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AD 844690

TECHNICAL REPORT NO. 68-48

SHORT-PERIOD MULTICOMPONENT STRAIN SYSTEM

Quarterly Report No. 3, Project VT/8704

1 September through 30 November 1968

SPONSORED BY

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ARPA ORDER NO. 824

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PROJECTS AGENCY, NUCLEAR TEST DETECTION OFFICE, UNDER  
PROJECT VELA UNIFORM, AND ACCOMPLISHED UNDER THE  
TECHNICAL DIRECTION OF THE AIR FORCE TECHNICAL APPLICATIONS  
CENTER UNDER CONTRACT NO. F33657-68-C-0948.

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GEOTECH

A TELEDYNE COMPANY

TECHNICAL REPORT NO. 68-48

SHORT-PERIOD MULTICOMPONENT STRAIN SYSTEM  
Quarterly Report No. 3, Project VT/8704  
1 September through 30 November 1968

by

Robert C. Shopland  
Richard H. Kirklin

Sponsored by

Advanced Research Projects Agency  
Nuclear Test Detection Office  
ARPA Order No. 624

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Acknowledgement

This research was supported by the  
Advanced Research Projects Agency,  
Nuclear Test Detection Office, under  
Project VELA-UNIFORM, and accomplished  
under the technical direction of the  
Air Force Technical Applications Center  
under Contract No. F33657-68-C-0948.

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GEOTECH  
A TELEDYNE COMPANY  
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Garland, Texas

12 December 1968

### IDENTIFICATION

AFTAC Project No.	VELA T/8704
Project Title:	Short-Period Multicomponent Strain System
ARPA Order No.	624
ARPA Program Code No.	8F10
Name of Contractor:	Teledyne Industries, Inc., Geotech Division
Contract No.	F33657-68-C-0948
Effective Date of Contract:	16 February 1968
Amount of Contract:	\$141,667
Contract Expiration Date:	15 February 1969
Project Manager:	R. C. Shopland (214) 271-2561

## CONTENTS

### Page

#### ABSTRACT

1. INTRODUCTION	1
2. OPERATION (Task 1a)	1
2.1 Operating problems	1
2.2 Maintenance	2
3. DETERMINE OPTIMUM OPERATING TOLERANCES (Task 1c)	2
3.1 Evaluation of non-seismic LP noise	2
3.2 Evaluation of the long-period strain detection capability	3
3.3 Suppression of long-period seismic noise	5
3.4 Evaluation of the 90-degree phase compensator	5
4. STRAIN APPLICATIONS (Task 2a)	6
4.1 Directional characteristics of the seismic noise at WMO	6
4.2 S-wave enhancement	7
4.3 Wave identification	10
4.3.1 Analysis of BOXCAR	10
4.3.2 Future investigations	12
4.4 Discrimination between earthquakes and explosions	14
5. IMPROVEMENT OF INSTRUMENTS (Task 2b)	14
6. TEST NEW SITE (Task 2c)	14
6.1 Garland site	14
6.2 Houlton, Maine	16

APPENDIX - Statement of work to be done

## ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Maximum values of coherence squared computed between the recordings of an omnidirectional strain seismograph system and horizontal inertial seismographs. The inertial seismograph outputs have been coordinate transformed to have maximum sensitivity to Rayleigh waves from one of 18 equally spaced directions ranging from $0^{\circ}$ to $170^{\circ}$	8
2	Enhancement of S, seen on the west trace, W, by a combination of horizontal east strain and inertial seismograph outputs	9
3	Seismogram illustrating the predominance of retrograde and prograde motion over several intervals of time during the Pn coda of BOXCAR	11
4	Seismogram illustrating the predominance of SH in the Lg phase of BOXCAR	13
5	Top: Coherence squared computed from recordings made at the Garland, Texas site by a vertical strain (SZ) and a vertical inertial (SPZ) seismograph Bottom: Ratios of the spectra of recordings by the vertical inertial minus the vertical strain seismographs to the vertical inertial	15
6	Power spectra of microseisms including train noise recorded at Garland, Texas	17

## TABLES

<u>Table</u>		<u>Page</u>
1	Percentage of events by phase recorded by the LP strain seismographs based upon 100 percent detection by the inertial seismographs	4
2	Phases detected by the horizontal strain seismograph by magnitude	4
3	Phases detected by the vertical strain seismograph by magnitude	5

## ABSTRACT

An examination of film recordings of strain noise, pressure fluctuations inside and outside of the strain vault, and wind velocity at WMO suggests that the long-period (LP) noise observed on the strain traces is caused by wind-pressure fluctuations that are coupled more strongly through the ground or by compression of the vault structure than through leakage of air through the vault enclosure. A study of the detection capability of the WMO LP strain seismographs shows that the environmental noise severely limits detection. From a study of the directional characteristics of the seismic noise, it appears that during periods of average to high-level microseismic activity the predominant microseisms in the band 0.1 to 0.5 Hz arrive at WMO from the directions north to east and, therefore, may be partially rejected by horizontal strain-inertial seismograph combinations. From a study of S-wave enhancement, it is concluded that while for any specific S arrival, a combination of strain and inertial seismograph outputs might provide enhancement by SH addition, SV addition, seismic noise cancellation, or a combination of the above, there is no one combination of seismograph outputs that can be used in general to provide enhancement of all recorded S waves. Recordings of the large NTS explosion BOXCAR are being used to study the usefulness of strain and inertial seismographs in identifying seismic waves and earthquake phases. By applying various techniques such as coordinate transformation, phase shifting, and summing of strain and inertial data, it has been possible to isolate P, prograde, and retrograde motion in sections of the Pn coda, and SH motion in the Lg phase. From a spectral analysis of the suppressed seismic noise at Garland, Texas, it has been determined that noise suppression of at least 6 dB occurs in the frequency band 1.0 to 2.0 Hz. Arrangements for transfer of strain operation from Garland to Houlton, Maine, are complete.



SHORT-PERIOD MULTICOMPONENT STRAIN SYSTEM  
Quarterly Report No. 3, Project VT/8704  
1 September through 30 November 1968

1. INTRODUCTION

This report discusses evaluation of a system of strain and inertial seismographs having matched amplitude and phase responses in the frequency range 0.01 to 10 Hz. It is submitted in compliance with Sequence Number A008 of Contract Data Requirements List, Contract F33657-68-C-0948. The Statement of Work is included as an appendix. Paragraph 2c has been modified in accordance with Contract Modification No. P002 effective 8 November 1968. During the reporting period, the major accomplishments were as follows:

- a. Measurements of background noise and detection capability of the long-period strain seismograph system at WMO were completed.
- b. A study was completed on the directionality of the short-period noise field at WMO and conclusions drawn regarding the capability of strain-inertial seismograph combinations to azimuthally discriminate against microseisms.
- c. Enhancement of transverse body waves from teleseismic events employing combinations of horizontal strain and inertial seismographs was investigated.
- d. The Pn coda and Lg phase of the NTS explosion BOXCAR were examined. Several wave types were isolated using coordinate transformations, phase shifting, and summing of strain and inertial seismographs.
- e. Milestone No. 1 was completed on 30 September with the installation of three Electromagnetic Calibrators, Model 30240, on the horizontal strain seismometers at WMO.
- f. A spectral analysis of the noise suppression capability of the vertical strain and inertial seismograph combination at Garland, Texas, was completed.
- g. An Engineering Change Proposal for transferring strain operations from Garland, Texas, to the LRSM site near Houlton, Maine, was submitted. Modifications of the system required for the Houlton operation have been completed and a detailed plan and schedule prepared.

2. OPERATION (Task 1a)

2.1 OPERATING PROBLEMS

High-gain operation required for investigating the suppression of LP microseisms was made possible in September by installing an additional operational amplifier in each LP strain channel to increase the ratio of microseismic background-to-tape noise.

Operation of the LP strain and inertial seismograph combinations, which depends on the use of coordinate transformed LP inertial seismographs in vault No. 7, was interrupted during most of the reporting period by retrofit of the inertial seismographs. Inertial data were made available temporarily on 19 November.

All SP strain and inertial seismographs were operating at normal recording levels during September, October, and most of November. At normal levels, seismic background is recorded on magnetic tape at approximately 12 dB above compensated tape noise, and at a trace amplitude of 1-2 mm on 16-mm film at X10 view. However, on 26 November, signal levels were reduced an average of 6 dB to reduce clipping of large signals.

## 2.2 MAINTENANCE

On 4 September, a lightning storm damaged the galvanometer in the SP north strain PTA and the PTA power supply in the SP north vertical seismograph. This and other minor damage were repaired on the same day.

Power for the strain PTA's was off on that date from 1100 to 1400Z due to a power failure.

Periodic checks of seismograph phase response show that the SP strain and inertial systems are remaining reasonably stable with only minor adjustments necessary to PTA galvanometer damping to maintain parameters.

The galvanometer bank in LP Develocorder No. 5 was replaced on 19 September. Film jamming in Develocorder No. 5 was corrected by adjusting the capstan and capstan pinch roller.

On 16 October, a lightning storm damaged a transformer in the power supply of the phototube amplifier in the short-period inertial north (SPN) channel. A galvanometer in the SP strain north (SN) channel was also replaced because of lightning damage.

A short circuit in the calibrator line of the SE strain seismometer was repaired on 12 November.

Intermittent loss of WWV and an occasional inoperative status of all data were caused by modifications of the WMO power system in November.

## 3. DETERMINE OPTIMUM OPERATING TOLERANCES (Task 1c)

### 3.1 EVALUATION OF NON-SEISMIC LP NOISE

A preliminary investigation of WMO strain data, directed toward gaining a better understanding of noise sources that limit the usefulness of the horizontal LP strain seismographs, has been conducted. As a first step, film records were examined to obtain a coarse indication of the degree of correlation among recordings of strain noise; atmospheric pressure fluctuations external

to the strain vault; internal pressure fluctuations; and wind velocity. Observations indicated a correlation among all four parameters. Strain and microbarograph signal (noise) levels increased with increasing wind velocity. Changes in SP pressure signal levels within the vault resulting from increased wind velocity were small, but measurable; however, no increase in the LP pressure signals was detected. The foregoing observations, along with the fact that the shallower strain seismometers at WMO are more responsive to SP wind noise than the deeper ones, suggest that the LP noise observed on the strain traces is coupled more strongly through the ground or by compression of the vault structure than through leakage of air into the vault enclosure. More precise measurements are required to confirm this thesis and to determine if steps can be taken to reduce environmental-induced strain noise.

The foregoing study required a comparison of observations of film from three separate recorders at WMO. Therefore, steps were taken on 24 November 1968, to have all data recorded on one Develocorder to facilitate analysis. Details are also being worked out for the recording of the necessary data on magnetic tape to permit correlation by machine techniques. It is possible that such measurements will lead to a more thorough understanding of the noise sources, the mechanism of transmission to the strain seismometer, and the character of the noise.

### 3.2 EVALUATION OF THE LONG-PERIOD STRAIN DETECTION CAPABILITY

The detection capability of the long-period strain seismographs at WMO has been studied using 33 events from the Galapagos Island region ( $\Delta \approx 37^\circ$ ). The events have magnitudes ranging from 3.9 to 5.0. Data were obtained directly from on-line recordings on 16-mm film.

Galapagos events recorded at WMO are characterised by an S phase that is strong relative to P, whereas, Love is extremely difficult to identify and the Rayleigh is weak. Also, recorded is an unidentified phase, peculiar to Galapagos events, that arrives 1 minute and 20 seconds after S.

Listed in table 1 are five phases and corresponding values of percentage detection by the strain seismographs, based upon 100 percent detection by the inertial seismographs. It is noted from table 1 that the S and R phases are detected a relatively high percentage of the time compared with other phases.

It should be pointed out that the strain and inertial recordings are matched in amplitude for normal mode Rayleigh waves. However, environmental noise reduces detection of Rayleigh waves to about one-third of that of the inertials. Body waves, as anticipated, are not recorded at large amplitudes on the strain seismographs, compared with the inertials. Furthermore, epicentral distance and apparent angle of incidence greatly influence the amount of body wave recorded. It is noted that the S wave is well recorded by the strain instruments at an epicentral distance of 37 degrees; however, this may not hold at other distances.

Shown in table 2 is the distribution, by magnitude, of the phases detected by the horizontal strain seismograph. Table 3 shows the distribution for the vertical strain. As may be seen from tables 2 and 3, environmental noise not only severely limits detection but also varies with time so as to mask the

Table 1. Percentage of events by phase recorded by the LP strain seismographs based upon 100 percent detection by the inertial seismographs

<u>Phase</u>	<u>Vertical strain</u>	<u>Horizontal strain</u>
P	-	3%
PP	-	9%
S	42%	91%
e	6%	15%
L	3%	9%
R	24%	39%

Table 2. Phases detected by the horizontal strain seismograph by magnitude

<u>Magnitudes</u>	<u>Phases</u>						<u>Number of events</u>
	<u>P</u>	<u>PP</u>	<u>S</u>	<u>e*</u>	<u>L</u>	<u>R</u>	
5.0			1			1	1
4.9			2	1		2	2
4.8			7	1		1	7
4.7			3		1	1	4
4.6		1	5			2	5
4.5			3				3
4.4			5	3	1	3	6
4.3	1	1	1				1
4.2			1			1	1
4.1			2			2	2
4.0							0
3.9						1	1

\*e ≡ unidentified phase

anticipated increase in detection capability with increasing earthquake magnitude. The expected relationship would be evident if a larger statistical sample were used.

Table 3. Phases detected by the vertical strain seismograph by magnitude

<u>Magnitudes</u>	<u>Phases</u>						<u>Number of events</u>
	<u>P</u>	<u>PP</u>	<u>S</u>	<u>e</u>	<u>L</u>	<u>R</u>	
5.0			1				1
4.9			1			2	2
4.8			3	1		1	7
4.7			2		1		4
4.6						1	5
4.5			1				3
4.4			4	1		3	6
4.3							1
4.2			1			1	1
4.1			1				2
4.0							0
3.9							1

### 3.3 SUPPRESSION OF LONG-PERIOD SEISMIC NOISE

LP data from strain-inertial combinations are now being collected to investigate the capability of suppressing LP microseisms. The operation, after being delayed by retrofit work on the LP inertial seismographs was started on 19 November 1968. Additional shutdowns are anticipated.

Environmental noise severely limits the recording of long-period microseisms at WMO, especially during periods of high wind. Consequently, background data over a lengthy period will be required to obtain a sufficient number of samples in which microseisms have undergone minimum masking by environmental noise.

### 3.4 EVALUATION OF THE 90-DEGREE PHASE COMPENSATOR

The 90-degree Phase Compensator, Model 15122, is an all-pass filter designed to provide phase matching of vertical strain and inertial seismograph data. Consideration was given to redesigning this unit to extend its present one-decade frequency range (0.2-2 Hz). In comparing the usefulness of the present compensator against the cost of redesign, it was concluded that a new design could not be justified.

The following factors support the usefulness of the present model:

- a. The present compensator is useful at one octave above and below its designed range, since phase mismatches of 10-15 degrees between strain and inertial outputs at these extremes still allow useful suppression of Rayleigh waves.

b. Extending the range of the phase compensator to higher frequencies is of little value, since at shorter wavelengths the vertical differential displacement output is no longer directly proportional to frequency.

c. Phase matching of LP vertical strain and inertial data can be accomplished off-line with the present phase compensator by increasing the magnetic-tape playback speed.

#### 4. STRAIN APPLICATIONS (Task 2a)

##### 4.1 DIRECTIONAL CHARACTERISTICS OF THE SEISMIC NOISE AT WMO

Studies on wave composition of the WMO microseismic field indicate the presence of a complex mixture of wave types and modes. Because of the complexity of the field, attempts to reduce the level of recorded microseisms using a vertical strain in conjunction with a vertical inertial seismograph have been unsuccessful. In addition to wave composition, however, there exists another property of the microseismic field that is of interest. This property is the directionality exhibited by microseisms.

The ability to reject microseisms by combining the outputs of horizontal strain and inertial seismographs will be in part dependent upon the degree to which microseisms exhibit directional characteristics. If predominant microseisms are multidirectional limited rejection will be possible, whereas, if predominant microseisms are essentially unidirectional they can be rejected. A limited study, therefore, has been conducted to determine the directional properties of the WMO microseismic field. Answers to the following questions have been sought. First, do there exist predominant microseisms independent of the wave composition in any given frequency band that appear to arrive along essentially one azimuth? Second, are the apparent directions of arrival stationary with respect to time?

In order to determine if there exist directionally predominant microseisms, coherence was computed between the recordings of a horizontal inertial and an omnidirectional vertical strain or summed orthogonal horizontal strain seismographs. Poor coherence on all pairs is interpreted as indicating the presence of multidirectional microseisms, whereas, high coherence on selected pairs suggests that there are predominant waves arriving from essentially one direction.

For each noise sample, the outputs of two orthogonal horizontal inertials were coordinate transformed to provide maximum directional sensitivity for all azimuths, 0 to 350 degrees by increments of 10 degrees. Coherence was then computed between each of the transformed outputs and the output of an omnidirectional strain. Only the highest value of coherence for any given frequency was retained. The orientation of that transformed inertial yielding the highest value of coherence, along with the phase of the cross spectra was then used to assign an apparent azimuth to the seismic noise at each frequency.

Three of the samples, recorded on 17 March, 20 June, and 16 October 1967, displayed high coherence ( $\approx 0.7$  coherence squared) over the band 0.1 to 0.5 Hz with apparent azimuths ranging from 30 to 90 degrees. The sample recorded on 17 March 1967, is illustrated in figure 1a. Beyond 0.5 Hz the coherence was generally low with values of coherence squared above 0.5 occurring only in narrow frequency bands. These bands were not over the same frequency interval and the signals did not have the same apparent azimuths.

Two samples of microseisms recorded 17 hours apart on 4 January 1968, suggest less unidirectionality of the microseisms in the band 0.1 to 0.5 Hz, that is, the computed coherence is generally low, figure 1b. Film seismograms, however, show the level of the microseismic background to have been lower on the 4th of January than during the periods covered by the other three samples.

From this study, it appears that during periods of average to high level microseismic activity the predominant microseisms in the band 0.1 to 0.5 Hz arrive at WMO from the directions north to east and, therefore, can be rejected by horizontal strain-inertial seismograph combinations.

#### 4.2 S-WAVE ENHANCEMENT

Enhancement of transverse body waves from teleseismic events employing combinations of horizontal strain and inertial seismographs has been investigated. Since the sensitivity of a strain seismograph to steeply incident waves is small compared to an inertial, enhancement was sought through seismic noise reduction rather than signal addition. That is, the strain and inertial outputs were combined so as to provide maximum cancellation of Rayleigh waves. On-line recordings of the WMO directional array, described in Technical Report No. 67-2, were used in the study. Approximately 6 months of recorded data were examined.

Essentially no enhancement was observed for most of the recorded S waves. One of the few samples that did exhibit enhancement is illustrated in figure 2. On the west trace, W, is seen some reduction of seismic noise preceding the S arrival. In this case, however, enhancement is primarily the result of signal addition. This suggests that perhaps signal addition rather than seismic noise reduction should have been sought, i.e., the strain and inertial outputs should have been summed to provide maximum addition of horizontally polarized transverse waves, SH, rather than cancellation of Rayleigh waves.

By closely examining figure 2 and noting that the azimuth is 313 degrees, one will see that the S could not have been entirely SH. Furthermore, the S was recorded by the vertical strain, not illustrated. These observations indicate the presence of both SH and SV in the S arrival, the magnitude of the horizontal component of SH and SV appearing nearly equal. Since SV is a vertically polarized transverse wave it is an apparent longitudinal wave, thus, enhancement of SH would have resulted in less enhancement of SV and, therefore, nothing would have been gained. Furthermore, seeking addition of SH would greatly reduce the ability to suppress the seismic noise preceding the S arrival. Therefore, one may conclude that while for any specific S arrival, a combination of strain and inertial seismograph outputs might provide enhancement by SH



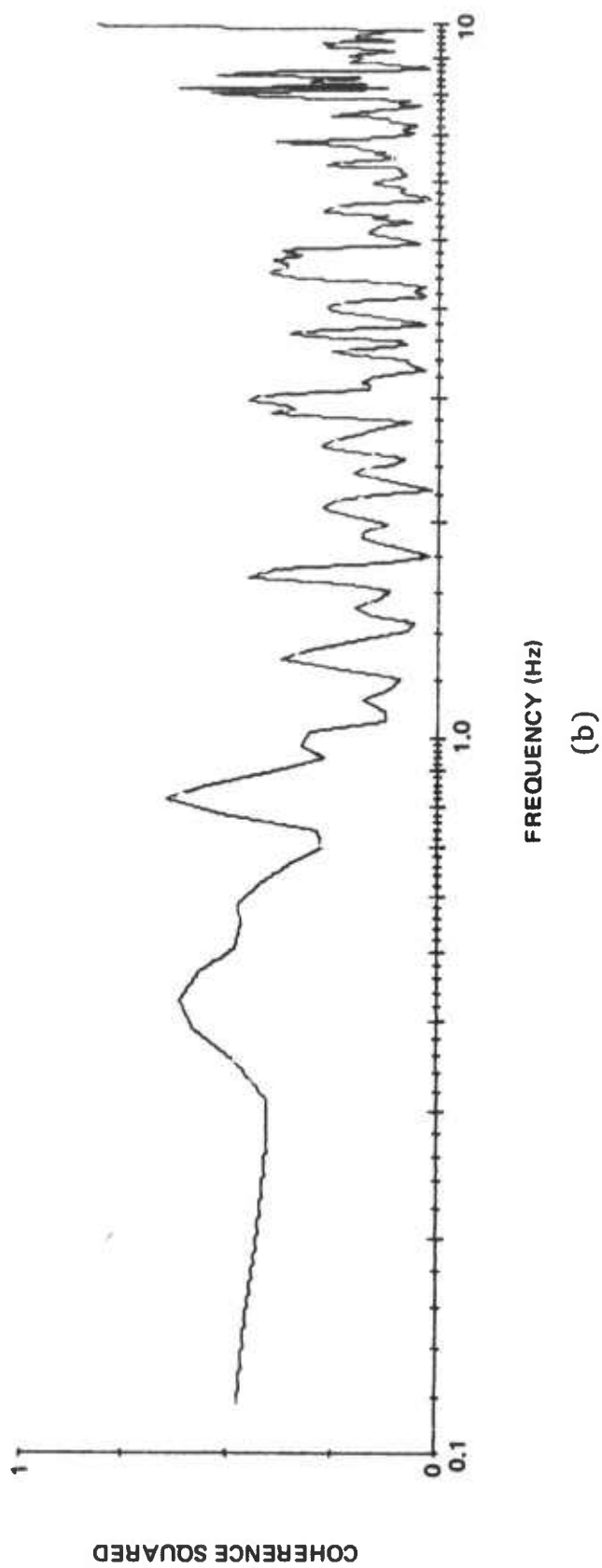
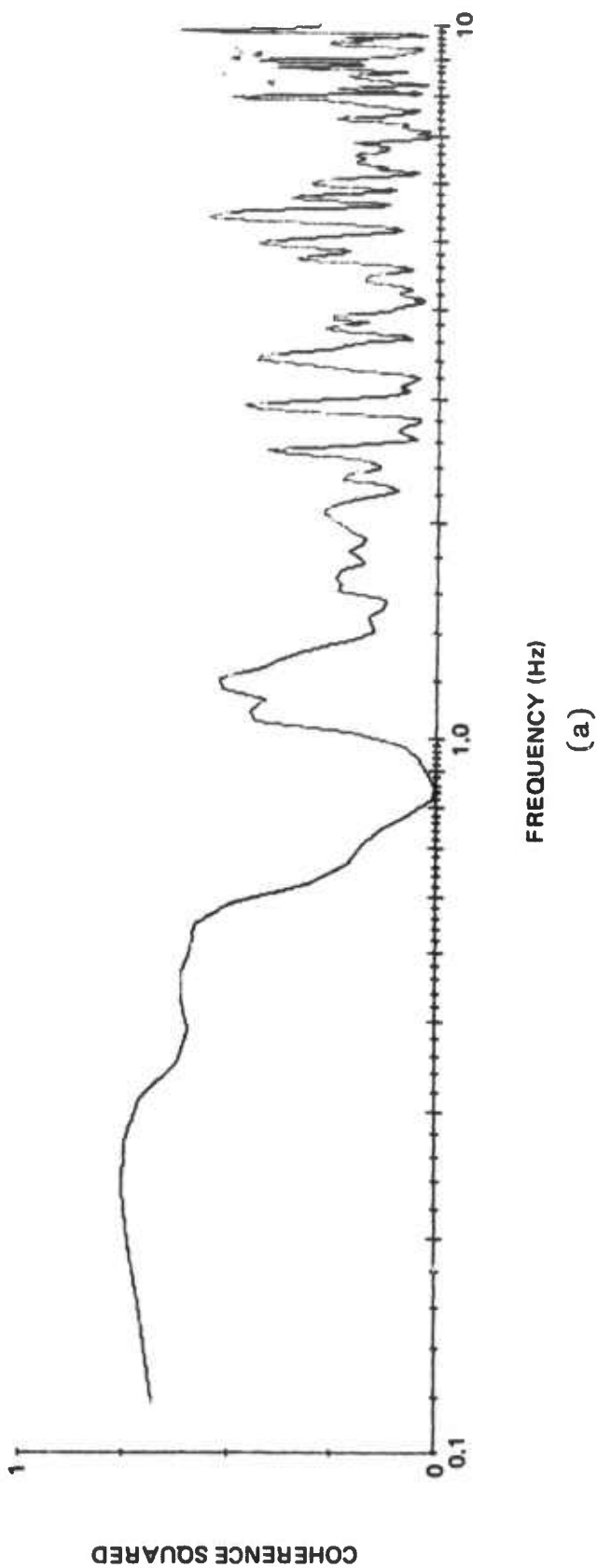


Figure 1. Maximum values of coherence squared computed between the recordings of an omnidirectional strain seismograph system and horizontal inertial seismographs. The inertial seismograph outputs have been coordinate transformed to have maximum sensitivity to Rayleigh waves from one of 18 equally spaced directions ranging from  $0^\circ$  to  $170^\circ$ .

G 4554

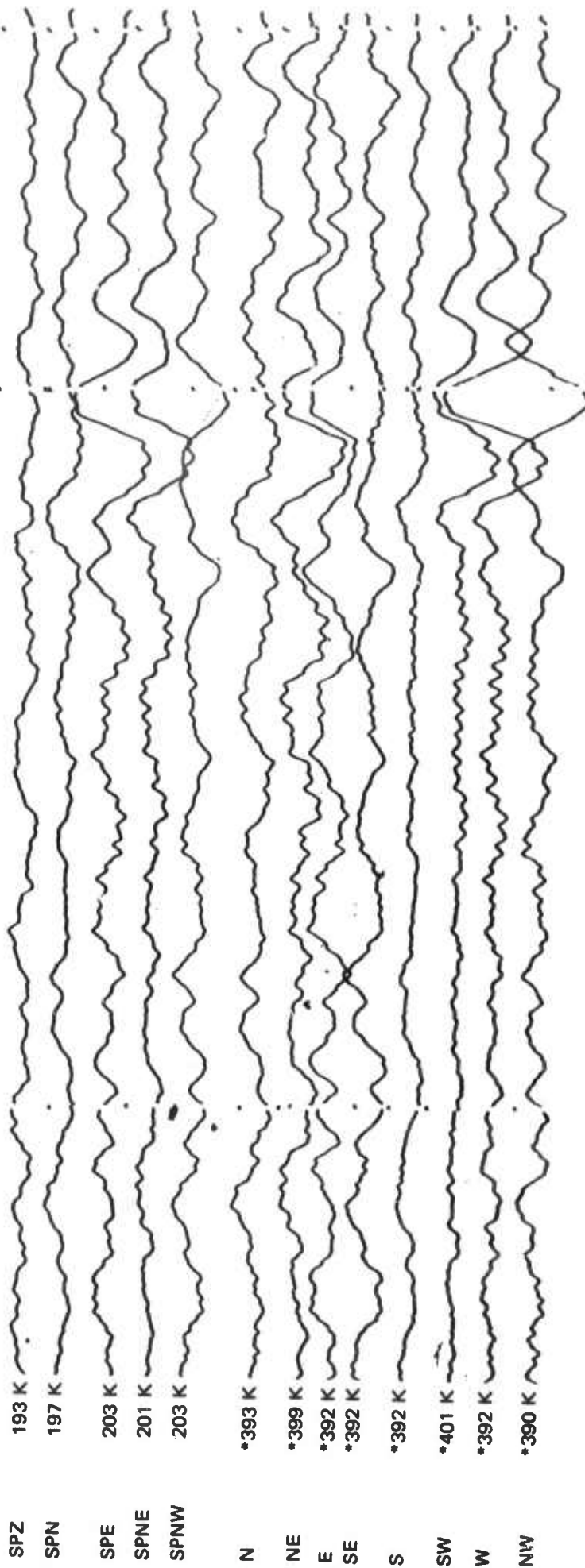


$$*MAGNIFICATION = \left( \frac{STRAIN\ MAGNIFICATION}{26} \right) + INERTIAL\ MAGNIFICATION \quad \text{WHERE}$$

$$\frac{STRAIN\ MAGNIFICATION}{26} = \frac{EQUIVALENT\ INERTIAL\ MAGNIFICATION\ (EQUATED\ FOR\ SEISMIC\ WAVE\ OF\ APPARENT\ SURFACE\ VELOCITIES\ OF\ 3.0\ km/sec)}{26}$$

MAG @  
1 Hz

04 13



WMO  
RECORD NO. 119  
29 APR 67

ORIGIN TIME 035520.8Z  
Andeanof Is.  
Distance 57.7°  
Azimuth 313°  
Magnitude 6.0

Figure 2. Enhancement of S, seen on the west trace, W, by a combination of horizontal east strain and inertial seismograph outputs

G 4555

addition, SV addition, seismic noise cancellation, or a combination of the above, there is no one combination of seismograph outputs that can be used in general to provide enhancement of all recorded S waves. Furthermore, the strain-inertial combination that will provide maximum enhancement of SV is the same combination that is used for seismic noise suppression. This combination is, of course, the one that was used in this study and from which no significant enhancement was observed for a large majority of the S waves examined.

### 4.3 WAVE IDENTIFICATION

#### 4.3.1 Analysis of BOXCAR

Recordings of BOXCAR, which was a large NTS explosion, are being used to investigate the usefulness of strain and inertial seismographs in identifying seismic waves and earthquake phases. Two methods of investigation have been employed as of this time. Horizontal strain and inertial recordings have been transformed and 'pseudo transformed', in the case of the strains, to have azimuthal responses equal to those of radial and transverse inertials. This isolates apparent SH waves from apparent longitudinal waves on both strain and inertial seismograms. The vertical strain and inertial recordings, after 90-degree phase compensation, have been summed in two polarities. This provides a means of distinguishing prograde from retrograde motion when one or the other is the predominant type.

Examination of the Pn coda of BOXCAR has revealed several short intervals of time during which a specific wave type was predominant. The presence of SH throughout the Pn coda is suggested by the transformed and pseudo transformed transverse instruments. Deviations from a great circle path of apparent longitudinal waves may, however, be responsible to a large extent for the excursions observed on the transverse traces. Further analysis is necessary before drawing conclusions.

For illustrative purposes and to serve as a guide when examining other earthquakes from the same epicentral region, the Pn coda of BOXCAR has been divided into eleven adjoining intervals over which the digitized outputs of the vertical strain and inertial seismographs have been combined so as to provide rejection of non-longitudinal motion, where identifiable. This is illustrated in figure 3, trace 4,  $\Sigma$ . The top trace of figure 3, SZ, is the vertical strain recording, the third trace, SPZ, is the vertical inertial recording of Pn. The relative gains and polarities of SZ and SPZ are those required to cancel the 6-second Rayleigh waves following the Lg phase of BOXCAR. Trace 2, SZ', is again the vertical strain recording, but modified for each of the eleven intervals. The  $\Sigma$  trace is the sum of SZ' and SPZ. All modifications to the vertical strain were linear operations except over intervals 3 and 6 (see figure 3). Intervals, 3 and 6, were modified by a cosine taper, i.e.,

$$SZ'_i = SZ_i \cdot \cos\left(\frac{\pi i}{2n}\right)$$

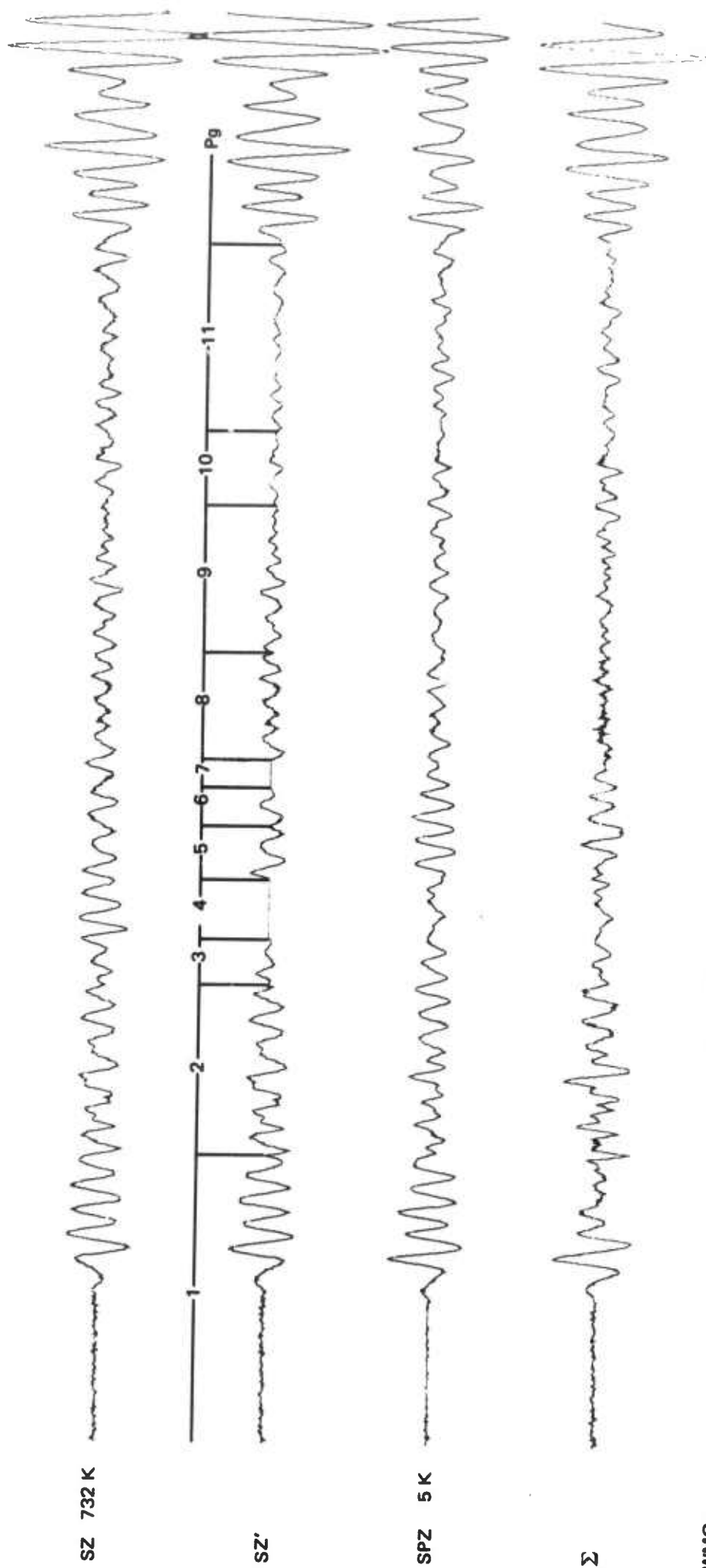
where n is the number of samples in the interval and the index number of the sample within the interval is  $i = 1, n$ . This was done to avoid discontinuous jumps on the  $\Sigma$  trace. Both intervals 3 and 6 precede an interval where SZ' equals zero.

MAG

@

1 Hz

10 SEC



WMO  
RECORD NO. 117  
26 APR 68

1 - SZ' = -SZ  
2 - SZ' = SZ  
3 - See Text  
4 - SZ' = 0  
5 - SZ' = SZ  
6 - See Text  
7 - SZ' = 0  
8 - SZ' = SZ  
9 - SZ' =  $\frac{1}{4}$  SZ  
10 - SZ' =  $\frac{1}{4}$  SZ  
11 - SZ' =  $\frac{1}{4}$  SZ  
Pg - SZ = -SZ

SZ - Vertical Strain  
SZ' - Vertical Strain Altered  
SPZ - Vertical Inertial  
Σ - Sum of SZ' and SPZ

Figure 3. Seismogram illustrating the predominance of retrograde and prograde motion over several intervals of time during the Pn coda of BOXCAR

G 4556

During the first interval, 1, where  $SZ' = -SZ$ , only the first cycle of the initial Pn arrival is seen to be essentially pure longitudinal motion. Prograde motion then contaminates the P and becomes dominant four cycles from the start of Pn. This motion has been rejected on  $\Sigma$ . Interval 2 appears to be a combination of longitudinal and retrograde motion. The apparent longitudinal motion is close to twice the frequency of the Pn. Over interval 2, in which  $SZ' = SZ$ , the retrograde motion has been rejected on  $\Sigma$  while the longitudinal added. The last few seconds of interval 2 and all of 3 through 6 appear to be composed of a mixture of wave types. The large excursions on SZ relative to SPZ over interval 4 have not been explained. The first cycle of 5 appears to be retrograde motion, however, beyond this cycle the phase relationship between SZ and SPZ starts to change. By the end of interval 7 the phase relationship between SZ and SPZ has changed nearly  $\frac{3\pi}{4}$ . As stated above, over 3 and 6,  $SZ'$  is SZ modified by a cosine taper; over 4 and 7,  $SZ' = 0$ . Over 5,  $SZ'$  is equal to SZ. The semi-complex period covering 3-7 is followed by 6 seconds of essentially pure retrograde motion then about 8 seconds of nearly pure prograde motion, intervals 8 and 9, respectively. Over 8,  $SZ'$  is equal to SZ; over 9  $SZ' = -3/4 SZ$ . Over both intervals a high degree of cancellation is observed on  $\Sigma$ . The intervals 10 and 11 appear to be composed of a mixture of wave types. Only during the last several seconds of 11 was rejection obtained on  $\Sigma$ . Over 10,  $SZ' = 1/2 SZ$ , and over 11,  $SZ' = -1/2 SZ$ . Following 11 is the Pg arrival where  $SZ'$  has been temporarily set equal to  $-SZ$  pending further investigation.

All traces of figure 3 appear somewhat jagged. This is caused by the introduction of some electronic noise in the process of 90 degree phase compensation and digitizing, however, the jaggedness is primarily a result of the mechanics of the X-Y plotter that was used to play out the digitized data.

Recordings by the WMO strain and inertial seismographs strongly suggest the Lg phase of BOXCAR to be composed essentially of SH, figure 4. Both transformed strain and inertial radial traces, STT and SPT respectively, have very large trace excursions during Lg while the excursions of the transformed strain and inertial radial traces, STR and SPR, respectively, during the same period, are the same as or only slightly greater than those excursions occurring in the late Pg coda immediately preceding the Lg arrival. Also, illustrated in figure 4 are the recordings of the vertical strain, SZ, and vertical inertial SPZ.

While only the Pn coda and the Lg phase of BOXCAR have been examined as of this reporting period and not all of the Pn coda is totally understood, the use of strain in conjunction with inertial seismographs has provided information regarding wave composition that could not readily be obtained from inertial seismographs alone.

#### 4.3.2 Future Investigations

Studies of the strain and inertial recordings of BOXCAR will be continued. These studies will include an examination of Pg, the Pg coda, and Rayleigh. The apparent phase velocity of the Pn coda will also be computed as a function of time. Recordings of another explosion will be compared to those of BOXCAR with emphasis placed on determining the similarities or differences in the complexity of the seismograms.

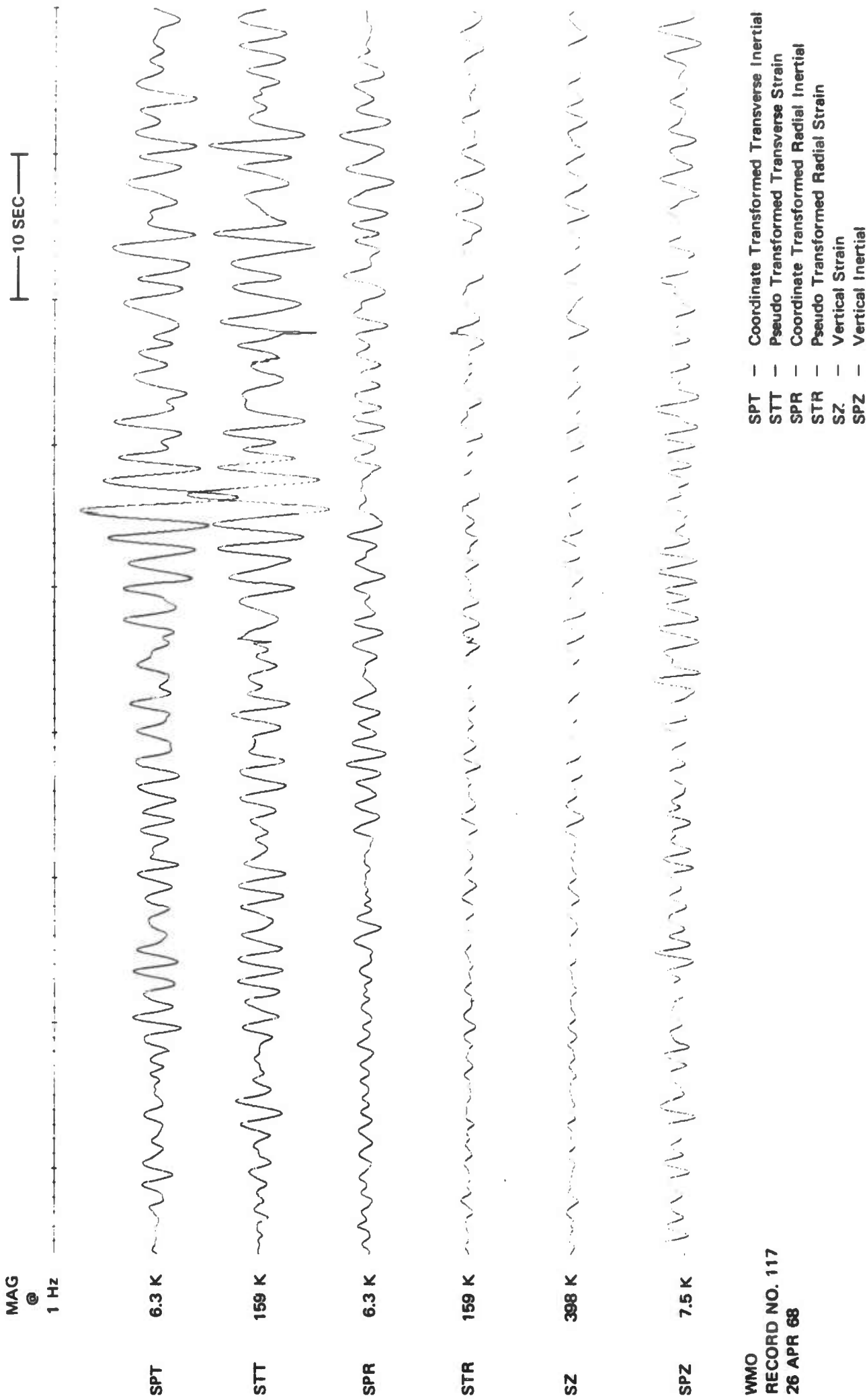


Figure 4. Seismogram illustrating the predominance of SH in the Lg phase of BOXCAR

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#### 4.4 DISCRIMINATION BETWEEN EARTHQUAKES AND EXPLOSIONS

The WMO seismograms of all natural occurring earthquakes from within a 200 km radius of NTS and recorded since January 1967, have been reviewed to select an earthquake to be used in conjunction with BOXCAR for a study of the discrimination problem. Only one event was found that was recorded with a marginal but suitable signal-to-noise ratio. Unfortunately, the vertical inertial was inoperative during the time the event was recorded at WMO. Therefore, only limited investigations will be possible until a more suitable event is recorded.

#### 5. IMPROVEMENT OF INSTRUMENTS (Task 2b)

Manufacture of three Model 30240 Electromagnetic Calibrators for the horizontal strain seismometers was completed on 24 September. Installation was completed on the north, northeast, and northwest strain seismometers in the period from 25 through 30 September.

Calibration constants of the new calibrators were measured in place during the first week of October. Calibrator constants measured with the same variable-capacitance transducer for the NW, N, NE, and E-oriented seismometers were 8.4, 8.0, 8.0, and 8.0 mμ/mA, respectively.

#### 6. TEST NEW SITE (Task 2c)

##### 6.1 GARLAND SITE

Spectra of two samples of seismic noise recorded at the Garland site have been computed to examine the degree of noise suppression attained by combining the outputs of vertical strain and vertical inertial seismographs.

The first noise sample was recorded during a period of normal microseismic activity, whereas the second sample contains train noise.

Ratios of the amplitude spectra of the combined outputs to that of the vertical inertial alone are illustrated for both noise samples in figure 5. Ratios less than unity indicate noise suppression, ratios greater than unity indicate addition of the noise. (These ratios may be compared with those computed for the WMO vertical strain-inertial combination, figure 2, page 5 of TR 68-37). From the ratios, noise suppression of at least 6 dB is seen from 1.0 to 2.0 Hz for the first sample and from 1.0 to 2.8 Hz for the sample with strain noise. Suppression to a lesser extent is observed out to 3 Hz and 3.4 Hz for the first and second samples, respectively.

Above each plot of ratios in figure 5, and corresponding to the same noise samples are plots of the coherence squared computed between the vertical strain and vertical inertial recordings. High correlation is observed between coherence and noise suppression. However, high correlation cannot always be

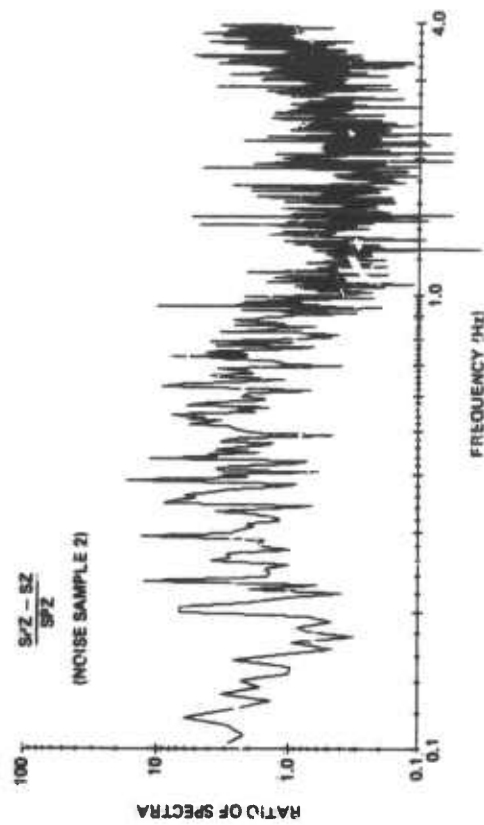
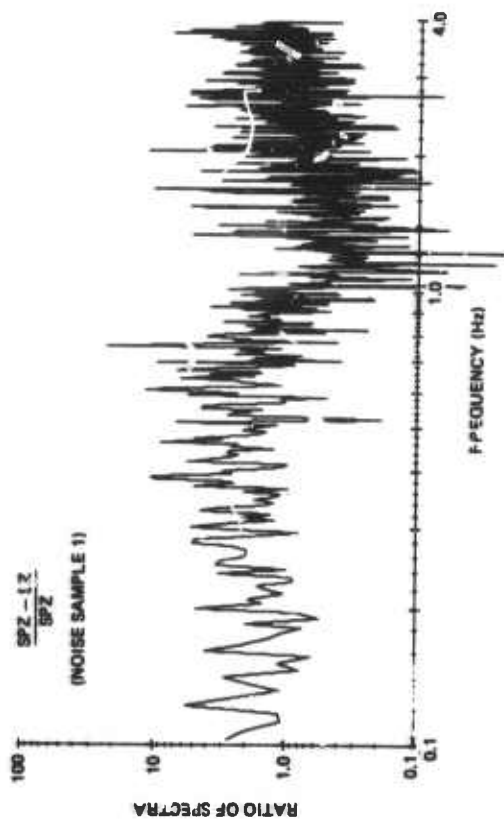
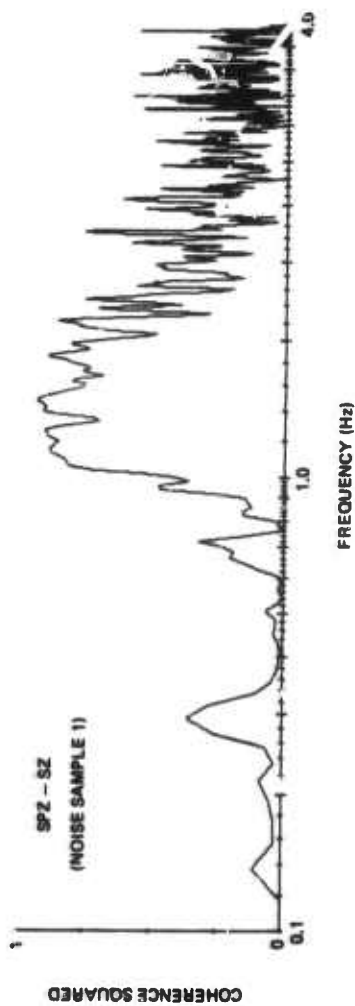
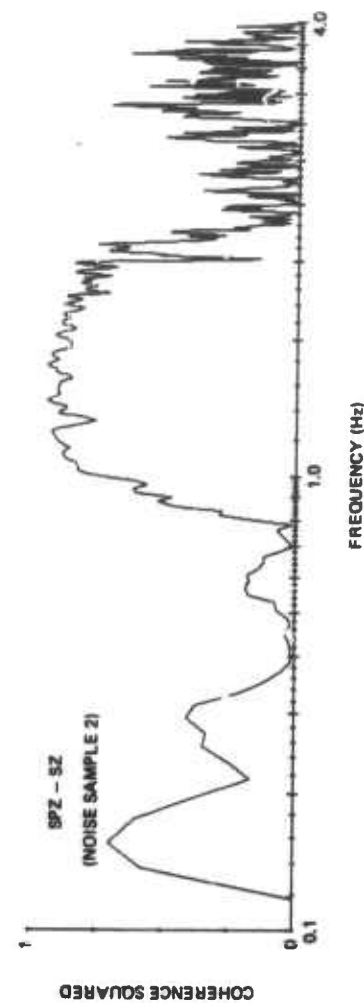


Figure 5. Top: Coherence squared computed from recordings made at the Garland, Texas site by a vertical strain (SZ) and a vertical inertial (SPZ) seismograph  
Bottom: Ratios of the spectra of recordings by the vertical inertial minus the vertical strain seismographs to the vertical inertial



expected, since the differences in response of strain and inertial seismographs changes with wave type.

Power spectra of the two noise samples show the predominant microseisms to be in the ranges 0.14 to 0.4 Hz and 1.0 to 5.0 Hz. Power spectra of the vertical inertial and vertical strain-inertial combination of the sample containing train noise are illustrated in figure 6. From the power spectra of figure 6 and ratios of figure 5 one sees that the vertical strain-inertial combination failed to suppress microseisms over the spectral high 0.14 to 0.4 Hz. These results are, however, in agreement with those obtained for WMO microseisms. Of much more importance is the significant suppression of microseisms in the range 1.0 to 2.0 Hz. This is particularly important since the microseismic level in the range 1.0 to 2.0 Hz is high at Garland, yet it is in this range that most regional and teleseismic P waves are expected.

## 6.2 HOULTON, MAINE

Following a successful demonstration of P-wave enhancement at Garland, Texas, it was recommended that tests with the vertical strain-vertical inertial combination be conducted at a location where the noise field is more typical of sites that are of marginal value for detecting low-level seismic events by conventional techniques. An Engineering Change Proposal, P-1358, dated 16 September 1968, contains recommendations and justification for amending Contract F33657-68-C-0948 to allow the strain operation to be moved from the present site at Garland, Texas, to the LRSM site at Houlton, Maine.

Planning was completed and work started on 11 November 1968, as authorized by Contract Amendment P002 with an effective date of 8 November. Casing for the boreholes was ordered on 11 November. The estimated delivery date of the casing is the week of 16 December. A leasing agreement with the landowner was negotiated on 17 November. A drilling contract for two boreholes at Houlton was negotiated on 20 November. The drilling contractor, Stanley E. Hillock of Portland, Maine, will commence drilling on 10 January 1969.

Arrangements were made for LRSM assistance in modifying, assembling, and checking out the complete system in Garland. Most of this work is now complete. Arrangements have also been made for assistance by the Houlton LRSM team in assembling and operating the system at Houlton. The system will be operated for a period of about 3 months. Magnetic-tape records, Develocorder records, and logs will be mailed routinely to the LRSM group in Garland. It is required that all tape records, except those containing data of special interest to the client, be available in the LRSM library at Garland for at least 30 days before being shipped elsewhere. Sufficient data will be processed to demonstrate the degree of noise suppression and P enhancement, and to determine the character of the noise at Houlton in terms of its effect on noise suppression.



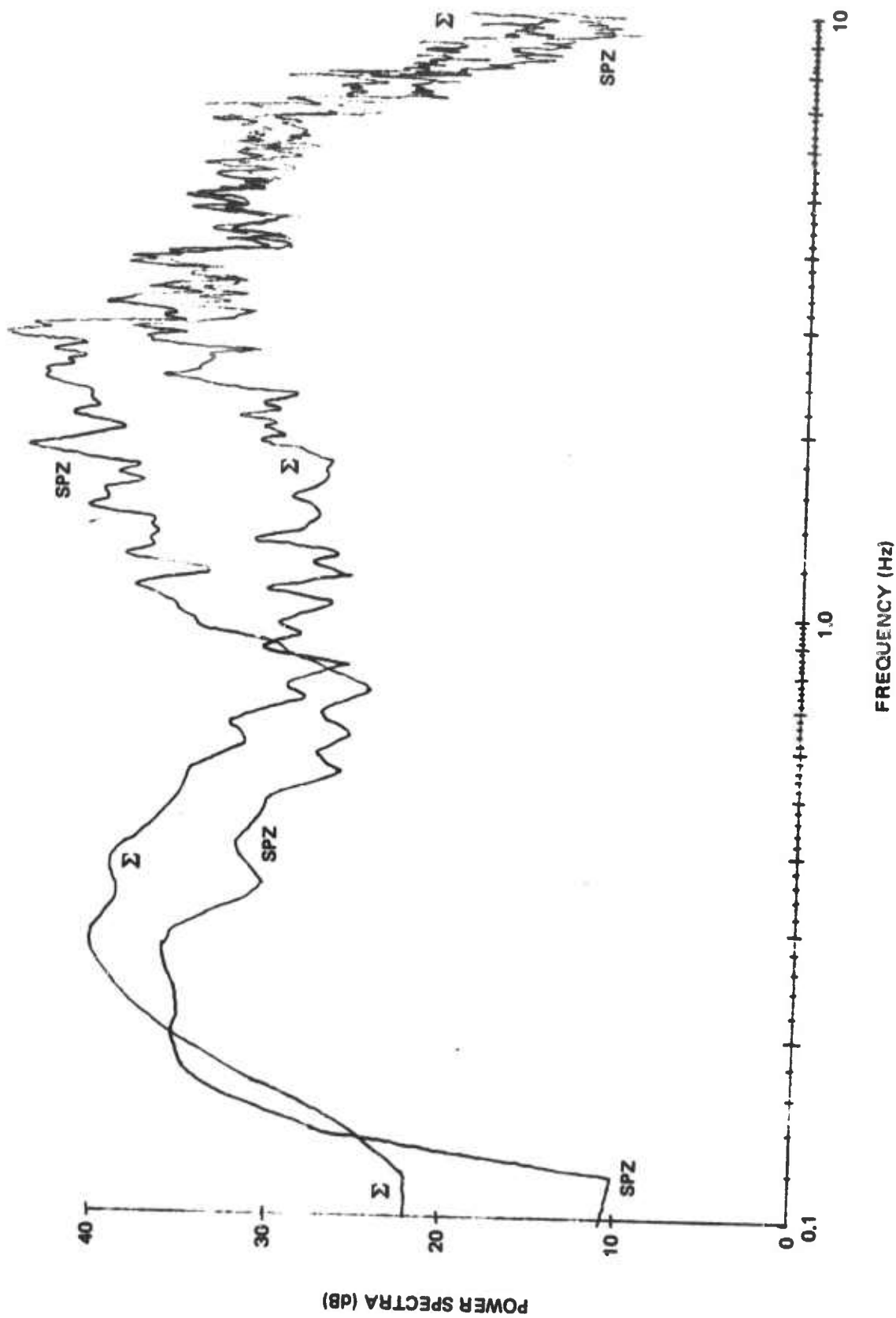


Figure 6. Power spectra of microseisms including train noise recorded at Garland, Texas.  
 SPZ - power spectra of the recording by a vertical inertial seismograph  
 $\Sigma$  - power spectra of the combined recordings of vertical inertial and  
 vertical strain seismographs  
 Hanning window, 20 samples/sec, 3700 sample length, 10% lags

APPENDIX to TECHNICAL REPORT NO. 68-48

STATEMENT OF WORK TO BE DONE  
(AFTAC PROJECT AUTHORIZATION NO. VELA T/8704/S/ASD)  
as amended by P002

STATEMENT OF WORK TO BE DONE  
(AFTAC PROJECT AUTHORIZATION NO. VELA T/8704/S/ASD)  
as amended by P002

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Tasks:

1. Operation:

- a. Routinely operate and maintain the short-period multicomponent strain seismograph system, and the companion pendulum seismographs, at the Wichita Mountains Seismological Observatory (WMSO).
- b. Record seismic data on film and magnetic tapes. Establish a library of seismic data, including records of background noise and signals and appropriate identifying logs, suitable for use in this and other projects.
- c. Evaluate the seismic data collected to determine optimum operating characteristics and adjust the instrumentation accordingly. Establish procedures and maintain quality control to assure collection of high-quality data.

2. Analysis and Investigations:

- a. Analyze data from the strain- and pendulum-seismograph systems to demonstrate further the application of strain seismograph systems to seismic detection and identification problems. This analysis should include, but not necessarily be limited to, the following:
  1. Investigate the use of multiple-strain/pendulum-input processes for suppressing complex noise fields.
  2. Study the usefulness of strain- and strain/pendulum-seismograph systems for identifying various types of seismic waves.
  3. Study the usefulness of strain- and strain/pendulum-seismograph systems in distinguishing between seismic signals from earthquakes and explosions.
- b. Investigate the characteristics and limitations of existing instrumentation and determine possible improvements. Recommend and make modifications as approved by the Project Officer.
- c. Install and operate vertical strain seismograph with a companion pendulum seismograph at Garland, Texas, and at Houlton, Maine, to demonstrate the extent of P-wave signal enhancement possible with the strain-pendulum combination operated at these sites. Determine the character of the noise field at each site in terms of its affect on the noise suppression problem.

Unclassified

CLASSIFICATION

REPORT OF PROGRESS AGAINST SELECTED MILESTONES (See instructions on reverse before filling in)					1. ARPA ORDER NUMBER 624	
2. PROJECT Short-Period Multicomponent Strain			3. COMPONENT			
4. NAME AND LOCATION OF PREPARING ACTIVITY Teledyne Industries, Inc., Geotech Division 3401 Shiloh Road, Garland, Texas					5. CONTRACT NUMBER F33657-68-C-0948	
					6. REPORT FOR MONTH ENDING 30 November 1968	
CODE a	MILESTONE b	SCHEDULED COMPLETION DATE c	ESTIMATED COMPLETION DATE d	DATE COMPLETED e	REMARKS f	
1	No. 4  Demonstrate the extent of P-wave signal enhancement possible with the strain-pendulum combination at Garland, Texas	30 Nov 1968		30 Sept 1968		
2	No. 5  Evaluate the usefulness of strain and inertial seismograph combinations in the enhancement of earthquake phases.	16 Feb 1969				

TYPED NAME AND TITLE Robert C. Shopland Senior Project Physicist		SIGNATURE <i>Robert C. Shopland</i>	TELEPHONE (214) 271-2561	DATE SIGNED 30 Nov. 1968
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SD FORM 350  
1 JAN 69Unclassified  
CLASSIFICATION

Unclassified  
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION	
Geotech, A Teledyne Company 3401 Shiloh Road, Garland, Texas 75040			
3. REPORT TITLE		2b. GROUP	
Short-Period Multicomponent Strain System Quarterly Report No. 3, Project VT/8704			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
1 September to 30 November 1968			
5. AUTHOR(S) (First name, middle initial, last name)			
Robert C. Shopland Richard H. Kirklin			
6. REPORT DATE		7a. TOTAL NO. OF PAGES	7b. NO OF REFS
12 December 1968		28	None
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S)	
F33657-68-C-0948		Technical Report No. 68-48	
b. PROJECT NO.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
VELA T/8704			
c.			
d.			
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Qualified users may obtain copies of this report from the Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314. This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Chief, AFTAC.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	
		Hq USAF (AFTAC/VELA Seismological Center) Washington, D. C. 20333	
13. ABSTRACT			
<p>An examination of film recordings of strain noise, pressure fluctuations inside and outside of the strain vault, and wind velocity at WMO suggests that the long period (LP) noise observed on the strain traces is caused by wind-pressure fluctuations that are coupled more strongly through the ground or by compression of the vault structure than through leakage of air through the vault enclosure. A study of the detection capability of the WMO LP strain seismographs shows that the environmental noise severely limits detection. From a study of the directional characteristics of the seismic noise it appears that during periods of average to high-level microseismic activity the predominant microseisms in the band 0.1 to 0.5 Hz arrive at WMO from the directions north to east and, therefore, may be partially rejected by horizontal strain-inertial seismograph combinations. From a study of S-wave enhancement, it is concluded that while for any specific S arrival, a combination of strain and inertial seismograph outputs might provide enhancement by SH addition, SV addition, seismic noise cancellation, or a combination of the above, there is no one combination of seismograph outputs that can be used in general to provide enhancement of all recorded S waves. Recordings of the large NTS explosion BOXCAR are being used to study the usefulness of strain and inertial seismographs in identifying seismic waves and earthquake phases. By applying various techniques such as coordinate transformation, phase shifting, and summing of strain and inertial data, it has been possible to isolate P, prograde, and retrograde motion in sections of the Pn coda, and SH motion in the Lg phase. From a spectral analysis of the suppressed seismic noise at Garland, Texas, it has been determined that noise suppression of at least 6 dB occurs in the frequency band 1.0 to 2.0 Hz. Arrangements for transfer of strain operation from Garland to Houlton, Maine, are complete.</p>			

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Seismology Strain seismographs Strain applications						