4618-11-F/5178-18-T

MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES

JOHN M. DE NOYER
DAVID E. WILLIS
JAMES T. WILSON

October 1963

Acoustics and Seismics Laboratory
Institute of Science and Technology
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

NOTICES

DDC Availability. Requests for additional copies by agencies of the Department of Defense, their contractors, and other government agencies should be directed to the:

Defense Documentation Center (DDC)
Cameron Station
Alexandria, Virginia

Department of Defense contractors must be established for DDC services to have their need to know certified by the cognizant military agency of their project or contract.

All other persons and organizations should apply to the:

U. S. Department of Commerce
Office of Technical Services
Washington 25, D. C.

Final Disposition. After this document has served its purpose, it may be destroyed. Please do not return it to the Institute of Science and Technology.

PREFACE

The Acoustics and Seismics Laboratory of The University of Michigan's Institute of Science and Technology has been conducting a program of research in seismic wave propagation during the last ten years. The studies include field measurement programs, data analyses, theoretical studies, and the development of instruments needed to implement the field and laboratory requirements.

This research has been sponsored in the past by the U. S. Army Signal Corps, the Office of Naval Research, the Air Force Office of Scientific Research, the Air Force Technical Applications Center, the National Science Foundation, and the Air Force Cambridge Research Laboratories. This report covers a two-year period of research, ending 15 July 1963 and sponsored by the Air Force Cambridge Research Laboratories under Contract AF 19(604)-8809.

About half of the data analyses reported in this report were sponsored by Air Force Contract AF 49(638)-1170, which is administered through the Air Force Office of Scientific Research of the Office of Aerospace Research as a part of the Advanced Research Projects Agency's VELA UNIFORM Program. The Hawaiian Data were collected under sponsorship of Air Force Contract AF 19(604)-6642. This report was prepared by D. E. Willis to fulfill contractual requirements for a final report on Contract AF 19(604)-8809 and as a technical report for the other two contracts.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of Leo A. Levereault and John N. Baumler, who assisted with the data collection, and to Dr. C. B. Stortz and J. V. Sasina, who assisted in the data analyses program. The equipment design and modification necessary for the field measurements were performed under the direction of Harry J. Bugajski. Dr. Wm. Marshall assisted in preparing the material included in Appendix A.

Many scientists of the countries visited, local government officials, and members of the US Embassies assisted greatly in obtaining the data discussed in this report. The authors would like to acknowledge the special help given by Mr. Eisenberg and Professors Ponce and Gajardo of the Instituto de Geofisica y Seismologia, Universidad de Chile; Professors Trautman and Sickinger of the Instituto de Fisica, Universidad de Concepción, Messrs. Kahn and Isa of the Geophysical Institute, Quetta, Pakistan; and Professor Galanopoulos and Mr. Katrambasas of the University of Athens. The assistance of these scientists contributed greatly to the success of the recording program.

The authors would also like to express their appreciation to AFCRL personnel, who provided invaluable assistance in arranging for transportation and official clearance through diplomatic channels to visit the foreign countries.

CONTENTS

Notices ii

Preface iii

Acknowledgments iv

List of Figures vi

Abstract 1

1. Introduction 1

2. Conclusions and Recommendations 2

3. Results and Discussion 4
    - 3.1. Field Measurements 4
    - 3.2. Data Analyses 5
    - 3.3. Design and Development of Instruments 7
    - 3.4. Fiscal Information 8

Appendix A. Site Locations and Descriptions 9

Appendix B. Seismic Background Noise 16

Appendix C. Equipment and Calibration Curves 23

Appendix D. Examples of Seismograms Recorded Outside the Continental United States 28

Appendix E. Three-Component Particle Velocity Data for Earthquake Recordings Outside the Continental United States 35

Appendix F. Vertical Component Predominant Frequencies for the Important Seismic Waves 45

Appendix G. Statistical Study of Amplitude Ratios of Shear-Surface Waves to Compressional Waves 49

Appendix H. Tabulation of Vertical Component Amplitude Ratio of the Shear-Surface Waves to Compressional Waves 54

References 58

Distribution List 59

FIGURES

1. Sketch Map of Island of Hawaii, Showing Recording Site Locations in Relation to Prominent Geological Features 10
2. Sketch Map of Recording Site in American Samoa 11
3. Map of Puerto Rico, Showing Site Location and Major Fault System . . . 12
4. Location Map Showing Pakistani Recording Site and Major Mountain Range Systems 14
5. Sketch Map of the Island of Crete, Showing Site Location 15
6. Sketch Map of Concepción, Chile, Area, Showing Site Location on the Tumbes Peninsula. 16
7. Three-Component Particle-Velocity Curves of Seismic Background Noise Recorded at Concepción, Chile 17
8. Three-Component Particle-Velocity Curves of Seismic Background Noise Recorded at Crete 18
9. Vertical-Component Particle-Velocity Curve of Seismic Background Noise Recorded in Kau Desert, Hawaii 19
10. Three-Component Particle-Velocity Curves of Seismic Background Noise Recorded at Cocoanut Point, American Samoa 20
11. Three-Component Particle-Velocity Curves of Seismic Background Noise Recorded at Quetta, Pakistan 21
12. Three-Component Particle-Velocity Curves of Seismic Background Noise Recorded at Rincon, Puerto Rico 22
13. Ampex CP-100 Magnetic Tape Recorder Used at Rincon, Puerto Rico . . 23
14. Complete Recording System Used to Record Earthquakes in Chile, Crete, American Samoa, and Pakistan 24
15. Complete Recording System Similar to That Used in Hawaii. 25
16. Average Response Curve for Three-Component Short-Period Seismometers 26
17. Response Curve of Seismic Preamplifier 26
18. Typical Response Curves of 1/3-Octave Polyfilter Used in the Particle-Velocity Calculations 27
19. Three-Component Seismogram of Chilean Earthquake of Magnitude 2.7, Recorded at Epicentral Distance of 115 km 29
20. Two-Component Seismogram of Chilean Earthquake of Magnitude 3.7, Recorded at Epicentral Distance of 310 km 29
21. Vertical Component Seismogram of Chilean Earthquake of Magnitude 2.9, Recorded at Epicentral Distance of 29 km 30
22. Three-Component Seismogram of Cretan Earthquake of Magnitude 2.7, Recorded at Epicentral Distance of 116 km 30
23. Two-Component Seismogram of Hawaiian Earthquake of Magnitude 2.7, Recorded at Epicentral Distance of 32 km 31

24. Three-Component Seismogram of American Samoa Earthquake of Magnitude 3.0, Recorded at Epicentral Distance of 110 km 32

25. Three-Component Seismogram of Pakistani Earthquake of Magnitude 2.7, Recorded at Epicentral Distance of 217 km 32

26. Three-Component Seismogram of Pakistani Earthquake of Magnitude 1.1, Recorded at Epicentral Distance of 21 km 33

27. Three-Component Seismogram of Puerto Rican Earthquake of Magnitude 1.8, Recorded at Epicentral Distance of 115 km 34

28. Three-Component Particle-Velocity Curves of Chilean Earthquake of Magnitude 2.7, Recorded at Epicentral Distance of 115 km 36

29. Two-Component Particle-Velocity Curves of Chilean Earthquake of Magnitude 3.7, Recorded at Epicentral Distance of 310 km 37

30. Three-Component Particle-Velocity Curves of Chilean Earthquake of Magnitude 2.9, Recorded at Epicentral Distance of 29 km 38

31. Three-Component Particle-Velocity Curves of Cretan Earthquake of Magnitude 2.7, Recorded at Epicentral Distance of 116 km 39

33. Three-Component Particle-Velocity Curves of American Samoa Earthquake of Magnitude 3.0, Recorded at Epicentral Distance of 110 km 41

32. Two-Component Particle-Velocity Curves of Hawaiian Earthquake of Magnitude 2.3, Recorded at Epicentral Distance of 32 km 40

34. Two-Component Particle-Velocity Curves of Pakistani Earthquake of Magnitude 2.0, Recorded at Epicentral Distance of 144 km 42

35. Three-Component Particle-Velocity Curves of Pakistani Earthquake of Magnitude 1.1, Recorded at Epicentral Distance of 21 km. 43

36. Three-Component Particle-Velocity Curves of Puerto Rican Earthquake of Magnitude 1.8, Recorded at 114 km 44

37. Amplitude Ratios of Shear-Surface Waves to Compressional Waves for Vertical-Component Earthquake Recordings Made at Epicentral Distances of 0 to 50 km 50

38. Amplitude Ratios of Shear-Surface Waves to Compressional Waves for Vertical-Component Earthquake Recordings Made at Epicentral Distances of 50 to 100 km 51

39. Amplitude Ratios of Shear-Surface Waves to Compressional Waves for Vertical-Component Earthquake Recordings Made at Epicentral Distances of 100 to 200 km. 52

40. Composite Amplitude Ratios of Shear-Surface Waves to Compressional Waves for Vertical-Component Earthquake Recordings 53

MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES

ABSTRACT

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-component seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

1

INTRODUCTION

The Seismics Group of the Acoustics and Seismics Laboratory of the Institute of Science and Technology at The University of Michigan has been conducting a program of research in seismic wave propagation studies over the past ten years. During this time a library of magnetic tape recordings of high-frequency (0.5 to 100 cps and higher) seismic energy generated by chemical explosions, nuclear detonations, and earthquakes has been collected. Nearly all of these recordings were made within the limits of the continental United States. An analysis of these recordings disclosed frequency differences in their spectra that depend in part on geological characteristics of the path followed by the seismic waves.

It was apparent that there was a lack of similar data for earthquakes originating outside North American. Although many earthquake recordings made at large epicentral distances are available from these areas, the high-frequency content of the original waves has been lost because of selective absorption. The objective of this project was to obtain high-frequency (short-period) magnetic tape recordings of earthquakes, suitable for detailed frequency analyses, from as many different geological provinces outside North America as time and funds would permit.

This type of data would be of special interest to the first zone stations designed for monitoring a nuclear test ban as well as for the overall VELA UNIFORM program.

The early part of this research program was used to design and construct new equipment and to modify existing equipment to provide reliable magnetic tape recorders that had low power consumption, good signal-to-noise characteristics, and enough ruggedness to withstand rough treatment in shipment. Because these recorders were to be operated in nearly inaccessible areas, extra precautions were used in designing this equipment. The actual field work on this project was delayed for a time because of the commitments of laboratory personnel and equipment when U. S. nuclear testing was resumed.

The first field trip was made to Concepción, Chile, during April 1962 by Dr. DeNoyer and L. Levereault. In May 1962 D. E. Willis and J. N. Baumler made a field trip to Puerto Rico. Dr. DeNoyer and L. Leverault began an around-the-world field trip at the end of May 1962 and ended it in August 1962. Recording stations were established in the American Samoa Islands (Pago Pago), Pakistan, and Greece. It was decided to limit the number of sites to five to allow ample time at each station to make enough recordings to provide adequate samples of the types of earthquakes for each area. These sites were chosen on the basis of seismic activity and accessibility.

Data collected under Contract AF 19(604)-8809 were used for comparison with earthquake data collected within the United States under Air Force Contracts AF 19(604)-6642 and AF 49(638)-1170. In addition, seismic background measurements were made at these recording sites for Air Force Contract AF 19(638)-200. The earthquake recordings are also being used for auditory recognition studies under Air Force Contract AF 49(638)-1079.

Three scientific reports [1, 2, 3] have been prepared which include data from these earthquake recordings. One will be published as a scientific journal article, one was presented at the International Union of Geodesy and Geophysics Meetings held in Berkeley, California (August 1963), and one is contained in a special VESIAC report submitted to ARPA.

2

CONCLUSIONS AND RECOMMENDATIONS

Detailed frequency analyses were made for 120 out of approximately 250 earthquakes that were recorded in Chile, Crete, the Island of Hawaii, American Samoan Islands, Pakistan, and

Puerto Rico. Most of these recordings were of earthquakes recorded at epicentral distances less than 200 km and of magnitude smaller than 4.0. The results obtained from these analyses disclosed that the predominant frequency of comparable size earthquakes recorded at about the same distance varied from one geologic area to the next. Most Chilean, Hawaiian, Puerto Rican, and Pakistani earthquakes were found to have seismic energy concentrated at higher frequencies than the American Samoan or Cretan earthquakes. The earthquake spectra of the latter two areas resemble more closely the spectra of Californian earthquakes.

The high-frequency content of many of these earthquake recordings was near or above the upper limit of the standard short-period seismograph. Hence, if any remote or unmanned seismograph stations were to be used to monitor events at first zone distances, it may be very desirable to have the high-frequency capabilities included in the system's design. The seismic waves from an explosive source which propagate along the same path as these earthquakes should contain seismic energy in the frequency range as high as or higher than that reported here.

A few earthquakes recorded in Pakistan and Chile contained high-frequency seismic energy that would not have been detected by standard short-period seismographs. In fact, if low magnifications and standard equipment had been used at the Pakistan site, many local earthquakes probably would not have been detected, since very little energy was generated in the 1- to 3-cps portion of the spectrum.

A study of the amplitude relationship between the shear surface-waves and compressional waves disclosed that the latter had consistently lower amplitudes, except that a few earthquakes contained high-frequency compressional waves with no equivalent energy in the shear waves. The horizontal-component seismograms usually had larger shear-to-compressional-wave amplitude ratios than the vertical-component seismograms.

A project such as this can hardly scratch the surface of the amount of research that can or should be performed on this subject. With the limited time and funds available, an attempt was made to find any gross differences in the seismic waves generated by earthquakes in these various geologic areas. This was accomplished. Further research, and field measurements at several field stations (such as the Geotech mobile stations, the USC&GS mobile stations or USGS stations equipped with magnetic tape recorders), working together for a longer time in any one area, would provide the type of data necessary to determine epicenters, focal depths, etc. and the quantity of data needed for statistical studies.

3
RESULTS AND DISCUSSION

3.1. FIELD MEASUREMENTS

Appendix A includes the site location and a brief discussion of the geological environment of each of the six areas where earthquake recordings were made. Appendix B gives typical three-component seismic background noise spectral curves for each of these areas. It should be pointed out that background noise varies with time, especially from quiet periods of nighttime recording to periods of daylight operation when man-made noise reaches a maximum. This variation in background noise affects the signal-to-noise ratio of the earthquake recordings. Earthquakes of smaller magnitude originating during the daytime are often masked in the noise. In some areas recordings were made only at night.

The seismic background noise was generally higher at the island sites because of the surf noise, particularly at the American Samoa site. Most of the recordings obtained here were of earthquakes of larger magnitude (the site is just north of the Tonga Trench, a very active seismic area). Undoubtedly many earthquakes of smaller magnitude occurred during the period of the operation of this station; however, the high noise levels masked them. In general it was found that the horizontal seismometers had higher short-period background noise levels than the vertical component. The seismometers and recording equipment were all matched and calibrated so that these differences in seismometer output could be correlated with true differences in background noise.

The approximate number of earthquakes recorded at each of the recording sites is shown in Table 3-I. A number of the recordings were overrecorded or underrecorded so that detailed frequency analysis was not possible. At Crete and Pakistan, where a large number of recordings were available, recordings were selected for analysis on the basis of magnitude and epicentral distance. The results are discussed in the next section.

TABLE 3-I. RECORDINGS OF EARTHQUAKES

Location	Number Recorded	Number Analyzed	Range in Distance (km)	Range in Magnitude
Chile	36	22	29-310	0.8-3.7
Crete	50±	26	14-402	0.7-6.8
Hawaii	41	20	11-60	1.1-2.8
American Samoa	16±	15	74-700	1.9-5.0
Pakistan	100±	18	10-1370	0.2-5.2
Puerto Rico	22	19	13-210	0.5-2.1

3.2. DATA ANALYSES

Since only one recording station was used for these foreign earthquake recordings, it was not possible to determine epicenter locations. Gutenberg and Jeffreys-Bullen tables were used to estimate epicentral distances since travel-time curves were not available for each area. S - P time intervals were determined from the character of the seismic waves shown on the three-component seismograms. Hence the epicentral distances computed may be in error by as much as 10%. For the purpose of this study these errors are not significant. A few of the larger magnitude earthquakes were listed by the USC&GS, whose epicentral location were used as a basis for checking our distance determinations.

Selected seismograms from each area are shown in Appendix D. An effort was made to choose earthquakes of approximately the same magnitude and epicentral distance to allow direct comparison. Some unusual recordings are also shown. Three-component particle-velocity curves for the predominant compressional and shear waves for these recordings are shown in Appendix E. Particle-velocity curves for many other compressional-, shear-, and surface-wave phases were computed but are not illustrated in this report.

The particle-velocity data were computed by measuring the amplitudes of individual phases on one-third octave seismograms. The latter were obtained by playing the demodulated signals from the FM magnetic tape recordings through a one-third octave polyfilter. Response curves of this filter are shown in Appendix C. The amplitudes were corrected for amplifier gain and seismometer response and were normalized to a 1-cps bandwidth. These amplitudes were then converted to particle velocities. Normalizing the third octave signal levels to a 1-cps bandwidth is valid only when the frequency spectrum of the signal is continuous within the band measured and does not have prominent "pure-tone" components. A seismic signal is not composed of "white noise," but the bandwidth of the one-third octave filters, especially below 40 cps, is fairly narrow. Hence no appreciable error is introduced. This type of analysis is probably not adequate for those recordings that have energy in the 100-cps region or higher. The few earthquake recordings that contain seismic energies at these high frequencies will be analyzed further by means of analog or digital computer techniques in order to obtain more meaningful spectral data.

The predominant energy in the seismic waves for earthquakes recorded in Chile, Hawaii, Pakistan, and Puerto Rico are often concentrated at frequencies near or above the upper frequency limits of the standard seismic station's short-period instruments. (This concentration is illustrated in Appendixes D, E, and F.) The earthquakes recorded at Crete and American Samoa, however, contained significantly lower-frequency energy, perhaps because the earthquakes recorded were of larger average magnitude, and, on the average, were recorded at greater epicentral distances. Although the data conflict and overlap, there is evidence of an overall tendency for the larger-magnitude earthquakes to generate lower-frequency seismic energy than smaller-magnitude earthquakes recorded at comparable distances.

The spectral data contained in Appendix E show that in general there is no major difference in the frequency content of a particular seismic wave as recorded on all three components. However, the shear waves were found to have larger maximum particle velocities and were usually of lower frequency. The horizontal components usually had larger shear-to-compressional wave amplitude ratios than the vertical component.

Several of the earthquake recordings obtained are especially interesting and will be discussed in more detail. An earthquake of magnitude 2.9 was recorded in Chile at an epicentral distance of 29 km. This particular earthquake was composed of some very-high-frequency seismic energy. This is illustrated in Figures 21 and 30. Measureable seismic energy as high as 500 cps was found in the vertical-component recording of the shear waves. At 100 cps the compressional and shear waves had particle-velocity amplitudes approximately 17% as large as the peak amplitudes. One possible explanation is that this high-frequency energy may be due in part to the transmission path of the seismic waves. If the recording station were near the epicenter (with the focus nearly below the recording station), the seismic waves might be transmitted through a rock material that had a lower absorption coefficient than a shallow earthquake located 25 or 30 km from the recording station.

Another Chilean earthquake of magnitude 3.7, epicentral distance 310 km, contained comparatively high frequency seismic energy for an earthquake recorded at that distance. The seismograms and particle velocity data for this earthquake are shown in Figures 20 and 29. The compressional waves have a double peak at 2 and 12.5 cps on the vertical component, and 2.5-3.2 and 10 cps on the east-west component. On both components the higher frequency peak has a larger particle velocity amplitude. This phenomenon would be difficult to observe on a standard short-period seismograph.

A Pakistani earthquake of magnitude 1.1 was recorded at an epicentral distance of 21 km. This earthquake (see Figures 26 and 35) had compressional-wave energy peaking at 32 cps and shear-wave energy peaking at 8 to 12.5 cps. These high-frequency compressional waves could not be detected by using standard equipment in an active seismic area where the normal instrument magnification might be low. At the Pakistan site, a large number of small earthquakes were recorded that appeared to originate beneath the seismic station. These recordings were characterized by high-frequency, SH, energy on the horizontal seismograms with very little energy on the vertical seismograms. These data are to be discussed in a separate report.

Many of the earthquakes had spectral curves that showed two predominant peaks. The shear-wave amplitudes averaged considerably higher than the compressional-wave amplitudes. This is demonstrated in Appendixes E, G, and H. Ratios of shear-surface waves to compressional-wave amplitudes varied as a function of distance and seismic region. At distances of 0 to 50 km the mean ratio for all areas peaked at 3.6; at 50 to 100 km it peaked at 3.0; at 100 to 200 km it peaked at 2.5; at 200 to 400 km it peaked at 2.0; and at 400 to 1000 km it peaked at 2.8. Since the data in the latter distance range are limited, this value for the ratio is not as reliable as those at smaller distances. Where sufficient data were available the mean, median, standard deviation above and below the mean, and range were computed for the S/P amplitude ratios for each of the six areas from which data were obtained. These are shown in Appendix G. In the 0 to 50 km range there was a considerable variation in S/P amplitude ratios for each area. The Chilean earthquakes averaged about 4.0 at frequencies between 5 and 12 cps; Hawaiian earthquakes averaged about 2.0 at frequencies between 2 and 25 cps; Pakistani earthquakes peaked above 7.0 at frequencies of 6.3 and 8 cps; and Puerto Rican earthquakes peaked at 7.7 at a frequency of 3.2 cps. In the 50- to 100- and 100- to 200-km ranges, with the exception of the American Samoa earthquakes, the mean S/P amplitude ratios peaked at approximately 2.0 over a fairly broad frequency range. For American Samoa earthquakes, this average ranged between 3.0 and 4.0.

3.3. DESIGN AND DEVELOPMENT OF INSTRUMENTS

An Ampex Model 351 slow-speed, 1/4-inch tape transport was purchased and modified for use as a field recorder. This recorder was chosen for its proven reliability. The top plate was modified to handle 1/2-inch tape (7 FM channels). Transistorized FM electronic plug-in record modules were designed and constructed in our laboratory, as well as the seismic preamplifiers, power supplies, etc. One transistorized FM plug-in reproduce module was purchased. The power consumption was reduced so that a single 12-volt 100-ampere hour battery would supply power to run the entire recording station, including WWV receiver and oscilloscope (for monitoring input and playback from tape recorder), for six hours. Battery power was used rather than engine generators because the latter generate considerable high-frequency noise that is difficult to eliminate. This noise source is particularly troublesome because of the broadband response of our recording system. Photographs of this equipment are shown in Appendix C.

The three-component seismometers were packaged into one unit with its own leveling device. An electronic clamping device (Zener diodes back-to-back) was installed to prevent damage to the seismometers when in shipment. The seismometers have no coil-locking device, and since we were using high-impedance coils (210,000 ohms), there was a chance of burning out the coils in shipment. The diodes damp the seismometer when the output voltage reaches 3 volts, but have no influence on the seismometer's performance at lower output voltages.

An inexpensive transistorized time pulser was designed and built to provide 1/4-second time pulses with an accuracy of 3 seconds per day (constant rate). This provided a time standard during periods of poor reception of radio time signals. Good radio time signals turned out to be the exception rather than the rule for most of the recording sites.

3.4. FISCAL INFORMATION

It is estimated that the $86,500 allocated for Contract AF 19(604)-8809 will be expended with the publication of the final report. The following is a list of the capital equipment and components purchased by this contract.

1 Ampex 351 Tape Transport (without electronics or heads)	$995
1 Kupfrian Inverter	175
1 Precision Inst. Co. FM Reproduce Discriminator	450
3 Hall-Sears Model HS-10 Seismometers	960

Appendix A

SITE LOCATIONS AND DESCRIPTIONS

The selection of the six recording sites used to record earthquakes in this study was based on the seismic activity associated with the area, geological environment, and accessibility. The sites are listed below according to their geotectonic classification:

I. Ocean Basin (Pacific)
    A. Central Pacific—Island of Hawaii
    B. Southwest Pacific—Island of Tutuila, American Samoa
II. Island Arc Structure
    Greater Antilles—Rincon, Puerto Rico
III. Continental
    A. Indian Sub-Continent—Quetta, West Pakistan
    B. Mediterranean—Crete, Greece
    C. South America (Andes)—Concepción, Chile

All of the islands in the Pacific Ocean Basin area are comprised of volcanic rock, coral formations, and secondary deposits derived from these. They contain no continental-type rock. The islands rise as volcanic piles from the deep floor of the basin. They rise as much as 15,000 feet before reaching the surface of the ocean, and some peaks, such as Mauna Loa, rise over 10,000 feet above the surface of the ocean. These islands have a minimum width of 10 miles across the base.

A.1. HAWAII

The two recording sites used on the Island of Hawaii are shown in Figure 1. One is on the east slope of the volcano Mauna Loa near the northeast rift zone (19° 29' 42" N, 155° 23' 18" W). The other site is located in the Kau Desert southwest of the Kilauea Crater (19° 20' 15" N, 155° 23' 18" W). The latter site falls within the southwest rift zone graben. These rift zones coincide with deep-seated fissures. The seismometers at the Mauna Loa site were located in a USGS seismograph vault. In the Kau Desert they were located about 100 feet from a USGS vault. In both areas the stations were set up on vesicular basalt. (The Kau Desert Site is on a recent lava flow of the Kamehame basalt.)

The Mauna Loa and Kilauea volcanoes have not passed beyond the early stages of a shield volcano and continue to erupt primitive olivine basalt.

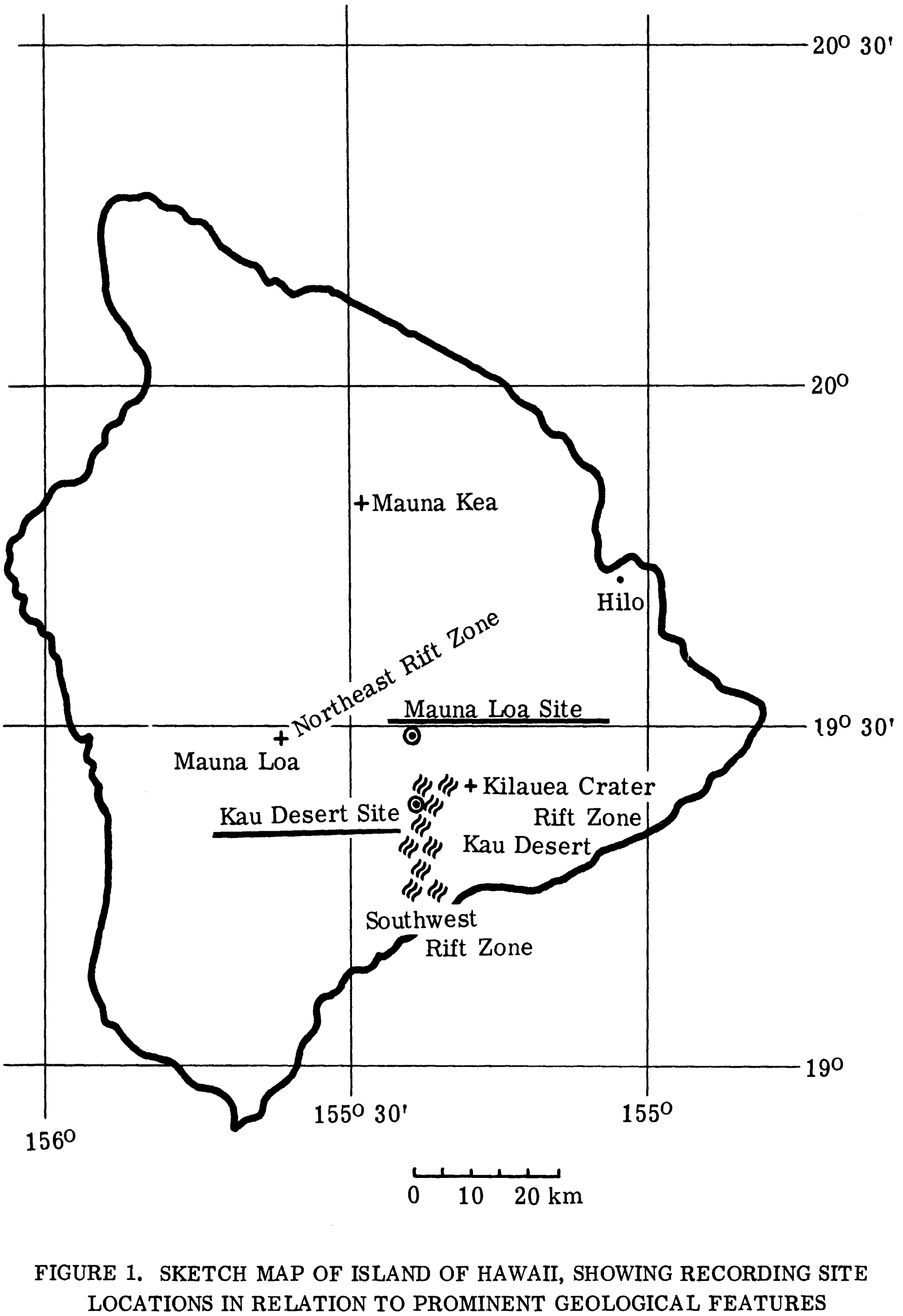


FIGURE 1. SKETCH MAP OF ISLAND OF HAWAII, SHOWING RECORDING SITE LOCATIONS IN RELATION TO PROMINENT GEOLOGICAL FEATURES

A.2. AMERICAN SAMOA

The American Samoa recording site (Figure 2) was at Cocoanut Point on Tutuila Island near the capital city of Pago Pago (14° 20.74' S, 170° 42.26' W). Cocoanut Point is a coral sand spit overlying recent lavas which flowed out over an old barrier reef complex, some 2000 feet thick that formed on the volcano during Pleistocene changes in sea level.

The seismometers were placed on the floor of a World War II pill box near the village of Nuuuli. The site is on a recent basaltic lava flow that extends into a lagoon of quiet water. A reef within a quarter of a mile from the recording location was probably responsible for much of the microseism activity (see Figure 10) in the 1- to 10-cps frequency range. Waves were breaking at the reef during all of the time recordings were being made.

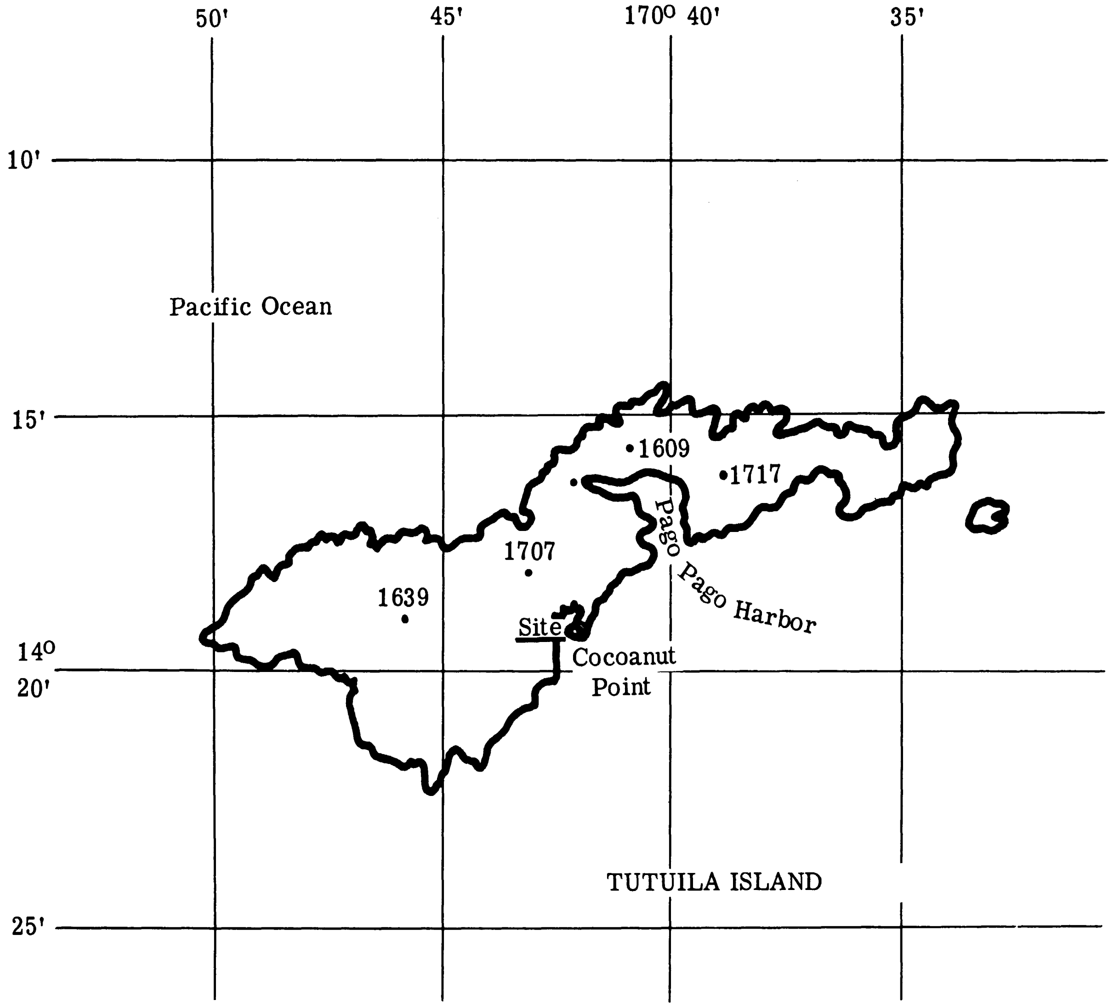


FIGURE 2. SKETCH MAP OF RECORDING SITE IN AMERICAN SAMOA

A.3. PUERTO RICO

The recording site in Puerto Rico was on the western edge of the island, 4.2 km southeast of the town of Rincon in the Municipio de Rincon (18° 19' 07'' N, 67° 13' 05'' W). The site, in an abandoned limestone quarry, is 2.2 km inland from the Caribbean Sea and had an approximate elevation of 25 meters. The rocks of the area are made up for the most part of Upper Cretaceous tuffs, ashes, shales, conglomerates, limestones, and a variety of intrusives. Pleistocene dune sands and beach deposits are found along the western edge of the region. The island is bounded by fractures, as shown in Figure 3. Small, frequent earthquakes are associated with the faults which bound the northern and southern limits of the island. However, the cross-fractures in the Anegada and Mona trenches are associated with earthquakes of greater intensity.

A.4. PAKISTAN

The Quetta, West Pakistan, site (30° 11.3' N, 66° 56.9' E) was at an elevation of 1740 meters. The recording station and the seismometers were situated on property belonging to the Pakistan Geophysical Observatory. The seismometers were placed on an outcrop of bedded Cretaceous limestone. The beds dip at an angle of approximately 20° to the west. Two major

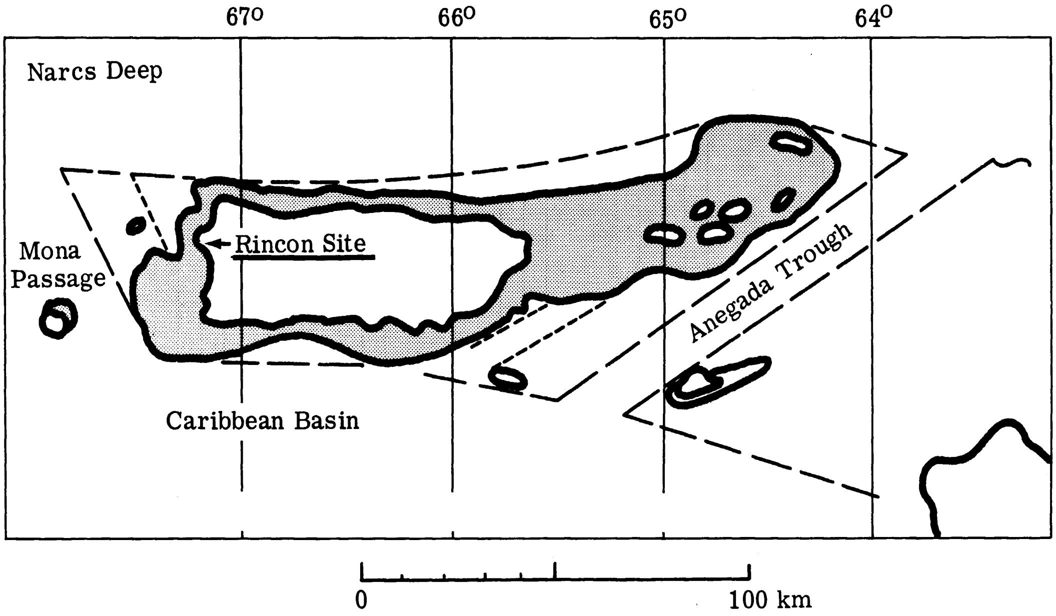


FIGURE 3. MAP OF PUERTO RICO, SHOWING SITE LOCATION AND MAJOR FAULT SYSTEM

▨ Shallow Platform—100 Fathoms or Less
— — Major Faults
----- Minor Faults

faults were present near the recording site. One fault was approximately 200 feet west of the instrument location, and the other fault about 1000 feet north of the seismometers.

Extensive Pleistocene and recent deposits are found in the valleys of the Quetta area. The mountains surrounding the Quetta area are made up of highly folded marine sediments of Triassic through Lower Miocene age. These mountains are flanking ranges to the Indian Peninsula and form mountain arcs on the Indo-Afghan and Indo-Baluchistan frontier. These ranges are generally transverse to the strike of the Himalayas and run approximately north-south. These general features are shown in Figure 4.

A.5. CRETE

The recording site used in Greece was about 8 km north of the town of Neapolis on the island of Crete (Figure 5). The seismometers were placed in a limestone quarry, and the recording station was located in the Aghii Pantes Chapel. The coordinates of the seismometer site were 35.259° N, 25.605° E. The rock outcrops on the island are marine sediments of Upper Jurassic, Middle Triassic, Upper Cretaceous, Miocene, and Pliocene ages. Seismic data indicate an absence of true ocean basin and close association with continental materials for long periods in the geologic past.

A.6. CHILE

The recording location in Chile was north of Concepción on the Tumbes Peninsula. The coordinates were 36° 37.1' S, 73° 5.0' W. The site location is shown in Figure 6. The seismometers were placed in a charcoal pit on the ranch of Mr. Sweet, U. S. Consul at Concepción. The charcoal pit was a small cave carved into the side of a granite gneiss hill. The entrance to the cave was just large enough to admit a man.

The Tumbes Peninsula area is an ancient element of the Andes, consisting of undifferentiated metamorphic rocks of Pre-Cambrian age. Cretaceous granites which are part of the Mesozoic batholiths which fringe the western coast of South America are located just east of the Tumbes Peninsula. Many shallow, intermediate, and deep-focus earthquakes are associated with this area.

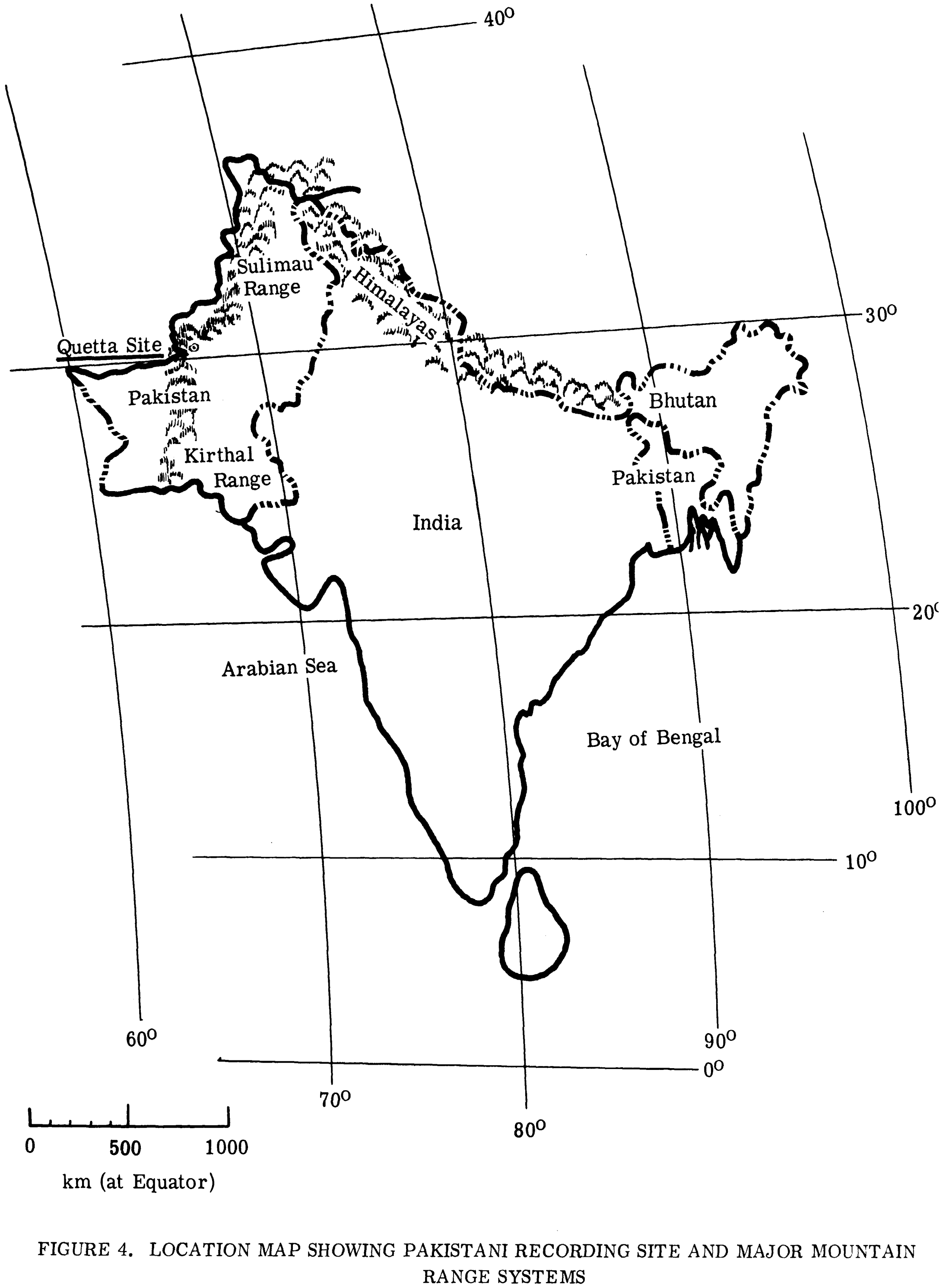


FIGURE 4. LOCATION MAP SHOWING PAKISTANI RECORDING SITE AND MAJOR MOUNTAIN RANGE SYSTEMS

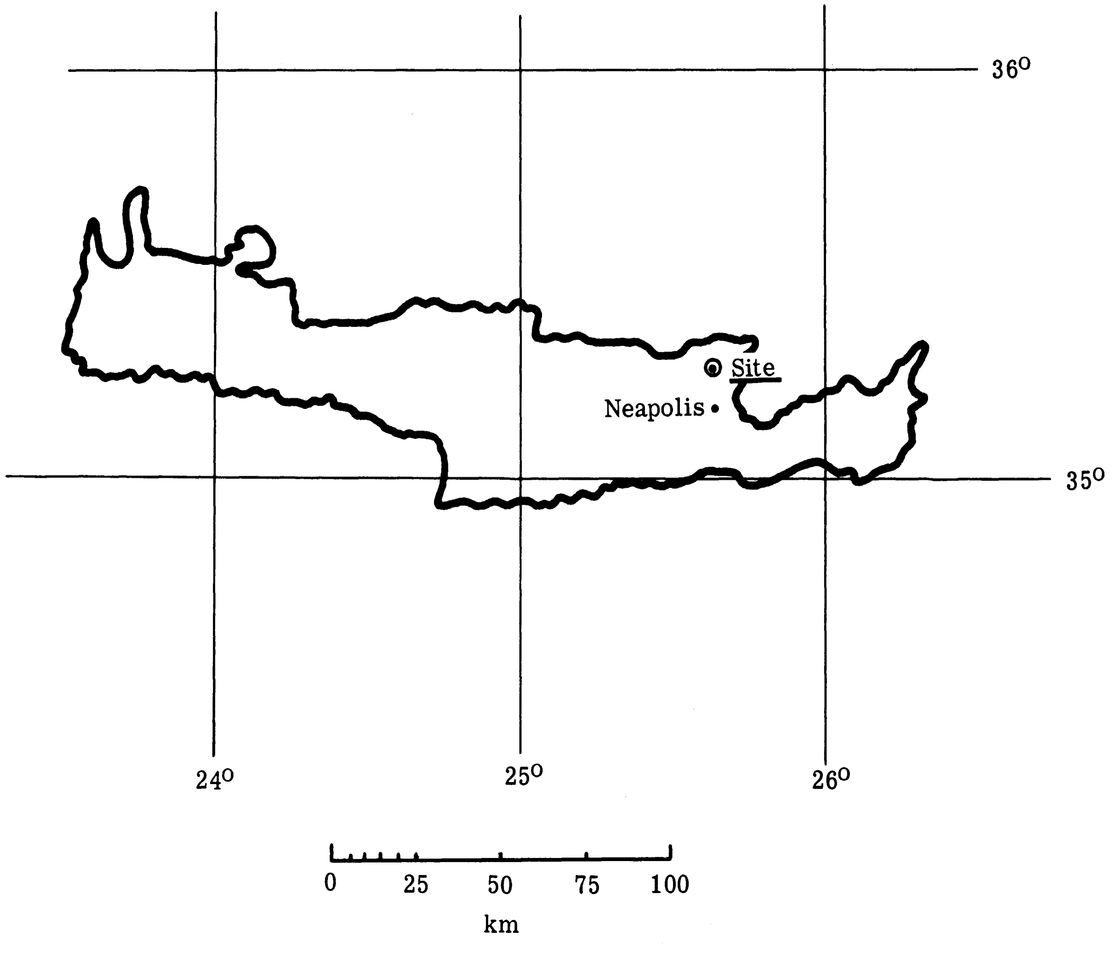


FIGURE 5. SKETCH MAP OF THE ISLAND OF CRETE, SHOWING SITE LOCATION

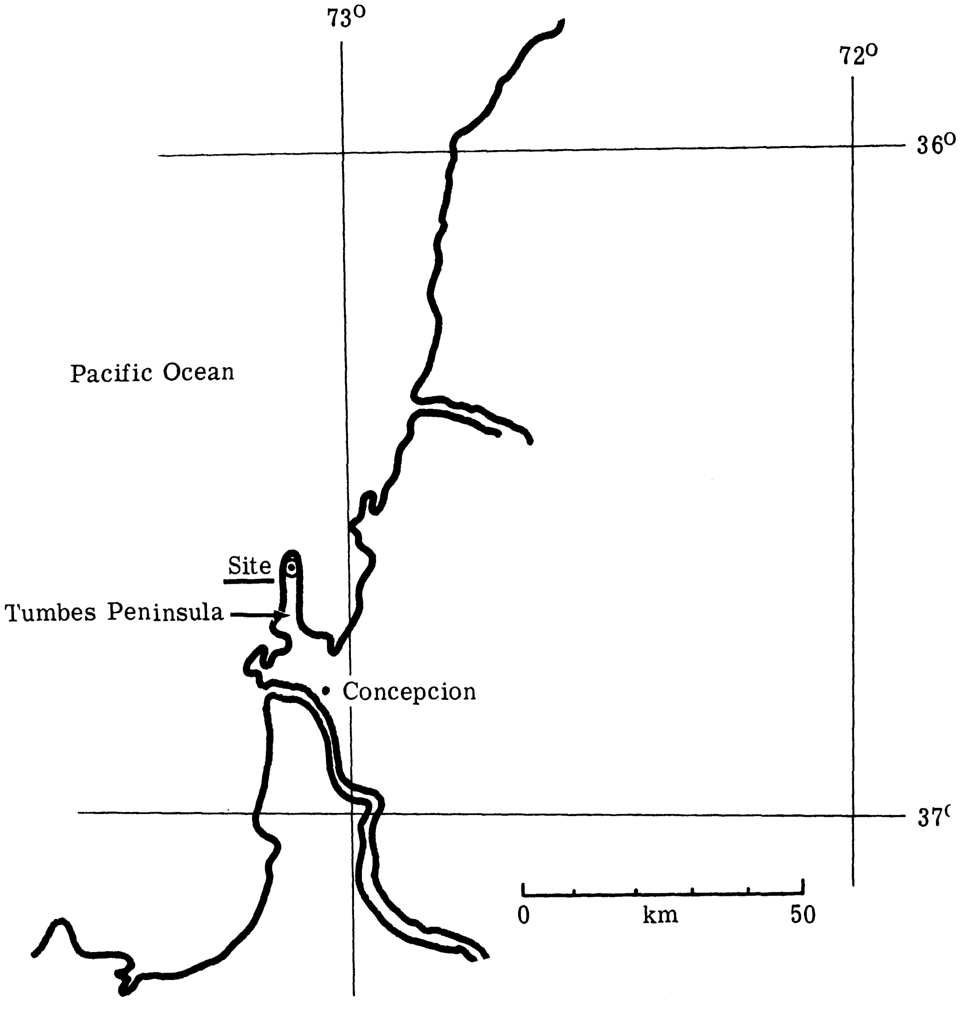


FIGURE 6. SKETCH MAP OF CONCEPCIÓN, CHILE, AREA, SHOWING LOCATION ON THE TUMBES PENINSULA

Appendix B

SEISMIC BACKGROUND NOISE

Typical three-component seismic background noise curves are presented in Figures 7 through 12 for each of the earthquake areas studied. The technique used in computing these

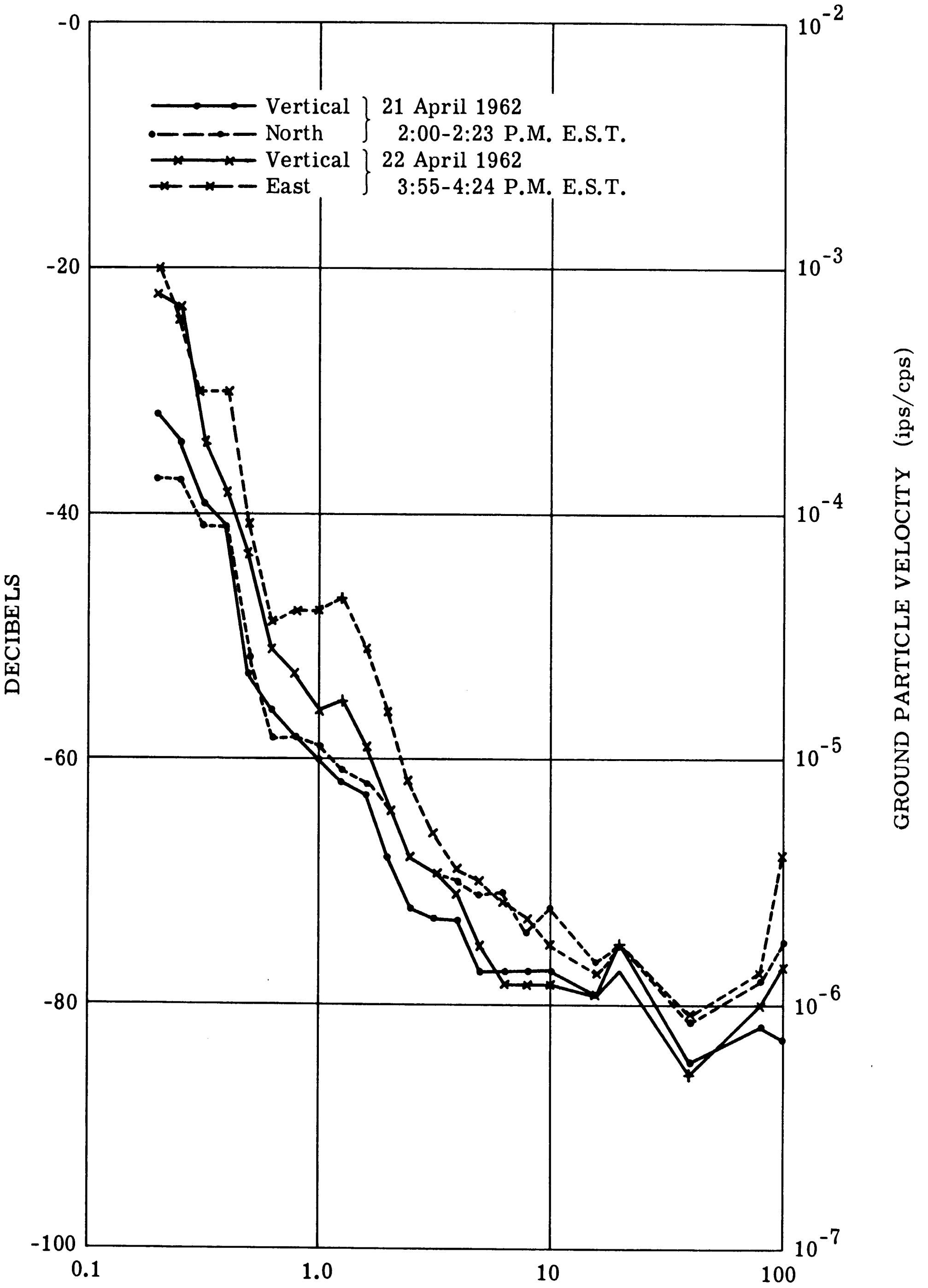


FIGURE 7. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF SEISMIC BACKGROUND NOISE RECORDED AT CONCEPCIÓN, CHILE

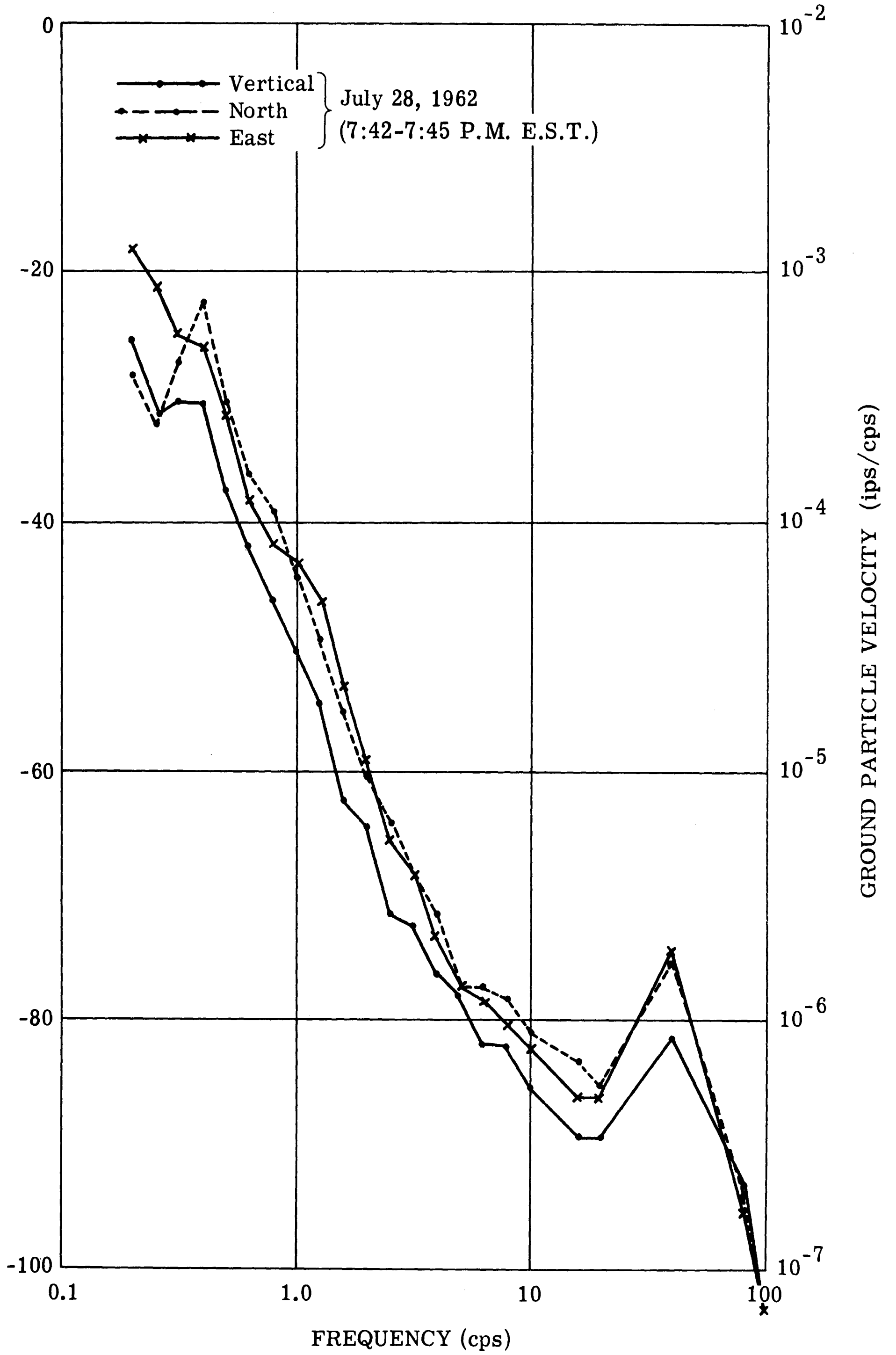


FIGURE 8. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF SEISMIC BACKGROUND NOISE RECORDED AT CRETE

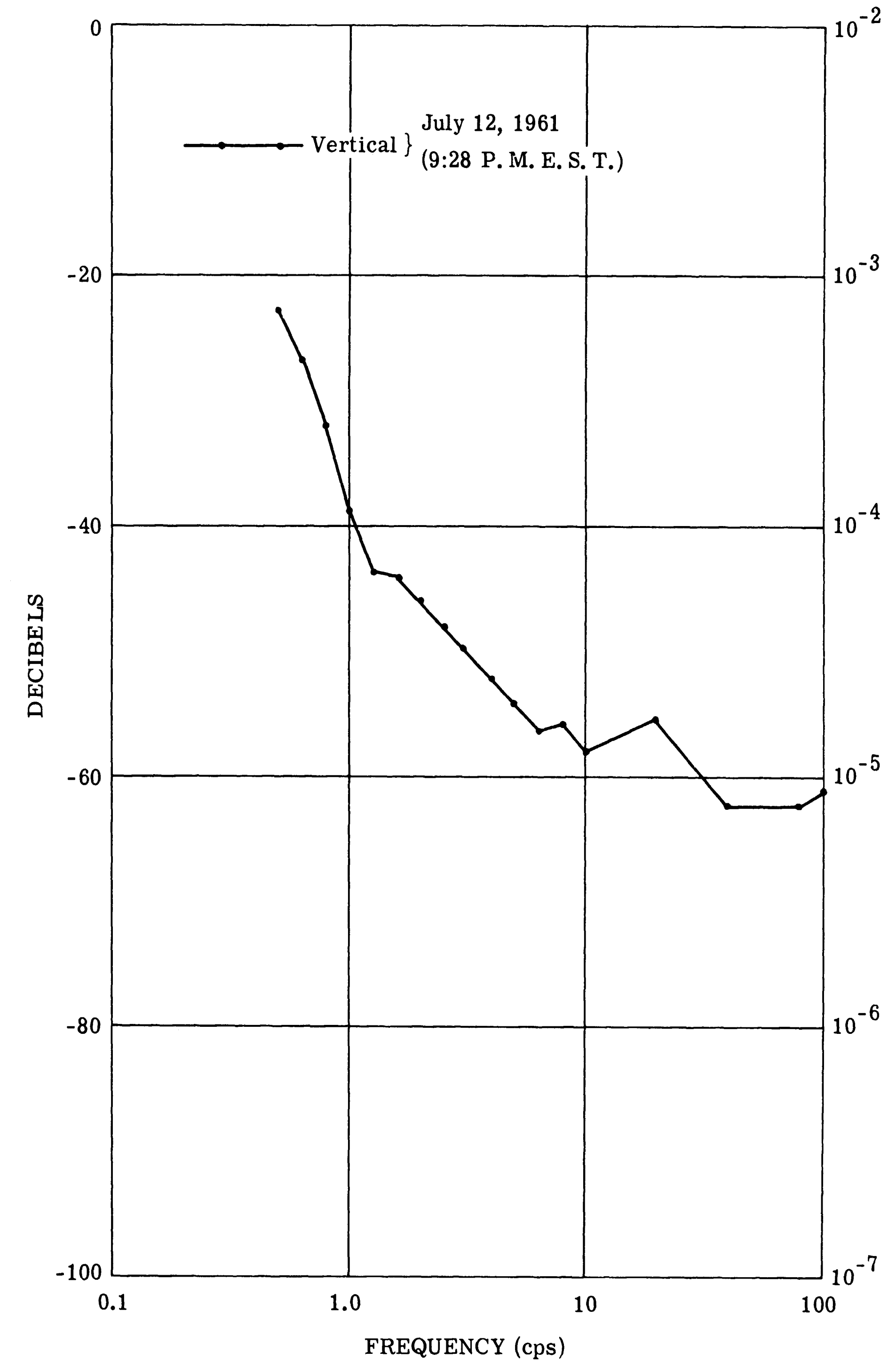


FIGURE 9. VERTICAL-COMPONENT PARTICLE-VELOCITY CURVE OF SEISMIC BACKGROUND NOISE RECORDED IN KAU DESERT, HAWAII

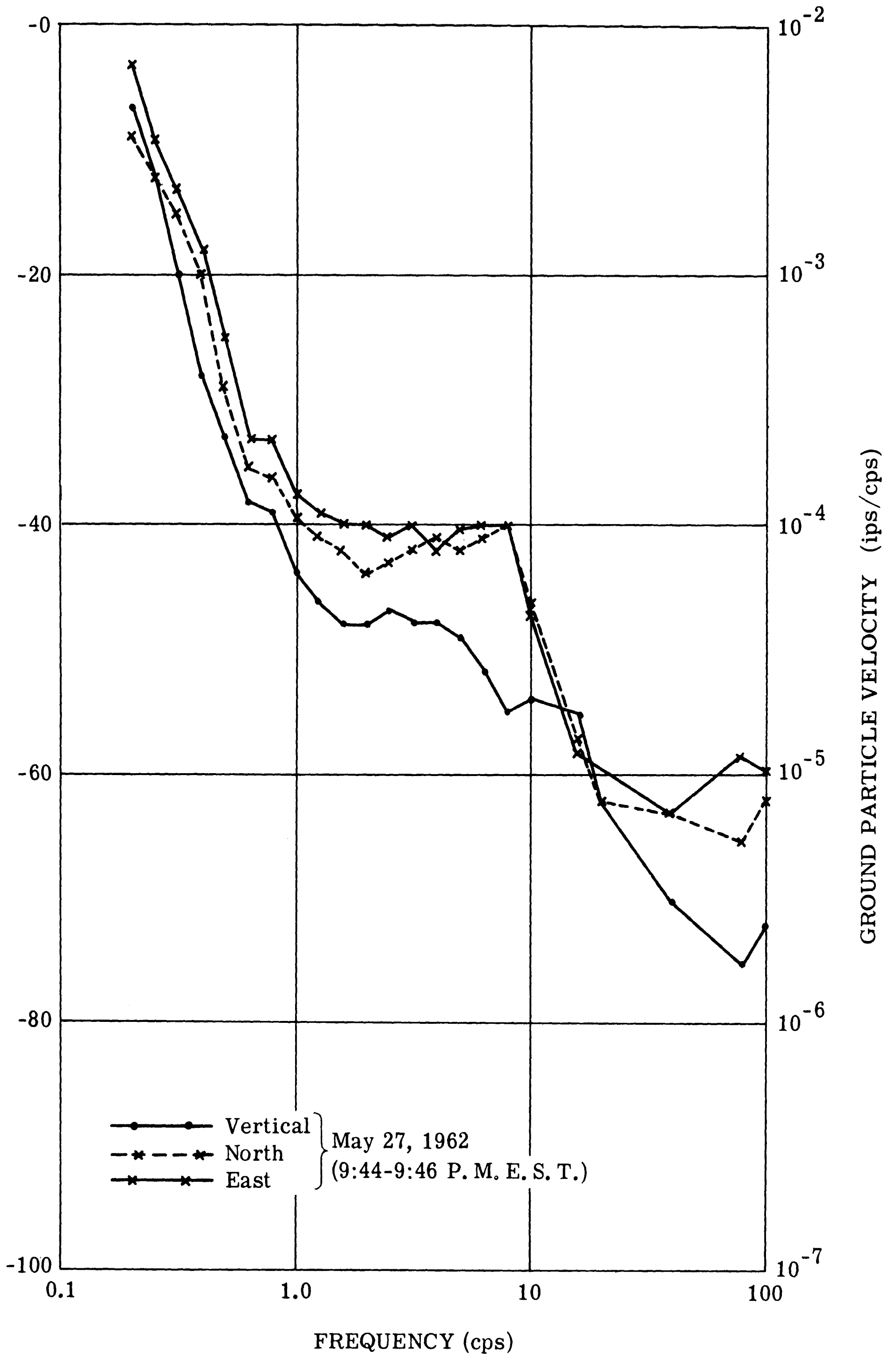


FIGURE 10. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF SEISMIC BACKGROUND NOISE RECORDED AT COCOANUT POINT, AMERICAN SAMOA

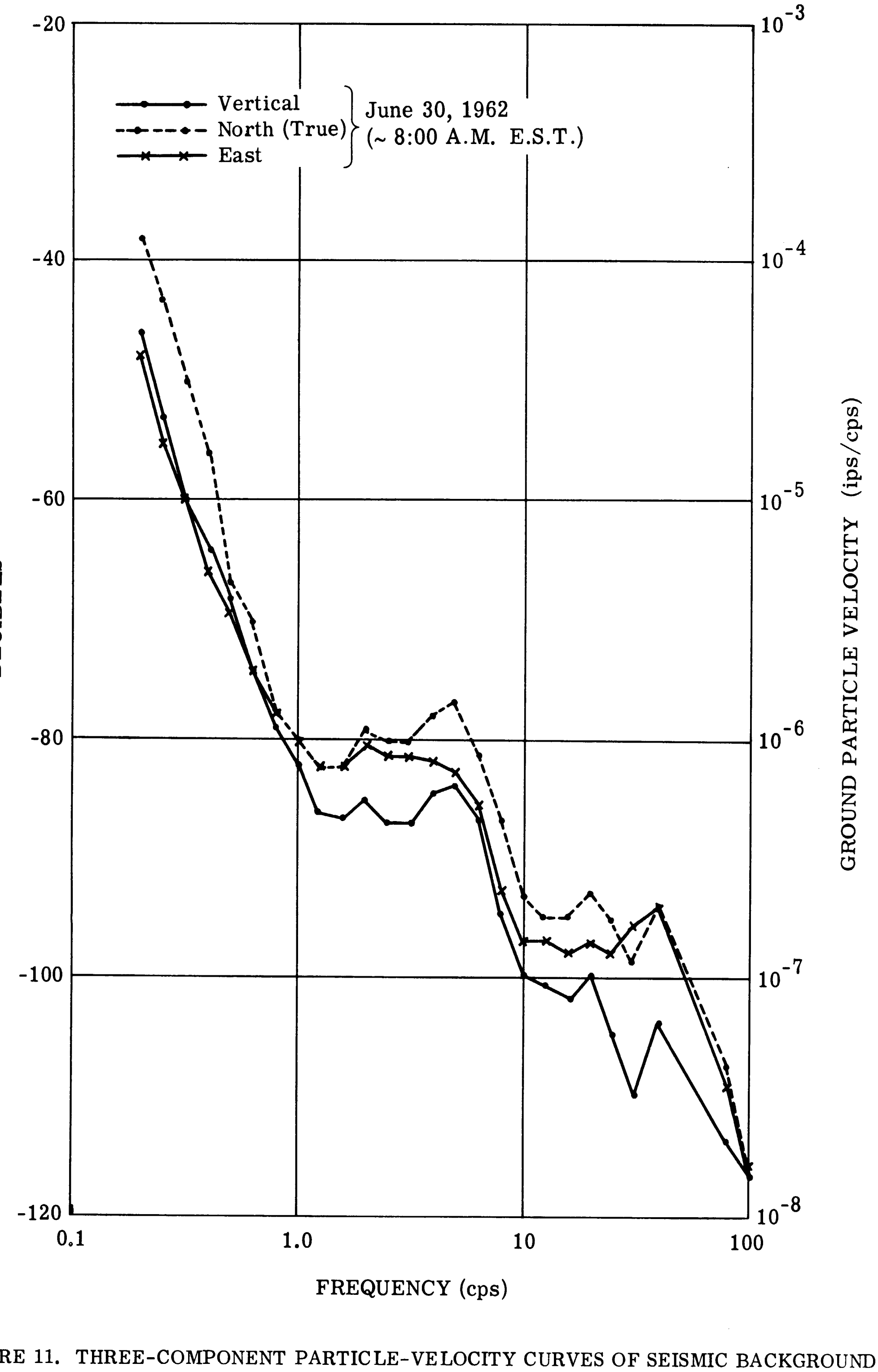


FIGURE 11. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF SEISMIC BACKGROUND NOISE RECORDED AT QUETTA, PAKISTAN

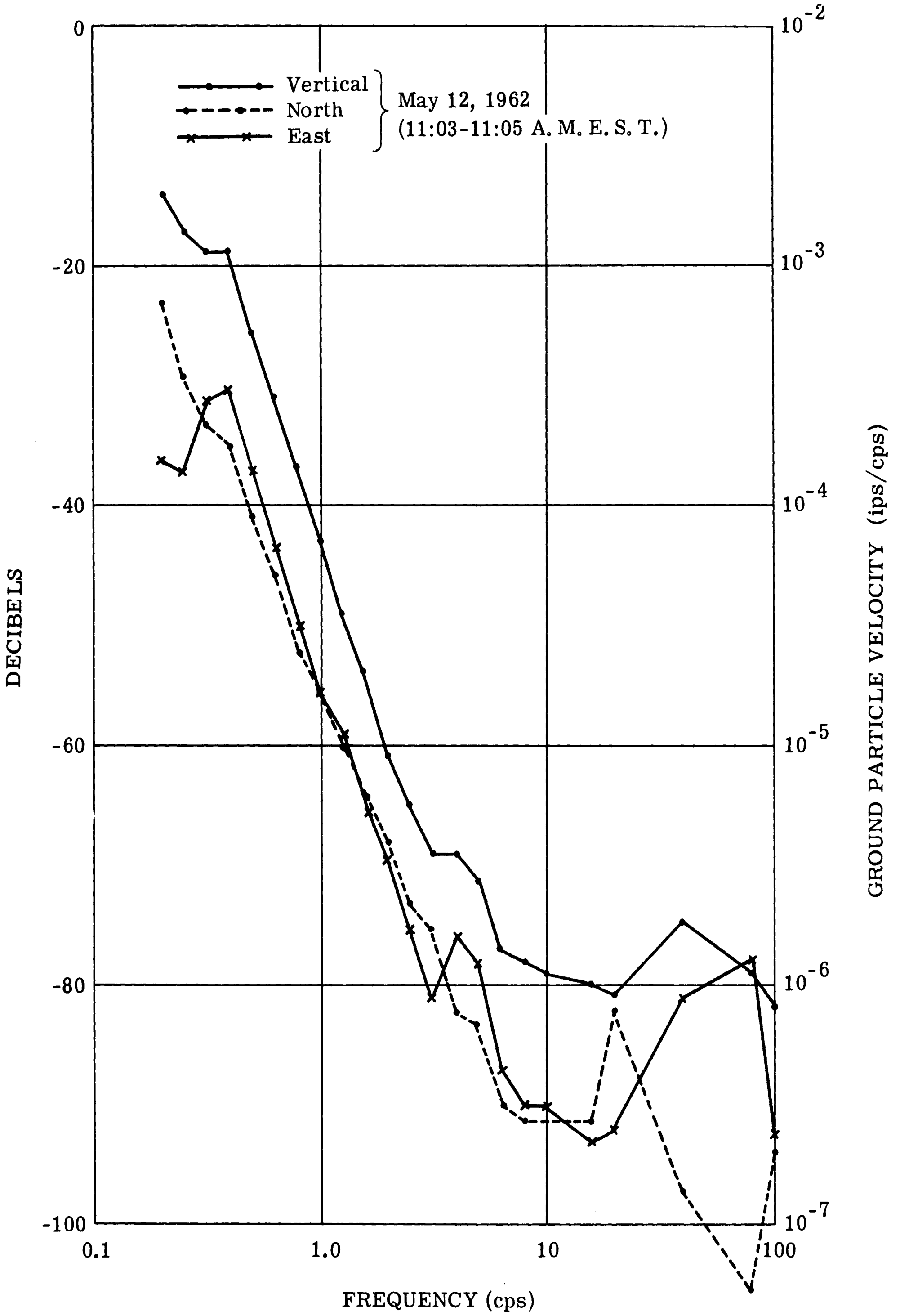


FIGURE 12. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF SEISMIC BACKGROUND NOISE RECORDED AT RINCON, PUERTO RICO

results are described in Reference 4. A detailed study of these noise measurements is being sponsored by the Air Force under Contract AF 19(638)-200 and will be reported at a later date.

Appendix C

EQUIPMENT AND CALIBRATION CURVES

FM magnetic tape recorders were used to facilitate the broadband recording and frequency analyses of the earthquakes recorded in the six areas outside of the continental limits of the United States. For the Puerto Rico recordings, an Ampex CP-100 (recording speed, 1 7/8 ips; bandwidth, d-c to 312 cps) tape recorder (Figure 13) was used in conjunction with a matched set of three-component Hall-Sears HS-10 2-cps seismometers. Double gains were used for each seismometer.

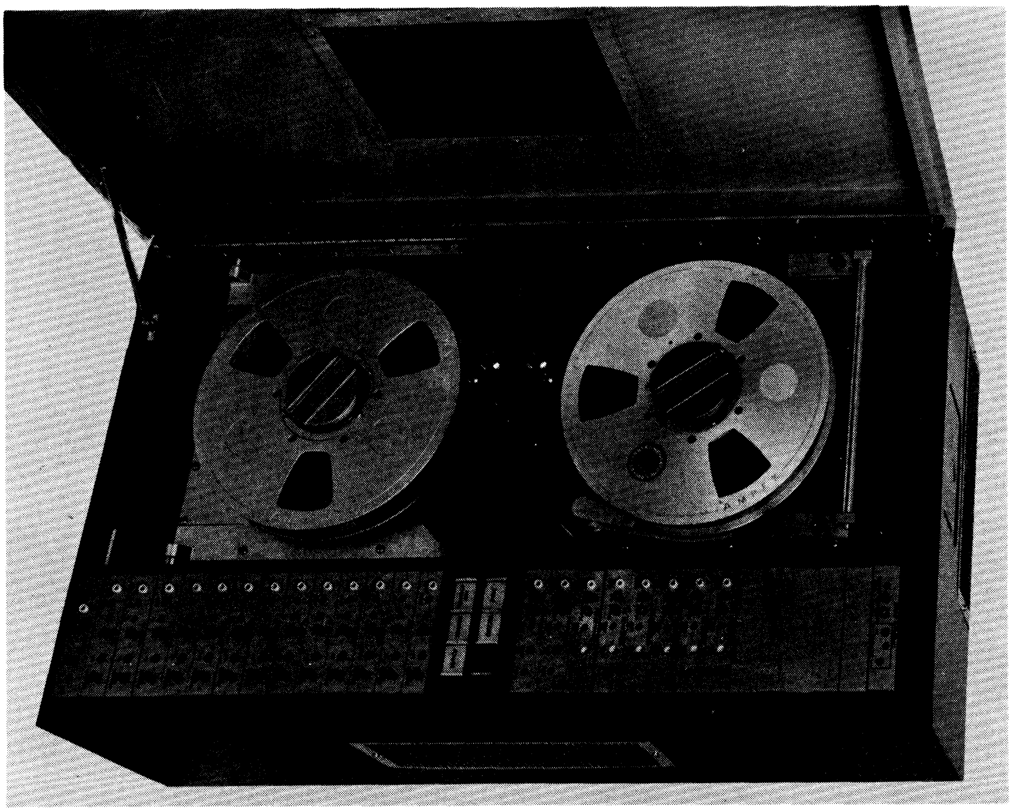


FIGURE 13. AMPEX CP-100 MAGNETIC TAPE RECORDER USED AT RINCON, PUERTO RICO

The recordings obtained in Chile, American Samoa, Pakistan, and Greece were made with the system shown in Figure 14. The tape transport used was a modified 7-channel Ampex model 351 (recording speed, 3 3/4 ips; bandwidth, d-c to 625 cps). Three-component Hall-Sears seismometers were also used for these recordings. Double gain settings were used for each seismometer at these recording sites.

Two modified Ampex model 601-2 FM-AM tape recorders were used for the Hawaiian recordings. A photograph of this recording system is shown in Figure 15. The recording speed used was 7 1/2 ips (used carrier frequency for 3 3/4 ips, bandwidth, d-c to 625 cps). Vertical and horizontal Mark I Willmore 1-cps seismometers were used at this site. Double gain recording was not attempted in Hawaii.

Response curves of the seismometers, seismic preamplifiers, and polyfilter are shown in Figures 16-18.

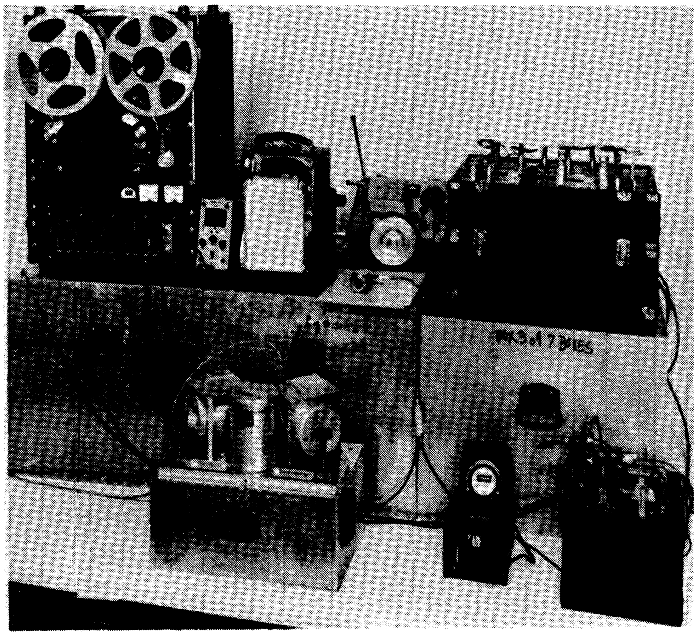


FIGURE 14. COMPLETE RECORDING SYSTEM USED TO RECORD EARTHQUAKES IN CHILE, CRETE, AMERICAN SAMOA, AND PAKISTAN. Shake table reference, 10^{-2} ips, P to P.

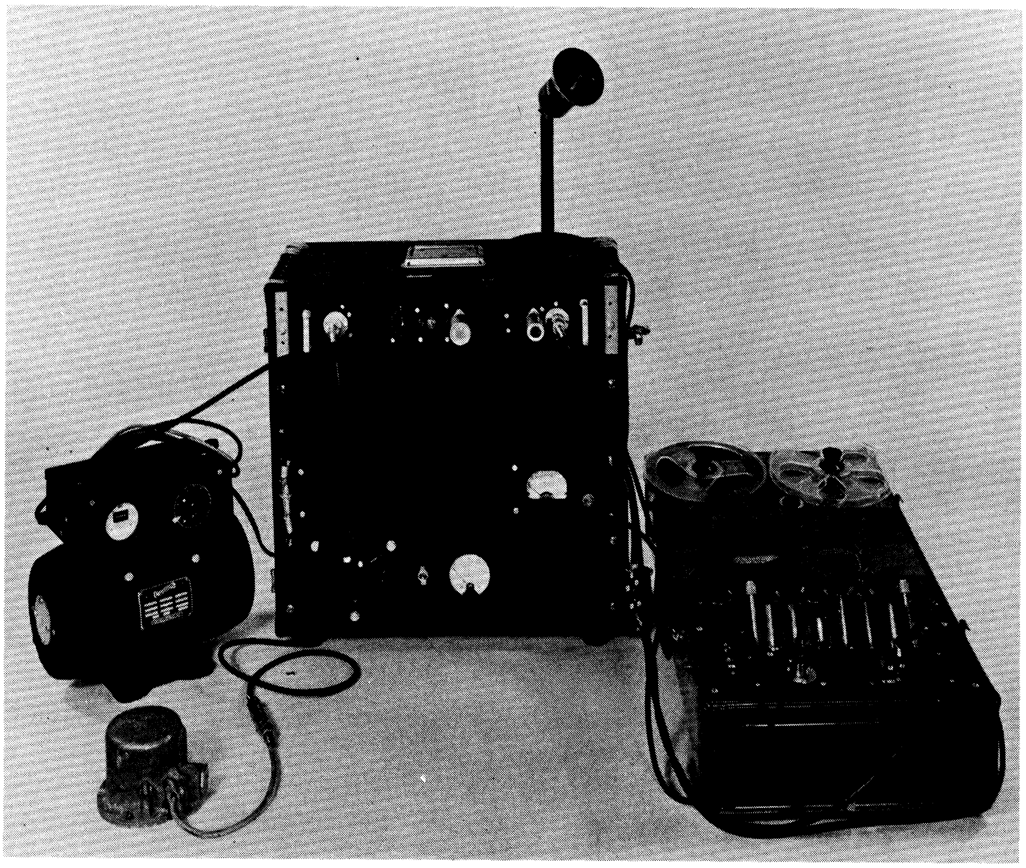


FIGURE 15. COMPLETE RECORDING SYSTEM SIMILAR TO THAT USED IN HAWAII. The seismometer shown here is of a higher natural frequency than that used for these recordings.

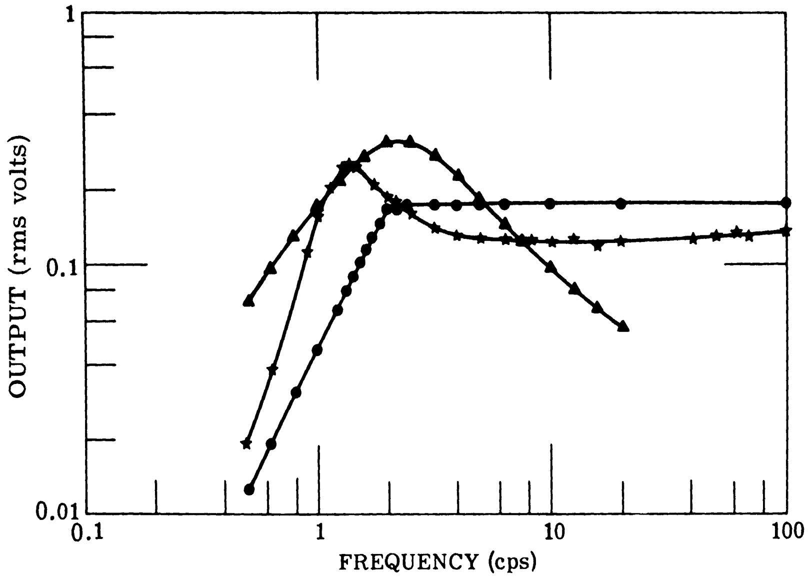


FIGURE 16. AVERAGE RESPONSE CURVE FOR THREE-COMPONENT SHORT-PERIOD SEISMOMETERS. The individual seismometers were within ± 1 db of the average.

★— 1 sec Willmore (V) #100 (100K coil)
●— 2 sec HS-10 (V) #21475 (210K coil)
▲— 1 sec Benioff (V)

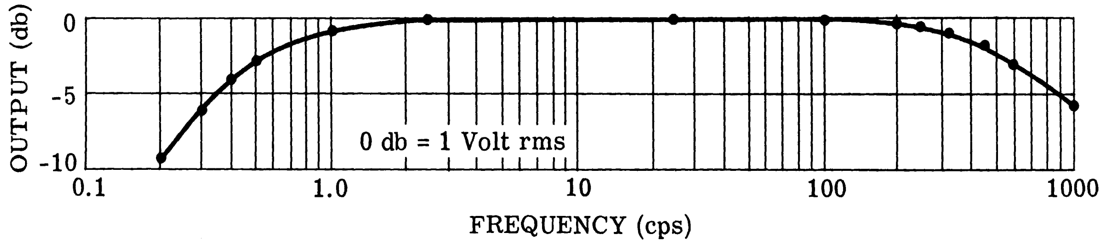


FIGURE 17. RESPONSE CURVE OF SEISMIC PREAMPLIFIER

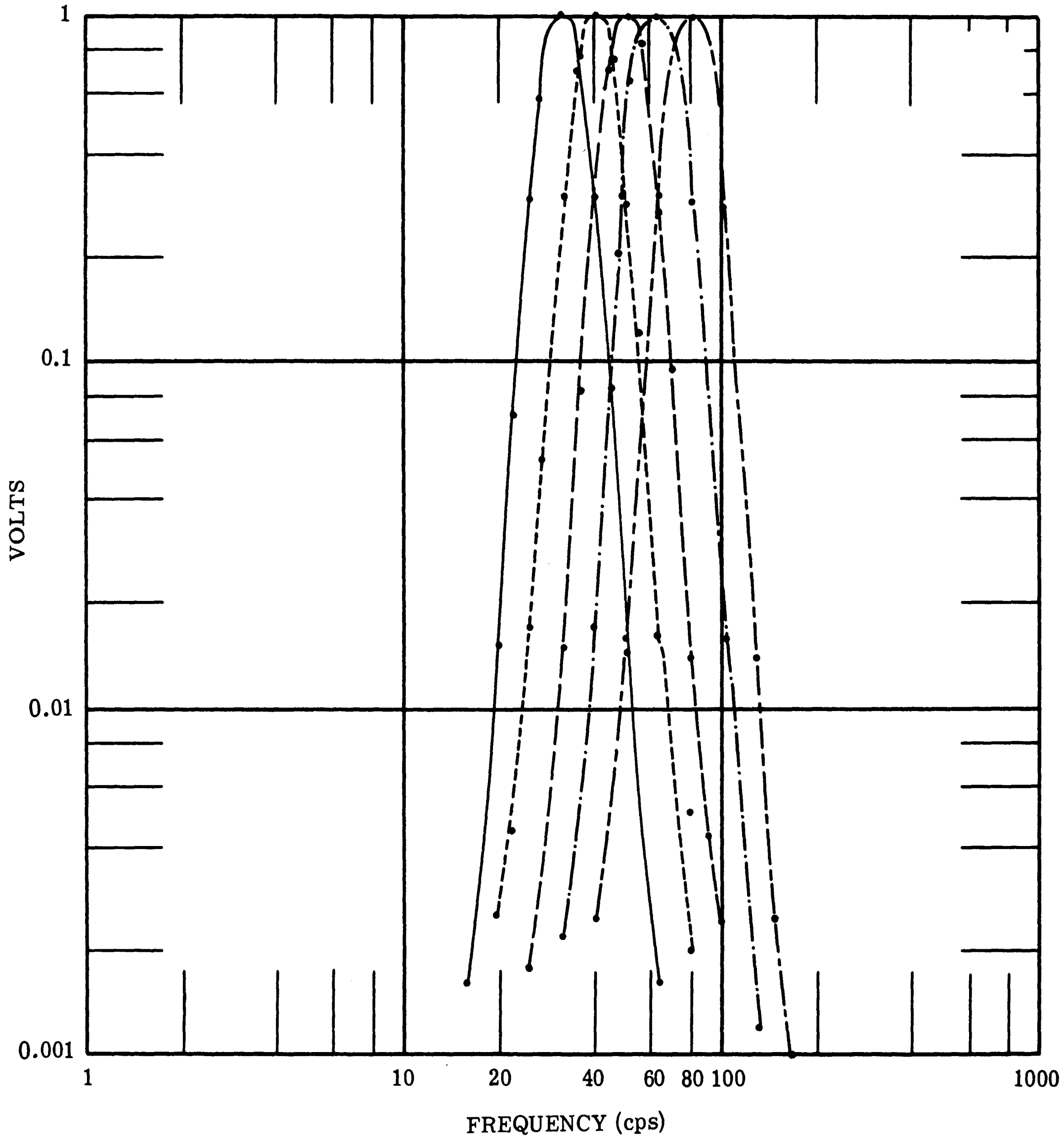


FIGURE 18. TYPICAL RESPONSE CURVES OF 1/3-OCTAVE POLYFILTER USED IN THE PARTICLE-VELOCITY CALCULATIONS. Center frequency.

——— 32.0 cps
------ 40.32 cps
— —— 50.8 cps
·—·—·— 64.0 cps
------- 80.45 cps

Appendix D

EXAMPLES OF SEISMOGRAMS RECORDED OUTSIDE THE CONTINENTAL UNITED STATES

Selected seismograms from each recording site are shown in Figures 19 through 27. The location, date, approximate time, net gain (record and playback), seismometer configuration (vertical, north-south, east-west) and variable passband filter setting (cps) are indicated on each seismogram. The time standard was either Eastern Standard Time or Hawaiian Standard Time.

Various passband filter settings were used to increase the signal-to-noise or to show a rough distribution of the seismic energy in several passbands. In Figure 2 the high-frequency seismic energy (100- to 500-cps passband) was difficult to reproduce because of the slow camera speed used. The maximum peak-to-peak amplitude in the compressional-wave train and shear-wave train is indicated by horizontal markers.

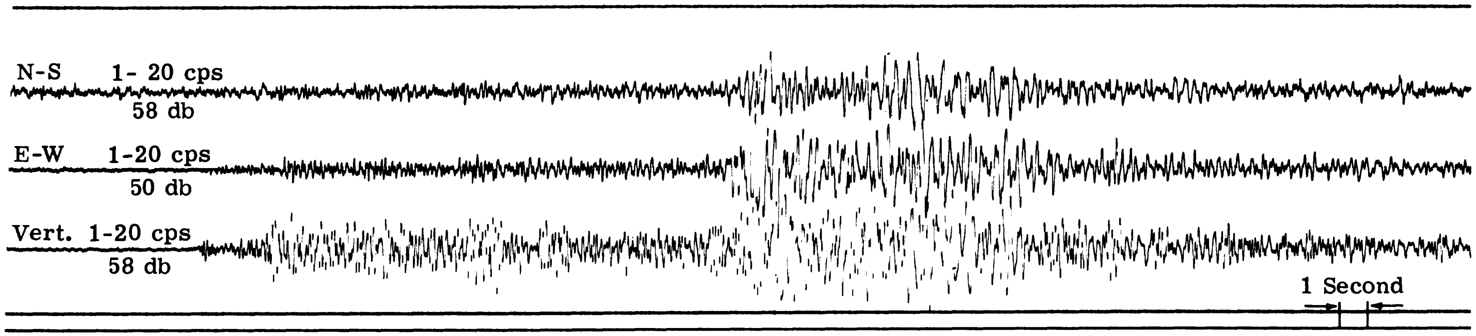


FIGURE 19. THREE-COMPONENT SEISMOGRAM OF CHILEAN EARTHQUAKE OF MAGNITUDE 2.7, RECORDED AT EPICENTRAL DISTANCE OF 115 km. Time approximately 1217 EST, 23 April 1962.

FIGURE 20. TWO-COMPONENT SEISMOGRAM OF CHILEAN EARTHQUAKE OF MAGNITUDE 3.7, RECORDED AT EPICENTRAL DISTANCE OF 310 km. Time approximately 1557 EST, 23 April 1962.

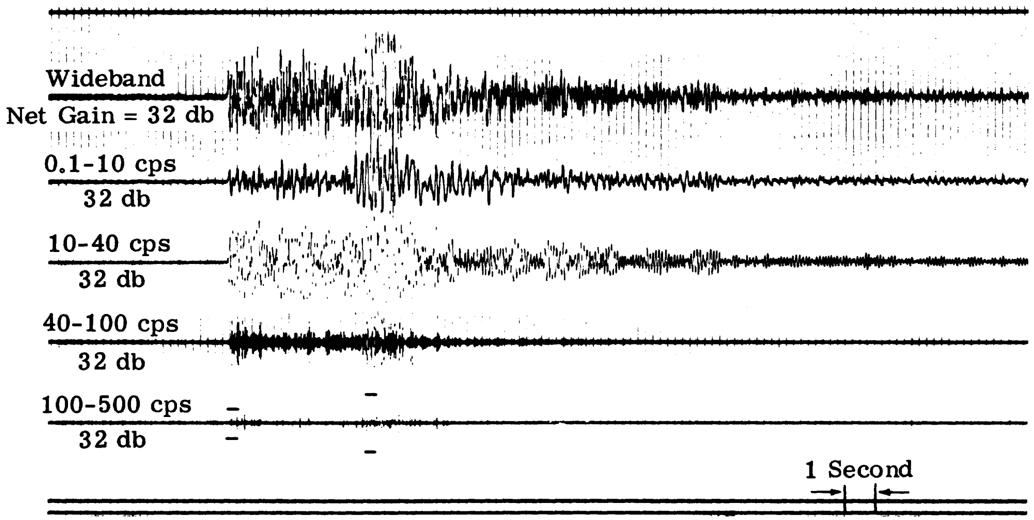


FIGURE 21. VERTICAL-COMPONENT SEISMOGRAM OF CHILEAN EARTHQUAKE OF MAGNITUDE 2.9, RECORDED AT EPICENTRAL DISTANCE OF 29 km. Various passbands. Time 23 April 1962.

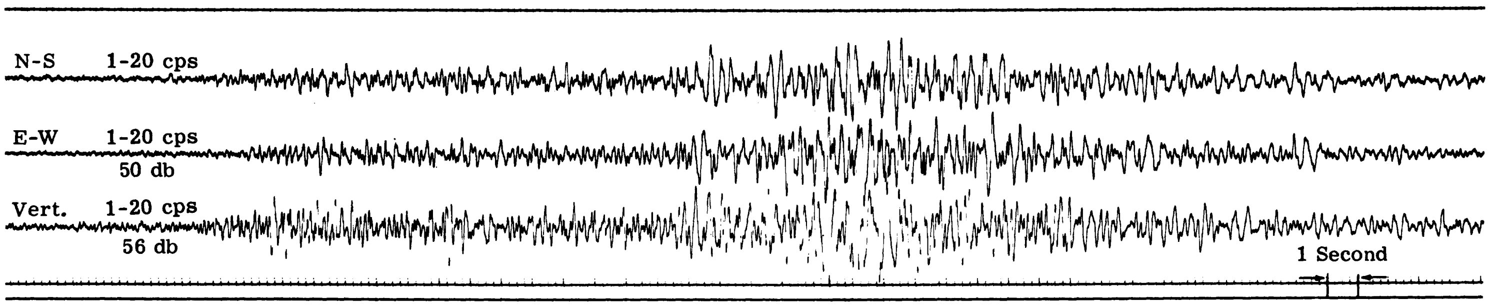


FIGURE 22. THREE-COMPONENT SEISMOGRAM OF CRETAN EARTHQUAKE OF MAGNITUDE 2.7, RECORDED AT EPICENTRAL DISTANCE OF 116 km. Time approximately 1732 EST, 31 July 1962.

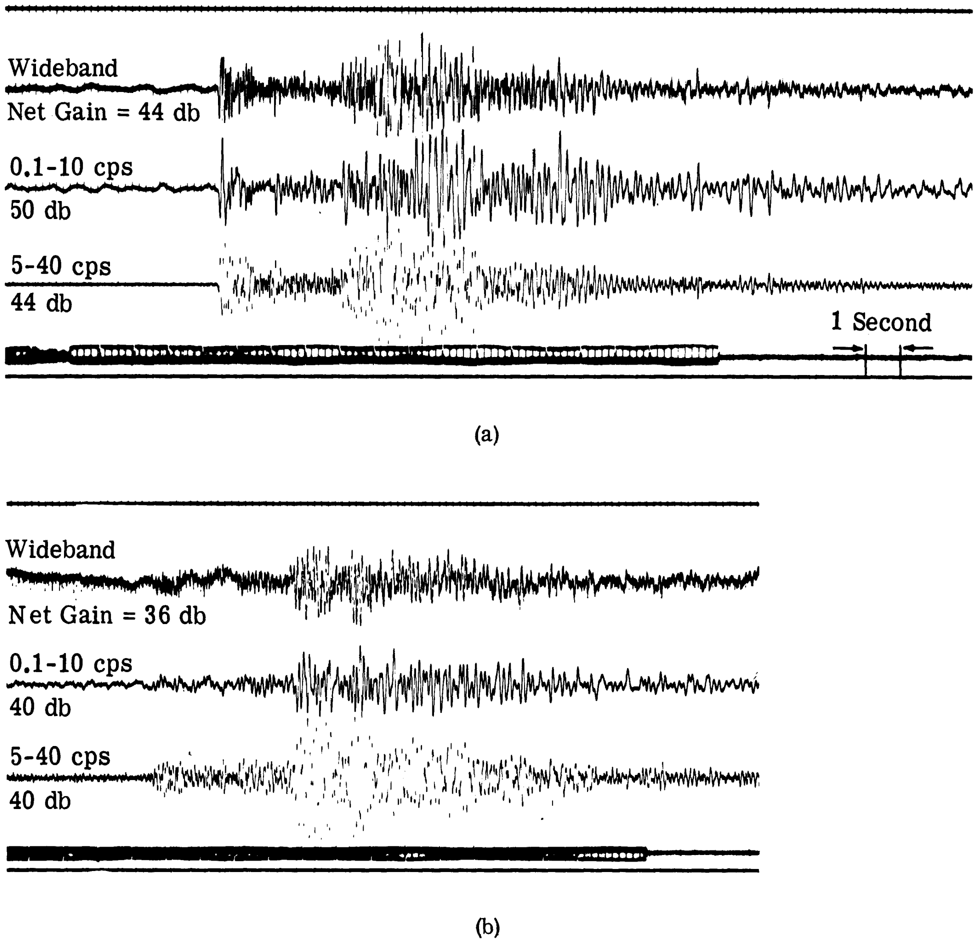


FIGURE 23. TWO-COMPONENT SEISMOGRAM OF HAWAIIAN EARTHQUAKE OF MAGNITUDE 2.7, RECORDED AT EPICENTRAL DISTANCE OF 32 km. Time approximately 1613 HST, 14 June 1961. (a) Vertical component. (b) E-W horizontal component.

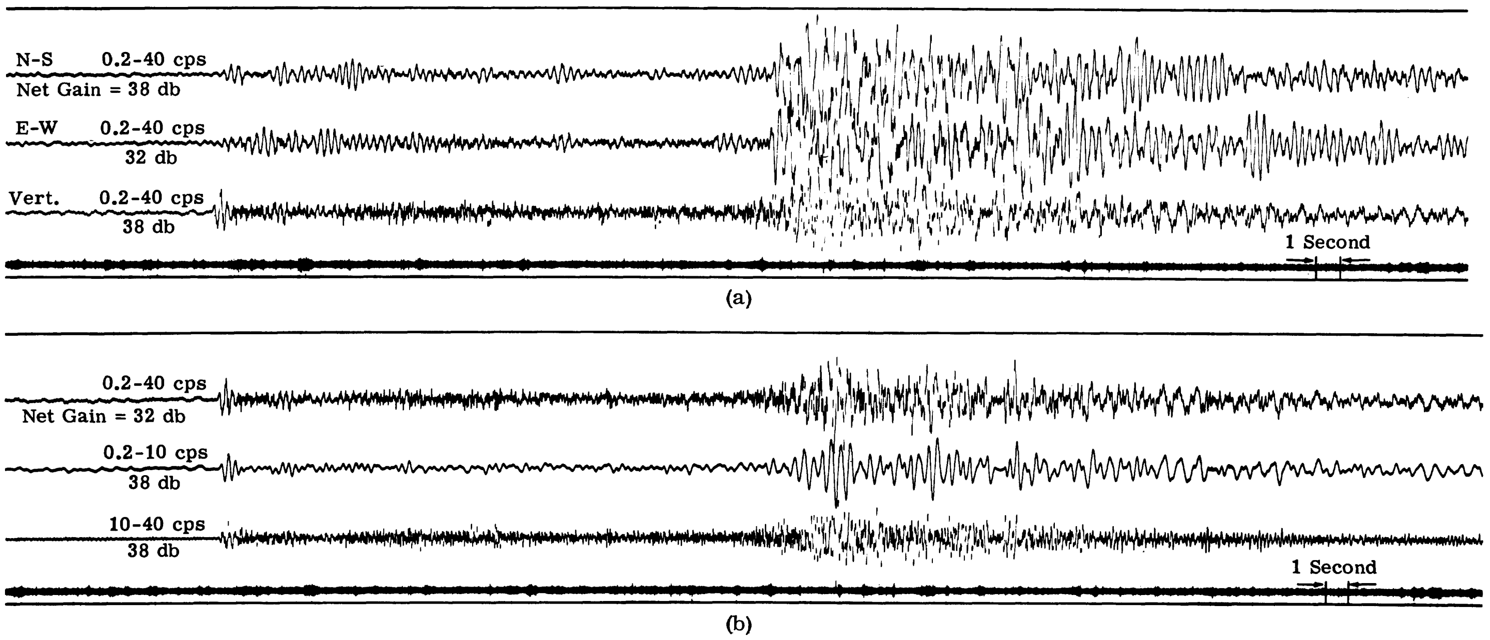


FIGURE 24. THREE-COMPONENT SEISMOGRAM OF AMERICAN SAMOA EARTHQUAKE OF MAGNITUDE 3.0, RECORDED AT EPICENTRAL DISTANCE OF 110 km. Time approximately 0554 EST, 28 May 1962. (a) Three-component recording using passbands of 0.1 to 40 cps. (b) Vertical-component recording using passbands of 0.2 to 5, 5 to 10, and 10 to 40 cps.

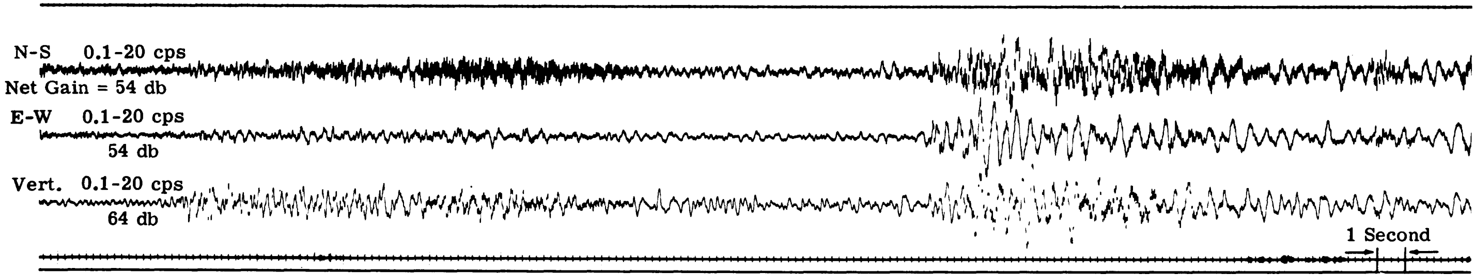


FIGURE 25. THREE-COMPONENT SEISMOGRAM OF PAKISTANI EARTHQUAKE OF MAGNITUDE 2.7, RECORDED AT EPICENTRAL DISTANCE OF 217 km. Time approximately 235 EST, 29 June 1962.

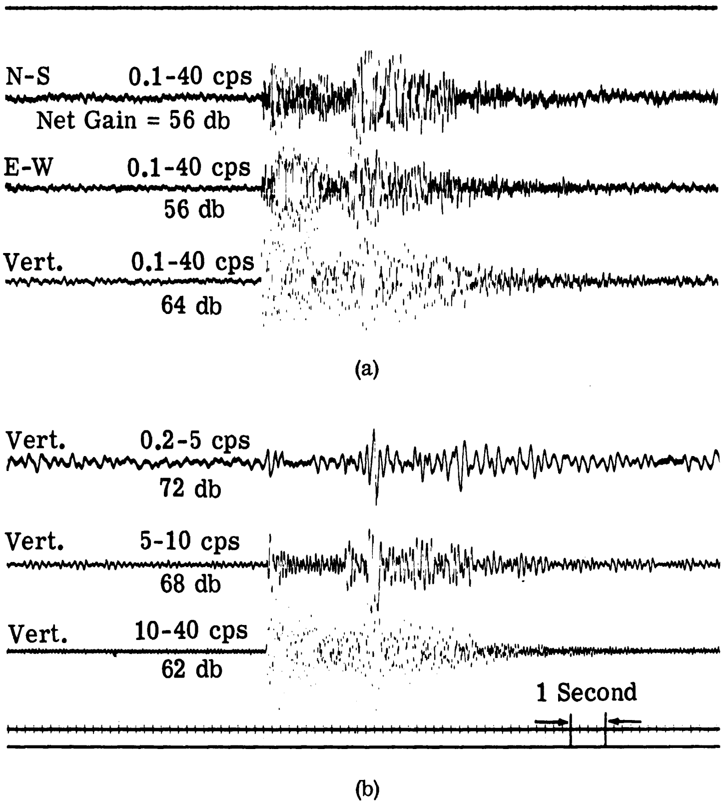


FIGURE 26. THREE-COMPONENT SEISMOGRAM OF PAKISTANI EARTHQUAKE OF MAGNITUDE 1.1, RECORDED AT EPICENTRAL DISTANCE OF 21 km. Time approximately 2354 EST, 2 July 1962. (a) Three-component recording using passband of 0.1 to 40 cps. (b) Vertical-component recording using passbands of 0.2 to 5, 5 to 10, and 10 to 40 cps.

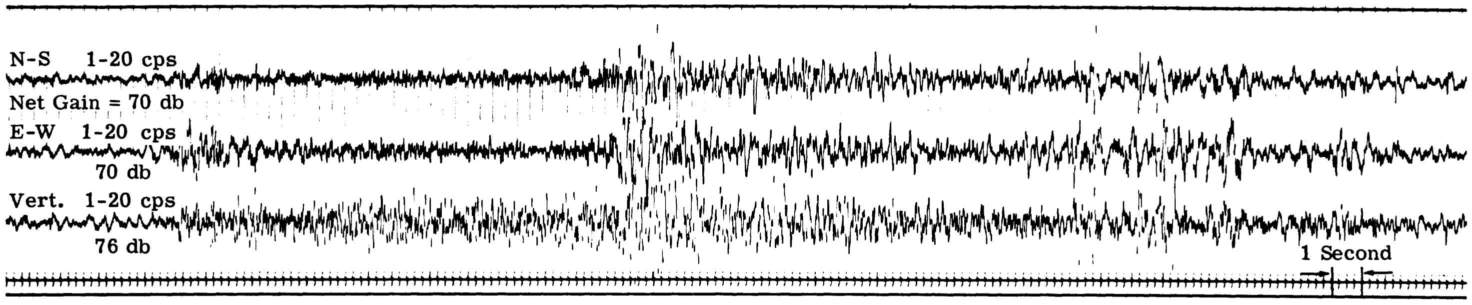


FIGURE 27. THREE-COMPONENT SEISMOGRAM OF PUERTO RICAN EARTHQUAKE OF MAGNITUDE 1.8, RECORDED AT EPICENTRAL DISTANCE OF 115 km. Time approximately 1936 EST, 18 May 1962.

Appendix E

THREE-COMPONENT PARTICLE VELOCITY DATA FOR EARTHQUAKE RECORDINGS OUTSIDE THE CONTINENTAL UNITED STATES

Three-component $\overline{\mathrm{P}}$ (or P_n or P) and $\overline{\mathrm{S}}$ (or S) particle velocity vs. frequency curves are shown in Figures 28 through 36 for most of the earthquake seismograms contained in Appendix D. An attempt was made to select an earthquake from each area that had comparable magnitudes and was recorded at approximately the same epicentral distance. In addition, spectral data are presented for several other earthquake recordings that were found to contain unusually high-frequency seismic energy.

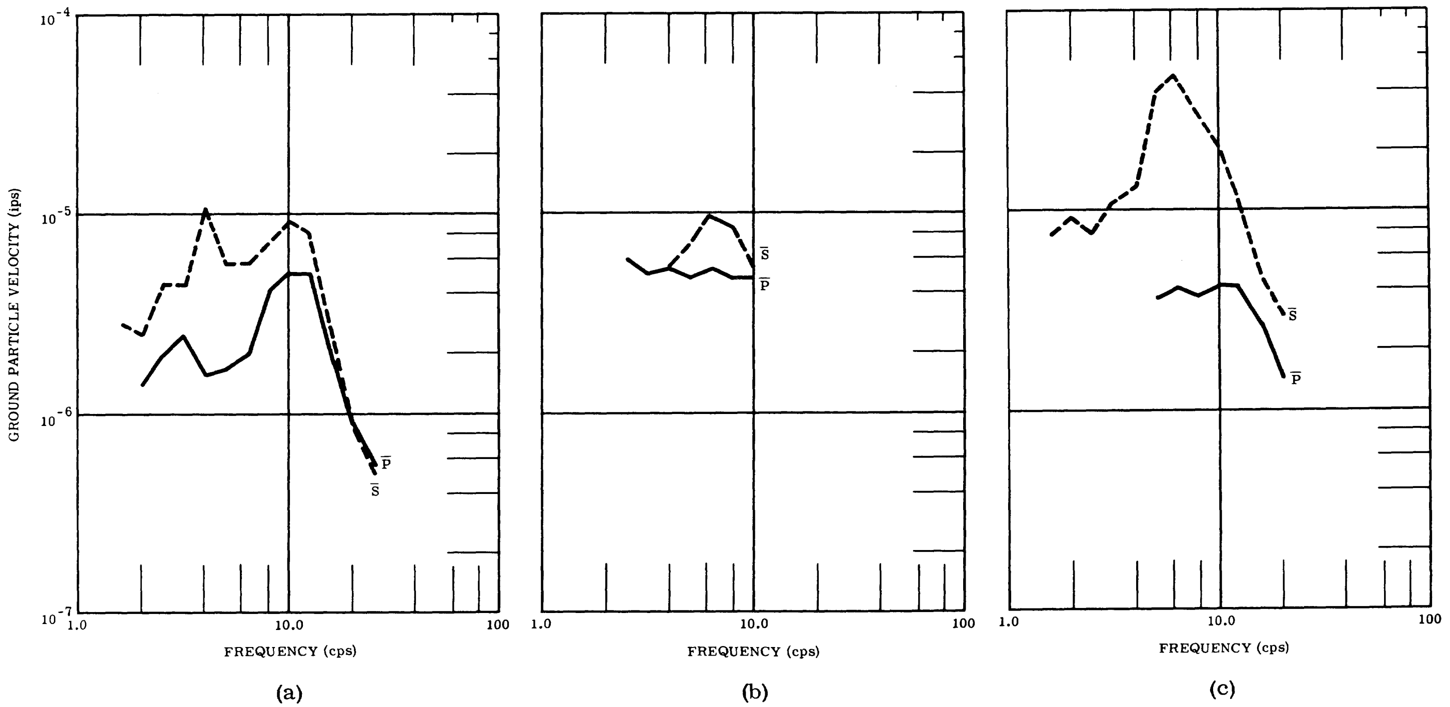


FIGURE 28. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF CHILEAN EARTHQUAKE OF MAGNITUDE 2.7, RECORDED AT EPICENTRAL DISTANCE OF 115 km. (a) Vertical component. (b) N-S component. (c) E-W component.

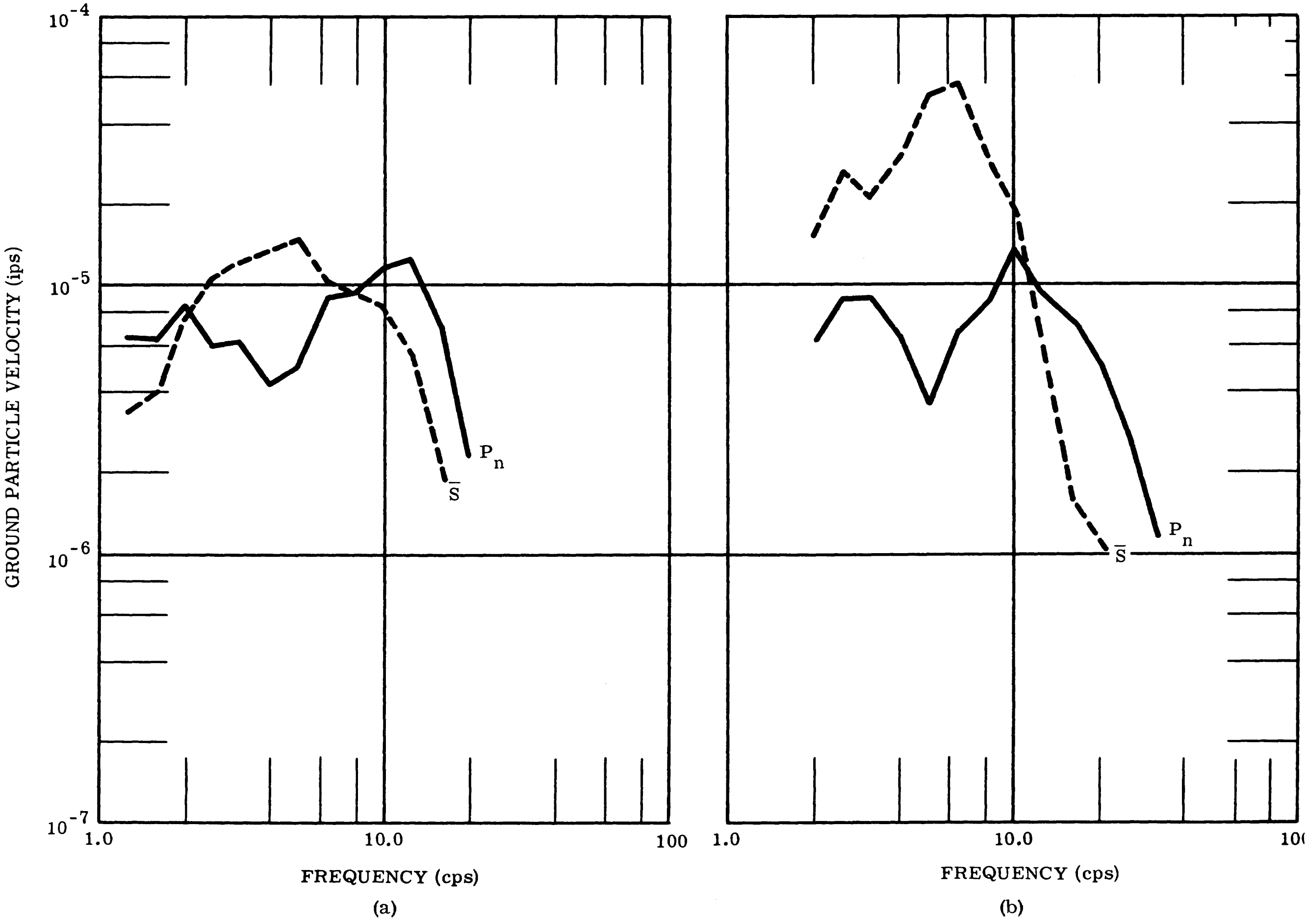


FIGURE 29. TWO-COMPONENT PARTICLE-VELOCITY CURVES OF CHILEAN EARTHQUAKE OF MAGNITUDE 3.7, RECORDED AT EPICENTRAL DISTANCE OF 310 km. (a) Vertical component. (b) E-W component.

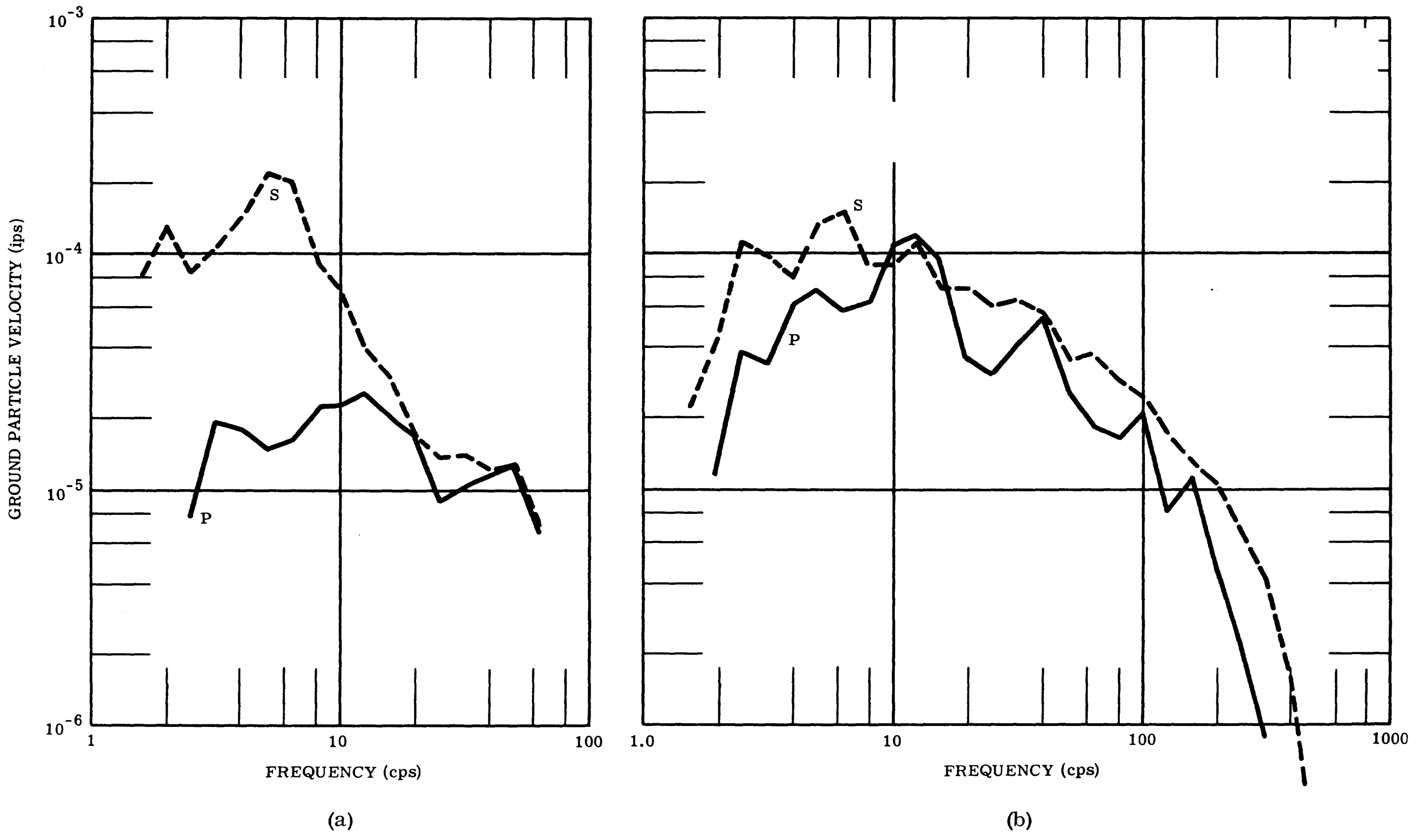
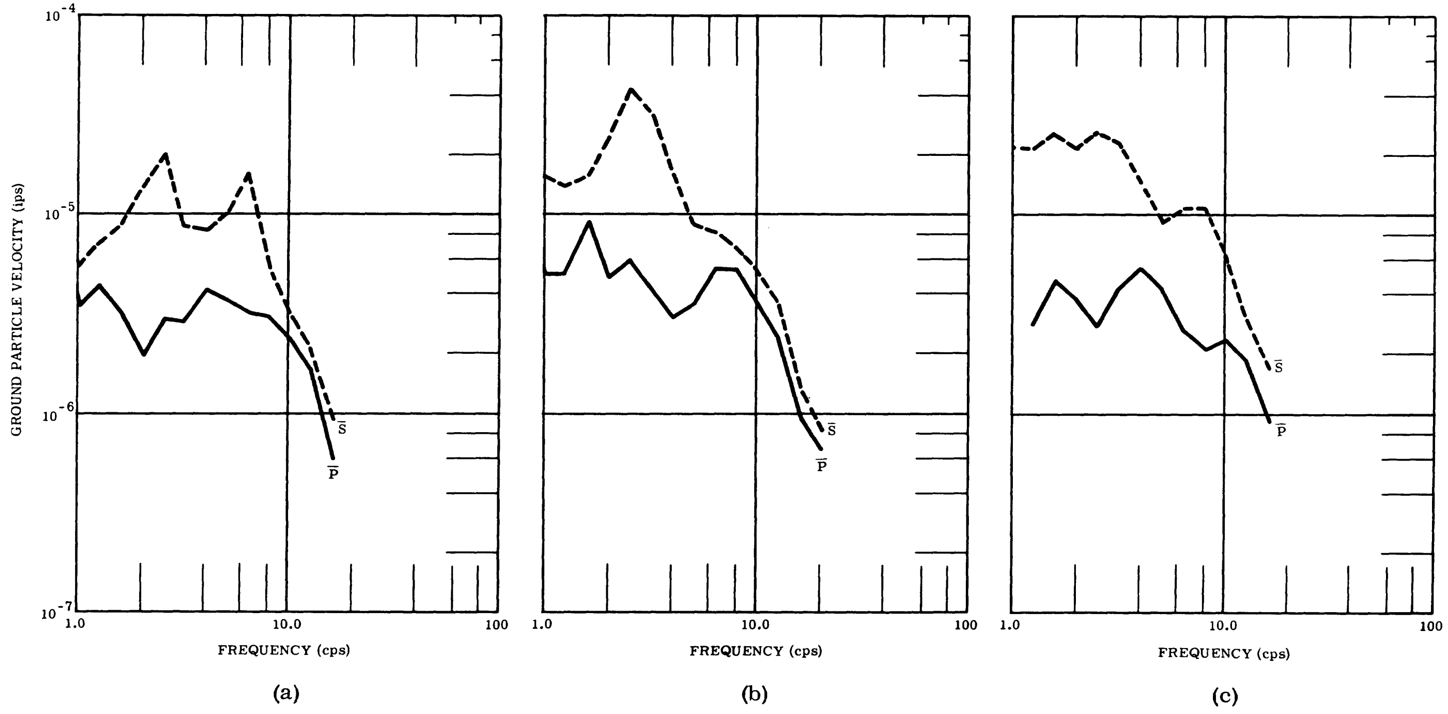


FIGURE 30. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF CHILEAN EARTHQUAKE OF MAGNITUDE 2.9, RECORDED AT EPICENTRAL DISTANCE OF 29 km. (a) N-S component. (b) Vertical component.



(a)

(b)

(c)

FIGURE 31. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF CRETAN EARTHQUAKE OF MAGNITUDE 2.7, RECORDED AT EPICENTRAL DISTANCE OF 116 km. (a) Vertical component. (b) N-S component. (c) E-W component.

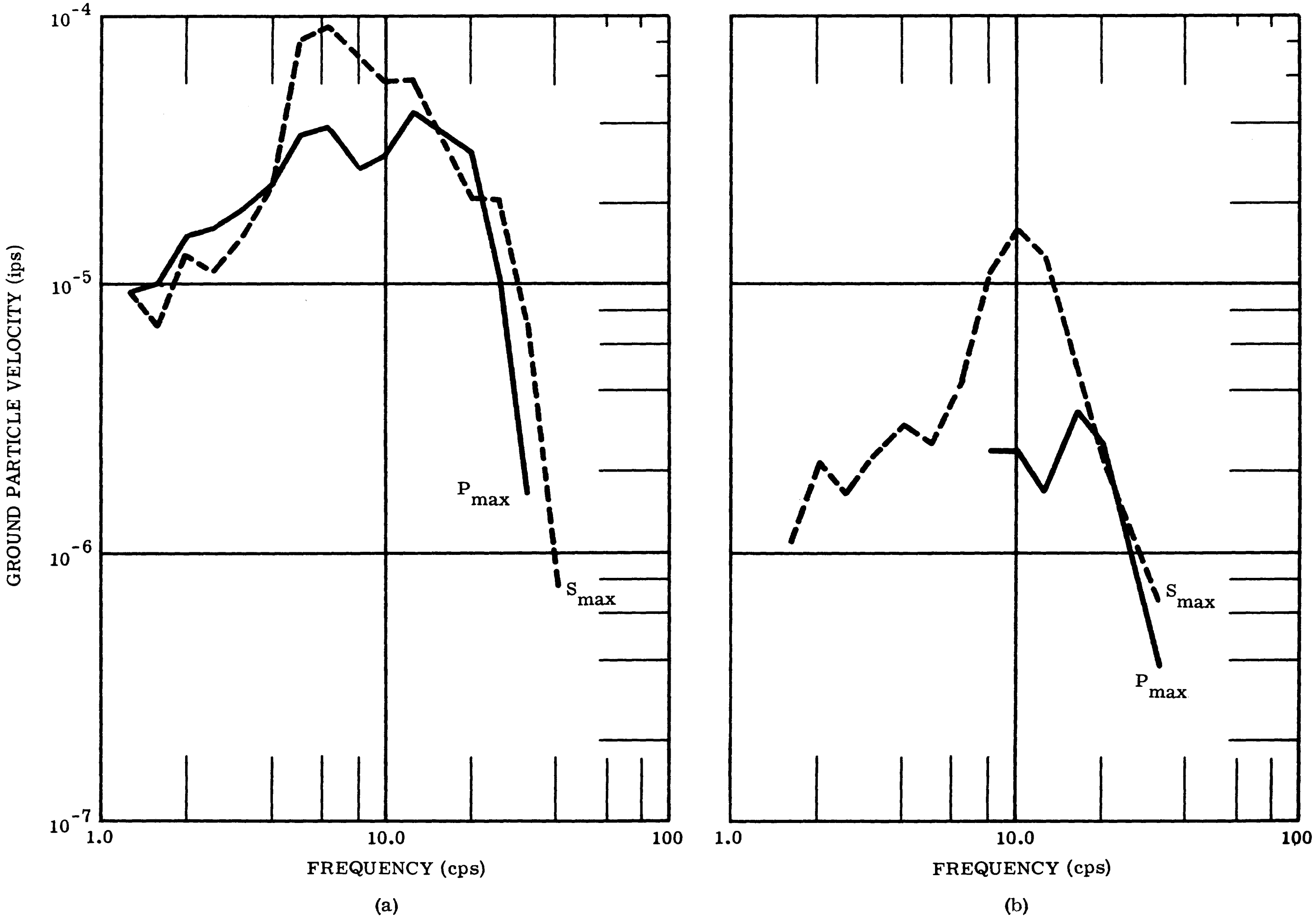


FIGURE 32. TWO-COMPONENT PARTICLE-VELOCITY CURVES OF HAWAIIAN EARTHQUAKE OF MAGNITUDE 2.3, RECORDED AT EPICENTRAL DISTANCE OF 32 km. (a) Vertical component. (b) Transverse conponent.

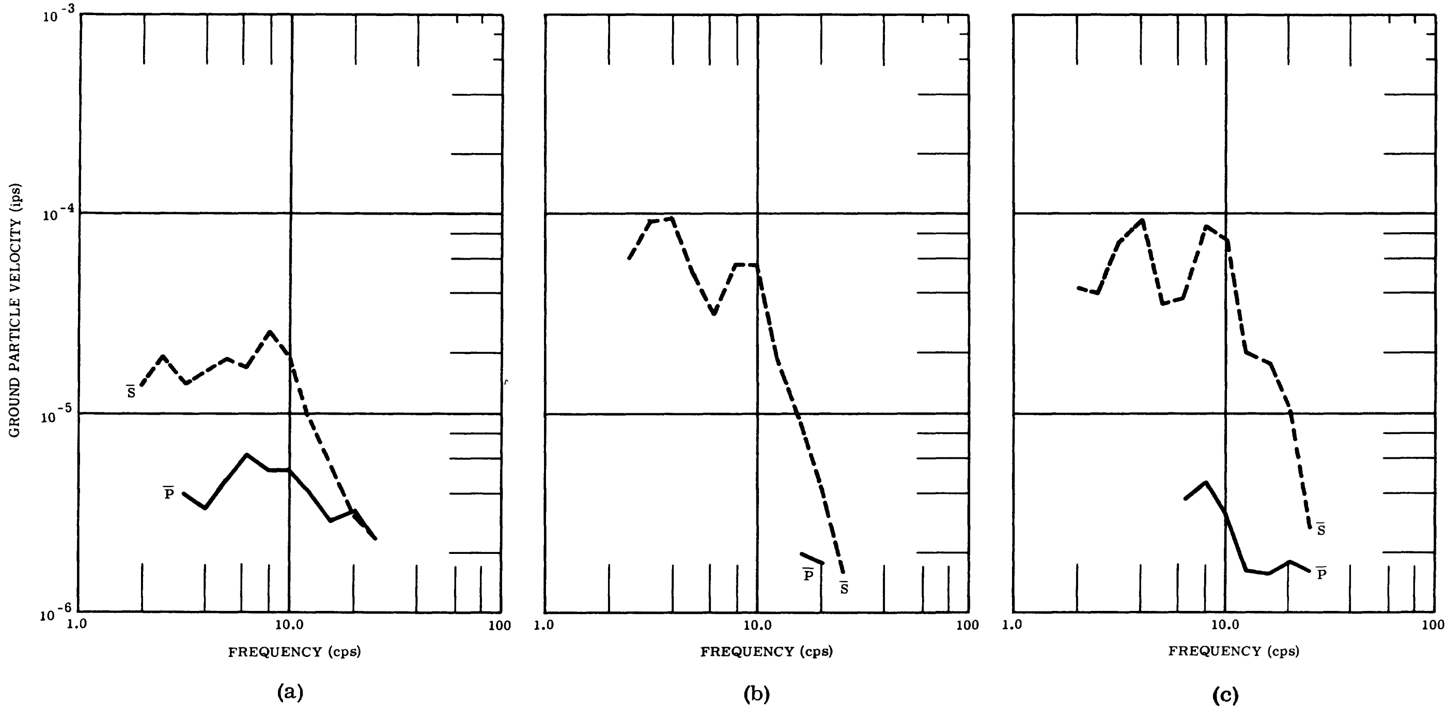
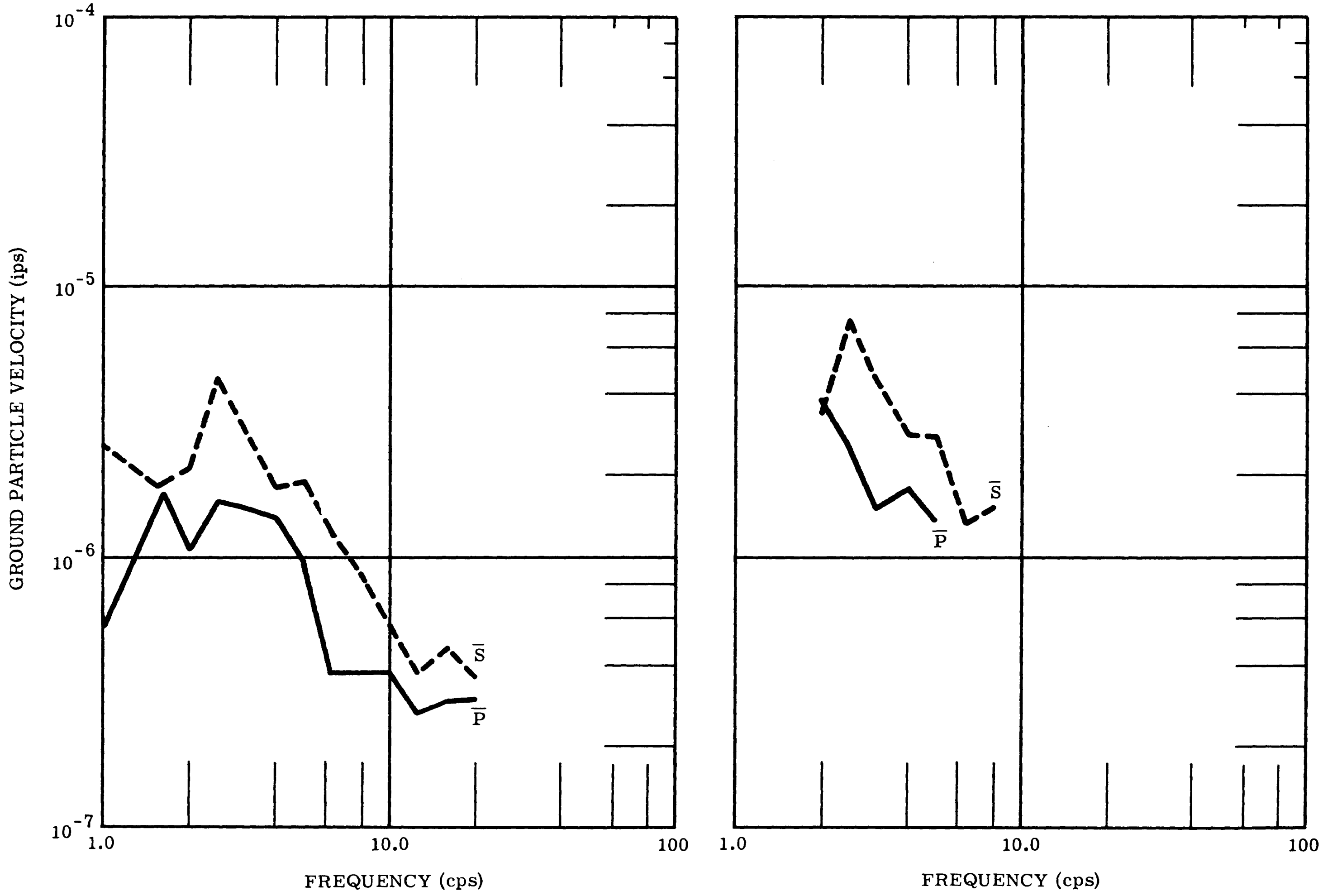


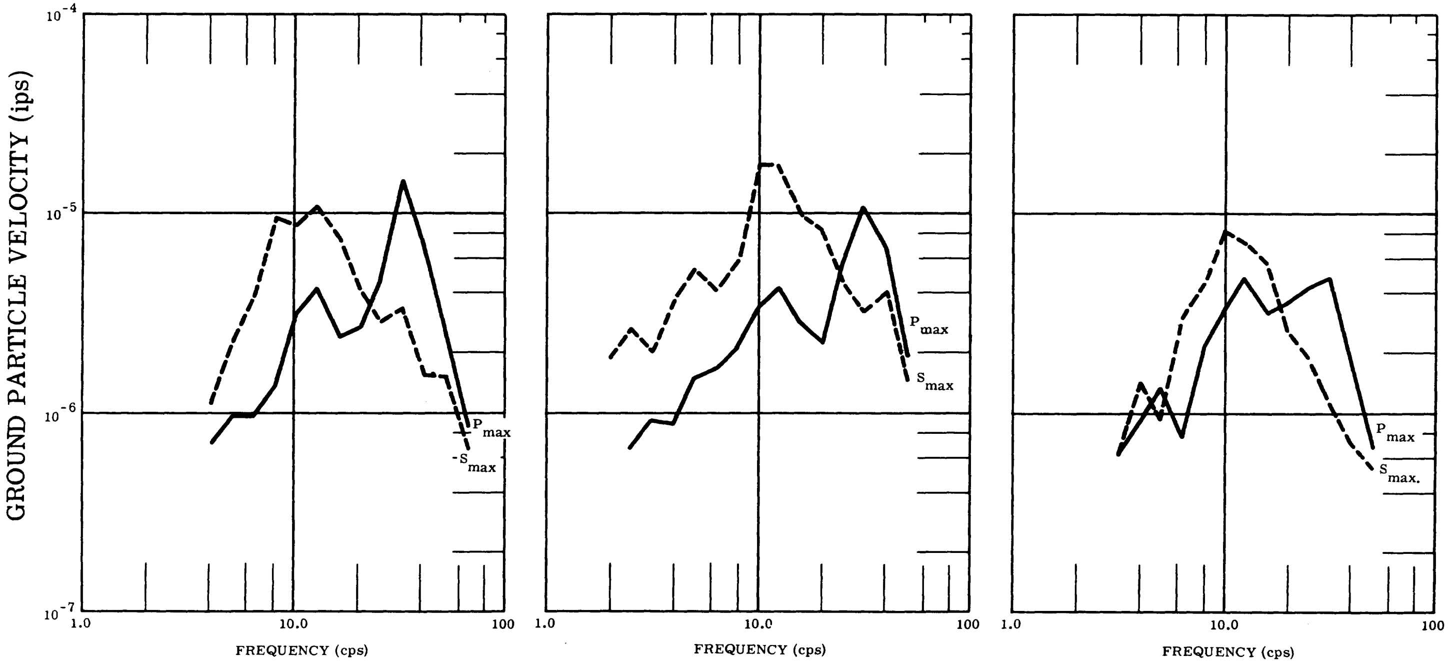
FIGURE 33. THREE-COMPONENT PARTICLE-VELOCITY CURVES AT AMERICAN SAMOA EARTHQUAKE OF MAGNITUDE 3.0, RECORDED AT EPICENTRAL DISTANCE OF 110 km. (a) Vertical component. (b) N-S component. (c) E-W component.



(a)

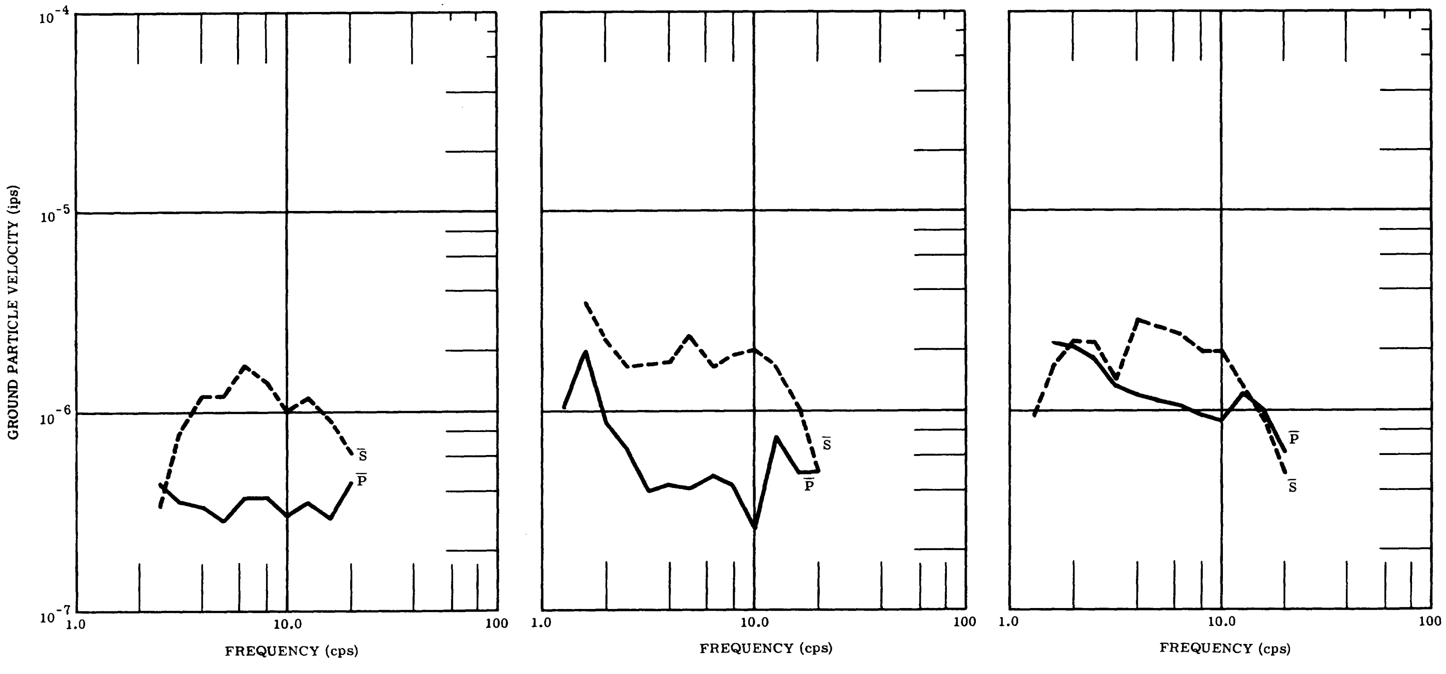
(b)

FIGURE 34. TWO-COMPONENT PARTICLE-VELOCITY CURVES OF PAKISTANI EARTHQUAKE OF MAGNITUDE 2.0, RECORDED AT EPICENTRAL DISTANCE OF 144 km. (a) Vertical component. (b) E-W component.



(a) (b) (c)

FIGURE 35. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF PAKISTANI EARTHQUAKE OF MAGNITUDE 1.1, RECORDED AT EPICENTRAL DISTANCE OF 21 km. (a) E-W component. (b) N-S component. (c) Vertical component.



(a) (b) (c)

FIGURE 36. THREE-COMPONENT PARTICLE-VELOCITY CURVES OF PUERTO RICAN EARTHQUAKE OF MAGNITUDE 1.8, RECORDED AT 114 km. (a) Vertical component. (b) N-S component. (c) E-W component.

Appendix F

VERTICAL COMPONENT PREDOMINANT FREQUENCIES FOR THE IMPORTANT SEISMIC WAVES

Detailed three-component particle-velocity curves were computed for three to fifteen individual events (depending on epicentral distance) for a majority of the earthquakes recorded at each site.

The data in this section are intended to show how the predominant frequencies of P_n, P_{max}, S_{max}, and the most prominent surface wave vary as a function of site location, epicentral distance, and magnitude for the vertical component earthquake recordings. In most records P_{max} and S_{max} correspond to $\overline{P}$ and $\overline{S}$. They are the largest-amplitude events in the compressional- and shear-wave trains. Space and costs prohibit including all of the spectral curves in this report.

In many cases the individual events have a broad spectral peak or contain two or more predominant peaks. These are indicated in Tables F-I through F-VI.

TABLE F-I. CHILEAN EARTHQUAKES

			Peak Frequencies (Vertical Component)		
Δ(km)	M	P_n	P_{max}	S_{max}	Predominant Surface Waves
24	0.8	-	32-40	10-12.5	-
24	1.1	-	32-40	10-12.5	-
24	1.0	-	32-40	8-12.5	-
29	1.4	-	10	12.5 & 8	-
29	1.2	-	32-40	12.5	-
29	2.9	-	12.5	6.3	-
29	1.0	-	32-40	10-12.5	-
29	1.2	-	40	12.5	-
37	1.7	-	12.5	12.5	-
37	1.1	-	12.5	6.3	-
37	-	-	10	12.5	-
47	1.3	-	12.5 & 40	12.5	12.5
47	2.5	-	10-12.5	12.5	12.5
50	2.8	-	12.5	12.5	12.5
85	2.3	-	10	10	3.2-5
103	3.4	-	4	2.5	2
115	2.0	-	10	12.5	2
115	2.7	-	5 & 12.5	2.5-6.3	4
127	2.3	-	5 & 12.5	2.5-5	2.5-5
140	2.7	-	12.5	12.5	5
275	3.1	10	10	3.2-8	4 & 12.5
310	3.7	12.5	2, 10-12.5	4-6.3	3.2

TABLE F-II. CRETAN EARTHQUAKES

		Peak Frequencies (Vertical Component)			
Δ(km)	M	P_n	P_{max}	S_{max}	Predominant Surface Waves
14	0.7	-	8-12.5	8	-
52	1.7	-	3.2-6.3	3.2-6.3	-
57	2.2		6.3	4	2
60	2.4		2	1-2.5	.5
68	2.1		8	8	6.3
68	1.9		5	3.2	2
71	2.0		6.3	3.2	1.6
76	2.2		8	8	1.25
76	2.7		4	1	1
78	2.5		3.2-5	2.5	1
87	2.1		2.5	4	2.5
87	2.8		1-2, & 4	2.5	.8
87	2.1		2	2.5	1-1.6
87	2.4		2-4	2.5	1.6-2.5
87	2.3		6.3	2-4	4
89	3.0		1	2.5	.63
116	2.7		4-6.3	2	1.6
128	2.7		2-4	1.6-2.5	1.6-2.5
140	2.6		2-6.3	2-2.5	2.5
142	2.8		5	4	1
144	2.6		4	2-4	2
150	2.5		2.5	2	1.6
167	3.2	2.5-4	1.6-4	1.6	1.25
355	3.3	1.6	2-2.5	2	1
402	5.1	10	0.8-1.6	0.8	0.8

TABLE F-III. HAWAIIAN EARTHQUAKES

Δ(km)	M	Peak Frequencies (Vertical Component)		
		P_{max}	S_{max}	Predominant Surface Waves
11	2.2	8-10	12.5	8
13	2.3	8-12.5	12.5	5
13	2.0	16	12.5	6.3
15	2.1	10	12.5	6.3
15	1.8	5	5	5
17	-	12.5-16	16	12.5
17	1.9	5	16	5
18	-	12.5	12.5-16	12.5
20	1.1	16	12.5-16	6.3
21	-	12.5	16	-
21	1.8	2.5	2	2
21	-	12.5	8 & 16	8
25	1.6	12.5	16	10-16
29	2.1	4	2 & 4	2.5
31	2.5	6.3	8 & 12.5	6.3
32	2.0	12.5	12.5	6.3
32	2.7	8	10	6.3
32	2.3	16	6.3 & 16	5
45	1.9	12.5	8-10	6.3-8
60	2.8	8	10-16	6.3

TABLE F-IV. AMERICAN SAMOA EARTHQUAKES

Δ(km)	M	Peak Frequencies (Vertical Component)			
		P_n	P_{max}	S_{max}	Predominant Surface Waves
74	1.9		1.25 & 8	1-3.2	1.25
110	3.0		4-8	8	2
140	3.8		4	1-3.2	1-1.6
145	3.3		2.5 & 10-20	3.2 & 8	2.5
185	3.7	6.3	2.5	3.2 & 8	2.5
190	4.2	5-6.3 &	10	4	1.6-2
200	4.	12.5			
200	4.5	2.5	2.5	4	1.6
200	3.6	2.5-4 & 16	1.6-4	8	1.6
220	4.1	8-20	8	4-8	4
315	4.3	1-1.6	1	1.6	1
390	4.2	3.2 & 10	3.2	4-8	1.6 & 8
700	5.0	2.5 & 8	5 & 8	2.5	2.-2.5

TABLE F-V. PAKISTANI EARTHQUAKES

			Peak Frequencies (Vertical Component)		
Δ(km)	M	P_n	P_{max}	S_{max}	Predominant Surface Waves
10	1.1		32	8 & 25	
14	1.3		12.5 & 40	16	
16	0.5		20	8 & 20	
19	0.3		25	6.3 & 25	
20	0.2		16 & 32	20	5
21	1.1		12.5 & 32	10	10
37	1.6		4 & 16	4 & 8	
48	1.3		3.2	3.2	4
53	1.1		8-12.5	4-5	
144	2.0		1.6	2.5	2.5
217	2.7	6.3-10	1-1.6	1-2.5	1
336	3.4	1.6	1.25	.6-.8	.6
700	4.0	5	1.25 & 4-6.3	1.6-4	2.5-3.2
860	4.3	3.2	3.2	1	.6
946		1-1.25	1-1.25		
1070	4.9	1 & 2	1	0.6	0.6
1120	4.7	1.25 & 6.3	1.25	.6	.6
1370	5.2	1 & 4	1.6	1 & 2.5	1-1.25
0.73*	0.3		25	25-32	50†

* Construction Shot

† Air Wave

TABLE F-VI. PUERTO RICAN EARTHQUAKES

			Peak Frequencies (Vertical Component)		
Δ(km)	M	P_n	P_{max}	S_{max}	Predominant Surface Waves
13	1.3		6.3 & 32	3.2	
34	0.9		10-16	5 & 12	
36	0.5		6.3 & 20	10	
45	1.2		5-16	& 5	
66	1.7		8	4	
85	2.1		20	5-8	6.3
88	2.1		5-6.3	2-6.3	1.6-4
90	1.7		5-6.3	2.5	1.6-2
90	1.4		6.3	6.3	2
92	2.0		6.3	4	1.6-4
94	2.1		2.5	2.5	1
94	1.8		6.3	2.5	1.6
95	1.7		2 & 12.5	6.3	1
110	1.7		2.5 & 12.5	5	1
114	1.8		2.5 & 6.3	6.3	.6 & 2.5
167	2.0		6.3	2.5	2.5
177	1.8		2.5	2.5	1.6-2
192	2.0	3.2	5	2.5-5	2-3.2
210	2.0	5	5	1.6-2.5	1

Appendix G

STATISTICAL STUDY OF AMPLITUDE RATIOS OF SHEAR-SURFACE WAVES TO COMPRESSIONAL WAVES

An examination of the particle-velocity curves of the various types of seismic waves for each earthquake analyzed disclosed that the shear-surface waves consistently contained larger particle-velocity amplitudes than the compressional waves. In order to make a quantitative study of these data, the envelope containing all of the individual spectral curves was plotted for the shear-surface waves and the compressional waves for each earthquake. The ratios of the amplitudes of these two envelopes as a function of frequency were then computed. The mean amplitude ratio, the median, the first standard deviation above and below the mean amplitude ratio, and the range or scatter were then computed for each of the six locations where there were sufficient data. These data are shown in Figures 37 through 39 for the distance ranges of 0 to 50 km, 50 to 100 km, and 100 to 200 km. A composite of the mean amplitude ratio for all the areas is shown in Figure 40.

These data in Figures 37 through 40 pertain to the vertical component only. Similar computations were made for the north-south and east-west horizontal components. However, these data are not very meaningful since the azimuth between the earthquake epicenters and the recording stations could not be determined from the data available.

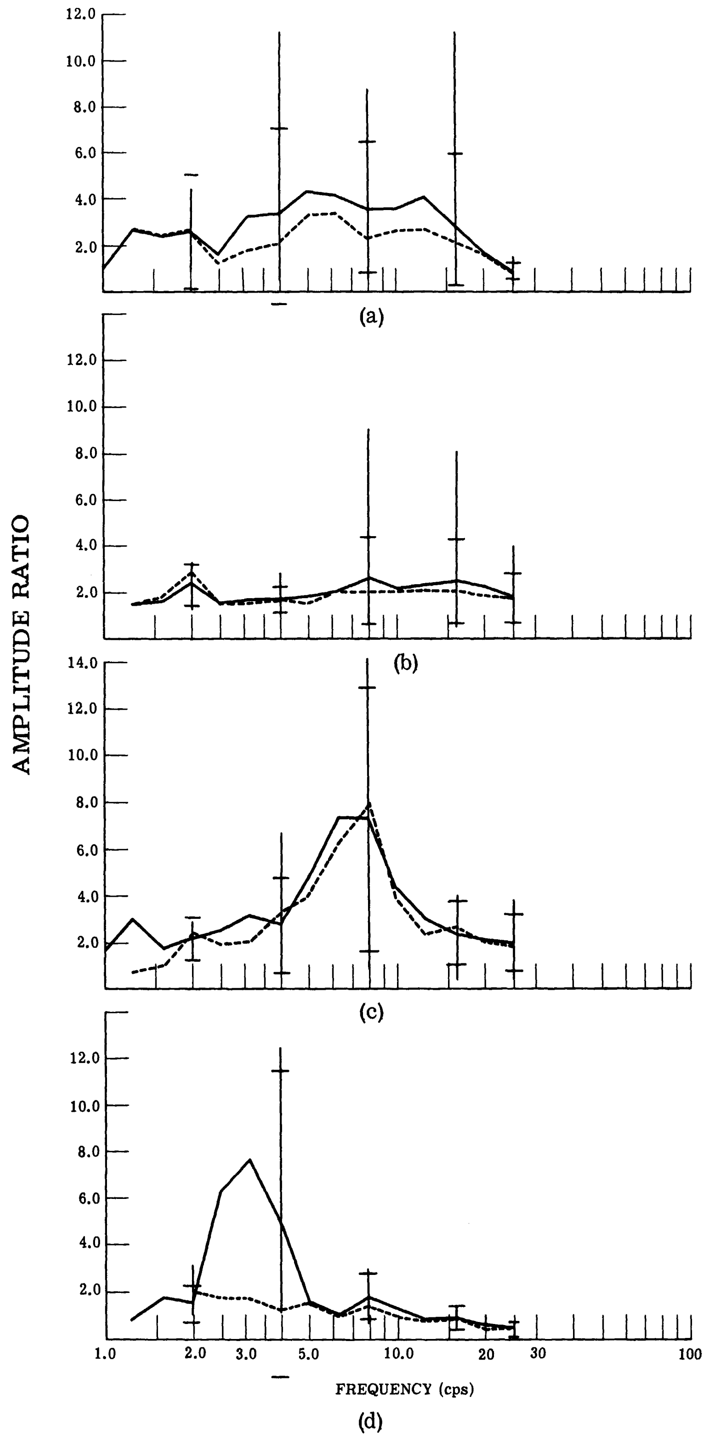


FIGURE 37. AMPLITUDE RATIOS OF SHEAR-SURFACE WAVES TO COMPRESSIONAL WAVES FOR VERTICAL-COMPONENT EARTHQUAKE RECORDINGS MADE AT EPICENTRAL DISTANCES OF 0 TO 50 km. —— vertical mean; - - - vertical median; | range; $\pm$ standard deviation. (a) Chilean earthquake. (b) Hawaiian earthquake. (c) Pakistani earthquake. (d) Puerto Rican earthquake.

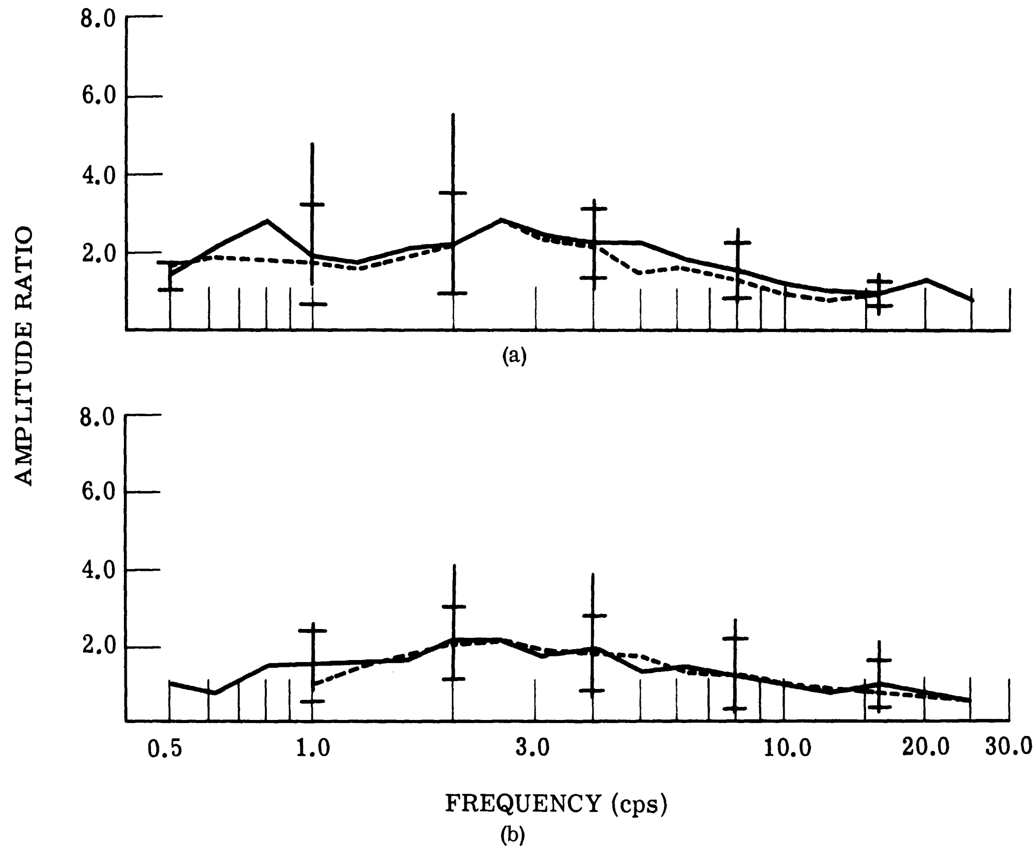


FIGURE 38. AMPLITUDE RATIOS OF SHEAR-SURFACE WAVES TO COMPRESSIONAL WAVES FOR VERTICAL-COMPONENT EARTHQUAKE RECORDINGS MADE AT EPICENTRAL DISTANCES OF 50 TO 100 km. Symbols as in Figure 37. —— vertical mean; - - - vertical median; | range ⊥ standard deviation. (a) Cretan earthquake. (b) Puerto Rican earthquake.

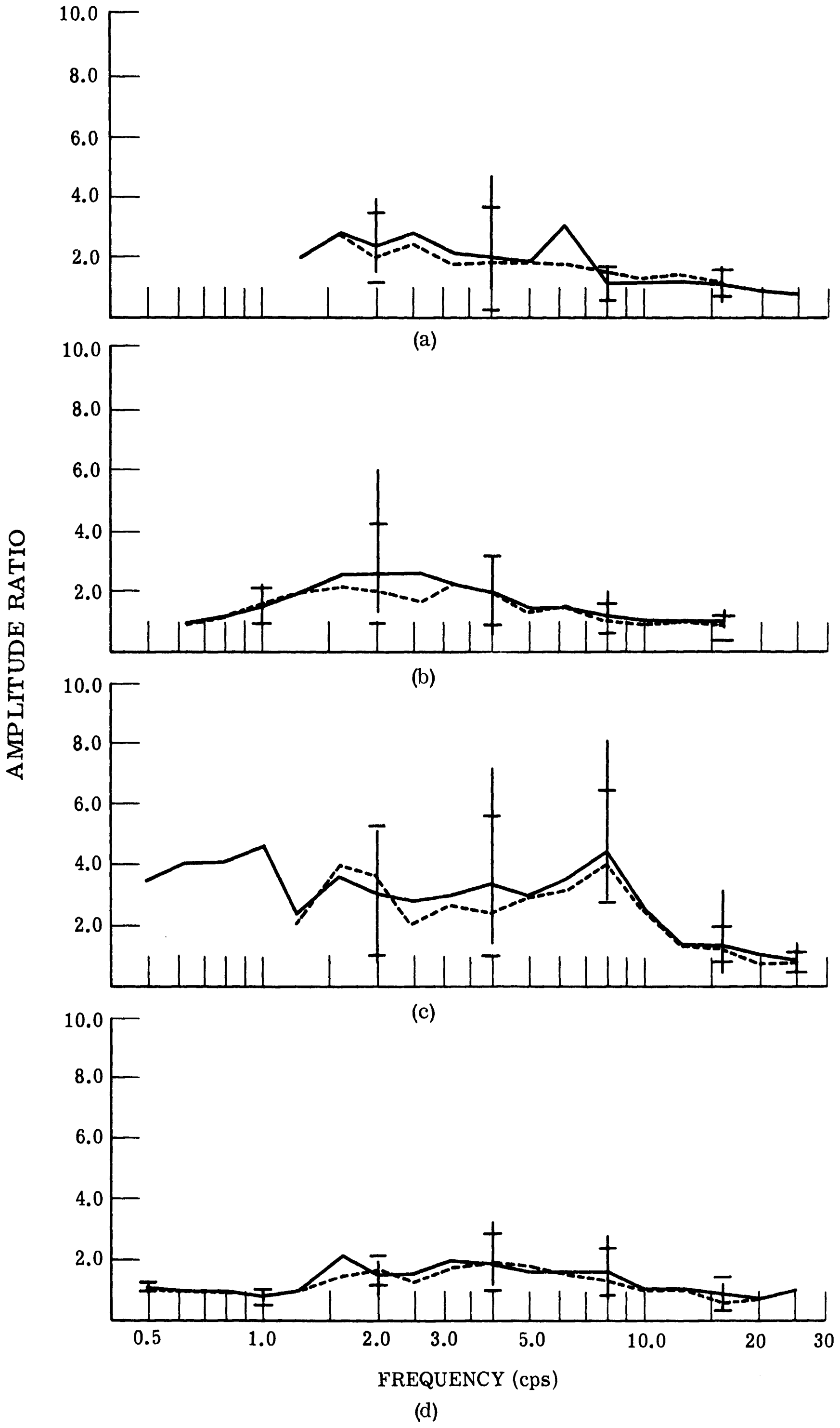


FIGURE 39. AMPLITUDE RATIOS OF SHEAR-SURFACE WAVES TO COMPRESSIONAL WAVES FOR VERTICAL-COMPONENT EARTHQUAKE RECORDINGS MADE AT EPICENTRAL DISTANCES OF 100 TO 200 km. Symbols as in Figure 37. (a) Chilean earthquake. (b) Cretan earthquake. (c) American Samoa earthquake. (d) Puerto Rican earthquake.

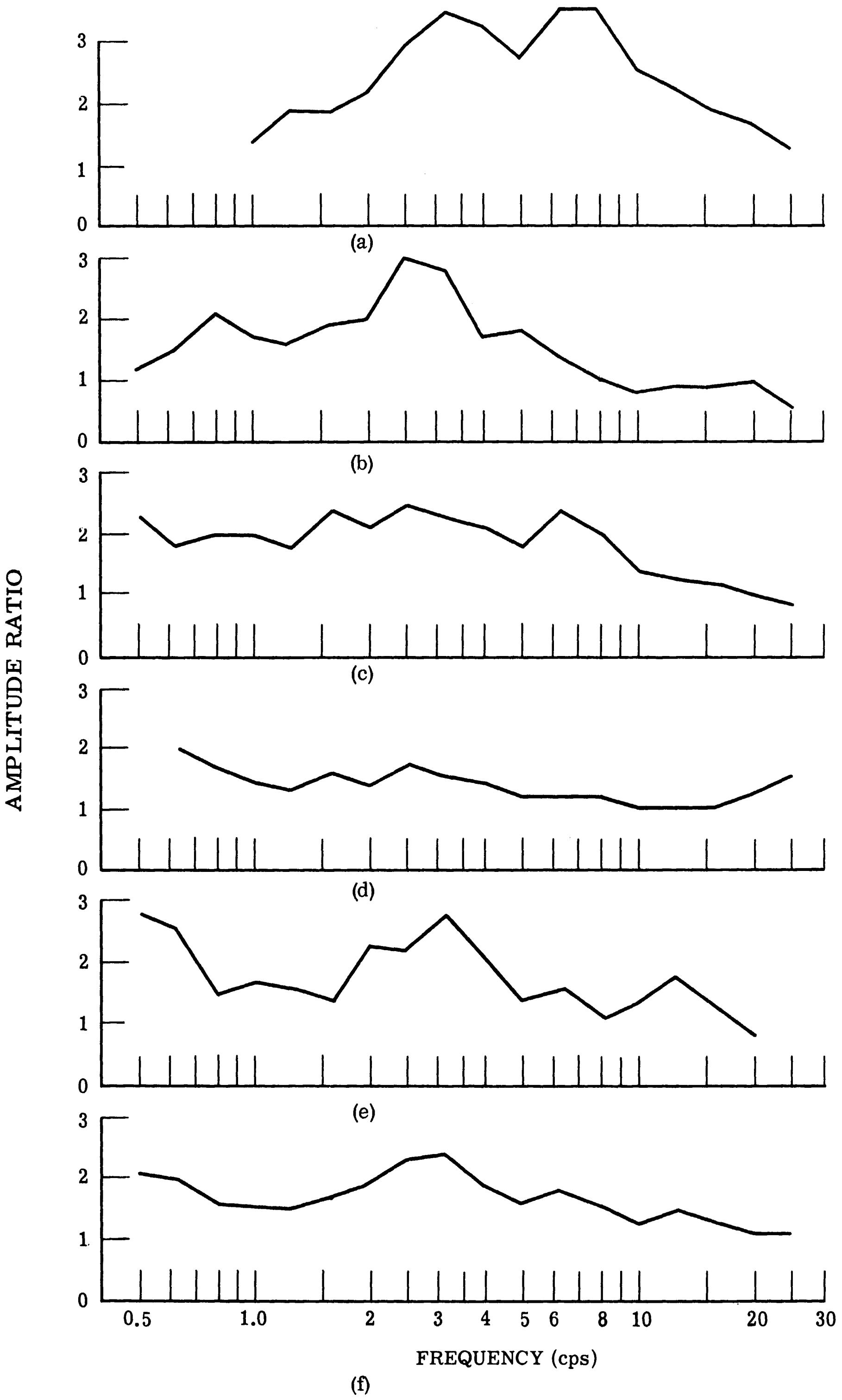


FIGURE 40. COMPOSITE AMPLITUDE RATIOS OF SHEAR-SURFACE WAVES TO COMPRESSIONAL WAVES FOR VERTICAL-COMPONENT EARTHQUAKE RECORDINGS. (a) 0 to 50 km. (b) 50 to 100 km. (c) 100 to 200 km; (d) 200 to 400 km. (e) 400 to 1000 km. (f) 0 to 1000 km.

Appendix H

TABULATION OF VERTICAL COMPONENT AMPLITUDE RATIO OF SHEAR-SURFACE WAVES TO COMPRESSIONAL WAVES

Statistical data were presented in Appendix G for the amplitude ratios of the shear-surface waves to compressional waves for a number of earthquake-recording sites. These data divided into several distance ranges for each area. Unfortunately there were not enough recordings at each distance range for each area to allow statistical analysis. Therefore it is necessary to present the data in tabular form to show more fully how these amplitude ratios change with distance for each area. Tables H-I through H-VI contain the amplitude ratios divided into the following distance ranges for each area: 0 to 50 km, 50 to 100 km, 100 to 200 km, 200 to 400 km, and 400 to 1000 km.

TABLE H-I. CHILEAN EARTHQUAKES

Vertical Mean S/P Amplitude Ratios

	Range (km)			
Frequency (cps)	0-50	50-100	100-200	200-400
0.5	--	--	--	--
0.6	--	--	--	--
0.8	--	--	--	--
1.0	1.1	--	--	--
1.25	2.5	--	2.0	--
1.6	2.4	--	2.8	--
2.0	2.7	1.6	2.4	0.7
2.5	1.6	3.2	2.8	1.0
3.15	3.2	2.7	2.2	1.5
4.0	3.4	2.1	2.0	1.5
5.0	4.3	3.0	1.9	1.1
6.3	4.1	1.4	3.0	1.1
8.0	3.5	0.8	1.2	0.9
10.0	3.6	0.9	1.2	0.5
12.5	4.1	1.3	1.2	0.4
16.0	2.9	1.3	1.1	0.3
20.0	1.6	0.9	0.9	0.5
25.0	0.9	0.6	0.8	--

TABLE H-II. CRETAN EARTHQUAKES

Vertical Mean S/P Amplitude Ratios

Frequency (cps)	Range (km)				
	0-50	50-100	100-200	200-400	400-1000
0.5	--	1.4	--	--	2.8
0.63	--	2.2	0.9	--	3.8
0.8	--	2.8	1.2	1.4	1.6
1.0	--	1.9	1.5	1.3	1.7
1.25	--	1.7	1.9	1.1	1.7
1.6	--	2.1	2.5	2.0	0.5
2.0	--	2.3	2.5	2.2	0.6
2.5	--	2.9	2.5	1.0	0.6
3.15	1.8	2.5	2.2	1.0	0.8
4.0	3.8	2.2	2.0	1.4	0.9
5.0	1.6	2.2	1.5	0.9	0.7
6.3	3.6	1.9	1.4	0.6	0.6
8.0	2.8	1.6	1.2	--	0.9
10.0	1.3	1.2	1.0	--	0.9
12.5	1.0	1.1	1.0	--	--
16.0	1.0	1.0	1.0	--	--
20.0	--	1.3	--	--	--
25.0	--	0.8	--	--	--

TABLE H-III. HAWAIIAN EARTHQUAKES

Vertical Mean S/P Amplitude Ratios

Frequency (cps)	Range (km)	
	0-50	50-100
0.5	--	--
0.63	--	--
0.8	--	--
1.0	--	--
1.25	1.5	--
1.6	1.6	--
2.0	2.4	--
2.5	1.5	--
3.15	1.6	--
4.0	1.6	1.1
5.0	1.8	1.4
6.3	2.0	1.2
8.0	2.5	0.9
10.0	2.1	0.6
12.5	2.3	0.5
16.0	2.5	0.3
20.0	2.2	--
25.0	1.7	--

TABLE H-IV. AMERICAN SAMOA EARTHQUAKES

Vertical Mean S/P Amplitude Ratios

Frequency (cps)	Range (km) 0-50	50-100	100-200	200-400	400-1000
0.5	--	--	3.4	--	--
0.63	--	--	4.0	--	--
0.8	--	--	4.0	--	--
1.0	--	--	4.5	1.3	--
1.25	--	--	2.3	1.5	1.8
1.6	--	--	3.6	1.4	2.2
2.0	--	--	3.1	1.5	4.5
2.5	--	3.6	2.7	1.3	4.5
3.15	--	4.0	2.9	1.2	6.3
4.0	--	1.4	3.3	1.3	4.0
5.0	--	1.1	2.6	1.5	2.5
6.3	--	0.9	3.5	2.4	3.2
8.0	--	0.6	4.5	2.1	2.0
10.0	--	0.4	2.5	2.1	2.8
12.5	--	--	1.4	2.0	2.5
16.0	--	--	1.4	1.4	1.8
20.0	--	--	1.1	1.6	--
25.0	--	--	0.9	1.5	--

TABLE H-V. PAKISTANI EARTHQUAKES

Vertical Mean S/P Amplitude Ratios

Frequency (cps)	Range (km) 0-50	50-100	100-200	200-400	400-1000
0.5	--	--	--	--	--
0.63	--	--	1.4	2.0	1.4
0.8	--	--	1.8	1.9	1.4
1.0	1.7	--	1.2	1.6	1.7
1.25	2.9	--	1.7	1.2	1.4
1.6	1.8	--	1.0	1.3	1.6
2.0	2.2	--	1.2	1.1	1.7
2.5	2.6	--	2.8	2.2	1.5
3.15	3.2	--	2.2	2.2	1.3
4.0	2.8	--	1.4	1.5	1.3
5.0	4.8	--	1.6	0.9	1.1
6.3	7.4	--	2.7	0.7	0.9
8.0	7.3	--	1.6	0.6	0.5
10.0	4.4	--	1.3	0.3	0.4
12.5	3.0	--	2.0	0.5	1.1
16.0	2.4	--	1.6	1.3	0.8
20.0	2.1	--	1.4	1.5	0.8
25.0	2.0	--	--	1.5	--

TABLE H-VI. PUERTO RICAN EARTHQUAKES

Vertical Mean S/P Amplitude Ratios

Frequency (km)	Range (km) 0-50	50-100	100-200	200-400
0.5	--	1.0	1.1	--
0.63	--	0.8	1.0	--
0.8	--	1.4	1.0	--
1.0	--	1.5	0.8	--
1.25	0.9	1.5	1.0	1.3
1.6	1.8	1.6	2.1	1.7
2.0	1.6	2.1	1.5	1.5
2.5	6.2	2.1	1.5	3.2
3.15	7.7	1.8	2.0	1.8
4.0	5.1	1.9	1.9	1.1
5.0	1.7	1.3	1.6	1.6
6.3	1.1	1.4	1.6	1.0
8.0	1.7	1.2	1.6	1.3
10.0	1.4	1.0	1.1	1.1
12.5	0.9	0.8	1.0	--
16.0	0.9	1.0	0.9	--
20.0	0.7	0.7	0.7	--
25.0	0.5	0.5	1.0	--

REFERENCES

1. D. E. Willis, J. M. DeNoyer, and J. T. Wilson, "Differentiation of Earthquakes and Underground Nuclear Explosions on the Basis of Amplitude Characteristics," Bull. Seis. Soc. Am., in publication (Vol. 53, October 1963).
2. D. E. Willis, J. M. DeNoyer, and J. T. Wilson, "Spectral Differences in Earthquakes and Underground Explosions," presented at I.U.G.G. Meetings in Berkeley, California, August 30, 1963.
3. D. E. Willis, J. M. DeNoyer, and J. T. Wilson, "High-Frequency Energy in Seismic Signals Recorded from Different Type Sources," in publication as a VESIAC Special Studies Report, Institute of Science and Technology, University of Michigan, Ann Arbor, Mich.
4. G. E. Frantti, D. E. Willis, and J. T. Wilson, "The Spectrum of Seismic Noise," Bull. Seis. Soc. Am., January 1962, Vol. 52, No. 1, pp. 113-121.

DISTRIBUTION LIST

Copy No.	Addressee
1-4	Headquarters Air Force Office of Scientific Research Office of Aerospace Research United States Air Force Washington 25, D. C. ATTN: SRPG
5-8	Advanced Research Projects Agency The Pentagon Washington 25, D. C.
9	RAND Corporation 1700 Main Street Santa Monica, California ATTN: Dr. R. Latter
10	California Institute of Technology Seismological Laboratory Pasadena, California ATTN: Dr. F. Press
11	Continental Oil Company P. O. Drawer 1267 Ponca City, Oklahoma ATTN: Dr. J. Crawford
12	Air Force Technical Applications Center Headquarters, USAF Washington 25, D. C. ATTN: TD-1
13	U. S. Coast & Geodetic Survey (Seismology Branch) Department of Commerce Washington 25, D. C.
14	National Science Foundation Washington 25, D. C. ATTN: Earth Sciences Division
15	Naval Research Laboratory Washington 25, D. C. ATTN: Librarian (Code 2027)
16-17	British Defense Research Staff British Embassy 3100 Massachusetts Ave., N.W. Washington 8, D. C. ATTN: Atomic Coordinating Office
18	U. S. Geological Survey Department of Interior Washington 25, D. C. ATTN: Crustal Studies
19	Institute for Defense Analysis Universal Building Connecticut Ave., N.W. Washington 25, D. C. ATTN: RESD
20	Defense Atomic Support Agency The Pentagon Washington 25, D. C. ATTN: Blast & Shock Division
21	U. S. Army Research Office Box CM, Duke Station Durham, North Carolina
22	Bell Telephone Laboratory Murray Hill, New Jersey ATTN: Dr. B. Bogert
23	Office of Aerospace Research Washington 25, D. C. ATTN: RROSG
24	U. S. Arms Control Disarmament Agency Department of State Washington 25, D. C. ATTN: Mr. D. Musser
25	Vela Data Analysis & Technique Development Center Headquarters, USAF Washington 25, D. C. ATTN: AFTAC-TD-1A
26	Air Force Cambridge Research Laboratory Hanscom Air Force Base Bedford, Massachusetts ATTN: SRZG
27	Seismological Laboratory California Institute of Technology Pasadena, California ATTN: Dr. V. Hugo Benioff
28	Shell Development Company P. O. Box 481 Houston 1, Texas ATTN: Dr. Sidney Kaufman
29	Gulf Research & Development Company Box 2038 Pittsburgh 30, Pennsylvania ATTN: Dr. T. J. O'Donnell

Copy No.	Addressee
30	Lamont Geological Observatory Palisades, New York ATTN: Dr. Jack E. Oliver
31	Institute of Technology St. Louis University St. Louis, Missouri ATTN: Father William V. Stauder, S.J.
32	Carnegie Institution of Washington Department of Terrestrial Magnetism 5241 Broadbranch Road, N.W. Washington 15, D. C. ATTN: Dr. John S. Steinhart
33	A. U. (Library) Maxwell AFB, Alabama
34	AWS (AWSSS/TIPD) Scott AFB, Illinois
35	AFCRL, OAR (CRTPM) L. G. Hanscom Field Bedford, Massachusetts
36	AFCRL, OAR (CRXR, Mr. John Marple) L. G. Hanscom Field Bedford, Massachusetts
37-53	AFCRL, OAR (CRXRA) Stop 39 L. G. Hanscom Field Bedford, Massachusetts
54-58	AFCRL, OAR (CRJW) L. G. Hanscom Field Bedford, Massachusetts
59	ESD (ESRDG) L. G. Hanscom Field Bedford, Massachusetts
60	ACIC (ACDRL-7) Second and Arsenal St. Louis 18, Missouri
61	NAFEC, Library Branch, Bldg. 3 Atlantic City, New Jersey ATTN: RD-702
62	Aeronautical Systems Division Wright-Patterson AFB, Ohio ATTN: (ASAPRD-Dist)
63	Institute of Technology Library MCLI-LIB, Bldg. 125, Area B Wright-Patterson AFB, Ohio
64	Hq. USAF (AFCSA, Secretary) Washington 25, D. C.
65	Hq. USAF (AFRDR) Washington 25, D. C.
66	ARA - AROL Library AFL 2292, Bldg. 450 Wright-Patterson AFB, Ohio
67-69	Defense Research Member Canadian Joint Staff 2450 Massachusetts Ave., N.W. Washington 8, D. C.
70	U. S. Geological Survey (Crustal Studies) Room 2292, Bldg. 25 Denver Federal Center Denver 25, Colorado
71-90	Defense Documentation Center (DDC) Cameron Station Alexandria, Va.
91	Documents Expediting Project (UNIT X) Library of Congress Washington 25, D. C.
92	National Research Council 2101 Constitution Avenue Washington 25, D. C.
93	Office of Secretary of Defense (DDR & E) Tech. Library Washington 25, D. C.
94	Library U. S. Weather Bureau Washington 25, D. C.
95	Scientific and Technical Information Facility P. O. Box 5700 Bethesda, Maryland ATTN: NASA Representative (S-AK-DL)
96	RAND Corporation 1700 Main Street Santa Monica, California ATTN: Dr. William W. Kellogg
97	Institute of Aerospace Sciences, Inc. 2 East 64th Street New York 21, New York
98	ONR (Geophysics Code N-416) Office of Naval Research Washington 25, D. C.

Copy No.	Addressee
99	Chief of Naval Research Code 418 Department of the Navy Washington 25, D. C.
100	Director U. S. Naval Research Laboratory Code 2027 Washington 25, D. C.
101	Dr. Joseph Kaplan Department of Physics University of California Los Angeles, California
102	Stanford Research Institute Menlo Park, California ATTN: Dr. Allen M. Peterson
103	Harvard College Observatory 60 Garden Street Cambridge 38, Massachusetts ATTN: Prof. Fred L. Whipple
104	Hq. AFCRL, OAR Mr. M. B. Gilbert, CRTE L. G. Hanscom Field Bedford, Massachusetts
105	Dr. J. P. Ruina Massachusetts Institute of Technology Cambridge, Massachusetts

AD

ponent seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

UNCLASSIFIED

DESCRIPTORS

Seismic waves
Earthquakes
Recording systems
Seismological stations

UNCLASSIFIED

AD

ponent seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

UNCLASSIFIED

DESCRIPTORS

Seismic waves
Earthquakes
Recording systems
Seismological stations

UNCLASSIFIED

AD

ponent seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

UNCLASSIFIED

DESCRIPTORS

Seismic waves
Earthquakes
Recording systems
Seismological stations

UNCLASSIFIED

AD

ponent seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

UNCLASSIFIED

DESCRIPTORS

Seismic waves
Earthquakes
Recording systems
Seismological stations

UNCLASSIFIED

AD Div. 2/10

Inst. of Science and Technology, U. of Mich., Ann Arbor
MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES, by John M. DeNoyer, David E. Willis, and James T. Wilson. Oct. 63. 58 p. incl. illus., tables, 4 refs.
(Report No. 4618-11-F/5178-18-T)
(Contract AF 19(604)-8809, AF 49(638)-1170)
Unclassified Report

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-com-
(over)

UNCLASSIFIED

I. DeNoyer, John M.,; Willis, David E.; Wilson, James T.
II. Air Force Cambridge Research Laboratories
III. Contracts AF 19(604)-8809, AF 49(638)-1170

Defense
Documentation Center
UNCLASSIFIED

AD Div. 2/10

Inst. of Science and Technology, U. of Mich., Ann Arbor
MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES, by John M. DeNoyer, David E. Willis, and James T. Wilson. Oct. 63. 58 p. incl. illus., tables, 4 refs.
(Report No. 4618-11-F/5178-18-T)
(Contract AF 19(604)-8809, AF 49(638)-1170)
Unclassified Report

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-com-
(over)

UNCLASSIFIED

I. DeNoyer, John M.,; Willis, David E.; Wilson, James T.
II. Air Force Cambridge Research Laboratories
III. Contracts AF 19(604)-8809, AF 49(638)-1170

Defense
Documentation Center
UNCLASSIFIED

AD Div. 2/10

Inst. of Science and Technology, U. of Mich., Ann Arbor
MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES, by John M. DeNoyer, David E. Willis, and James T. Wilson. Oct. 63. 58 p. incl. illus., tables, 4 refs.
(Report No. 4618-11-F/5178-18-T)
(Contract AF 19(604)-8809, AF 49(638)-1170)
Unclassified Report

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-com-
(over)

UNCLASSIFIED

I. DeNoyer, John M.,; Willis, David E.; Wilson, James T.
II. Air Force Cambridge Research Laboratories
III. Contracts AF 19(604)-8809, AF 49(638)-1170

Defense
Documentation Center
UNCLASSIFIED

AD Div. 2/10

Inst. of Science and Technology, U. of Mich., Ann Arbor
MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES, by John M. DeNoyer, David E. Willis, and James T. Wilson. Oct. 63. 58 p. incl. illus., tables, 4 refs.
(Report No. 4618-11-F/5178-18-T)
(Contract AF 19(604)-8809, AF 49(638)-1170)
Unclassified Report

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-com-
(over)

UNCLASSIFIED

I. DeNoyer, John M.,; Willis, David E.; Wilson, James T.
II. Air Force Cambridge Research Laboratories
III. Contracts AF 19(604)-8809, AF 49(638)-1170

Defense
Documentation Center
UNCLASSIFIED

AD Div. 2/10

Inst. of Science and Technology, U. of Mich., Ann Arbor MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES, by John M. DeNoyer, David E. Willis, and James T. Wilson. Oct. 63. 58 p. incl. illus., tables, 4 refs.
(Report No. 4618-11-F/5178-18-T)
(Contract AF 19(604)-8809, AF 49(638)-1170)
Unclassified Report

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-com-
(over)

UNCLASSIFIED

I. DeNoyer, John M.,; Willis, David E.; Wilson, James T.
II. Air Force Cambridge Research Laboratories
III. Contracts AF 19(604)-8809, AF 49(638)-1170

Defense
Documentation Center
UNCLASSIFIED

AD Div. 2/10

Inst. of Science and Technology, U. of Mich., Ann Arbor MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES, by John M. DeNoyer, David E. Willis, and James T. Wilson. Oct. 63. 58 p. incl. illus., tables, 4 refs.
(Report No. 4618-11-F/5178-18-T)
(Contract AF 19(604)-8809, AF 49(638)-1170)
Unclassified Report

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-com-
(over)

UNCLASSIFIED

I. DeNoyer, John M.,; Willis, David E.; Wilson, James T.
II. Air Force Cambridge Research Laboratories
III. Contracts AF 19(604)-8809, AF 49(638)-1170

Defense
Documentation Center
UNCLASSIFIED

AD Div. 2/10

Inst. of Science and Technology, U. of Mich., Ann Arbor MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES, by John M. DeNoyer, David E. Willis, and James T. Wilson. Oct. 63. 58 p. incl. illus., tables, 4 refs.
(Report No. 4618-11-F/5178-18-T)
(Contract AF 19(604)-8809, AF 49(638)-1170)
Unclassified Report

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-com-
(over)

UNCLASSIFIED

I. DeNoyer, John M.,; Willis, David E.; Wilson, James T.
II. Air Force Cambridge Research Laboratories
III. Contracts AF 19(604)-8809, AF 49(638)-1170

Defense
Documentation Center
UNCLASSIFIED

AD Div. 2/10

Inst. of Science and Technology, U. of Mich., Ann Arbor MEASUREMENTS OF NEAR AND REGIONAL EARTHQUAKES OUTSIDE THE CONTINENTAL UNITED STATES, by John M. DeNoyer, David E. Willis, and James T. Wilson. Oct. 63. 58 p. incl. illus., tables, 4 refs.
(Report No. 4618-11-F/5178-18-T)
(Contract AF 19(604)-8809, AF 49(638)-1170)
Unclassified Report

A field measurement program was conducted in a number of areas outside the continental limits of the United States as a part of a research study on the propagation of seismic waves generated by earthquakes. These measurements were made in Chile, Crete, Hawaii, American Samoa, Pakistan, and Puerto Rico. Over 250 earthquakes, as detected by short-period three-com-
(over)

UNCLASSIFIED

I. DeNoyer, John M.,; Willis, David E.; Wilson, James T.
II. Air Force Cambridge Research Laboratories
III. Contracts AF 19(604)-8809, AF 49(638)-1170

Defense
Documentation Center
UNCLASSIFIED

AD

ponent seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

UNCLASSIFIED

DESCRIPTORS

Seismic waves
Earthquakes
Recording systems
Seismological stations

UNCLASSIFIED

AD

ponent seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

UNCLASSIFIED

DESCRIPTORS

Seismic waves
Earthquakes
Recording systems
Seismological stations

UNCLASSIFIED

AD

ponent seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

UNCLASSIFIED

DESCRIPTORS

Seismic waves
Earthquakes
Recording systems
Seismological stations

UNCLASSIFIED

AD

ponent seismometers, were recorded on FM magnetic tape recorders. Detailed frequency analyses were made for 120 of these recordings. The spectral data varied among areas for earthquakes of comparable size and magnitude. Except in Crete and American Samoa, the earthquakes recorded at epicentral distances less than several hundred kilometers generally contained a significant amount of seismic energy above 10 cps. In some instances the earthquakes contained no low-frequency energy that would be detected by standard seismograph station short-period instruments. One Chilean earthquake contained seismic energy as high as 500 cps.

In most cases the shear-surface waves had amplitudes larger than the compressional waves. This amplitude relationship was more pronounced for horizontal component recordings than for the vertical component.

UNCLASSIFIED

DESCRIPTORS

Seismic waves
Earthquakes
Recording systems
Seismological stations

UNCLASSIFIED