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VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

QUARTERLY REPORT NO. 3
1 APRIL 1977 TO 30 JUNE 1977

TEXAS INSTRUMENTS INCORPORATED
Equipment Group
Post Office Box 6015
Dallas, Texas 75222

Contract Number: F08606-77-C-0004
Amount of Contract: $560,000
Beginning 1 October 1976
Ending 30 September 1977

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Alexandria, Virginia 22314

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Program Code No. 7F10
ARPA Order No. 2551

1 July 1977

Acknowledgment: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM, and accomplished under the technical direction of the Air Force Technical Applications Center under Contract Number F08606-77-C-0004.

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This third quarterly report summarizes progress under the VELA Network and Automatic Processing Research program, Contract Number F08606-77-C-0004, during the period 1 April 1977 to 30 June 1977. Work in the following areas is summarized:

- Evaluation of ILPA and SRO data;
- Development of detection methods;

This report summarizes work in the following areas: (1) (2) (3) → (cont on p. (i))

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20. continued

- Methods of extracting long-period event waveforms;
- Interactive seismic signal processing; and
- Determining path corrections and extracting source parameters from long-period data.

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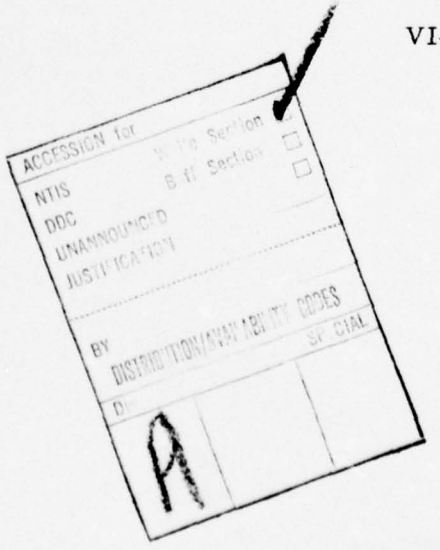

SECTION I
INTRODUCTION AND SUMMARY

This third quarterly report summarizes the progress made during the period between 1 April 1977 to 30 June 1977 in the VELA Network Evaluation and Automatic Processing Research program being carried out by Texas Instruments Incorporated at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. The five program tasks are:

- Evaluate the performance of the Iranian Long Period Array (ILPA) and the Seismic Research Observatories (SRO)
- Develop advanced methods for detecting seismic events and evaluate the event detection capability of postulated networks of seismic detectors
- Extract long-period seismic event waveforms given the location and origin time of an event
- Develop and demonstrate function processes for interactive signal processing; standardize and automate the processing functions; also demonstrate their feasibility for the graphics processing of events
- Compute instrument and path corrected spectra of a network of long-period seismic sensors and estimate seismic source parameters.

The Research Objective Plan drawn up and approved for performing these tasks is approximately on schedule. During this quarter we presented ten papers at the Spring American Geophysical Union meeting and one at a special symposium of the Institute of Electrical and Electronics Engineers. A

demonstration of our interactive seismic processing system was provided for the VELA Seismological Center and others. Associated data items were delivered.

For both the ILPA and SRO data evaluations, work was concentrated in the following areas:

- Expand the data base using the National Earthquake Information Service (NEIS) lists available
- Maintain data preparation software which is primarily the conversion of edit and beamform programs to the Terminal Support (TS) system
- Prepare software for extended noise analysis
- Perform the routine signal processing and analysis needed to evaluate each station separately and to evaluate all stations as a network designed to locate and measure earthquakes and presumed explosions.

To develop advanced methods for detecting seismic events, four research tasks are being pursued. These are as follows:

- Perfect and test methods for automatically timing the arrival of seismic events
- Determine the feasibility of using an adaptive beamformer to detect weak signals generated by seismic events
- Develop an automatic method to associate the detections of an event received at a sub-set of seismic stations and to predict the arrival times of event phases at all stations of the network
- Improve the efficiency and accuracy of estimating a seismic network's capability to detect and locate events of a given magnitude and from a given location.

To develop event waveform extraction techniques, two tasks are being performed as follows:

- Extract long-period bodywaves from edited single sensor three component data and from array data
- Cascade several methods of long-period event waveform estimations to optimize the extraction of weak signals.

To develop interactive graphics signal analysis capability, the following three tasks are being performed:

- Standardize seismic processing functions for performing discrimination analysis
- Extend the Interactive Seismic Processing System (ISPS) by developing a seismic programming language to generate displays, plots, and tables from data and information files stored on the disk, and to perform simple analysis functions on this data
- Develop software for transfering data to a mass store.

The final program task is to derive accurate transmission path corrections and source parameters from long-period data. This is broken down into three tasks as follows:

- Use newly developed and existing software for spectral analysis corrected for instrument response, path attenuation, and dispersion
- Form a suitable data base with long-period waveforms measured at a large number of stations providing adequate azimuthal coverage of the event

- Compare these to theoretical spectra and radiation patterns derived from the best fit source model as a means of estimating the source parameters associated with an event.

SECTION II
ILPA AND SRO EVALUATION

A. CURRENT STATUS

1. SRO

During the last quarter, our major emphasis has been on signal processing and analysis. To date, a total of 890 long-period events have been processed and analyzed, with an additional 225 events processed but not yet analyzed. Processing and analysis of 850 short-period events have been completed, with an additional 250 events complete at most stations.

Measurement of short-period RMS noise in the 0.5 - 4.0 Hz passband has been carried out along with the short-period signal analysis. During June, we also began measuring the maximum one-second noise amplitude.

During the last quarter we have also created and checked out long-period noise analysis programs which will compute RMS noise levels (with and without corrections for instrument response), RMS noise level trends, maximum 25 second noise amplitudes, and noise spectra.

We have held off processing long-period noise samples until a new unified SRO processing program, which combines our existing edit, data preparation, and plot programs, was completely checked out. This program will reduce the amount of computer time we will use. It is now ready for use. We also have available a list of the time gates we intend to use as noise samples.

Preliminary results on short-period noise measurements indicate a very strong correlation between noise levels and distance from the coast, whereas much less correlation was observed for the long-period data.

2. ILPA

Two major areas have been emphasized during the last quarter. In the area of signal processing, a total of 537 events from the time period 5/1/76 - 11/12/76 have been processed and analyzed for event detections and data quality. Surface wave magnitude estimates are currently being measured for those events which have been detected. Estimation of signal coherency has been initiated. The program to accomplish this was converted to TS during the last quarter and six test events processed by it.

In the area of noise analysis, the programs to study propagating noise have been converted to TS and tested during the last quarter. Furthermore, a total of 146 noise samples covering the period 5/1/76 - 3/12/77 have been processed and visually examined for the presence of unreported events. Approximately 40 of these samples show signals and hence will not be included in the noise analysis.

Preliminary results indicated that about 0.1 increase of magnitude capability was obtained by the array over a single site. This was based on data collected right after the array was installed and was greatly influenced by malfunctions. Better results are expected when the array operations improve.

B. FUTURE PLANS

During the next quarter, work will be concentrated on the following areas:

- Routine signal processing and analysis
- Noise analysis
- Report preparation.

SECTION III
DETECTION METHODS

A. CURRENT STATUS

The short-period (SP) detection and timing algorithm is nearing completion. Several detection and timing criteria have been tried on NORSAR single site data. The abundance of secondary SP signal arrivals makes it unfeasible to use moving-window phase regression, which was successfully used on long-period (LP) data. SP detection and timing will, instead, be based on envelope detection. However, the instantaneous phase and frequency functions may serve as a detection confirmation.

For the adaptive beamforming task, the evaluation of the new ABF was started this quarter using the recorded short-period array data from the Korean Seismic Research Station (KSRS). First, a strong event from Kamchatka was used. Second, a signal from a presumed explosion in eastern Kazakh was studied in detail. The ABF performance with this event was investigated in different passbands and with various convergence rates. Third, an ensemble of thirteen weak events, which was studied under Project 6705, was also reprocessed. The new ABF performance appeared to be consistent in both high and low amplitude signals. The preliminary conclusion is that the detection capability of the new ABF processor is equivalent to increasing the number of elements in a conventional beamforming array by a factor of three or four. It should increase the detection capability of arrays by about 0.3 m_b units. We need to examine more data to confirm this preliminary result.

Under the Detection Association Processor (DAP) task, depth dependence was put into the automatic event location algorithm. Functions

were constructed for more accurately generating the travel time and ray parameter. The earth model to be used to generate simulated event detection bulletins was modified with the above improved functions to more accurately reflect the effect of depth on the simulated observations of seismic waves.

B. FUTURE PLANS

The following developments are expected in the next quarter:

- Complete evaluation of a detector for timing of the onset of short-period P-waves
- Complete evaluation of the new ABF algorithms
- Develop improved detection association processor (DAP) software and test modifications with simulated network detection bulletins
- Complete development and demonstrate new network capability evaluation software
- Prepare reports.

SECTION IV
EXTRACTION OF EVENT WAVEFORMS

A. CURRENT STATUS

An adaptive filter was developed to extract long-period bodywave phases based on their expected polarization. Tests of the processor indicated the need to modify the polarization criteria used for detecting shear waves. Tests were performed using the Wiener filter cascaded with the three component adaptive filter (TCA) to extract weak surface waves. Preliminary results indicated approximately 0.4 magnitude improvement in detection capability of three component surface waves can be expected by cascading the Wiener filter and the TCA filter. Processing of events is continuing in order to evaluate improvements in the detection threshold.

B. FUTURE PLANS

In the next quarter, the modified processor for the extraction of bodywaves will be evaluated. The processing of surface waves, using the cascaded Wiener-TCA filter, will be completed during the next quarter. Preparation of the report will be continued.

SECTION V
INTERACTIVE SEISMIC PROCESSING

A. CURRENT STATUS

During the past quarter, the Extended Interactive Seismic Processing System (ISPSE) was demonstrated and delivered to AFTAC along with system and user documentation. On delivery, ISPSE featured the programmable mode of operation developed during the first half of the contract period together with a standard processing function for baseline discrimination. Also work on design and implementation of the Interactive Seismic Programming Language (ISPL) (the additional feature required to complete ISPSE) was begun. ISPL consists of the Interactive Seismic Programming Language Compiler (ISPLC) and the Interactive Seismic Programming Language Interpreter (ISPLI). ISPLC in turn has two main parts, PASS1 for editing and syntax analysis which has recently been completed (i.e., all associated routines designed, coded, and debugged), and PASS2 for semantic analysis and matrix generation on which work is proceeding. Also a modification to the Cepstrum method is being incorporated into the Short-Period Earthquake/Explosion Discriminator (SPEED) processing module. This module, together with user functions compiled via ISPL, will permit the definition of a more comprehensive standard function for discrimination processing by the end of the contract period.

Under the KSRS data transfer task, the long-period and short-period reformat programs have been coded. We have received the necessary information for constructing the KSRS transfer from Geotech and VELA Seismological Center. As a preliminary test, some LP data has been successfully transferred to the mass data store.

B. FUTURE PLANS

Currently work is focused on the design, coding, and checkout of routines associated with the PASS2 portion of ISPLC. When this task is complete, similar efforts will be directed toward the ISPLI module. Also, we are imbedding ISPL in the ISPSE system, maintaining SPEED, and designing high level statements for ISPL.

The data structures required to integrate ISPL into ISPSE are being designed and constructed. The 'procedure' for editing and interpreting routines is being modified to accept the user defined functions.

ISPSE is being modified to give the seismologist the capability to measure the maximum amplitude of a signal trace for a specified frequency. Defaults 1.0 and 25.0 second periods for short- and long-period waveforms, respectively, will be set up. The analyst may specify any period for the magnitude measurement.

The following developments are expected to be completed during the fourth quarter under the KSRS transfer task:

- Transmit a sample of raw data reformated into 11 events to the mass store SP file
- Construct the written operational procedure for the operator for long-period, short-period, and coarse status transmission
- Retrieve and analyze the transmitted test data and submit the result for approval
- Document the KSRS reformat and transmission programs and document the ILPA programs.

Problems

After the last update to ISPSE, the PDP system software generated a task that could not be installed. Currently all effort is being applied to determine the nature of this problem. A solution to this problem is of paramount importance before other efforts on ISPSE can be continued.

SECTION VI

SOURCE PARAMETERS FROM LONG-PERIOD SURFACE WAVE DATA

A. CURRENT STATUS

1. Software Development and Data Preparation

During the early part of this quarter, the last piece of computer program needed in this task was written in order to correct the observed surface wave spectra from the Special Data Collection System (SDCS) stations. Also the processing of the edited event signals using the PDP-15 computer was finally completed for all selected NTS (Nevada Test Site), EKZ (eastern Kazakh), and PNE (peaceful nuclear explosion) events.

2. Analysis

During the first and second quarter, the analysis part of this task was done whenever the processed data were available. After the completion of the data preparation during the early part of this quarter, analysis work has been progressing smoothly. The analysis work consists of three main areas: (1) examination of the observed surface waves, (2) estimation of the surface wave travel path attenuation, and (3) estimation of the seismic source parameters.

The surface wave group velocities for the travel paths from the NTS, EKZ, and PNE to all available observation stations were examined using data from all of the selected NTS, EKZ, and PNE events. By combining many events, surface wave group velocities for each travel path were obtained.

The observed surface wave amplitude spectra of the selected NTS, EKZ, and PNE events were examined for the period range between 10 and 50 seconds. The amplitude spectral ratios of the Love wave to Rayleigh wave (LQ/LR) were calculated for each event at all available observation stations. These ratios were compared among the NTS, EKZ, and PNE events for any indications of geological and source-oriented dependence. Also, the relative excitations of the Love waves for a suite of NTS events were examined in terms of the ratios of the observed Love wave amplitude spectra of a particular NTS event to a reference NTS event.

Preliminary results indicate that LQ/LR ranges from zero to ten for NTS events.

The average surface wave attenuation coefficients along the travel paths between the NTS and the observation stations and those along the travel paths between the EKZ and the region-station attenuations were estimated by the isotropic-source method using all available events. The travel paths between the NTS and the observation stations were logically divided into two groups: oceanic path and continental path. In addition, wherever applicable, the two-station method was employed to calculate the surface wave attenuation coefficients for the travel path between two observation stations. These results were compared with the existing estimates of surface wave attenuation.

Preliminary results on ocean path attenuation at NTS are 1.8×10^{-4} km^{-1} at 10 seconds period with gradual decrease to 1.1×10^{-4} at 50 seconds. For continental paths to NTS and EKZ the attenuations were from 4×10^{-4} at 10 seconds, to 1.6×10^{-4} at 20 seconds, with gradual decrease to 0.8×10^{-4} at 50 seconds.

The seismic source parameter estimations for all selected NTS, EKZ, and PNE events were completed. Theoretical radiation patterns based on the estimated source parameters were generated for several events

with a large number of observation stations. The observed values were superimposed to make comparisons between the observations and the theoretical radiation patterns.

Preliminary results indicate that NTS induced earthquakes are nearly vertical strike-slip with relative strength ranging from 0.5 to 1.0. An EKZ induced earthquake was dip-slip with a relative strength of 0.56.

B. FUTURE PLANS

The analysis work needed in this task is practically done. All these results will be organized and the writing of the first draft of the technical report for this task will be started.