	0.00-1.22	152	(Same as Refraction Line 1 above)		
					2	1.22+	2225	2	1.22+	890			
			3		1	0.00-1.22	335	1	0.00-1.22	193*			
					2	1.22+	2164	2	1.22-3.81	320*			
			4		1	0.00-1.22	366	1	0.00-0.98	126*			
					2	1.22+	2134	2	0.98-1.98	188*			
								3	1.98-7.32	346*			
			5		1	0.00-1.22	305	1	0.00-1.37	213*			
					2	1.22+	2134	2	1.37-7.25	338*			
			6		1	0.00-1.22	277	1	0.00-0.61	152*			
					2	1.22+	2438	2	0.61-9.91	359*			
			7		1	0.00-2.13	335	1	0.00-2.13	134	0.00-2.13	—	Compact gravelly sand with cobbles
					2	2.13+	3352	2	2.13+	1341	2.13+	—	Coral ledge underlain with materials similar to surface, containing occasional coral heads
			8		1	0.00-1.22	244	1	0.00-0.76	229	(Same as Refraction Line 7 above)		
					2	1.22+	2743	2	0.76-10.36	368			

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity, m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					Marshall Islands (Concluded)								
Mid-Pacific (Cont'd)	Roi-Namur, Kwajalein Atoll Altair	--	1	09---- N/16730-- E	1	0.00-1.83	320	1	0.00-1.68	141*		(No soils data)	
					2	1.83+	1463	2	1.68-10.97	212*			
	Roi-Namur, Kwajalein Atoll Telescope	--	1		1	0.00-1.22	328	1	0.00-1.00	162*			
					2	1.22+	1341	2	1.10-9.38	179*			

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
						Panama							
Canal Zone	(Dry season)	303	1	090856 N/794412 W	1	0.00-2.70	396	1	0.00-2.70	165*	0.00-0.08	OH	—
					2	2.70+	1234	2	2.70+	494	0.08-3.00	CL	—
		304	1	090854 N/794414 W	1	0.00-3.05	351	1	0.00-3.05	178*	0.00-0.15	OH	—
					2	3.05+	1265	2	3.05+	506	0.15-3.00	MH	—
		305	1	900852 N/794412 W	1	0.00-4.30	427	1	0.00-4.30	171	0.00-0.04	OL	—
					2	4.30+	2790	2	4.30+	1116	0.04-3.00	MH	—
			2		1	0.00-2.40	335	1	0.00-2.40	155*			
					2	2.40+	1936	2	2.40+	774			
		306	1	090849 N/794414 W	1	0.00-2.10	412	1	0.00-2.10	214*	0.00-0.15	OH	—
					2	2.10-7.30	1357	2	2.10-7.30	543	0.15-3.00	CH	—
					3	7.30+	2592	3	7.30+	1037			
		307	1	090847 N/794413 W	1	0.00-3.05	305	1	0.00-3.05	152*	0.00-0.05	OH	—
					2	3.05-13.15	1402	2	3.05-13.15	561	0.05-3.00	MH	—
					3	13.15+	2043	3	13.15+	817			
		308	1	090845 N/794412 W	1	0.00-1.50	396	1	0.00-1.50	183*	0.00-0.08	OH	—
					2	1.50-7.00	641	2	1.50-7.00	256	0.08-3.00	MH	—
					3	7.00+	1494	3	7.00+	997			
		309	1	090844 N/794416 W	1	0.00-3.85	305	1	0.00-3.85	149*	0.00-0.08	OH	—
					2	3.85+	1770	2	3.85+	708	0.08-2.90	MH	—
		310	1	090849 N/794911 W	1	0.00-1.50	305	1	0.00-1.50	152*	0.00-3.00	MH	—
					2	1.50-5.35	671	2	1.50-5.35	268			
					3	5.35+	1281	3	5.35+	512			
			2		1	0.00-2.10	351	1	0.00-2.10	140			
					2	2.10+	945	2	2.10+	378			
		311	1		1	0.00-2.13	305	1	0.00-2.13	161*	0.00-0.12	OH	—
					2	2.13+	670	2	2.13+	268	0.12-3.00	CH	—
		316	1	090011 N/794006 W	1	0.00-3.00	1036	1	0.00-3.00	208*	0.00-0.15	MH	—
					2	3.00+	1292	2	3.00+	517	0.15-1.00	MH	—
		317	1	900019 N/794003 W	1	0.00-4.00	412	1	0.00-4.00	165*	0.00-0.25	MH	—
					2	4.00+	3445	2	4.00+	1378	0.25-1.00	MH	—
		318	1	090022 N/794007 W	1	0.00-4.00	351	1	0.00-4.00	110	0.00-0.20	MH	—
					2	4.00+	1235	2	4.00+	494	0.20-3.00	MH	—
		319	1	—	1	0.00-3.00	488	1	0.00-3.00	195	0.00-0.24	OH	—
					2	3.00+	1022	2	3.00+	409	0.24-1.00	MH	—

(Continued)

* Measured value.

Table D1 (Continued)

Location: Subdivision	Location: Site Identification	Location: Site No.	Location: Refraction Line	Location: Geo Coor Latitud ude	Compression Wave: Layer No.	Compression Wave: Layer Depth, m	Compression Wave: Velocity m/sec	Shear Wave: Layer No.	Shear Wave: Layer Depth, m	Shear Wave: Velocity m/sec	Soil Description: Depth m	Soil Description: USCS Classification	Soil Description: General
					Panama (Continued)								
Canal Zone (Cont'd)	(Dry season) (Cont'd)	320	1	090016 N/784015 W	1	0.00-2.40	320	1	0.00-2.40	128	0.00-0.30	MH	--
					2	2.40-13.55	666	2	2.40-13.55	274	0.30-1.00	CH	--
					3	13.55+	3445	3	13.55+	1378	1.00-2.00	MH	--
		321	1	090042 N/794021 W	1	0.00-3.00	396	1	0.00-3.00	189*	0.00-0.16	MH	--
					2	3.00+	686	2	3.00+	274	0.16-1.00	MH	--
		322	1		1	0.00-2.40	351	1	0.00-2.40	128*	0.00-0.26	OH	--
					2	2.40+	1296	2	2.40+	518	0.26-1.00	CH	--
		323	1	090037 N/794036 W	1	0.00-1.95	519	1	0.00-1.95	180*	0.00-1.00	MH	--
					2	1.95+	1159	2	1.95+	464			
		324	1	090045 N/794037 W	1	0.00-2.10	320	1	0.00-2.10	128*	0.00-0.18	OH	--
					2	2.10-5.80	1143	2	2.10-5.80	457	0.18-1.00	MH	--
					3	5.80+	2516	3	5.80+	1006			
		325	1	090045 N/794029 W	1	0.00-2.25	381	1	0.00-2.25	128*	0.00-0.15	OH	--
					2	2.25+	1433	2	2.25+	573	0.15-1.00	CH	--
		326	1	090051 N/794024 W	1	0.00-2.55	305	1	0.00-2.55	159*	0.00-0.27	OH	--
					2	2.55-13.40	503	2	2.55-13.40	201	0.27-0.90	MH	--
					3	13.40+	3689	3	13.40+	1476			
		327	1	090051 N/794024 W	1	0.00-5.80	306	1	0.00-5.80	134*	0.00-0.13	OH	--
					2	5.80+	1082	2	5.80+	433	0.13-1.00	MH	--
		328	1	090052 N/794030 W	1	0.00-1.50	244	1	0.00-1.50	116*	0.00-1.00	MH	--
					2	1.50-9.55	412	2	1.50-9.55	165			
					3	9.55+	1037	3	9.55+	415			
		Alpha Area Stake D-3	1	090037 N/784050 W	1	0.00-4.15	274	1	0.00-4.15	166*		(No soils data)	
					2	4.15+	2805	2	4.15+	1122			
		Alpha Area Stake R-18	1	090057 N/794036 W	1	0.00-4.10	366	1	0.00-4.10	146			
					2	4.10+	3003	2	4.10+	1201			
	(Wet season)	303	1	090856 N/794412 W	1	0.00-2.90	400	1	0.00-2.90	217*	0.00-0.08	OH	--
					2	2.90+	1365	2	2.90+	546	0.08-3.00	CL	--
		304	1	090854 N/794414 W	1	0.00-2.30	405	1	0.00-2.30	179*	0.00-0.15	OH	--
					2	2.30-5.95	1005	2	2.30-5.95	402	0.15-3.00	MH	--
					3	5.95+	1500	3	5.95+	600			

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
						Panama (Continued)							
Canal Zone (Cont'd)	(Wet season) (Cont'd)	305	1	090852 N/794412 W	1	0.00–4.00	380	1	0.00–4.00	278†	0.00–0.04	OL	--
					2	4.00–10.10	1240	2	4.00–10.10	496	0.04–3.00	MH	--
					3	10.10+	2750	3	10.10	1100			
		306	1	090849 N/794414 W	1	0.00–2.40	390	1	0.00–2.40	208†	0.00–0.15	OH	--
					2	2.40–6.35	1000	2	2.40–6.35	400	0.15–3.00	CH	--
					3	6.35+	1775	3	6.35+	710			
		307	1	090847 N/794413 W	1	0.00–2.40	430	1	0.00–2.40	200†	0.00–0.05	OH	--
					2	2.40–8.15	960	2	2.40–8.15	384	0.05–3.00	MH	--
					3	8.15+	1860	3	8.15+	744			
		308	1	090845 N/794412 W	1	0.00–1.45	470	1	0.00–1.45	208†	0.00–0.08	OH	--
					2	1.45–9.25	600	2	1.45–9.25	240	0.08–3.00	MH	--
					3	9.25+	1910	3	9.25+	764			
		309	1	090844 N/794416 W	1	0.00–3.65	430	1	0.00–3.65	178†	0.00–0.08	OH	--
					2	3.65–7.80	1100	2	3.65–7.80	440	0.08–2.90	MH	--
					3	7.80+	1910	3	7.80+	764			
		310	1	090849 N/794411 W	1	0.00–3.60	385	1	0.00–3.60	228†	0.00–3.00	MH	--
					2	3.60+	1790	2	3.60+	716			
		312	1		1	0.00–1.50	420	1	0.00–1.50	168		(No soils data)	
					2	1.50–6.40	725	2	1.50–6.40	290			
					3	6.40+	1925	3	6.40+	770			
		316	1	090011 N/794006 W	1	0.00–3.90	425	1	0.00–3.90	131†	0.00–0.15	MH	--
					2	3.90+	1570	2	3.90+	626	0.15–1.00	MH	--
		317	1	090013 N/794003 W	1	0.00–1.70	390	1	0.00–1.70	102†	0.00–0.25	MH	--
					2	1.70–8.10	690	2	1.70–8.10	276	0.25–1.00	MH	--
					3	8.10+	2330	3	8.10+	932			
		318	1	090022 N/794007 W	1	0.00–2.50	350	1	0.00–2.50	119†	0.00–0.20	MH	--
					2	2.50+	570	2	2.50+	228	0.20–3.00	MH	--
		320	1	090016 N/784015 W	1	0.00–1.60	250	1	0.00–1.60	122†	0.00–0.30	MH	--
					2	1.60+	583	2	1.60+	233	0.30–1.00	CH	--
											1.00–2.00	MH	--
		321	1	090042 N/794021 W	1	0.00–2.05	375	1	0.00–2.05	185†	0.00–0.16	MH	--
					2	2.05+	790	2	2.05+	316	0.16–1.00	MH	--
		323	1	090037 N/794036 W	1	0.00–1.75	355	1	0.00–1.75	279†	0.00–1.00	MH	--
					2	1.75+	1620	2	1.75+	648			
		324	1	090045 N/794037 W	1	0.00–2.75	395	1	0.00–2.75	116†	0.00–0.18	OH	--
					2	2.75–7.70	1320	2	2.75–7.70	528	0.18–1.00	MH	--
					3	7.70+	3300	3	7.70+	1320			

(Continued)

† Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					Panama (Concluded)								
Canal Zone (Cont'd)	(Wet season) (Cont'd)	325	1	090045 N/794029 W	1 2	0.00-5.20 5.20+	580 2400	1 2	0.00-5.20 5.20+	116* 960	0.00-0.15 0.15-1.00	CH CH	-- --
		326	1	090049 N/794023 W	1	0.00+	39[illegible]	1	0.00+	122*	0.00-0.27 0.27-0.90	OH MH	-- --
		327	1	090051 N/794024 W	1 2	0.00-5.65 5.65+	375 830	1 2	0.00-5.65 5.65+	132* 332	0.00-0.13 0.13-1.00	OH MH	-- --
		328	1	090052 N/794030 W	1 2	0.00-6.05 6.05+	300 550	1 2	0.00-6.05 6.05+	143* 220	0.00-1.00	MH	--
		359	1	09[illegible] N/794[illegible] W	1 2	0.00-3.05 3.05+	380 1125	1 2	0.00-3.05 3.05+	152 450		(No soils data)	
		360	1		1 2 3	0.00-1.45 1.45-6.45 6.45+	235 615 2375	1 2 3	0.00-1.45 1.45-6.45 6.45+	94 246 950			
		361	1		1 2 3	0.00-2.20 2.20-5.15 5.15+	385 880 1520	1 2 3	0.00-2.20 2.20-5.15 5.15+	154 352 568			
		362	1	090827 N/794303 W	1 2	0.00-3.85 3.85+	410 1650	1 2	0.00-3.85 3.85+	164 660			
		363	1	090838 N/794339 W	1 2 3	0.00-1.60 1.60-5.90 5.90+	300 525 1575	1 2 3	0.00-1.60 1.60-5.90 5.90+	120 210 630			
		364	1	090837 N/794340 W	1 2	0.00-3.90 3.90+	330 1530	1 2	0.00-3.90 3.90+	132 636			
		365	1	090844 N/794343 W	1 2 3	[illegible]-1.30 [illegible]-6.05 6.05+	335 655 2460	1 2 3	0.00-1.30 1.30-6.05 6.05+	134 262 948			
		366	1	090848 N/794350 W	1 2	0.00-8.50 8.50+	360 2400	1 2	0.00-8.50 8.50+	144 960			
		367	1	090853 N/794354 W	1 2	0.00-3.75 3.75+	350 1625	1 2	0.00-3.75 3.75+	140 646			

(Continued)

* Measured value.

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
						Puerto Rico							
Arecibo	Palmas Altas	PR01	1	182900 N/663300 W	1	0.00-1.35	280	1	0.00-1.35	112		(No soils data)	
					2	1.35-2.82	924	2	1.35-2.82	370			
Arecibo	Palmas Altas	PR06	1	182900 N/663300 W	1	0.00-1.69	219	1	0.00-1.69	88			
					2	1.69-7.91	1444	2	1.69-7.91	576			
Dorado	Sabana Seca	PR10	1	182850 N/661912 W	1	0.00-2.24	308	1	0.00-2.24	123			
					2	2.24-5.99	1536	2	2.24-5.99	614			
Comerio	Rio Hondo	PR11	1	181100 N/661618 W	1	0.00-0.41	112	1	0.00-0.41	45			
					2	0.41-9.19	337	2	0.41-9.19	135			
Mayaguez	Guanajibo	PR12	1	180830 N/670910 W	1	0.00-0.36	134	1	0.00-0.36	54			
					2	0.36-1.23	364	2	0.36-1.23	146			
Mayaguez	Guanajibo	PR13	1	180830 N/670910 W	1	0.00-0.30	109	1	0.00-0.30	[illegible]			
					2	0.30+	486	2	0.30+	19			
Cabo Rojo	Boqueron	PR16	1	180130 N/670935 W	1	0.00-2.22	207	1	0.00-2.22	83			
					2	2.22-5.25	1829	2	2.22-5.25	732			
Cabo Rojo	Laguna Cartagena	PR19	1	180100 N/670715 W	1	0.00-2.41	156	1	0.00-2.41	62			
					2	2.41-7.19	1217	2	2.41-7.19	487			

(Continued)

Table D1 (Continued)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
						West Germany							
Bayern	--	444	1	494302 N/101435 E	1	0.00-0.80	320	1	0.00-0.80	110*	0.00-0.15	CL	--
					2	0.80-4.00	570	2	0.80-4.00	200*	0.50-0.60	CL	--
					3	4.00+	2600	3	4.00+	1430	1.10-1.15	CH	--
											1.80-1.90	CL	--
		445	1	494331 N/101426 E	1	0.00-1.80	220	1	0.00-1.80	105*	0.00-0.15	CL	--
					2	1.80-7.20	1830	2	1.80-7.20	350*	0.90-1.00	CL	--
					3	7.20+	3000	3	7.20+	1650	2.30-2.40	CL	--
		448	1	494513 N/102440 E	1	0.00-1.60	340	1	0.00-1.60	125*	0.00-0.15	OH	--
					2	1.60+	2400	2	1.60	300*	0.40-0.45	OH	--
											0.60-0.70	CL	--
											1.10-1.20	SM	--
		461	1	491819 N/122114 E	1	0.00-0.60	200	1	0.00-0.60	80*	0.00-0.15	CL	--
					2	0.60+	690	2	0.60+	280*	0.35-0.45	CL	--
											0.75-0.85	CL	--
		463	1	492106 N/122208 E	1	0.00-0.70	270	1	0.00-0.70	110	0.00-0.15	OH	--
					2	0.70-3.50	1380	2	0.70-3.50	160	0.60-0.70	CL	--
					3	3.50+	275	3	3.50+	1510	1.50-1.60	CL	--
											2.00-2.10	SP	--
		468	1	492115 N/122432 E	1	0.00-1.20	330	1	0.00-1.20	95*	0.00-0.15	CL	--
					2	1.20-5.80	925	2	1.20-5.80	300*	0.55-0.65	CL	--
					3	5.80+	3000	3	5.80+	1650			
		473	1	483543 N/121112 E	1	0.00-1.00	200	1	0.00-1.00	80	0.00-0.15	CL	--
					2	1.00-5.20	355	2	1.00-5.20	142	0.50-0.75	CL	--
					3	5.20+	1970	3	5.20+	788			
		473	1	483515 N/121457 E	1	0.00-1.80	190	1	0.00-1.80	75	0.00-0.15	ML	--
					2	1.80+	1660	2	1.80+	664	0.70-0.80	SP	--
		481	1	483149 N/121440 E	1	0.00-0.70	200	1	0.00-0.70	80			
					2	0.70-8.30	480	2	0.70-8.30	192		(No soils data)	
					3	8.30+	1500	3	8.30+	600			
Hessen	--	403	1	503628 N/094210 E	1	0.00-0.45	167	1	0.00-0.45	67			
					2	0.45+	600	2	0.45+	240			
		404	1	504928 N/094759 E	1	0.00-0.42	150	1	0.00-0.42	60			
					2	0.42+	575	2	0.42+	230			
		405	1	505150 N/093054 E	1	0.00-0.31	92	1	0.00-0.31	37			
					2	0.31-1.56	525	2	0.31-1.56	210			
		406	1	504342 N/091037 E	1	0.00-0.16	114	1	0.00-0.16	46			
					2	0.16-0.79	250	2	0.16-0.79	100			

(Continued)

* Measured value.

Table D1 (Continued)

Location: Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Compression Wave: Layer No.	Layer Depth, m	Velocity m/sec	Shear Wave: Layer No.	Layer Depth, m	Velocity m/sec	Soil Description: Depth m	USCS Classification	General
						West Germany (Continued)							
Hessen (Cont'd)	—	407	1	503548 N/094152 E	1	0.00–0.17	150	1	0.00–0.17	60		(No soils data)	
					2	0.17–1.77	367	2	0.17–1.77	147			
		408	1	504911 N/094755 E	1	0.00–0.14	150	1	0.00–0.14	76			
					2	0.14–1.51	359	2	0.14–1.51	144			
		419	1	504425 N/094507 E	1	0.00–0.30	170	1	0.00–0.30	70	0.00–0.15	ML	—
					2	0.30–1.90	455	2	0.30–1.90	182	0.30–0.40	CL	—
					3	1.90+	1350	3	1.90+	540	0.80–0.95	CL	—
		422	1	504422 N/094444 E	1	0.00–0.40	90	1	0.00–0.40	35	0.00–0.15	CL	—
					2	0.40–7.10	505	2	0.40–7.10	202	0.35–0.40	CL	—
					3	7.10+	1740	3	7.10+	957			
		426	1	504716 N/094150 E	1	0.00–0.40	130	1	0.00–0.40	50*	0.00–0.15	CL	—
					2	0.40+	970	2	0.40+	400*			
		431	1	502852 N/090127 E	1	0.00–0.70	220	1	0.00–0.70	85*	0.00–0.15	CL	—
					2	0.70–4.70	575	2	0.70–4.70	180*	0.90–1.00	CL	—
											2.60–3.00	CL	—
					3	4.70+	2200	3	4.70+	1210	3.60–3.70	CL	—
		432	1	502618 N/090153 E	1	0.00–1.20	320	1	0.00–1.20	160*	0.00–0.15	CL	—
					2	1.20–6.40	1230	2	1.20–6.40	440*			
					3	6.40+	2950	3	6.40+	1620			
		441	1	502907 N/090850 E	1	0.00–0.50	145	1	0.00–0.50	60	0.00–0.15	ML	—
					2	0.50+	815	2	0.50+	326	0.30–0.40	CL	—
Niedersachsen	—	409	1	524924 N/094827 E	1	0.00–0.19	150	1	0.00–0.19	60	—	—	—
					2	0.19–1.89	325	2	0.19–1.89	130	—	—	—
Nordhein/Westfalen	—	414	1	513848 N/090530 E	1	0.00–0.60	200	1	0.00–0.60	80	0.00–0.15	CL	—
					2	0.60–3.00	1690	2	0.60–3.00	676	0.45–0.55	CH	—
					3	3.00+	2890	3	3.00+	1156			
		416	1	513632 N/090725 E	1	0.00–1.70	315	1	0.00–1.70	110*	0.00–0.15	CL	—
					2	1.70–4.90	605	2	1.70–4.90	250*	0.60–0.70	CL	—
											1.30–1.40	CL	—
					3	4.90+	2100	3	4.90+	1150	2.15–2.30	CL	—
		417	1	513614 N/090152 E	1	0.00–1.00	330	1	0.00–1.00	135*	0.00–0.15	OH	—
					2	1.00–6.00	1270	2	1.00–6.00	317*	0.50–0.70	CH	—
											1.70–1.80	CL	—
					3	6.00+	1980	3	6.00+	1090	2.50–2.75	CL	—

(Continued)

* Measured value.

Table D1 (Concluded)

Location					Compression Wave			Shear Wave			Soil Description		
Subdivision	Site Identification	Site No.	Refraction Line	Geographic Coordinates Latitude/Longitude	Layer No.	Layer Depth, m	Velocity m/sec	Layer No.	Layer Depth, m	Velocity m/sec	Depth m	USCS Classification	General
					West Germany (Concluded)								
Nordrhein/Westfalen (Cont'd)	--	483	1	512822 N/063252 E	1	0.00-0.40	250	1	0.00-0.40	100	0.00-0.15	CL-ML	--
											0.30-0.40	CL	--
					2	0.40-4.40	400	2	0.40-4.40	160	0.85-0.95	CL	--
					3	4.40+	1850	3	4.40+	740	1.65-1.75	SM	--
		485	1	512832 N/063300 E	1	0.00-1.40	130	1	0.00-1.40	52	0.00-0.15	SC	--
											0.55-0.65	SP	--
					2	1.40+	1350	2	1.40+	540	0.90-1.00	SP	--
											2.90-3.00	SP	--

APPENDIX E: BACKGROUND NOISE AND SUPPLEMENTAL TERRAIN DESCRIPTION DATA FOR SELECTED AREAS AND SITES

1. The four areas selected for data collection were Barksdale AFB, Louisiana; Fort Hood, Texas; March AFB, California; and U. S. Naval Weapons Station, Seal Beach, California. Brief descriptions of these areas were presented in the main text. This appendix presents descriptions of the physiography, geology, and soils for the selected areas. Potential background noise sources are also identified for data collection sites.

2. Maps indicating the location of the selected data collection sites are presented in Figures E1-E4. The Universal Transverse Mercator (UTM) grid coordinates for the selected sites are presented in Table E1. A discussion of the physiography, geology, and soils is presented in the following paragraphs. Potential background noise sources and their respective distances from the data collection sites are presented in Table E2. The types of sources identified by the alpha-numeric symbols are keyed to the list of potential sources in Table 3 of the main text.

3. Barksdale AFB, Louisiana. The Barksdale AFB reservation is located just east of Bossier City in Bossier Parish, northwest Louisiana. Shreveport, the second largest city in Louisiana (population: 180,000 in 1970), is located across the Red River from Bossier City. Bossier Parish has a total land area of about 2150 km^2 (823 mi^2); an additional 75 km^2 (28 mi^2) are in lakes, streams, and ponds. The Red River forms the western boundary of the parish.

4. Bossier Parish is in the upper part of the western Gulf Coastal Plain, a young coastal plain which grades inland to a mature plain. There are three major physiographic divisions in the parish: the alluvial valley of the Red River, the broad stream terraces that border most major streams (locally known as flatwoods), and the Tertiary uplands of the western Gulf Coastal Plain. The Red River flows southward in a meandering course, covering some 95 km (60 mi) within the parish. Although there are many flat, slowly drained areas, the drainage system is generally well developed. Natural surface drainage is mainly to the south, towards the Gulf of Mexico. All major surface drainage systems in the parish flow to the Red River.

5. Climate in Bossier Parish is influenced principally by its subtropical latitude, the huge land mass to the north, and the proximity of the warm waters of the Gulf of Mexico. Local modifications are caused by variations in topography. Changes in temperature are sometimes extreme. Average yearly temperature at Barksdale AFB is 18.3°C (65.0°F). Average yearly precipitation is 1186 mm (46.7 in.).

6. The three major physiographic divisions of the parish are found in the reservation. The western half of the reservation lies in the alluvial valley of the Red River. Main base installations, e.g., Base Headquarters, runways, ammunition storage areas, etc., are in this western sector. The broad stream terraces are found in the eastern half, between Red Chute Bayou and Flag Lake in the northern sector and in the southeastern sector of the reservation. The Tertiary uplands are located in the northeast sector of the reservation. Most of the highlands in the eastern half are in forest. Surface drainage in the reservation is generally from north to south. Topographic elevations range from 61 m (200 ft) to 91^{+} m (300 ft) in the eastern sector of the reservation to 48± m (160± ft) in the western alluvial plain. The highest elevations (104^{+} m) are found in the northeast sector.

7. Surface geology of the reservation is relatively simple. Recent alluvium is found in the western half, i.e. in the Red River alluvial valley and the flood plain of Fifi Bayou. Pleistocene terrace deposits of the Prairie Formation are found in the highlands between Red Chute Bayou and Fifi Bayou. These terrace deposits consist mostly of sparsely graveliferous quartz sand and clay with maximum elevations of about 67 m (220 ft). Undifferentiated Pleistocene terrace deposits consisting mainly of quartz and ironstone gravel, quartz sand, and clay are found in the southeast sector of the reservation, at elevations ranging from 60 m (200 ft) to 122 m (400 ft). Massive to cross-bedded quartz sands of the Carrizo Formation (Eocene) overlie lignitic sands and silty clays of the undifferentiated Wilcox Group in the northeast sector of the reservation. The younger Carrizo Formation is found at elevations greater than 91 m (300 ft). Strata of the Carrizo Formation

and the undifferentiated Wilcox crop out in the vicinity of the Sligo oil and gas field, where they form the Tertiary uplands.

8. The pedogenesis of soils reflects the physiographic and geologic characteristics of the region. Accordingly, three main types of pedological conditions can be recognized in the reservation: soils of the Red River alluvial valley, soils of the Pleistocene terrace deposits, and soils of the Tertiary uplands.

a. Soils of the Red River alluvial valley: these alluvial soils occupy the western half of the reservation. They consist mainly of stratified reddish-brown to dark-brown and dark-gray to gray silty clay or clay (CH-MH), silt loam (CL-ML), very fine sandy loam (ML), silty clay loam (CL), and very plastic (fat) clay (CH). Soil profiles can change very rapidly with location. Local differences in surface elevation ordinarily do not exceed 3 m (10 ft) in the alluvial valley and average less.

b. Soils of the Pleistocene terrace deposits: these soils developed on the stream terrace deposits that are found along the eastern margin of the Red River alluvial valley. Two main pedologic conditions can be recognized: soils that developed on dissected stream terraces and soils that developed on nearly level to very gently sloping terraces. In the first case, the soils consist mainly of dark grayish-brown to red very fine sandy loam (ML) stratified with yellowish-red to red plastic (fat) clay (CH). In the second case, the soils consist mostly of gray to grayish-brown silt loam (ML) over silty clay or clay (CL-CH) and sandy silt (ML) over plastic (fat) clay (CH) or silty clay (CL-CH). Soil profiles vary with location. In the flatwoods, the topography is generally level to gently sloping, except for dissected areas along streams. Local relief seldom exceeds 6 m (20 ft), except along escarpments.

c. Soils of the Tertiary uplands: these soils have developed on the Tertiary uplands of the western Gulf Coastal Plain.

In the Barksdale AFB reservation, two main pedologic conditions can be recognized: soils that developed on gently sloping to rolling uplands and soils that developed on gently sloping to hilly sandy uplands. In the first condition, the soils are mainly yellowish-red to brown fine sandy loam (SM-ML) that contains some ironstone gravel over silty clay or clay (CH-MH) of medium to high plasticity or gravelly fine sandy loam (SM) and silty clay or clay (CL-CH) over stratified sandy clay (SC) and clay (CL). The silty clay or clay contains 10-20 percent of ironstone gravel. In the second condition, the soils consist mostly of brownish-yellow to yellowish-red loamy fine sand (SM) over sandy clay (CL) or clayey-sand (CL-ML) and grayish-brown fine sandy loam (SC) over dark-red fine sandy loam (SM) to sandy clay loam (SM-SC). The topography of the Tertiary uplands is varied; there are gently sloping divides and hilly, broken, strongly dissected escarpments.

<u>Potential background noise sources</u>

9. Seismic and acoustic potential background noise sources present in the reservation can be classified, on the basis of their nature, into cultural and natural. Cultural background noise sources are prevalent in the western half of the reservation, for it is here that most of the buildings and operational activities of the base are found. As previously stated, the western sector of the reservation borders on the urban (industrial and residential) areas of Bossier City. Main base installations, e.g., Base Headquarters, runways, taxiways, parking aprons, ammunition storage areas, etc., are located in the western half. U. S. I-20, U. S. 80, and the Illinois Central Railroad run east-west just north of the reservation. U. S. 71 and the Kansas City Southern Railroad run northwest-southeast along the west margin of the reservation. Several paved and unpaved roads and trails are found in the vicinity of or inside the reservation. Bottom lands of the Red River located north, west, and south of the reservation are generally level and largely used for agriculture. Crop lands and pasture (dairy and beef cattle) are the

main agricultural use. Some of the land inside the western half of the reservation is used for pasture and small (family type) vegetable gardens. Natural background noise sources in the western half comprise primarily the surface drainage features and the vegetative cover, mostly grasslands and shrubs. Deer are fairly abundant in the reservation. Other principal game animals are gray squirrel, fox squirrel, cottontail rabbit, and swamp rabbit. During the winter season, numerous species of ducks and wild geese are common.

10. The uplands and stream terraces are mostly wooded, mixed pine and various hardwoods. A small precentage of these lands is in pastures. A base housing project is located at the southwest end of Flag Lake. There are several oil and gas wells in the east half of the reservation. Other hydrocarbons production related facilities, e.g., separation units, compressors, pipelines, etc., are found in this sector of the reservation. There is a good network of roads in the highlands, mostly related to the oil and gas production activities.

Data collection sites

11. On the basis of the physiographic, geologic, and pedologic diversity found in the reservation and on the basis of the potential background noise sources identified from topographic maps and aerial photographs of the reservation, nine sites were originally selected for the field data collection effort. Seismic refraction surveys were made in all these sites to determine the seismic range in site conditions. Based on the seismic range obtained and on a field reconnaissance of potential background noise sources found in the reservation, three sites were finally selected for detailed seismic and acoustic data collection: Sites 1A, 5, and 7 (Figure E1).

Site 1-A

12. The topographic map elevation is 50 m. This site is located on the west side of the alert area of the airfield. This is a maximum security area protected by intrusion sensing devices. The site is located in the alluvial plain of the Red River, in nearly level to very gently sloping river front lands.

Site 5

13. The topographic map elevation is 61 m. Site 5 is located on the east margin of a light duty road that runs north to the village of Bodcau. The site location is on the dissected stream terrace (Prairie formation) just west of Flag Lake.

Site 7

14. The topographic map elevation is 81 m. Site 7 is located on the south side of a light duty road. The site is located on a gently sloping to rolling Tertiary upland (undifferentiated Wilcox group) of the western Gulf Coastal Plain.

Fort Hood, Texas

General location

15. The Fort Hood military reservation is located in Bell and Coryell Counties of east central Texas. The Main Post area is about 72 km (45 mi) southwest of Waco. The town of Killeen [Population: 35,507 (1970 Census)] borders on the southern boundary of the reservation, just east of the Main Post area. The area of the reservation is 87,131 hectares (217,827 acres). Fort Hood has a good network of all-weather roads; there are paved airfields at North Fort Hood and at West Fort Hood. The commercial airport at Killeen services the Main Post area. With the exception of the North Fort Hood, Main Post, and West Fort Hood cantonment facilities, most of the reservation is unpopulated open range. Access to most areas in the reservation is usually unrestricted to the general public. A large ($23,800^+$ hectares) off-limits impact area is located in the center of the reservation. A map of Fort Hood, excluding the southwestern sector is presented in Figure E2.

Physiography

16. North and east of the Edwards Plateau of Texas is the Central Texas section of the Great Plains physiographic province, a region from which much of the plateau-making limestone strata have been removed. The eastern part of the Central Texas section is a submaturely dissected plateau which extends from Fort Worth south to the Colorado River; the name "Comanche Plateau" has been given to this region. The higher and more sharply eroded western part of the Comanche Plateau has been called

the "Lampasas Cut Plain." The Fort Hood reservation is in the Lampasas Cut Plain. At Fort Hood, the Lampasas Cut Plain consists mainly of a partly dissected plain from which rise remnants of the old plateau. These remnants now stand as sparsely wooded, commanding hills and ridges 30 to 60 m above the general level of the plain. The plain itself is smooth and grass-covered in places and dissected and sparsely wooded in others. The smooth areas are separated by dissected areas that are characterized by V-shaped valleys, 30 to 45 m deep, which slope steeply to narrow bottoms. The terrain varies from gently rolling plains throughout the southern part to fairly high hills and generally broad valleys in the rest of the reservation. Main surface drainage in the southern part is provided by Clear Creek and Nolan Creek. Clear Creek is in the southwest sector and is not shown in the map (Figure E2). The northern portion is drained by Owl Creek, Henson Creek, Turnover Creek, and the Leon River. The reservation is traversed from west to east by Cowhouse Creek which drains the central part. All streams drain into the Belton Reservoir, but are not affected by the level of the lake. Several lakes, 25 hectares or less, are found in the reservation; most of them are artifically impounded. The vegetation includes open grasslands, dense thickets of juniper, other brush, heavy stands of live oak, and moderate stands of post oak and Spanish oak in various combinations. Wooded areas vary in size, type, and density of growth, especially in the vicinity of streams and lakes. The average yearly rainfall at Fort Hood is 772 mm (30.4 in.). Maximum rainfall is in September and May, the minimum is in July. Average snowfall is less than one day/month during December, January, or February. Measurable amounts of snow are rare. The mean annual temperature is 20°C (68°F). Maximum temperatures occur in July and August, at which time the mean miximum is 43.5°C. The coldest months are December and January; mean minimum is 3.5°C.

Geology

17. The surface geology of this area strongly reflects the physiographic conditions described above. The Balcones Fault Zone, with its east-facing fault scarps, runs south from the vicinity of Waco through just west of Austin and generally marks the boundary between the predominately Cretaceous rocks of the Comanche Plateau and the younger Tertiary rocks of the western Gulf Coastal Plain. About 15 km east of the reservation,

in the vicinity of the town of Belton, several north-south trending faults have faulted the exposed Cretaceous strata. No major faults were observed during the field reconnaissance of the reservation; however, several minor faults (e.g., in Cowhouse and Owl Creeks) were seen. Most of the remnants of the old plateau, e.g., Seven Mile Mountain, Black Mountain, Post Oak Mountain, Royalty Ridge, etc., are capped by resistant limestone strata of the Lower Cretaceous Washita Group and the underlying upper part of the Fredericksburg Group. The Comanche Peak Limestone underlies the Fredericksburg Group and, in places, is also found capping some of the highlands, e.g., Blackwell Mountains, Lone Mountain, Dalton Mountains.

18. The Comanche Peak Limestone outcrops extensively along the valleys of Owl and Nolan Creeks, where it overlies the Walnut Clay (Lower Cretaceous). The Walnut Clay is exposed over large areas of the reservation and forms, in most places, the present surface of the partly dissected plain. The Walnut Clay consists mainly of a sequence of clay, limestone, and shale; the limestone is usually chalky or marly, nodular, and contains a few thin (less than 1 m) hard beds rich in sparry calcite. Massive beds of megafossils (Texigryphaea) are common in the lower part of the Walnut Clay. In a normal stratigraphic sequence, the Paluxy Sand underlies the Walnut Clay: however, over much of the reservation, the Glen Rose Formation (Lower Cretaceous) directly underlies the Walnut Clay, which indicates that over much of this area the Paluxy Sand pinches out. The Glen Rose is the oldest formation exposed in the reservation; it consists primarily of a fine grained, in parts arenaceous, chalky to hard limestone with abundant marine megafossils and which is interbedded with less resistant units of clay, marl, and sand. The Glen Rose Formation outcrops extensively along the upper valley of Cowhouse Creek and its tributaries. Several Pleistocene river terrace deposits are found along the valley of the Leon River, and along the valleys of Cowhouse Creek and Table Rock Creek. These deposits consist mainly of fine alluvial sediments (fine sand, silt, and clay); thin beds of gravel (less than 25 cm) are common near the base of exposed sections. Recent alluvium is found in the floodplains of most major streams; these deposits are generally deficient in coarse sand and gravel.

Soils

19. Soils in the reservation range from clay soils (CL or CH) to sandy clay loams (SC), depending on parent material and physiographic position. Residual soils are generally high in fines (clay soils), the amount of coarse material (rock fragments) in the solum varying with topographic position. Residual soils predominate over most of the reservation. Alluvial soils are mainly silty clays (CH), clay loams (CL), silty clay loams (CL), and sandy clay loams (CL-SC); these soils are found in river terrace deposits and in the floodplains of major streams. These alluvial soils are deficient in sand and gravel; a few local gravel deposits were seen during the field reconnaissance. At most five percent of the reservation can be classed as alluvial soils. The soils at Fort Hood are usually dark brown in the deeper solums and light brown to yellowish-brown in the shallower soil cover of steep and high lands. The darker soils are generally high in fat clays (CH), especially of the montmorillonite type. These clays expand or contract excessively with increases or decreases in moisture. Most valley walls and slopes have very little soil cover; bedrock is frequently exposed. Shallow, stoney clay soils (GC), often less than 15 cm deep, develop in hills and ridges from weathered limestone.

Potential background noise sources

20. On the basis of their nature, seismic and acoustic potential background noise sources can be classified into cultural and natural. At Fort Hood, cultural background noise sources are prevalent in or near developed or urban areas, e.g., the North Fort Hood, Main Post, and West Fort Hood cantonment facilities. U. S. and State highways, e.g., U. S. 190 and State 36, and railroads, e.g., the Atchinson, Topeka, and Santa Fe, cross the reservation and are open to unrestricted traffic. Highway traffic is normally light, except during the morning and evening rush hours. Most of the reservation lands are relatively undeveloped; natural background noise sources predominate in these areas. However, military training operations and tactical exercises can intermittently and very pronouncedly disrupt natural conditions, especially in the large impact area located in the center of the reservation.

Data collection sites

21. Based on previous REMBASS field studies conducted by WES at Fort Hood, and on the evaluation and analysis of the terrain data obtained from available literature sources, 16 field sites were considered and visited prior to the final selection of sites for the field data collection effort. Of these, three sites were selected as being representative of the environmental range of variation found in the reservation: Sites 5A, 8A, and 9.

Site 5A

22. The topographic map elevation is 305 m. The site is located just south of Elijah Road, in the west-central part of the reservation. The site is on a partially dissected area which developed on the Walnut Clay.

Site 8A

23. The topographic map elevation is 284 m. The site is located northeast-southwest on a flat hill which lies between the north and south forks of Nolan Creek, in the southeastern part of the reservation. The flat hill is a tableland developed on Lower Cretaceous limestone (Duck Creek Limestone?)

Site 9

24. The topographic map elevation is 232 m. The site is located northwest-southeast along a tank trail on the north or left bank of North Nolan Creek, in the southeastern part of the reservation. The site is in the floodplain of North Nolan Creek.

March AFB, Riverside, California

General location

25. Base Headquarters facilities are located 2 km south of the town of Edgemont, which is about 8 km southeast from downtown Riverside. The Escondido Freeway (U. S. 395) and the Atchison, Topeka, and Santa Fe Railroad run northwest-southeast through the reservation, the larger sector of the reservation being west of the freeway. Base Headquarters and airfield facilities are located in the eastern sector. A base

residential area (Arnold Heights) is located about 0.5 km west of the airfield, across the Escondido Freeway. The estimated area of the reservation is 3250 hectares (32.50 km^2). There is a good network of all weather roads in and around the reservation.

Physiography

26. The reservation is located in the Los Angeles Ranges section of the Pacific Border physiographic province; this section is characterized by narrow ranges and broad fault blocks with interspersed alluviated lowlands and isolated hills or groups of hills. The so-called "Valley of Southern California" consists of all the lowlands between the San Gabriel and the San Bernardino Mountains on the north and east, the San Jacinto and the Santa Ana Mountains on the south, and the Pacific Ocean on the west. Southeast of the Santa Ana River, a valley nearly 40 km wide between the San Jacinto and the Santa Ana Mountains extends to the southeast for at least 65 km. Broad irregular belts of alluvium occupy a part of this area, the remainder of which is diversified by hills and low mountains. The name "Perris Plain" has been given to the main alluvium covered area. As seen from the mountains on either side, the surface of this valley, a down-faulted block or graben, is a lowland. The eastern sector of the reservation is in the Perris Plain. Most of the western sector lies on hills which border the alluvial plain.

27. There are no perennial streams in the reservation. The western sector is drained mainly by intermittent streams which flow into the Gage Canal or into Lake Mathews, a reservoir located about 10 km southwest of the reservation. The eastern sector is drained by intermittent streams which either disappear in the alluvial fill of the graben or flow into the Perris Valley storm drain. The average yearly precipitation at March AFB is 230 mm. The wettest month is January. The driest month is August. The mean yearly temperature is 17°C. The mean yearly maximum is 24.5°C. The mean yearly minimum is 9.5°C.

Geology

28. As previously stated, the reservation is in a down-faulted block or graben which lies between the San Jacinto Mountains and the Santa Ana Mountains. The general trend of the graben is northwest-southeast; the San Jacinto Fault Zone is on the north side of the graben

and the Elsinore Fault Zone on the south. No faults have been mapped in the reservation. The eastern sector and a strip 1 to 2 km wide located west of the Escondido Freeway (Highway 395) are in the Recent alluvial fill. Most of the western sector lies on hills composed of Mesozoic tonalite (quartz diorite) and diorite. The Recent alluvial deposits are generally unconsolidated. A depth greater than 400 m has been reported for the alluvial fill in this area.

Soils

29. The soils at the reservation consist of soils developed on the alluvial fill (San Joaquin loam and sandy loam) and residual soils developed on the abyssal rocks (Holland sandy loams). The soils of the alluvial fill are mainly loams (ML and CL) and sandy loams (SM and SC). These soils are red to light red in color, with variations of yellowish-red, brownish-red, or pronounced reddish-brown color. The soils are underlain at depths ranging from a few centimeters to a meter by a red or reddish-brown, practically impervious hardpan. The hardpan varies in thickness from a few centimeters to as much as 2 m. It consists of materials similar to the overlying subsoil, cemented by precipitation of iron salts carried in solution by percolating water. The hardpan is generally underlain by a more permeable substratum which resembles the surface material. These soils are low in organic matter, contain little or no concentration of lime, and have a tendency to bake and become hard during extended dry periods. The surface is generally marked by conspicuous low mounds and intervening shallow depressions or "hog wallows." Owing to the impervious hardpan and to the accumulation of surface water in the depressions, the soils become wet and boggy after heavy or prolonged rains. The residual soils develop on the abyssal rocks (tonalite and diorite) and consist primarily of sandy loams (SM and SC). Residual soils range in color from dark brown or brown to slightly reddish-brown. The solum sometimes extends to bedrock with little change, but in most places the surface soil is underlain by a subsoil somewhat redder in color, heavier in texture and more compact, which passes at a depth of less than 2 m into partly weathered rock material and then into solid rock. These residual soils are found on hilly to mountainous topography;

a stony sandy loam (GC), common on hill tops and slopes, contains considerable quantities of rock fragments. Rock outcrops are also common in these areas.

Potential background noise sources

30. On the basis of their nature, potential seismic and acoustic background noise sources at March AFB can be classified into cultural and natural. Cultural background noise sources predominate in the eastern sector of the reservation, i.e., the area east of the Escondido Freeway (U. S. 395), for it is here that the airfield and Base Headquarters facilities are located. In addition, frequent landings and takeoffs of aircraft and low overhead flights augment the mix of cultural background noises. The Escondido Freeway is heavily traveled, especially during the morning and evening rush hours. The western sector is also exposed to a fairly heavy concentration of cultural background noises, especially in the vicinity of the freeway and the Arnold Heights base residential area. The northwestern and southwestern areas of the reservation have the lowest concentration of cultural background noise sources and, consequently, natural background noises predominate in these areas; however, even in these two areas, the mix of background noises can be seriously and intermittently affected by activities in nearby orchards, in the weapons storage area, and in several gravel pits located in the southwestern part of the reservation.

Data collection sites

31. Two sites were selected at March AFB for field data collection. Table E2 provides a listing of potential background noise sources identified within given distances from each field data collection site.

Site 1

32. The topographic map elevation is 451 m. The site is located at the southeast end of the runway, off a taxiway. The site is on the alluvial fill which blankets the graben in this area. Boring records in the vicinity of this site show 90 cm of sandy loam (SM), 140 cm of sandy clay loam (CL), and 75 cm of sandy loam (SM). Total depth of the bore hole is 3.05 m (10 ft).

Site 2

33. The topographic map elevation is 521 m. The site is located on the northwest side of a light duty road to the weapons storage area. The site is on residual soil with abundant rock fragments, which developed on a hill underlain by tonalite (quartz diorite).

U. S. Naval Weapons Station, Seal Beach, California

General location

34. The reservation is located in Orange County. It is bounded on the north by the San Diego Freeway (U. S. 405), on the east by the Bolsa Chica Channel, on the south by the Bolsa Chica Channel and the Pacific Coast Highway (State 1), and on the west by Bay Boulevard and Los Alamitos Boulevard. The reservation is in the middle of a very highly developed area. Los Alamitos Naval Air Station is just north of the station, directly across the San Diego Freeway; the city of Garden Grove borders on the east, Huntington Beach on the east and south, and Seal Beach on the south and west. Huntington Harbor, an industrial area and protected harbor, and its industrial canal are immediately south of the reservation. The Pacific shoreline is 0.5 to 15 km from the southern boundary of the reservation. Major oil fields are located 3 to 7 km west and south of the reservation. Westminster Avenue separates the northern one-third of the station from the rest of the reservation. Administrative facilities are situated in the western sector (Landing Hill area). An intricate network of railroad spurs services the various storage areas. The estimated area of the reservation is 1920 hectares (19.20 km^2). Of these, about 260 hectares are in a tidal marsh.

Physiography

35. The U. S. Naval Weapons Station is located in the Los Angeles Ranges section of the Pacific Border physiographic province. This physiographic section is characterized by narrow mountain ranges and broad fault blocks which contain extensive alluviated lowlands and many subdued ridges, isolated hills or knobs, and groups of hills. The hills and ridges subdivide the lowlands into more or less distinct valleys or

basins. The largest continuous lowland or "plain" in central-southern California is the Coastal Plain on which Los Angeles is situated. It extends along the Pacific Coast from the Santa Monica Mountains on the northwest to the San Joaquin Hills on the southeast, a distance of 80 km; its width from the sea back to the Puente Hills varies from 24 km to 32 km. Its area is approximately 2000 km^2.

36. The Coastal Plain is a smooth broad plain that slopes gently in a southwesterly direction to the Pacific Ocean. The greater part of this plain, located between Los Angeles and Wilmington and eastward to the vicinity of Whittier, Yorba Linda, and Santa Ana, consists of low alluvial fan deposits and the combined alluvial delta deposits of the Los Angeles, San Gabriel, and Santa Ana rivers. These are mainly detrital deposits washed down from the surrounding hills and mountains. Near the shoreline, the alluvium has been to some extent worked over and redeposited by wave action. Areas of eroded remnants of older waterlaid deposits (fluviatile and/or marine) occur as flat topped to rolling mesas in and around the margins of the coastal plain. The lower and flatter portions of the plain are poorly drained. The streams of the coastal plain are actively degrading their mountain courses and aggrading their valley reaches with great rapidity. The larger streams have more or less continuous channels reaching to the sea, but all such streams are interrupted, i. e. their courses consist of alternating dry washes and flowing water. The lower reaches of the Los Angeles, San Gabriel, and Santa Ana Rivers have been altered and channelized. Near the coast, these rivers and their related man-made channels, e.g., the Bolsa Chica Channel, are affected by tidal water levels. Several natural, tidal marshes originally existed in the stretch of coast from San Pedro southeast to Newport Bay. Many of these marshes have been filled and reclaimed or otherwise altered for the development of industrial areas, harbors, and seaside resorts. A belt of sand beach, some of it artificially protected and maintained, extends from Long Beach to Newport Beach; parts of this belt are subjected to periodic inundations during high tides and stormy periods.

37. The Naval Weapons Station is located in the section of the Coastal Plain that developed between the San Gabriel and Santa Ana Rivers. The northern sector of the reservation is mantled by generally undisturbed coastal plain sediments; the southern sector has been greatly altered by land fills and other reclamation projects. A relatively undisturbed tidal marsh covers most of the southwestern section of the reservation. The topography of this marsh ranges from flat to depressed; sloughs and estuaries drain the marsh. High tides inundate the marsh and cause the terrain to be water-logged most of the time. The topography of the reservation slopes gently to the southwest, from 6 m at the northeast cor r to sea level at the tidal marsh. Landing Hill, a nonmarine terrace deposit in the southern part of the western boundary, has a topographic elevation of 17 m. The average yearly precipitation at the Los Alamitos Naval Air Station is 250 mm. January is the wettest month, June is the driest. The mean yearly temperature is 16.5°C. The mean maximum is 22°C; the mean minimum is 10.5°C.

Geology

38. The shoreline throughout this section of coast shows evidence of recent emergence. Remnants of older shorelines are found along the present coastline, north and south of Seal Beach. The Seal Beach Fault trends NW-SE across the reservation and closely parallels the present shoreline. This fault is part of the Newport-Inglewood Fault Zone, well known for the Long Beach earthquake of March 1933. The Seal Beach Fault cuts across Landing Hill and may have displaced the north-south trend of the hill. Land reclamation projects and the high industrial development of this area have distorted the original terrain conditions. Most of the reservation is mantled by Recent deposits; these include floodplain deposits, marsh deposits and, in reclaimed areas, artificial fill. Landing Hill is a Quaternary nonmarine terrace deposit. Major oil fields and production facilities are located a few kilometers west and south of the reservation. The geology of these fields is directly related to major faulting in this area.

Soils

39. Most of the reservation is covered by clay loams (CL-CH) and clays (CH) of the Chino soil series. The clay loam is dark-gray or black, usually high in organic matter and of a smooth silty texture. It is commonly micaceous and somewhat friable; it tends to puddle when wet and has a tendency to bake and harden when exposed and dry. Material similar to the surface soil may extend two or more meters in depth; in most areas, however, the lower part of the soil profile consists of brown or grayish-brown to gray layers of material varying from fine sand to silt and clay. The lighter textured strata are usually of a pronounced brownish color and are friable and porous. The layers of heavier texture have a darker color, are more compact, and generally contain small lime concretions or nodules. In poorly drained areas, the subsoil is mottled gray, brown, and yellow. In the vicinity of tidal marshes, the subsoil is a compact gray or drab mottled silty clay or clay, commonly high in marine salts and small marine shells. The Chino clay is generally black in color and rests upon a rather heavy, compact dark-colored calcareous subsoil. The organic content of this clay is high and its surface frequently cracks during dry periods. Shallow, basin-like depressions with sluggish drainage are common near the coast; a high water table is characteristic of these areas. The wet and marshy areas contain accumulations of alkali. Two main soil types of the Ramona soil series are found in the Landing Hill area, a sandy loam (SM-SC) and a clay loam (CL). The sandy loam is the surface soil on the east-west trending southern part of the hill; the surface soil on the northeast-southwest trending northern part of the hill is clay loam. The sandy loam is brown to reddish-brown, light to medium textured, and frequently contains small, angular rock particles that give it a gritty feel. It is underlain by a compact clay loam which is normally redder than the surface soil and which becomes hard and flinty where exposed. The clay loam is usually encountered at 25 to 60 cm below the surface. At varying depths, generally about 2 m, the clay loam merges into a more permeable stratum that closely resembles the surface soil in texture and color. The Ramona clay loam is a brown to dark-brown, light to heavy micaceous clay loam, 25 to

50 cm deep. This clay loam is compact and sticky when wet and hard and flinty when dry. The subsoil is usually redder than the surface soil; it is more dense and compact and ranges in texture from heavy clay loam to clay. At a depth of 120 to 150 cm, the soil profile changes to a stratum that is lighter in color and texture, which frequently contains stratified fine gravel, and which may be several meters deep.

40. The soils of the tidal marshes vary in texture from sand to clay. The sand content increases near the ocean. The surface soil color varies from brown or dark-grayish brown to dark gray. The subsoil also exhibits a considerable variation in texture. In most places, the subsoil is mottled and contains calcareous nodules and partially decomposed vegetation. These soils are water-logged most of the year and contain a considerable amount of salt.

Potential background noise sources

41. Cultural background noise sources predominate at the Naval Weapons Station. As previously stated, the reservation is in the middle of a highly developed area. It is surrounded by several highly urbanized and industrial areas. Its proximity to the Huntington Harbor and the Pacific Ocean makes it very susceptible to marine traffic induced background noises, especially in the southern sector of the reservation. Oil wells and pipelines in the reservation, and nearby oil fields, further increase the mix of cultural background noises. Intermittent air traffic at Los Alamitos Naval Air Station is a significant contributing factor to the cultural background noise mix. Heavily traveled highways and boulevards, e.g., the San Diego Freeway, also contribute to the mix of background noises.

Data collection sites

42. Based on the seismic and acoustic background noise studies conducted at Barksdale AFB, Fort Hood, and March AFB, on the range of environmental variation established for military installations in CONUS, and on a field reconnaissance of the reservation, four sites were selected at the Naval Weapons Station for field data collection. Table 1 has a listing of potential background noise sources identified within a given distance (e.g. 0.5 km) from each field data collection site.

Site 1

43. The topographic map elevation is 1.50 m. The site is located on the east side of a road in the tidal marsh, near an oil well pump and storage tanks. Three small diameter pipelines run along the east shoulder of the road. The site is in a tidal marsh developed on the coastal plain, about 3 km east of the San Gabriel River.

Site 2

44. The topographic map elevation is 2.70 m. The site is located between two roads and a railroad spur. The site is on the coastal plain modified by land fill.

Site 3

45. The topographic map elevation is 1.50 m. The site is on the east side of a road. The site is on a land filled area of the coastal plain.

Site 4

46. The topographic map elevation is 4.50 m. The site is located near the northern boundary of the reservation, just south of the San Diego Freeway. The site is on a relatively undisturbed area of the coastal plain.

Table E1

Universal Transverse Mercator (UTM) Coordinates of Data Collection

Military Reservation	Site No.	UTM Grid Coordinates
Barksdale AFB, Louisiana	1A	3618, 9672
	5	4413, 9830
	7	4892, 9625
Fort Hood, Texas	5A	0620, 5204
	8A	3106, 4502
	9	3401, 4666
March AFB, California	1	7736, 4744
	2	7137, 5193
Seal Beach Naval Weapons Station, California	1	0006, 3392
	2	0212, 3404
	3	0111, 3324
	4	0190, 3725

Table E2

Potential Background Noise Sources for Data Collection Sites

Area	Site No.	Potential Background Noise Sources Between Indicated Distances from Site*					
		0.0-0.5 km		0.5-1.0 km		1.0-2.0 km	
		Cultural	Natural	Cultural	Natural	Cultural	Natural
Barksdale AFB, La.	1A	4,8,9, 10,30	6N,7N	1,2,4,8, 9,10,14, 26,30,31	6N,7N	1,2,3,4, 5,7,8,9, 10,12,14, 21,26,27, 30,31	6N,7N, 16N
	5	9,10	6N,15N, 16N	2,9,10, 30	6N,8N, 15N,16N	2,3,5,10, 21,30	6N,7N, 8N,15N, 16N
	7	9	15N	9,10,21, 30	15N	9,10,18, 21,30	6N,15N, 16N
Fort Hood, Texas	5A	9,10	6N,16N	9,10,16 17	6N,15N, 16N	8,9,10, 11,16,19	6N,8N 15N,16N
	8A	9,10	6N,15N, 16N	[illegible],10	6N,15N, 16N	9,10,18,	6N,8N, 15N,16N
	9	8,10	6N,7N, 15N,16N	8,9,10	6N,7N 15N,16N	8,9,10, 30	6N,7N, 8N,15N, 16N
March AFB,	1	4,9,10, 30	16N	4,9,10, 22	6N,16N	2,3,4,7, 9,10,14, 22,26,30	6N,16N
	2	2,9,10, 18,30	6N,16N	2,8,9, 10,14,18, 30	6N,16N	3,8,9,10, 11,14,18, 22,30	6N,15N, 16N

(Continued)

* Alpha-numeric symbols are related to background noise sources in Table 3 of main text

Table E2 (Concluded)

Area	Site No.	Potential Background Noise Sources Between Indicated Distances From Site*					
		0.0-0.5 km		0.5-1.0 km		1.0-2.0 km	
		Cultural	Natural	Cultural	Natural	Cultural	Natural
Seal Beach	1	3,9,21	6N,7N, 8N,16N	1,3,8,9, 30	6N,7N 8N,16N	1,2,3,6, 8,9,10, 21,27,30, 31	6N,7N, 8N,16N
	2	3,9,10, 14,30	6N	3,9,10, 14,30	6N,16N	1,2,3,6, 8,9,10, 27,30,31	6N,16N
	3	9,30	6N,7N, 8N,16N	3,6,9, 10,30	6N,7N, 8N,16N	1,2,3,6, 8,9,10, 21,30,31	6N,7N, 8N,16N
	4	1,3,7, 9,14,30	16N	1,3,5, 7,9,14, 30	6N,16N	1,3,4,5, 7,8,9,10, 13,30,31	

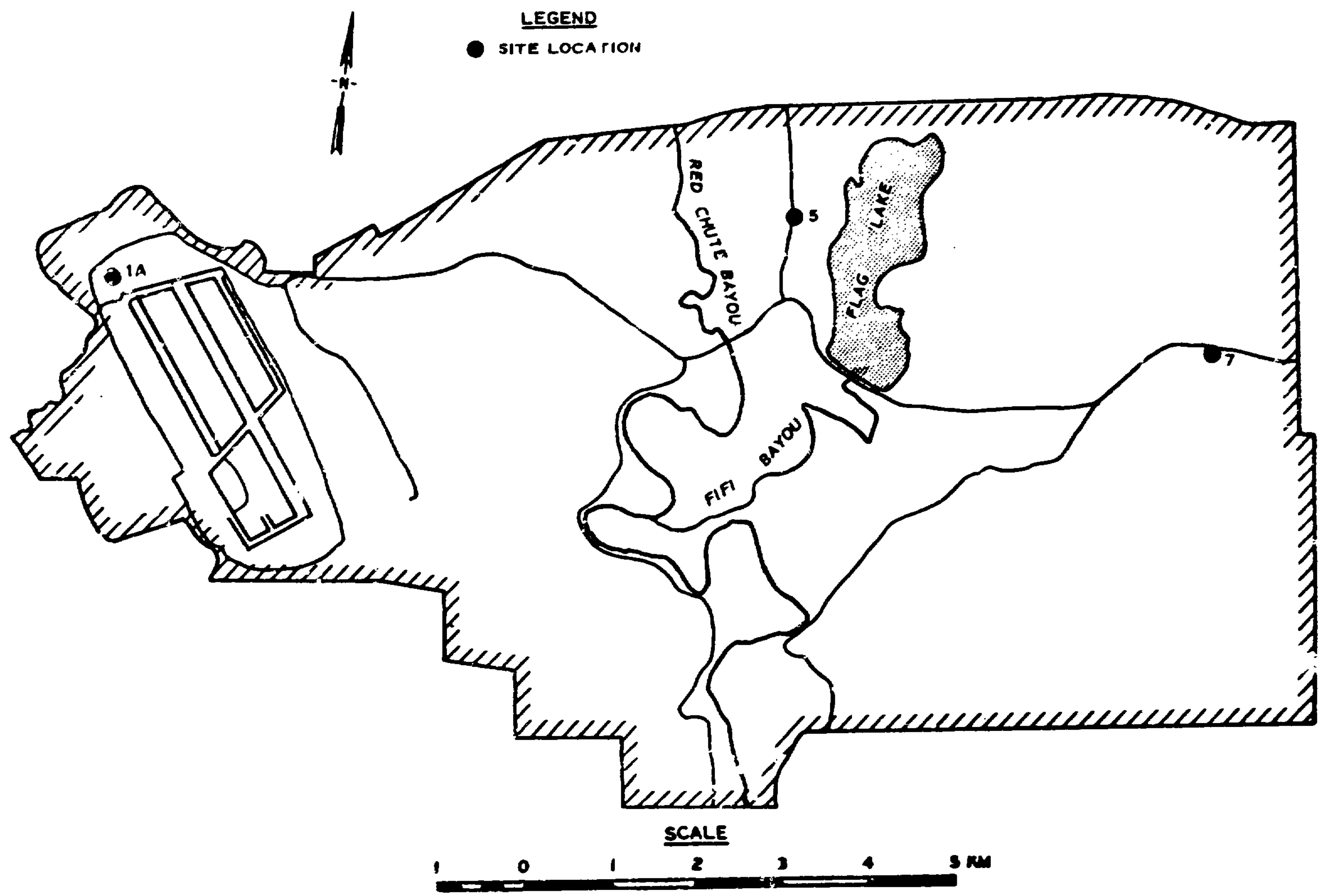


Figure E1. Site locations at Barksdale AFB, Louisiana

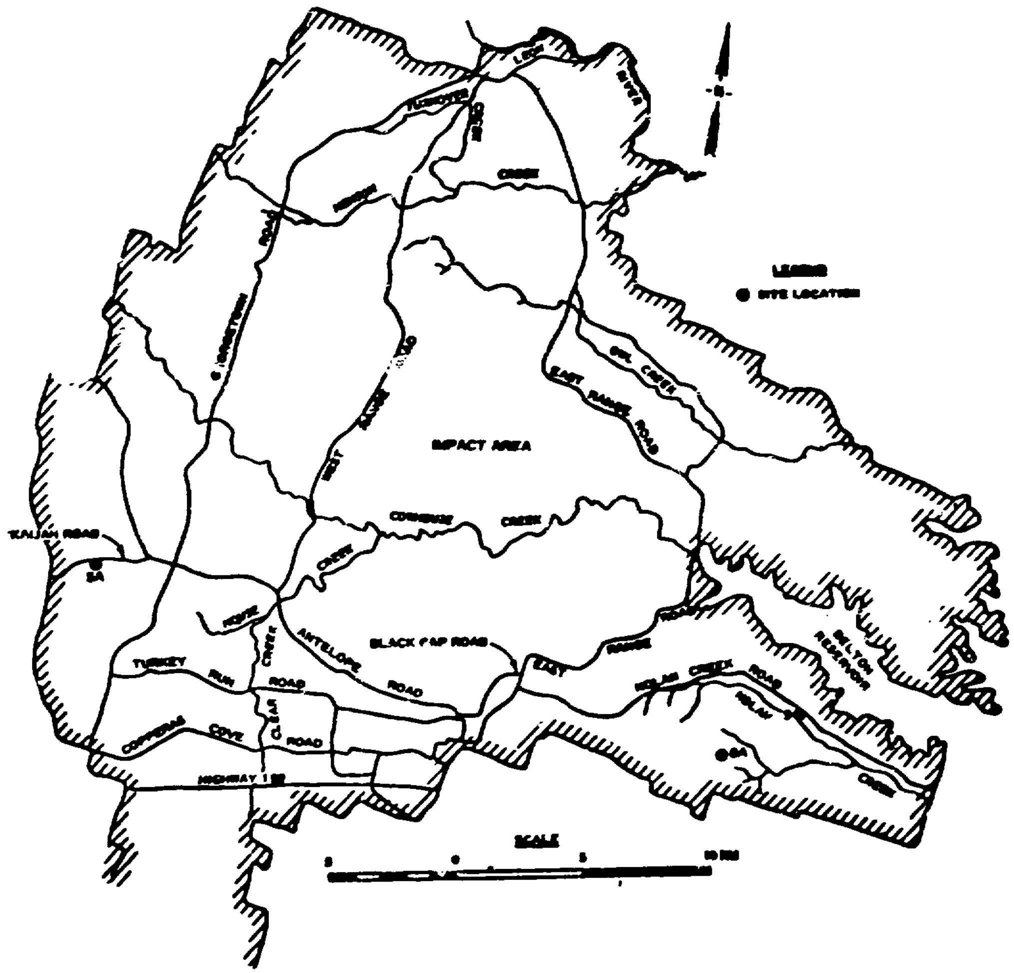


Figure E2. Site locations at Fort Hood, Texas

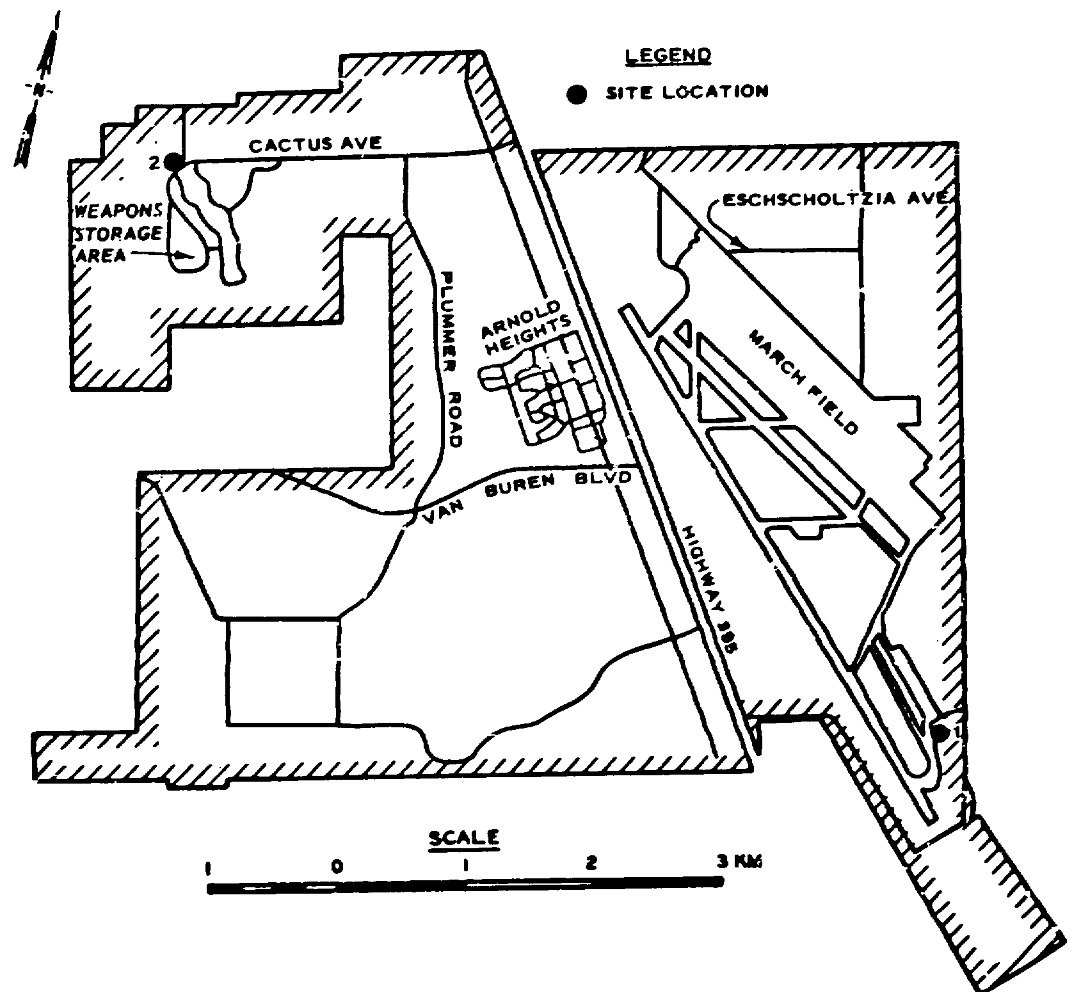


Figure E3. Site locations at March AFB, California

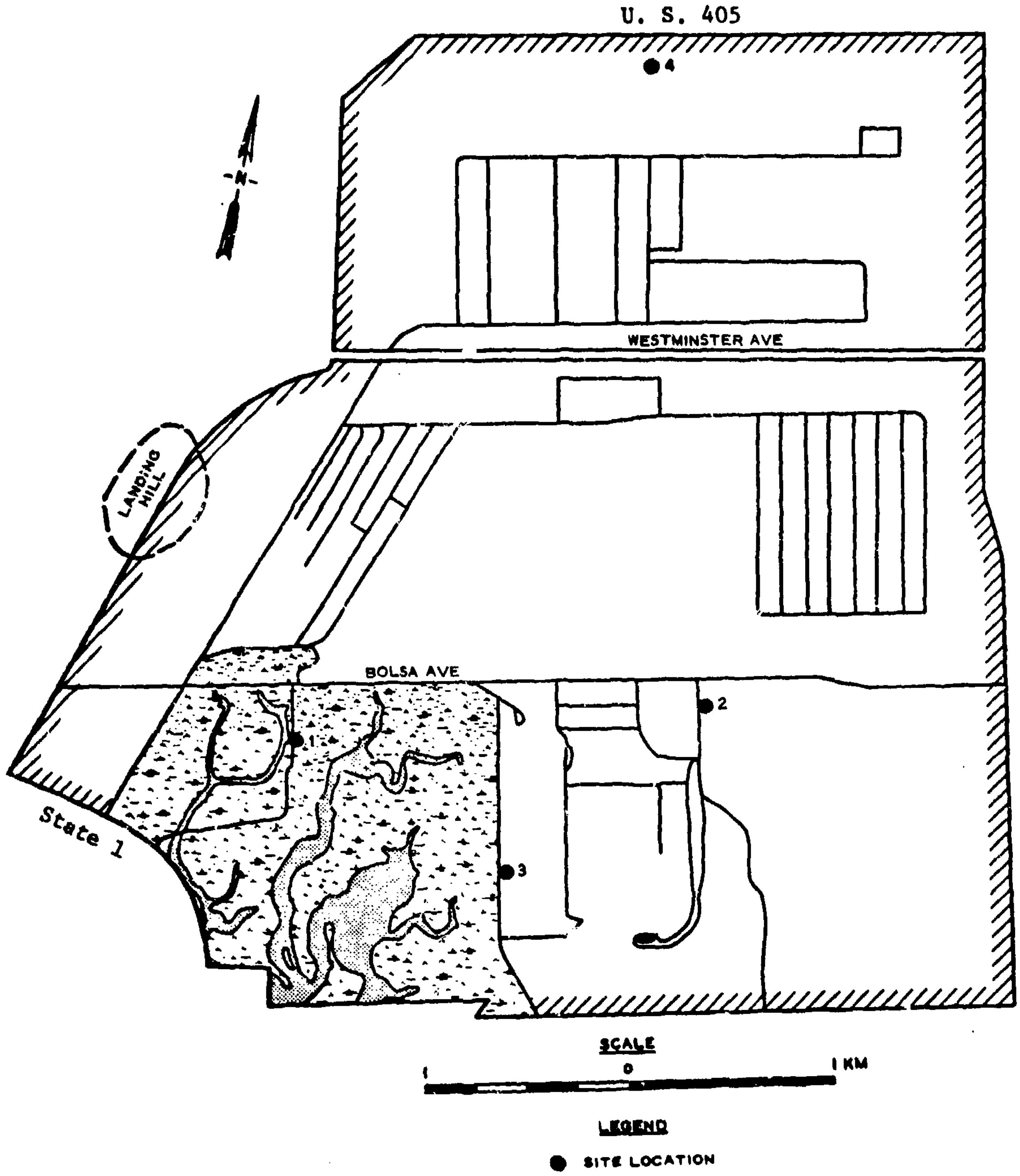


Figure E4. Site locations at Seal Beach Naval Weapons Station, California

APPENDIX F: INDEX OF MEASURED SIGNATURE DATA

1. This appendix presents an index of the measured signature data collected during this study. The objective of the index is to organize the data according to the data collection variables defined by area, site, target type, and travel mode and to relate these variables to the analog tape numbers and test numbers of the data. Other information such as sensors used and notable background noise sources are also presented.

2. Table F1 identifies the measured signature data. Abbreviations are used to condense the information. For example, under target type, targets are identified as background noise (B.N.), defined to be signature sources whose presents or location was not controlled during testing. Military vehicles that appear in the table and an associated description are tabulated below:

Vehicle	Description
M151	1/4-ton truck
M113	Armored personnel carrier
M35	2 1/2-ton truck
M60	Armored tank
Blazer	Chevrolet, 4-wheel drive
1600	International dump truck
Van	WES, Instrumentation van

Aircraft appearing in the table and associated description[20] are tabulated below:

Aircraft	Description
Cobra AH-1G	Turbine-powered helicopter
Chinook CH-47C	Turbine-powered helicopter
Kiowa OH-58A	Turbine-powered helicopter
Lear jet (240)	Two engine, jet-powered aircraft
C130	Four engine, propeller driven, turbine-powered aircraft
T-37	Two engine, jet-powered aircraft
B-52	Eight engine, jet-powered aircraft
KC-135	Four-engine, jet-powered aircraft

Multiple targets of a different type, such as an M151 and man, are identified under the target-type column by M151/Man.

3. Target-travel mode defines the method of movement of personnel or the vehicle speed. Methods of movement of personnel are identified by the symbols C, CR, W, RN denoting creep, crawl, walk, and run, respectively. Several tests may occur having the same vehicle type or personnel travel mode. This occurs because tests were repeated, different individuals were used as targets, or different vehicle speeds were run. In the latter instances the speeds are separated by commas in the target-travel mode column. When multiple targets are involved, such as M151/Man, the travel mode is identified in a form like 8, 16, 32/W. Such a format means that the multiple targets were an M151 and Man. The M151 moved at speeds of 8, 16, and 32 km/hr while the man walked along the personnel path.

4. Sensors for the respective tests are identified by abbreviations. The abbreviations are associated sensor type are tabluated below:

Abbreviation	Sensor
V	Vertical-sensing geophone
RN	Radial-sensing geophone (i.e. in direction along linear portion of personnel path, Figure 1)
T	Tranverse-sensing geophone (i.e. perpendicular to vertical and radial-sensing geophones)
M	Microphone
MC	Miles cable
MAG	Magnetic sensor

Repeated sensor abbreviations mean that more than one sensor of the same kind (i.e. vertical-sensing geophones, etc.) were used or that signatures from the same sensor were recorded on different channels (for example, in the FM recording mode on one channel and the direct recording mode on another). The field data logs can be used to identify the recording configuration for repeated sensor abbreviations (Appendix A).

Table F1

Signature Data

Area	Site No.	Target Type*	Target Travel** Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Barksdale AFB, La.	1A	BN		V, R, R, V, M, M, MC	Lec-82	150-161	B52, Lawn Mower, Generators, Fire Truck, Train
		Man	W	V, R, T, V, MC, M	Lec-83	162-165	Automobile (Station Wagon)
		Man (3)	W			166-167	
		BN				168	Train, B52
		Man	C			169-173	B52
		Man (3)	C			174-175	
		Man	C			176	
		Man	RN			177-181	
		Man (3)	RN			182-183	KC135
		Man	CR			184-185	
		Man (3)	CR			186	
		BN		MAG, M, V, MC, M		187-189	Trains, Jet Aircraft
		BN		V, R, V, V, M, M, MC		190	Electromagnetic, from lights
		BN				191-194	B52, KC135, Generator, T37, Train
		M151	8, 32	V, R, T, V, M, MC	Lec-84	195-196	Man, Aircraft (Jet)
		M151	32			197	
		M151/Man	32/W		Lec-85	198-199	
		M151/Man	32/CR			200	
		M151/Man	32/RN			201	Aircraft (Jet)
		M151/Man	32/CR			202	

(Continued)

* Numbers in parentheses indicate number of targets (information is presented only when the number of targets exceeds one).
** Numerical values denote vehicle speed in KPH.

(Sheet 1 of 12)

Table 71 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Barksdale AFB, La.	1A	M35	8	V, R, T, V, M, MC	Lec-85	203	Vehicle, KC135
		M35	32			204	B52, KC135
		M35/Man	32/W			205	
		M35/Man	32/CR			206	
		M35/Man	32/RN			207	
		M35/Man	32/CR			208	
		Man	W	MAG, MC, V, V, MC, M		209	
	5	Man	W	V, R, T, V, V, M	Lec-78	1-8	B52 (5000 ft above surface), Wind (8-16 KPH)
		Man (3)	W			9	Light Truck
		BN				10	B52
		Man (3)	W			11	
		Man	W			12	
		BN				13	KC135, Truck, Lowboy
		Man	W			14	
		BN				15	KC135
		Man	W			16	
		BN				17-18A	Aircraft (2 Jets), B52, Light Truck
		Man	C			19-22	Light Truck
		Man (3)	C			23-24	
		Man	CR			25-28	
		Man	RN			29-32	
		Man	RN			33-34	

(Continued)

(Sheet 2 of 12)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Barksdale AFB, La.	5	Man (3)	CR	V, R, T, V, V, M	Lec-78	35-36	
		BN				37	Automobile, Light Truck
		Man (6)	W	V, R, T, V, M, M		38-41	
		Man	C			42-43	
		Sweep Generator				44-45	
		M151	8, 32			48-51	
		M151/Man	8, 16, 32/W		Lec-79	52-56	
		M151/Man	8, 32/C			57-58	
		M151/Man	32/C			59	
		M35	8, 32			60-63	1/2-Ton Truck
		M35/Man	32/W			64	Aircraft (Jet)
		M35/Man	32/CR			65	
		M35/Man	32/CR			66	
		M151/Man	32/CR			67	
		Bulldozer				68	Dump Truck
		BN				69	
		BN			Lec-80	70	C130, Light Rain
	6	BN				71-87	Train, C130, B52, Vehicle KC135
	7	BN			Lec-81	88-100	Rain, Tractor, Vehicle B52, KC135
		1600	8, 32			101-102	Logging Truck
		1600/Man	8, 32/W			103-104	
		1600/Man (3)	8, 32/W			105-106	

(Continued)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Barksdale AFB, La.	7	1600/Man	8, 32/C	V, R, T, V, M, M	Lec-81	107-108	
		BN				109	Rain
		1600/Man (3)	8, 32/C			110-111	
		BN				112	Light Truck (approximate speed, 30 KPH)
		1600/Man	8, 32/RN			113-114	
		1600/Man (3)	8, 32/RN			115-116	
		Van	8, 32			117-118	
		Van	8, 32				
		Van/Man	8, 32/W			119-120	
		Van/Man	8, 32/C			121-122	
		Man	RN			123-124	Aircraft (Jet)
		BN				124A	Train
		Van/Man	8/RN			125	
		Van/Man (3)	8, 32/W		Lec-82	126-127	
		Van/Man (3)	8, 32/C			128-129	
		Van/Man (3)	8, 32/RN			130-131	
		Man	W			132-136	Aircraft (Jet)
		Man (3)	W			137-140	Light Truck, 40 KPH
		Man	C			141-145	Truck
		Man (3)	C			146-147	
		BN				148	
		Man	RN			149-152	Aircraft (Propeller)
		Man (3)	RN			153-154	
		Man	CR			155-157	

(Continued)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Fort Hood, Texas	5A	BN		V, R, T, V, V, M	Lec-85	1-2	Aircraft (Propeller), Light Truck, Helicopter, Automobile, Man, Wind 13 KPH, Tank M60
		Man	W			3-8	Helicopter
		Man (3)	W			9	Helicopter
		Man	CR			10-11	
		Man (3)	CR			12	Truck
		Man	RN			13	
		BN				14	Mil Truck, Wind 13-14 KPH
		Man				15	
		Man (3)	RN			16	
		BN				17-18	APC M113
		Man	C			19-21	
		Man (3)	C			22	
		M35	8, 32			23-26	Wind 16-27 KPH
		M35	8, 32		Lec-86	27-29	Automobile
		M35/Man	32/CR			30	
		M35/Man	32/W			31	
		M113	8, 32			32-34	
		M113/Man	32/C			35	
		M113/Man	32/W			36	
		M60A1	8, 32			37-38	
		M60A1/Man	32/C			39	
		M60A1/Man	32/W			40	
		M151	8, 32			41-42	

(Continued)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Fort Hood, Texas	5A	Helicopter, OH58	110	V, R, T, V, V, M	Lec-86	43	
		M151/Man	32/C			44	
		M151/Man	32/W			45	Wind 6-13 KPH
		M151				46	
		Helicopter, OH58	110			47	
		M151	32			48	Helicopter (AH1 Cobra)
		BN				49-50	Auto, Helicopter, Light Truck
		Blazer	8, 32			51-52	
		Blazer/Man	8, 32/C			53	Helicopter
		Blazer/Man	8, 32/W			54	
	8A	Man	W		Lec-87	55-56	
		Man (3)	W			57	
		BN				58	Aircraft (Prop.), Automobile
		Man	RN			59-60	
		Man (3)	RN			61	
		Man	CR			62-63	
		Man (3)	CR			64	
		Man	C			65	Aircraft (Prop.)
		BN				66	Helicopter (OU1)
		Man	C			67-68	
		Man (3)	C			69	
		BN				70	

(Continued)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Fort Hood, Texas	8A	M113	8, 32	V, R, T, V, V, M	Lec-89	121-124	Artillery
		M113/Man	32/W			125	Artillery
		M113/Man	32/C			126	
		M35	8, 32			127-130	Artillery
		M35/Man	32/W			131	
		M35/Man	32/C			132	
		Blazer	8			133-134	Artillery
		Helicopter, Cobra (AH1)	130			135	
		Blazer	32			136-137	Artillery
		Blazer/Man	32/W			138	
		Blazer, CR/Man	32/C			139	
		BN				140	Artillery, Wind 11-14 KPH
		Helicopter OH58	130			141	
		M151	8, 32			142-145	Artillery
		M151/Man	32/W			146	
		M151/Man	32/C			147	
		BN				148	Artillery, Wind 8-11 KPH
	9	BN			Lec-87	71	Automobile, Light Truck
		Man	W			72-74	Automobile
		Man (3)	W			75	
		BN				76	Automobile, Light Truck
		Man	RN			77-78	

(Continued)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Fort Hood, Texas	9	Man (3)	RN	V, R, T, V, V, M	Lec-87	79	
		Man	CR			80-81	
		Man (3)	CR			82	
		BN				83	Automobile, Light Truck
		Man	C			84-85	
		Man (3)	C			86	
		BN				87	Automobile, Light Truck
		M60A1	8, 32		Lec-88	88-90	
		BN				91	Track Vehicles (M113 and Vulcan)
		M60A1	32			92	
		M60A1/Man	32/W			93	
		M60A1/Man	32/C			94	
		M113	8			95	
		BN				96	Helicopter (Chinook)
		M113	8,32			97-100	M35, Helicopter (Chinook)
		M113/Man	32/W			101	
		M113/Man	32/C			102	
		BN				103	
		M35	8			104	
		BN				105	Tracked Vehicle
		M35	8			106	
		BN				107	Tracked Vehicle
		M35	32			108-109	Jackhammer

(Continued)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Fort Hood, Texas	9	M35/Man	32/W	V, R, T, V, V, M	Lec-88	110	
		M35/Man	32/C			111	
		M151	8			112-113	Helicopter
		Helicopter, Huie	130			114-115	
		M151	32			116-117	
		M151/Man	32/W			118	
		M151/Man	32/C			119	
		BN				120	Automobile
March AFB, Riverside, California	1 Alert Area	Man	W		Lec-90	1-4	KC135, Aircraft (Jet)
		Man (3)	W			5	
		Man	C			6-7	
		Man (3)	C			8	KC135
		Man	RN			9-10	
		Man (3)	RN			11	
		BN				12-13	KC135, OB1
		Man	CR			14-15	OB1
		Man (3)	CR			16	
		BN				17-22	Lawnmower, C130, B52, Truck, KC135, Aircraft (Jet, Prop.)
		BN		V, R, T, V, M, M		23-29	DC9, Fire Truck, KC135, Aircraft (Jet), Lear Jet
		BN			Lec-91	30-35	KC135, Concrete Saw, Aircraft (Jet), Lear Jet
		Man	RN	V, R, T, V, M, MC		36-39	

(Continued)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
March AFB, Riverside, California	1 Alert Area	Man (3)	RW	V, R, T, V, M, MC	Lec-91	40-41	
		Man	CR			42-44	
		Man (3)	CR			45	
		Man	W			46-47	
		Man (3)	W			48	
		Man	C			49-50	
		Man (3)	C			51	
		BN				52	Aircraft (Prop., OB1)
	2 WSA	Man	W	V, R, T, V, V, M		53-56	Wind 16-26 KPH
		Man (3)	W			57-58	
		Man	C			59-60	
		Man (3)	C			61	Wind 16-22 KPH
		Man	CR			62-63	
Seal Beach, Calif.	NWS	Man	W	V, R, T, V, M, M		70-73	Wind 29-32 KPH
		Man (3)	W			74	
		Man	C		Lec-92	75-76	
		Man (3)	C			77	Wind 24-29 KPH
	1 NWS	BN				78	Tide, Heavy Engine (Oil Wells), Wind 15-18 KPH
		Man	RW			79-80	Wind 24-29 KPH
		Man (3)	RW			81	Wind 24-29 KPH
		Man	CR			82-83	
		Man (3)	CR			84	

(Continued)

(Sheet 10 of 12)

Table F1 (Continued)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Seal Beach, Calif.	1 NWS	BN		V, R, T, V, M, M	Lec-92	85-86	Oil Well Pump, Train Work Engine, Aircraft (Prop.), Heavy Equipment
		BN				87-91	Oil Well Pump, Train Work Engine, Helicopter (Huie), Aircraft (Prop.), Wind 16-19 KPH
	2 Train Track	BN		V, R, T, V, V, M		92	Aircraft (Jet), Truck
		Man	W			93-94	
		Man (3)	W			95	
		Man	RN			96-97	
		Man (3)	RN			98	
		BN				99-105	Train Engine, Wind 11-12 KPH
		Man	CR			106-107	Wind 12-16 KPH
		Man (3)	C			108	
		BN				109-110	Heavy Equipment (Fork Lift)
		Man	W	V, R, T, V, M, MC	Lec-93	111-112	
		Man (3)	W			113	
		Man	C			114-115	
		Man	W			116-117	
		Man	C			118	
		BN				119	
		Man	C			120-122	
		Man	C	V, R, T, V, V, M		123-124	Aircraft
		Man (3)	C			125	
		Man	C			126	

(Continued)

Table F1 (Concluded)

Area	Site No.	Target Type	Target Travel Mode	Sensors	Tape No.	Test No.	Notable Background Noise Source
Seal Beach, Calif.	3 Marsh	Man	W	V, R, T, V, V, M	Lec-93	127	
		BN				128	
		Man	W			129-130	
		Man (3)	W			131	Pile Driver
		BN				132	Pile Driver, Small Aircraft
		Man	RN			133-134	
		Man (3)	RN			135	
		BN				136	Heavy Equipment (Motor Patrol-Grader)
		Man	C			137-138	
		Man (3)	C			139	
		BN				140	Aircraft (Prop.), Helicopter
		BN		V, R, T, M, V, M		141-142	Helicopter, Aircraft (Prop.), Highway Traffic, Pile Driver, DC6, DC9
	4 Inter-state	BN				143	Interstate Traffic
		Man	W			144-145	
		Man (3)	W			146	
		Man	RN			147-148	
		Man (3)	RN			149	
		BN				150	

APPENDIX G: DESCRIPTION OF PREDICTED SIGNATURE DATA

1. The predicted signatures for the personnel travel modes creeping, crawling, walking, and running were made for each of the 144 matrix elements (Table 8). Intruder-to-sensor distances were 2 m for the man-creeping signatures and 5 m for the man-crawling and man-running signatures. Man walking signatures were predicted for intruder-to-sensor distances of 5 and 15 m. In addition, M-35 predictions for an intruder-to-sensor distance of 75 m were made to provide guidance concerning potential background noise problems.

2. The predicted signatures of the intruder and background noise sources discussed above were written on 7-track magnetic tapes with a packing density of 556 bits per in. Each predicted signatures consisted of two parts: the time domain and frequency domain. Each part (time or frequency domain) of a predicted signature was preceded by an identification line. Examples of the identification lines for intruder and background noise signatures are presented in Figure G1. Each tape contains sets of 144 predicted signatures, a set for each source (travel mode or background noise). The tape numbers, components of the ground motion, order of the data sets (as defined by the source) and the source-to-sensor distances are tabulated below:

Tape Number	Component of Ground Motion	Source	Source-to-Sensor Distance, m
1057	Vertical	Man-creeping	2
		Man-crawling	5
		Man-walking	5
		Man-running	5
6038	Radial	Man-creeping	2
		Man-crawling	5
		Man-walking	5
		Man-running	5
	Vertical	Man-walking	15
		M35 - Speed = 32 KPH	75

Each set of 144 predicted signatures is separated from the set that follows by an end of file marker.

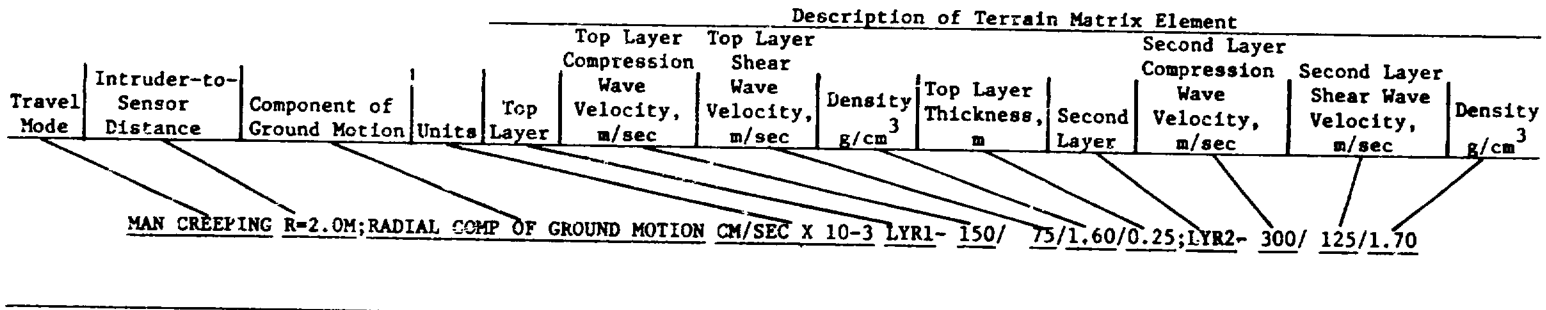
3. As noted in paragraph 2, the predicted signatures consisted of two parts: the time domain and frequency domain. The time domain consists of 1024 amplitude values of the particle velocity of the ground motion; the time increment between adjacent amplitude values is 0.000667 sec. The frequency domain signal consists of 129 values. The freqeuncy increment between adjacent values is 1.4648 Hz. The data on the tapes for each pradicted signature are described in Table G1. The identification lines and amplitude values for the time and frequency domains are organized according to record numbers. The record numbers, mode/format, units, and their respective descriptions are presented in Table G1.

Table G1

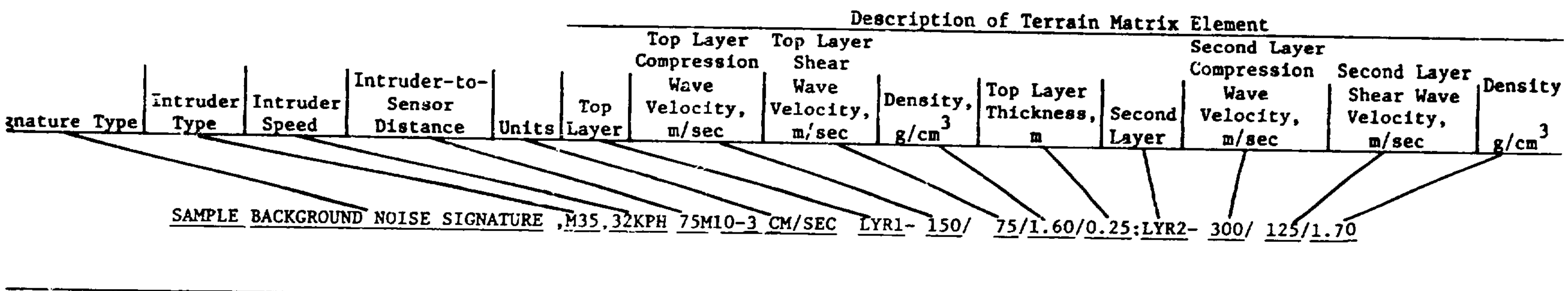
Description of Data for Each Predicted Signature

Tape Track 7 Tape Density 556

Record No.	Mode/Format	Units	Description
1	Floating/113A	Alphanumeric characters	Identification of predicted signature
2-172	Floating/6E12.4	10-3 x cm/sec	Amplitude of time domain signal 1024 particle velocity values. Time spacing = 1/1500 sec
173	Floating/113A	Alphanumeric characters	Identification of predicted signature
174-196	Floating/6E12.4	10-3 x cm/sec	Amplitude of frequency domain signal 129 particle velocity values. Frequency spacing = 1500/1024 Hz



a. Intruder signatures



b. Background noise signatures

Figure G1. Example of identification lines for predicted intruder and background noise signatures

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.

Cress, Daniel H
Terrain considerations and data base development for the design and testing of devices to detect intruder-induced ground motion / by D. H. Cress. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
66, [153] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; M-78-1)
Prepared for Air Force Systems Command, Hanscom Air Force Base, Mass., under Military Interdepartmental Purchase Request No. 7700016, Project title: "Terrain Target Analysis."
References: p. 65-66.

1. Data collections. 2. Ground motion. 3. Mathematical models. 4. Pattern recognition. 5. Seismic sensors. 6. Terrain analysis. I. United States. Air Force. Systems Command. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; M-78-1.
TA7.W34 no.M-78-1