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AN INTERACTIVE SYSTEM FOR LONG-PERIOD SEISMIC PROCESSING. TECHNICAL REPORT NO. 11. VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

Frode Ringdal, et al

Texas Instruments, Incorporated

Prepared for:

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This report describes an interactive graphics processing system developed for the PDP-15 computer at the Seismic Data Analysis Center. The system is designed to process long-period seismic data and includes options for interactive bandpass filtering, matched filtering, spectral analysis and parameter measurements. The main intention of the program development has been to investigate the feasibility of utilizing interactive graphics for event detection purposes in

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a potential world-wide seismic surveillance system. An evaluation of the expected operational capabilities of the system has been carried out, using data recorded by the Very Long-Period Experiment network as a source. Conclusions from this evaluation and recommendations for future study are presented.

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AN INTERACTIVE SYSTEM FOR LONG-PERIOD SEISMIC PROCESSING

TECHNICAL REPORT NO. 11

VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH

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ABSTRACT

This report describes an interactive graphics processing system developed for the PDP-15 computer at the Seismic Data Analysis Center. The system is designed to process long-period seismic data and includes options for interactive bandpass filtering, matched filtering, spectral analysis and parameter measurements. The main intention of the program development has been to investigate the feasibility of utilizing interactive graphics for event detection purposes in a potential world-wide seismic surveillance system. An evaluation of the expected operational capabilities of the system has been carried out, using data recorded by the Very Long-Period Experiment network as a source. Conclusions from this evaluation and recommendations for future study are presented.

ACKNOWLEDGMENTS

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SECTION I
INTRODUCTION

This report describes an interactive processing system developed by Texas Instruments Incorporated for the purpose of analyzing long-period seismic signals. The system utilizes the interactive graphics facilities of the PDP-15/50 computer at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. The program development was conducted as part of the System Study task of the VELA Network Evaluation and Automatic Processing Research program.

The main intention of the program system has been to investigate the feasibility of utilizing interactive graphics for event detection purposes in a potential world-wide seismic surveillance system. Although the software package is general in nature, an interface to one specific seismic system (the Very Long-Period Experiment (VLPE) network) has been designed, and a preliminary evaluation has been conducted using data recorded by this network as a source.

Interactive processing is today a very important aspect of numerous computer applications. It provides an efficient means for a user to comprehend his data base, to direct a computer in its operations upon that data base, and to examine the results of those operations - all within an appropriate time interval. The principal advantages of interactive processing are:

- It reduces the waiting time between intermediate processing steps, thus increasing productivity
- It reduces the need for hard-copy output because a video display of intermediate results is sufficient in many applications

- It provides an efficient means to retain human judgment in the analysis loop, and thus avoids the problems inherent in fully automating analytical decisions.

Interactive processing is particularly well suited for those applications that are characterized as a series of sub-processes with active intermediate decision points. Seismic signal analysis belongs to this class of problems. Typical intermediate decision points are exemplified as follows:

- Data quality control; elimination or correction of bad data segments.
- Alignment of signal traces for beamforming.
- Selection of the "best" bandpass filter or matched filter from a filter library.
- Selection of a signal peak for magnitude measurements.
- Selection of time windows for computing quantities such as seismic noise level and the AR and AL discriminants (Brune et al., 1963).
- Rapid visual control of detection/no-detection decisions on individual signal traces.

In addition, several non-routine seismic signal processing techniques may benefit greatly from interactive processing. Examples include the complex Cepstrum technique, identification of later phases (such as pP), and detection association techniques for network processing. For a discussion of these and related topics we refer to Sax (1974).

The interactive system described in this report deals primarily with standard processing techniques such as bandpass filtering, linear chirp or reference waveform matched filtering, computation of power spectra and measurements of selected event parameters. In Section II we present a functional description of the system. Section III gives some examples of application and includes a brief evaluation of the processing effectiveness in a potential surveillance mode. Finally, conclusions and recommendations for future study are presented in Section IV.

A documentation of the developed software has been issued separately from this report (Ringdal and Shaub, 1974). This documentation also contains a user description of the programs, including a step-by-step solution of a sample problem.

SECTION II

DESCRIPTION OF THE ILPPS INTERACTIVE SYSTEM

A. PROGRAM PURPOSE

The overall purpose of the Interactive Long-Period Processing System (ILPPS) is to provide an interactive graphics capability for detecting and analyzing seismic surface waves. Although the software has been designed to operate on a specific computer system (the PDP-15/50), the design philosophy is sufficiently general to apply to other potential configurations. The ILPPS system is primarily intended to support two objectives:

- To provide an analyst with a convenient tool to perform interactive signal analysis for research purposes.
- To establish an operationally flexible system which might be used to process a large number of events in a world-wide seismic surveillance network.

In order to achieve these objectives, the ILPPS system has been designed with emphasis on establishing a convenient sequential processing capability to accomodate the requirements of an operational surveillance system. At the same time, enough flexibility has been built in to allow the analyst to select non-standard processing functions at various intermediate steps in the analysis.

B. SYSTEM CONFIGURATION

1. Hardware

The ILPPS system has been implemented for the PDP-15/50 computer system located at SDAC. This configuration comprises the following hardware features:

- Central Processing Unit with 64 K words memory (24 K are used by ILPPS).
- Standard peripheral equipment including four magnetic tape stations, card reader and line printer.
- Two disk drives; one large capacity disk capable of storing 10 million words and one fixed-head disk of 256 K word capacity.
- A video display interactive graphics console with keyboard, light pen, and interrupt pushbuttons.
- A VARIAN electrostatic printer/plotter and a CALCOMP digital plotter.

For a more detailed description of the system hardware configuration we refer to Teledyne/Geotech (1973).

2. Software

The initial implementation of ILPPS runs under the RSX Plus II operating system for the PDP-15 computer. RSX provides a multiprogramming environment and thus allows for the execution of other tasks concurrently with ILPPS. This capability is clearly of considerable importance when operating in an interactive mode, since the computer will be inactive between processing steps, while the analyst makes his decisions. This wait time will for most applications be considerably larger than the actual CPU time utilized.

The ILPPS software is coded primarily in FORTRAN. The only exceptions are certain input/output functions for which assembly language has been utilized.

3. Data Base

In the initial version of the ILPPS package, the capability exists to process data recorded by the Very Long-Period Experiment (VLPE) Network. Table II-1 lists the individual VLPE stations. For further description of the network, we refer to Lambert et al. (1973).

C. FUNCTIONAL DESCRIPTION

1. General Features

The basic structure of the ILPPS software package is outlined in Figure II-1. The main features of the system may be described as follows:

- An interactive graphics console which serves as the physical interface between the computer system and the analyst.
- A system supervisor which provides a command language to control processing module execution within the interactive environment.
- A set of independent processing modules which perform analysis functions such as the selection, display, and filtering of seismic waveforms.

This modular design approach provides for a simple logical structure of the system. It furthermore facilitiates future extensions of the

TABLE II-1

VERY LONG-PERIOD EXPERIMENT (VLPE)
STATION AND LOCATION

Station Number	Station Name	Designator	Latitude	Longitude
1	Charters Towers, Australia	A	20.09S	146.26E
2	Chiang Mai, Thailand	CHG	18.79N	98.98E
3	Fairbanks, Alaska	FBK	64.90N	148.01W
4	Toledo, Spain	TLO	39.86N	4.02W
5	Eilat, Israel	EIL	29.55N	34.95E
6	Kongsberg, Norway	KON	59.65N	9.59E
7	Ogdensburg, New Jersey	OGD	41.07N	74.62W
8	Kipapa, Hawaii	KIP	21.42N	158.02W
9	Albuquerque, New Mexico	ALQ	34.94N	106.46W
10	La Paz, Bolivia	ZLP	16.50S	68.13W
11	Matsushiro, Japan	MAT	36.54N	138.21E

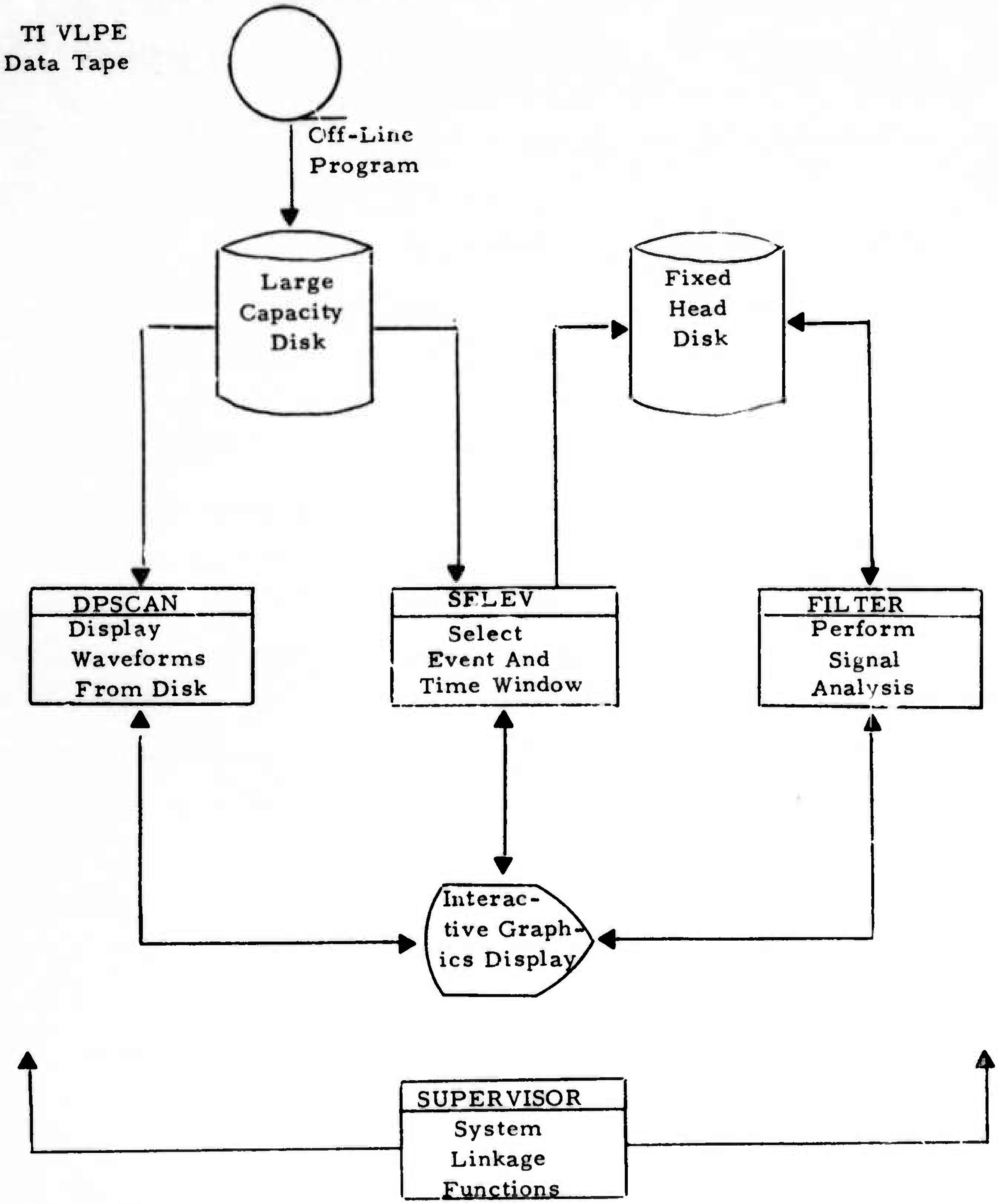


FIGURE II-1

TI INTERACTIVE LONG-PERIOD PROCESSING SYSTEM - GENERAL FLOW system functions, either by modifying existing processes or by including additional software modules. This is especially important in view of the experimental nature of the ILPPS system.

A number of additional design considerations apply to the ILPPS system. The most important of these are listed below:

- The data base is completely disk-oriented; thus event data are stored on disk by an off-line program prior to system execution. The capability exists to input new event data to the disk while existing events are being processed.
- Although the system is initially designed to process VLPE network data, the off-line approach to system input makes adaption to other types of seismic data easy.
- Data communication between distinct processing modules is performed via temporary disk files, in order to minimize memory requirements.
- For ease of operation, analyst control of the program flow is maintained mainly via pushbutton interrupts. At each decision point, a function selection panel is displayed; giving key-words to explain to the analyst the available options.
- All keyboard entries may be made in free format. A comprehensive error checking system recognizes possible syntax errors as well as input values that are out of range.

It might be noted that the ILPPS system in most practical applications will accept as input long-period seismic waveforms corresponding to a known event. Normally the event will have been detected by a short-period station or network; thus an approximate location and origin time are known. This approach is reasonable, since short-period P-wave detection is usually much easier than identification of surface waves. However, the ILPPS programs are general enough to process waveforms for which no event information is provided, in case this should be desired.

2. Processing Options

The following paragraphs detail some of the processing options within the ILPPS system. A further description of some examples of application will be presented in Section III.

a. System Supervisor

- Creates, updates, and retains user procedures. Previously created procedures may be accessed from a disk storage file.
- Accesses system processing modules either individually or in a procedural mode.
- Maintains a complete record of system functions performed, with hard-copy output to the printer.

The internal structure and design of the ILPPS system supervisor was influenced substantially by that of the Numerical Analysis Problem Solving System (Roman, 1973).

b. DPSCAN Processing Module

- Lists summary of all events in current data base
- Provides random access to any event in the data base
- Allows rapid scanning of individual events by displaying one station component at a time (maximum 4096 seconds time window).

c. <u>SELEV Processing Module</u>

- Provides random access to any individual data channel (i. e., the vertical, transverse, or radial component trace for a specified station and event)
- Allows analyst option to select a time window for processing by use of a moving cursor
- Stores selected traces on a disk file for later access by the FILTER routine
- Allows simultaneous selection of any number and combination of traces, stations and events; the only restriction being the amount of computer core storage available for the display file.

d. <u>FILTER Processing Module</u>

- Displays simultaneously all traces selected by the SELEV routine
- Performs bandpass filtering, linear chirp matched filtering, or reference waveform matched filtering of any individual trace
- Includes a sequential processing capability for selecting optimum chirp filter length
- Can adjust scaling parameters (horizontal or vertical) and select various levels of annotation
- Provides a save-restore capability to and from disk for the displayed picture
- Displays signal or noise power spectra and chirp impulse response.

- Includes an option to apply a set of narrow-band filters to a wave-form to determine its dispersion characteristics.
- Measures, interactively, the following parameters:
  - M_s (Love or Rayleigh waves)
  - RMS Noise level
  - AR or AL parameters (Brune et al., 1963)
- Retains measured parameters in a disk storage file.

3. Program Execution

All individual analysis programs are executed under control of the system supervisor. The analyst may initiate any one of these by entering a PERFORM statement while the system is in supervisory state. The system supervisor also includes options to create user procedures combining various sequences of calls to system modules and to execute such procedures by a single request. Figure II-2 shows an example of the system log in a simple case where the analyst has requested the DPSCAN, SELEV and FILTER modules individually.

Within each analysis package, program control is maintained via the pushbutton interrupt panel. This provides for rapid selection and execution of processing options and minimizes the necessary manual interaction. As an aid to the analyst, a set of key words describing each of six possible interrupt options is displayed at each decision point.

Figure II-3 shows, as an example, the key word system within the FILTER program module. This figure illustrates the hierarchy used in ILPPS to organize the various program options. For example, in order to filter the current work trace with a narrow band filter (0.040-0.050 Hz), the analyst hits pushbuttons 2, 1 and 4 in that sequence (from panels 2., 2.1 and 2.1.1 in the figure, respectively).

```
TI-SAPSS LOGGED ON :  4/19/74 AT 10:58:29 ,  ENTER COMMAND.

.... .PERFORM DPSCAN
 SYSTEM FUNCTION DPSCAN INITIATED
 EVENT LIST REQUESTED, (Y,N)?
.... N
ENTER DESIRED EVENT NUMBER
.... 13
.... .PERFORM SELEV
 SYSTEM FUNCTION SELEV INITIATED
ENTER EVENT SEQUENCE NUMBER FROM LIST
.... 13
ENTER STATION NUMBER (1,15)
.... 6
ENTER COMPONENT NUMBER (1,3)
.... 2
ENTER NUMBER OF COPIES TO BE SAVED : TS =  1037   TL =  1022 SEC
.... 3
ENTER EVENT SEQUENCE NUMBER FROM LIST
....
.... .PERFORM FILTER
 SYSTEM FUNCTION FILTER INITIATED
TRACE 3    AMP= 1464.5 NM      PER= 23.2 SEC      MS= 4.93
.... .PERFORM LOGOFF



TI-SAPSS LOGGED OFF :  4/19/74 AT 11: 2:30
```

FIGURE II-2

EXAMPLE OF SYSTEM LOG OUTPUT

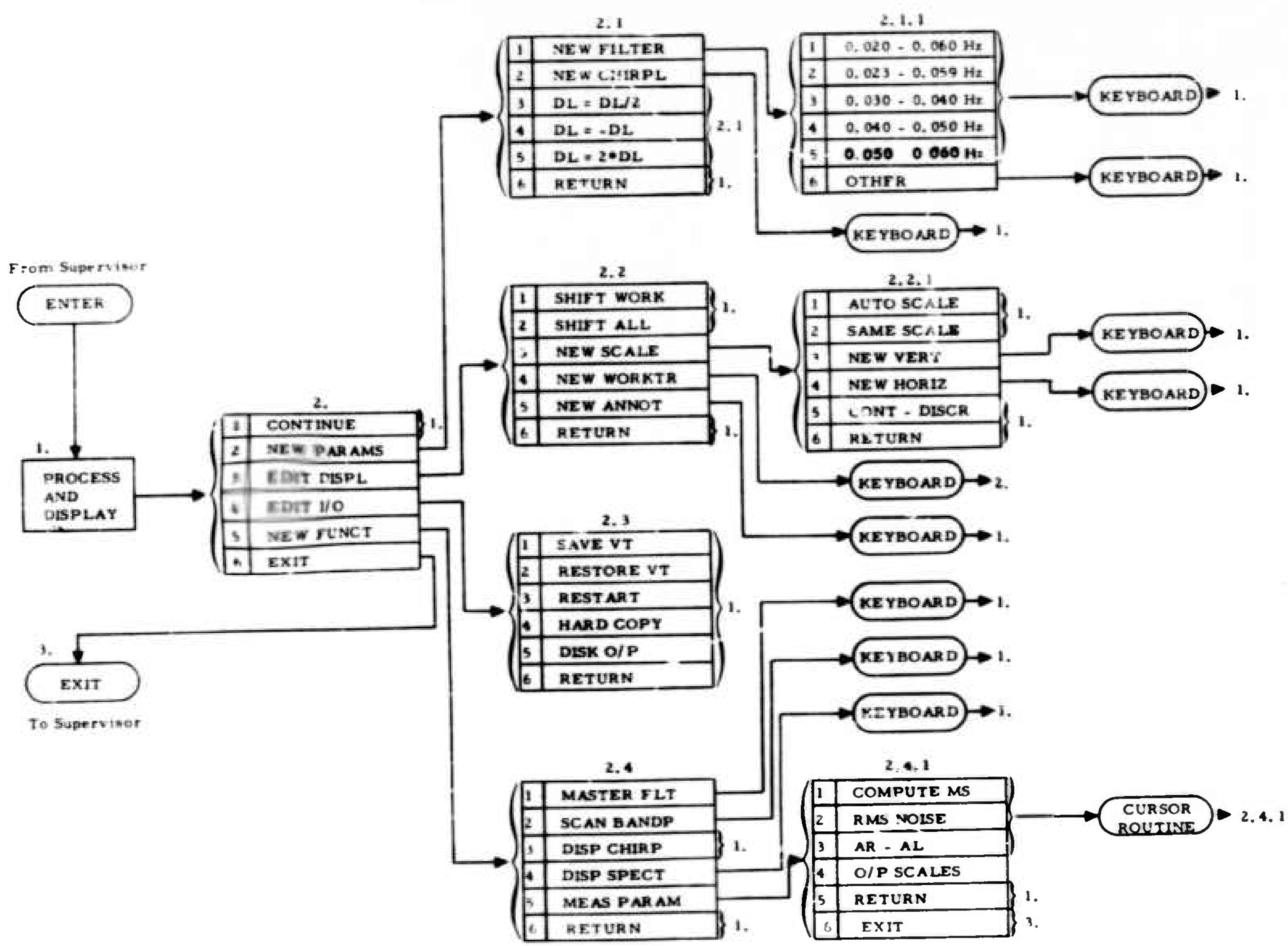


FIGURE II-3

FUNCTION SELECTION PANELS FOR THE FILTER PROGRAM MODULE

The net effect of this approach to the function selection problem is to have the pushbutton panel act as a set of programmable function keys. The hierarchical organization of the processing options makes it feasible to access easily a large number of functions within this framework.

SECTION III

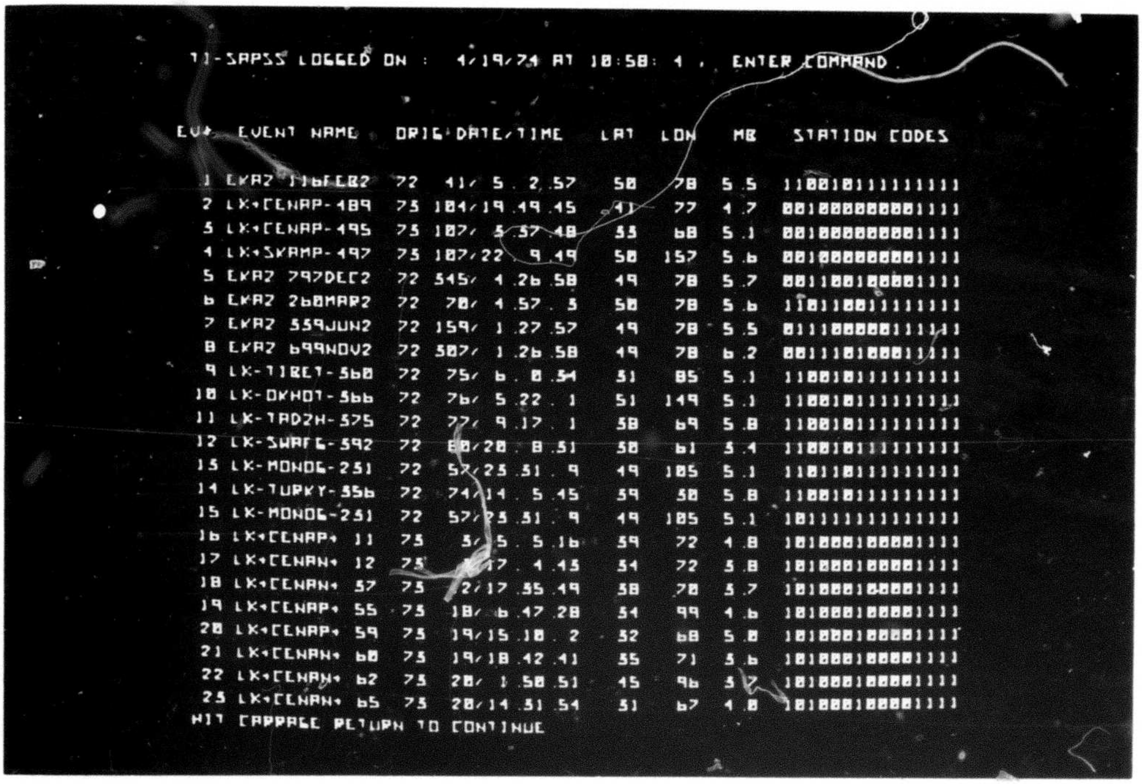
OPERATIONAL ASPECTS

A. EXAMPLES OF APPLICATION

In this section, we present a number of examples to illustrate some of the capabilities of the ILPPS system. These examples are not intended to describe how to operate the system - for this we refer to the software documentation (Ringdal and Shaub, 1974). However, they should give some insight into data selection, simultaneous display capabilities and signal analysis options.

Figure III-1 shows the first page of the event directory listing the event data sets that are currently available on the disk. Epicentral information has been obtained from short-period data (e. g., the LASA or NORSAR seismic bulletins). Station codes indicate (by a 0 in the appropriate column) which of 15 VLPE stations have data available for the particular event.

An example of an event waveform record for station number 9 (ALQ) (vertical component, unfiltered) for an event from central Asia is displayed in Figure III-2. The event annotation (two top lines) has been derived from short-period information, and estimated arrival times of long-period P, S, LQ, and LR waves are marked. The tick marks on the time axis occur at 100-second intervals; the total time period covered is 4096 seconds. The traces are scaled automatically, with the scale factor displayed at the bottom of the screen. The right-hand part of the screen shows the six presently available processing options corresponding to the six pushbuttons of the display unit.



11-SAPSS LOGGED ON : 4/19/74 AT 10:58: 4 , ENTER COMMAND.

EV#	EVENT NAME	ORIG	DATE/TIME	LAT	LON	MB	STATION CODES
1	EKAZ 116FEB2	72	41/ 5. 2.57	50	78	5.5	110010111111111
2	LX+CENAP-489	73	104/19.49.45	41	77	4.7	001000000001111
3	LX+CENAP-495	73	107/ 5.57.40	35	68	5.1	001000000001111
4	LX+SKAMP-497	73	107/22. 9.49	50	157	5.6	001000000001111
5	EKAZ 797DEC2	72	345/ 4.26.58	49	78	5.7	001100100001111
6	EKAZ 260MAR2	72	70/ 4.57. 5	50	78	5.6	110110011111111
7	EKAZ 559JUN2	72	159/ 1.27.57	49	78	5.5	011100000111111
8	EKAZ 699NOV2	72	307/ 1.26.58	49	78	6.2	001110100001111
9	LK-TIBET-560	72	75/ 6. 0.54	51	85	5.1	110010111111111
10	LK-OKHOT-566	72	76/ 5.22. 1	51	149	5.1	110010111111111
11	LK-TADZH-575	72	77/ 9.17. 1	58	69	5.8	110010111111111
12	LK-SWAFG-592	72	80/20. 8.51	50	61	5.4	110010111111111
13	LK-MONDG-251	72	57/25.51. 9	49	105	5.1	110110111111111
14	LK-TURKY-556	72	74/14. 5.45	59	50	5.8	110010111111111
15	LK-MONDG-251	72	57/25.51. 9	49	105	5.1	101111111111111
16	LK+CENAP+ 11	75	5/ 5. 5.16	59	72	4.8	101000100001111
17	LK+CENAN+ 12	75	[illegible]/17. 4.45	54	72	5.8	101000100001111
18	LK+CENAN+ 57	75	2/17.55.49	58	70	5.7	101000100001111
19	LK+CENAP+ 55	75	18/ 6.47.28	54	99	4.6	101000100001111
20	LK+CENAP+ 59	75	19/15.10. 2	52	68	5.0	101000100001111
21	LK+CENAN+ 60	75	19/18.42.41	55	71	5.6	101000100001111
22	LK+CENAN+ 62	75	20/ 1.50.51	45	96	5.7	101000100001111
23	LK+CENAN+ 65	75	20/14.51.54	51	67	4.8	101000100001111

HIT CARRAGE RETURN TO CONTINUE

FIGURE III-1

DISPLAY OF ILPPS EVENT DIRECTORY

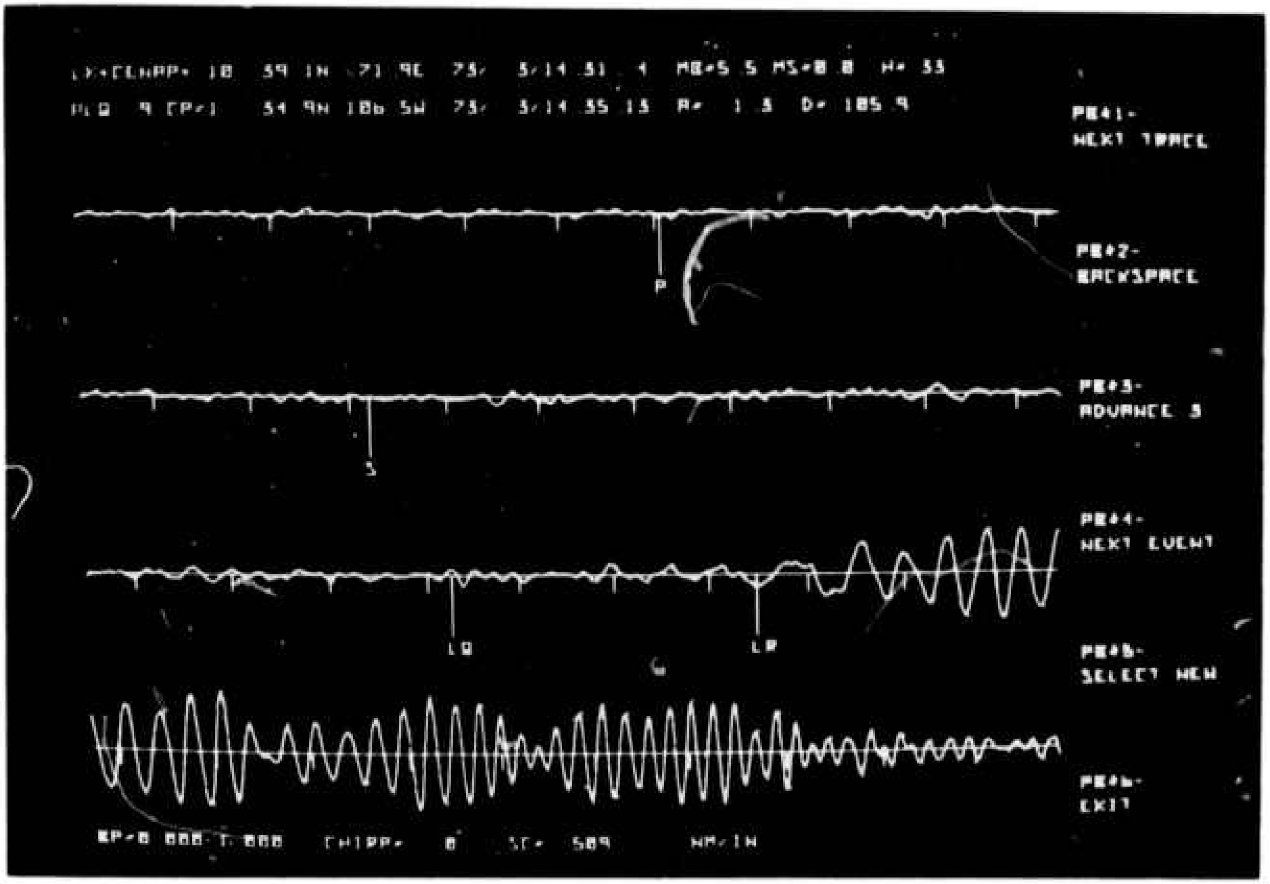


FIGURE III-2

DISPLAY OF A SAMPLE WAVEFORM
(4096 SECONDS)

In Figure III-3, a simultaneous display of four different station recordings of the same event is shown. Each station is represented by its vertical component. The time window in each case is 1024 seconds. The annotation below the traces identifies event name, station number, component number, station azimuth and distance from epicenter, data start time, filter band, and scale.

Figure III-4 gives a simultaneous display of the three rotated components (LRV, LQT, LRR, respectively) of station number 11 (MAT) for a central Asian event. In this case, all traces have been bandpass filtered; the vertical trace by a 0.020-0.060 Hz filter; the two horizontal traces by a 0.015-0.060 Hz filter.

Figure III-5 shows an application of a linear chirp filter to a central Asian event recorded by station 6 (KON, vertical component). The top trace is the unfiltered waveform; the middle trace is the same waveform filtered with a narrow-band filter (0.040-0.050 Hz) and the third trace is obtained by applying a linear chirp of 600 seconds over a frequency band of 0.020-0.060 Hz to the original trace.

Figure III-6 is identical to Figure III-5, except that the impulse response of the chirp filter (time-inverted) is displayed in the middle trace.

Figure III-7 shows a waveform recorded by station 9 (ALQ) in the top trace, and the log power spectrum of the same event in the bottom trace. Frequency increments are linear, with the rightmost point corresponding to the Nyquist frequency of 0.25 Hz.

Figure III-8 illustrates reference waveform filtering. The top trace is the vertical component of station 8 (KIP) for a presumed explosion from

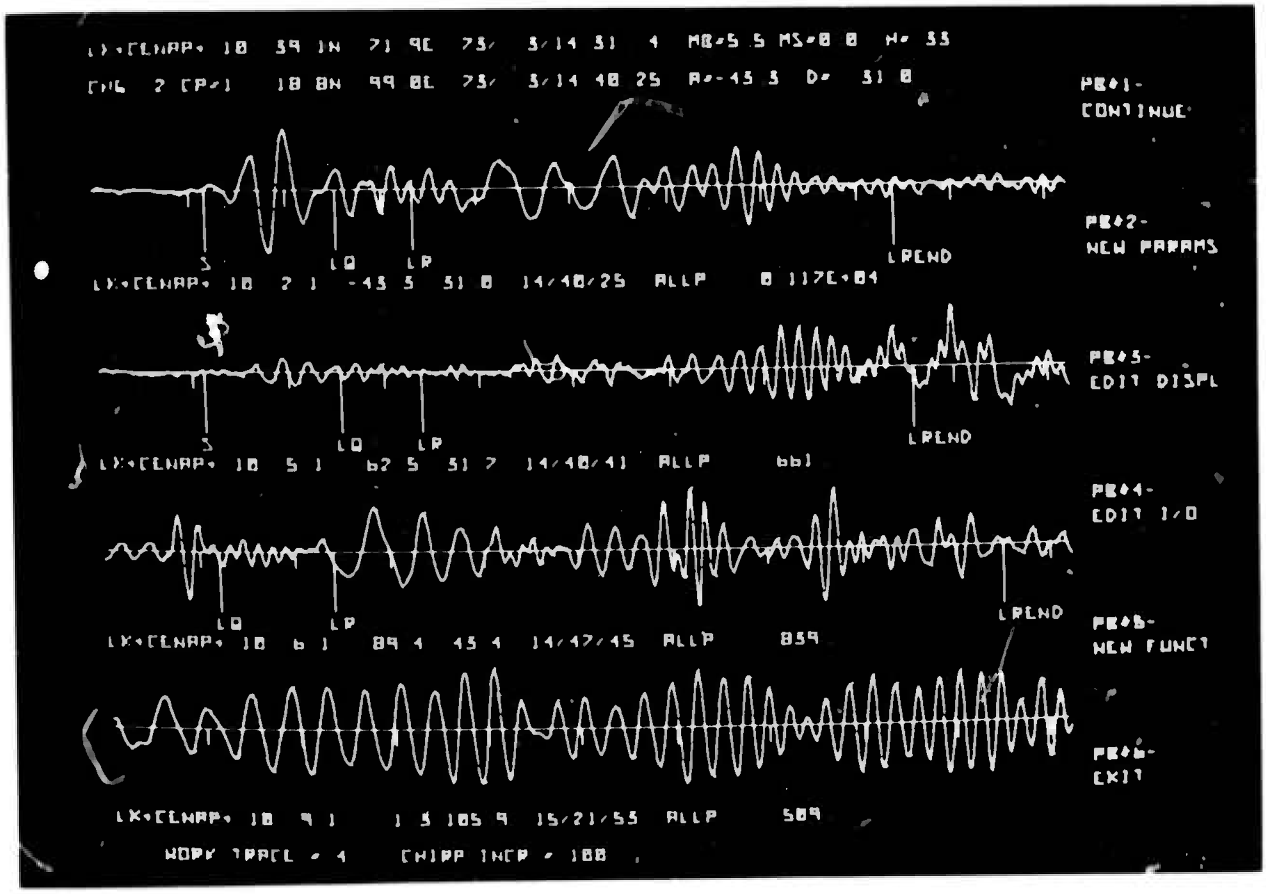


FIGURE III-3

SIMULTANEOUS DISPLAY OF 4 STATION RECORDINGS (VERTICAL COMPONENT) OF THE SAME EVENT

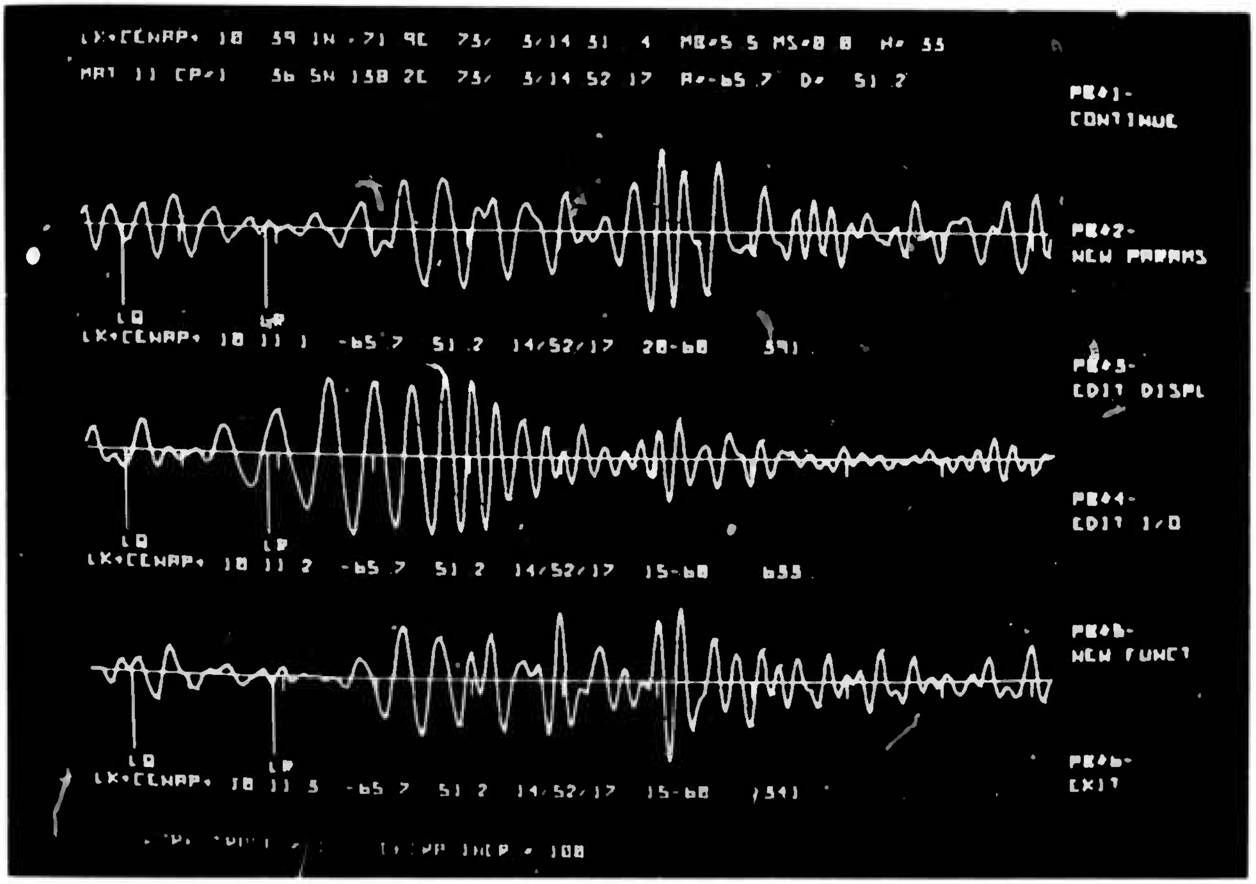


FIGURE III-4

DISPLAY OF THREE ROTATED COMPONENTS
(FROM TOP TO BOTTOM: LRV, LQT, LRR)
OF A VLPE STATION

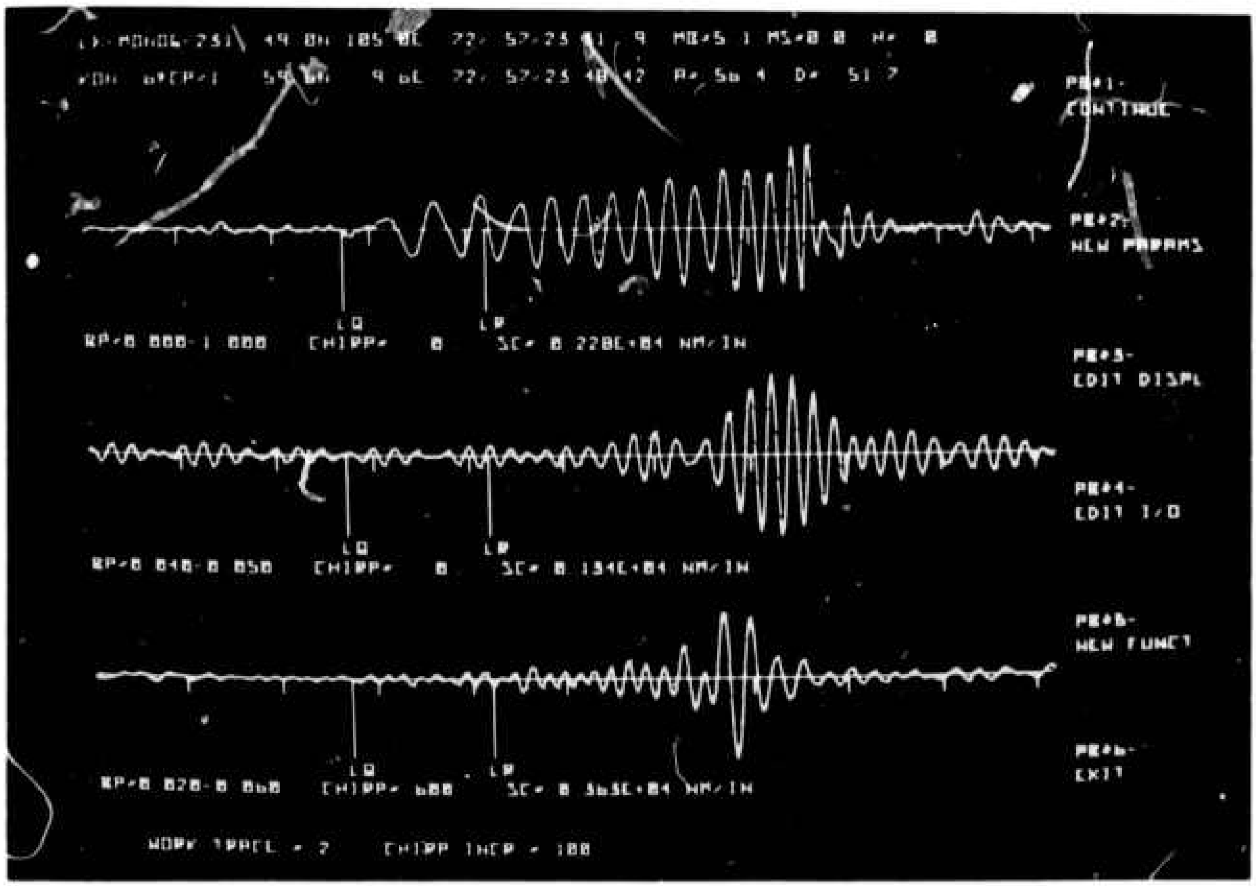


FIGURE III-5

EXAMPLE OF AN ORIGINAL EVENT WAVEFORM (TOP TRACE), FILTERED BY A NARROW-BAND FILTER (MIDDLE TRACE) AND BY A LINEAR CHIRP FILTER (BOTTOM TRACE)

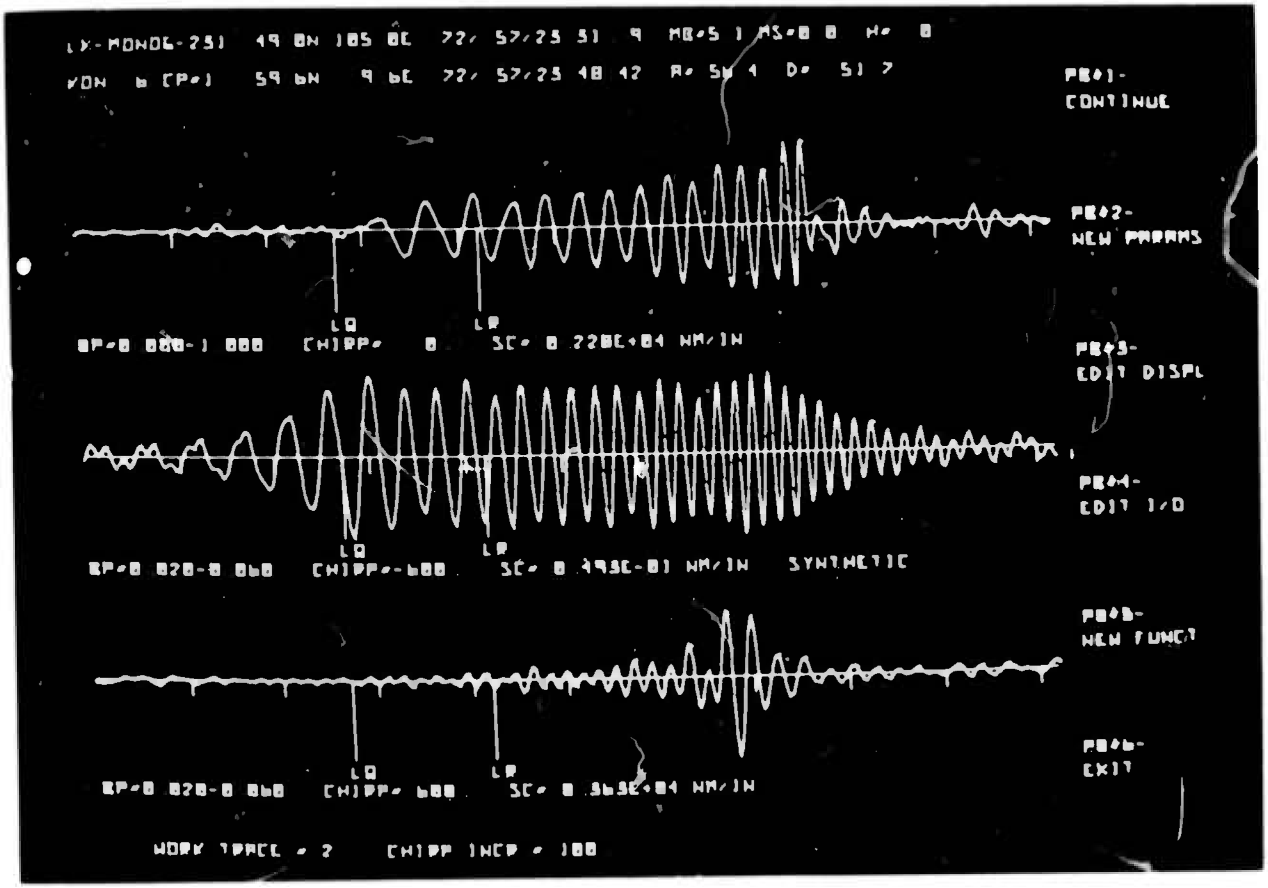


FIGURE III-6

SIMULTANEOUS DISPLAY OF A WAVEFORM (TOP TRACE)
THE WAVEFORM FILTERED BY A LINEAR CHIRP FILTER (BOTTOM TRACE)
AND THE INVERTED IMPULSE RESPONSE (MIDDLE TRACE)

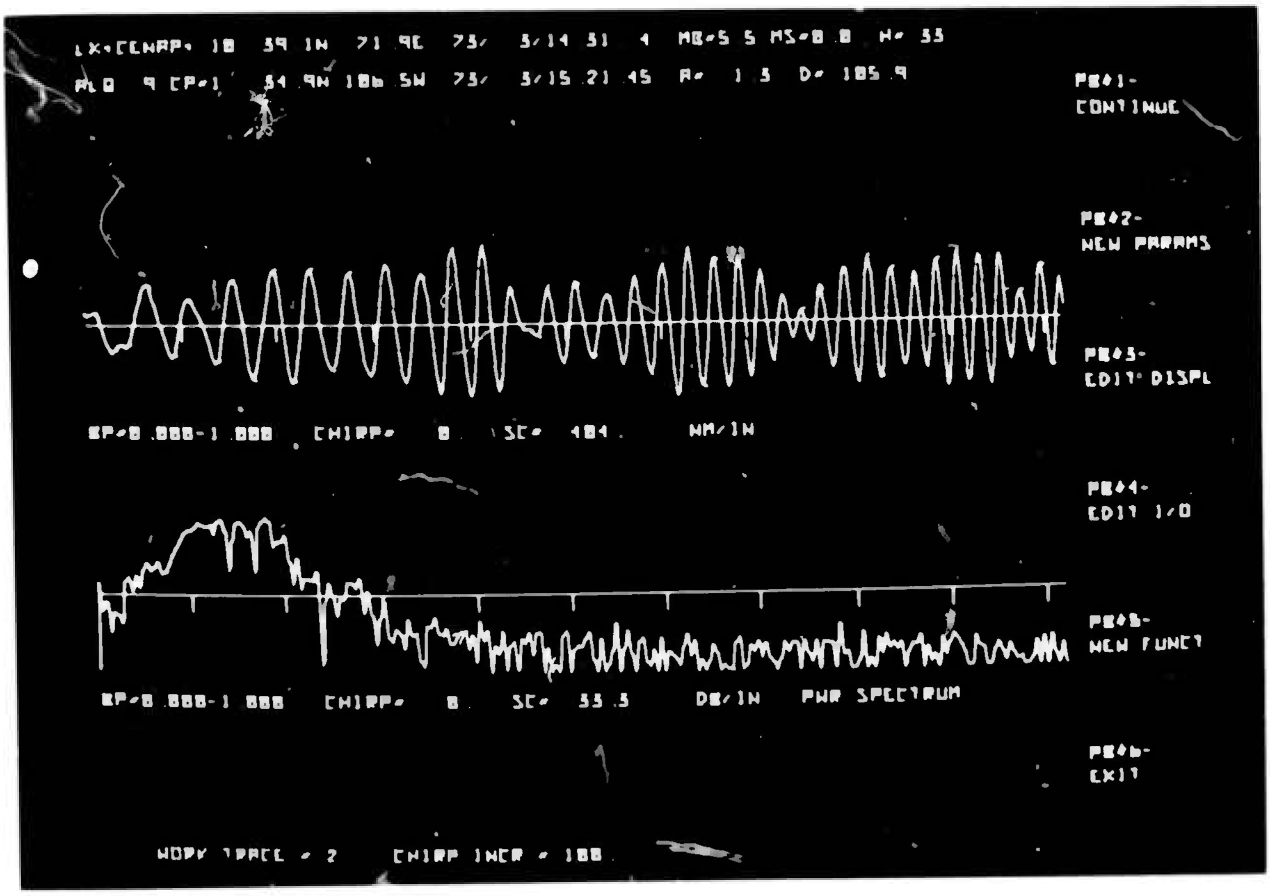


FIGURE III-7

DISPLAY OF A SEISMIC WAVEFORM
AND ITS POWER SPECTRUM

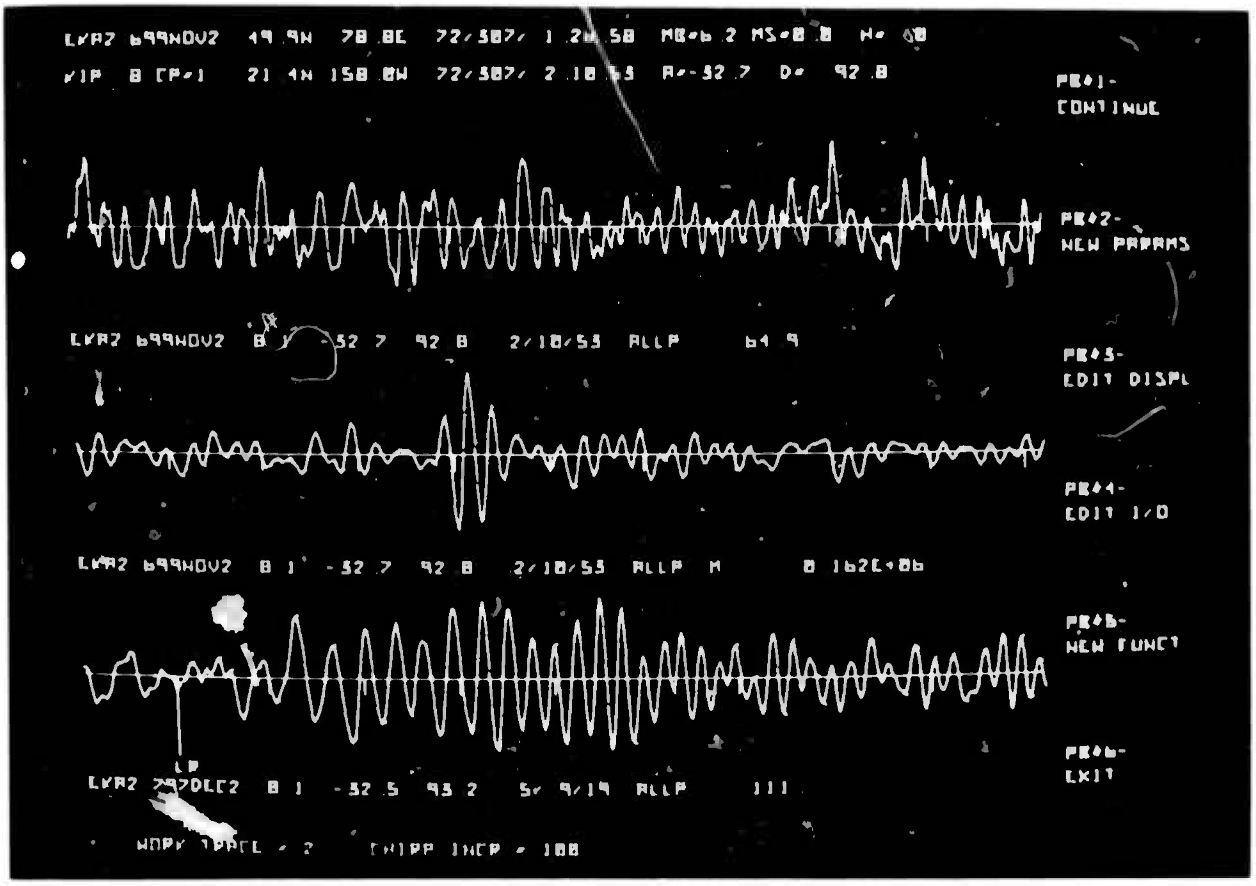


FIGURE III-8

DISPLAY OF A RECORDED WAVEFORM (TOP TRACE)
A REFERENCE EVENT FROM THE SAME LOCATION (BOTTOM TRACE)
AND THE CROSS-CORRELATION BETWEEN THE TWO (MIDDLE TRACE)

eastern Kazakh; the bottom trace is the reference waveform; which is a much larger event from the same site. The middle trace is the cross correlation between the top and bottom traces. It is observed that the signal-to-noise ratio of the middle trace is substantially improved over that of the top trace.

Figure III-9 pictures the outputs of a suite of narrow-band filters applied to a selected recording. The multiple filter option is designed to give an efficient way of computing group velocity curves for various transmission paths. Figure III-10 shows the second part of this option, the Hilbert transforms of the same traces with cursor marks (set by the analyst) at the local maxima. Finally, in Figure III-11 the travel times are translated into group velocities. The box surrounding a point indicates how the analyst may select points on the actual group velocity curve for the path in question.

B. EVALUATION

1. Description of Experiment

The ILPPS system might conveivably be used in the future either for research purposes or in a potential surveillance mode. Clearly, both applications demand a high quality of the data analysis. Apart from this, the requirements differ. In a research application, the most valuable feature is flexibility and adaptability to non-standard operations. In a surveillance system, the real-time aspect implies that processing efficiency is of primary importance.

We describe here an experiment that was conducted in order to evaluate the effectiveness of ILPPS in a potential world-wide surveillance system. Data recorded by the VLPE network was utilized for the evaluation; the stations of this network were previously listed in Table II-1.

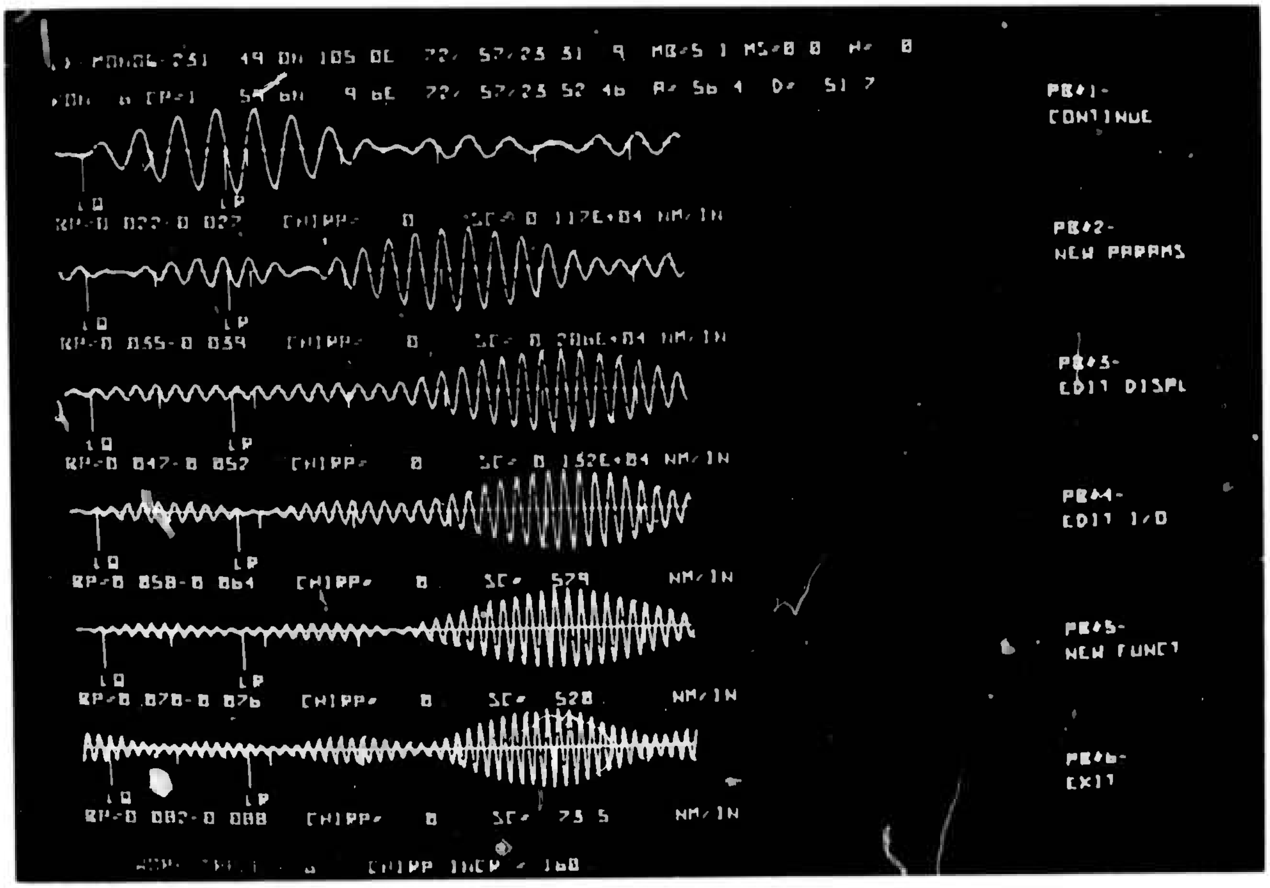


FIGURE III-9

DISPLAY OF A SET OF NARROW-BAND FILTER OUTPUT TRACES FOR A DISPERSED WAVEFORM

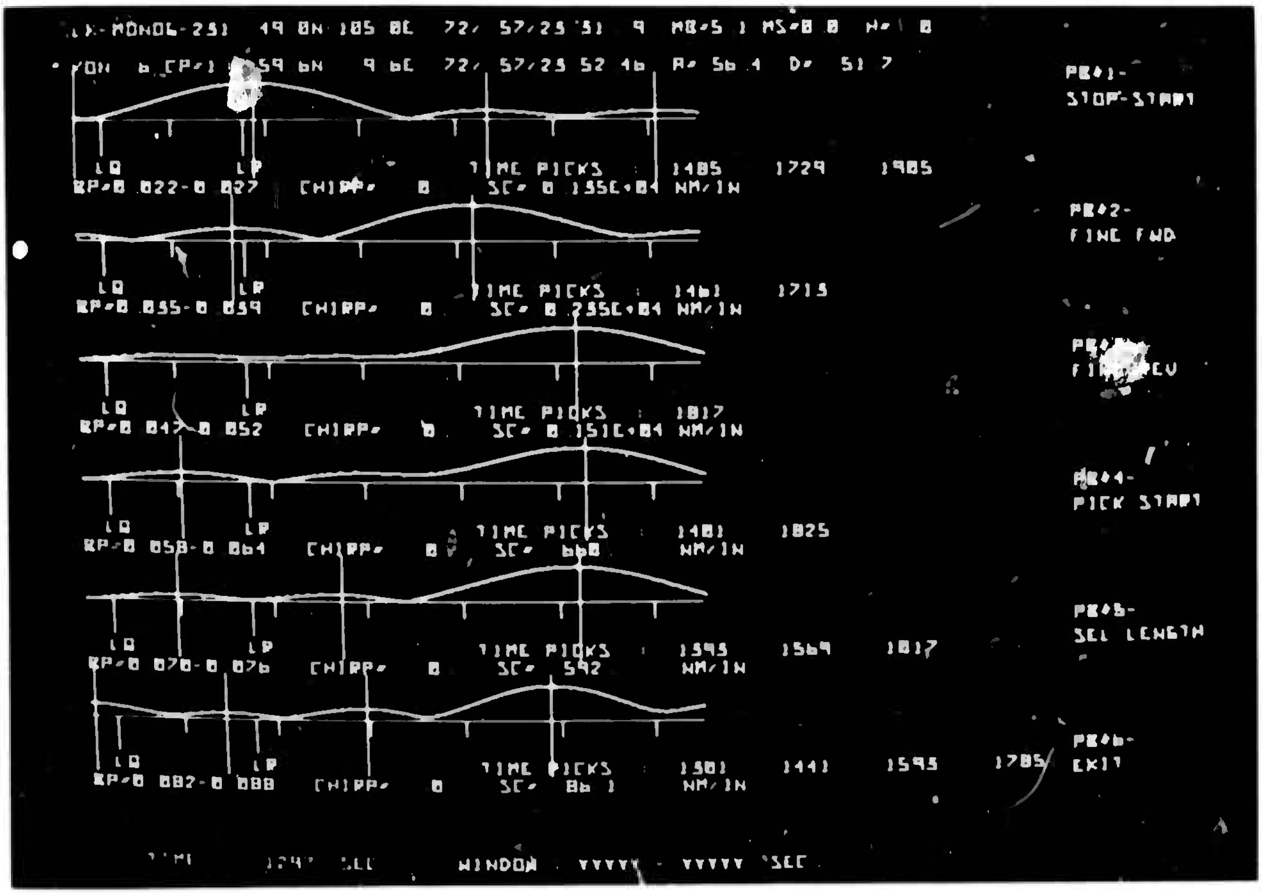


FIGURE III-10

A SET OF ENVELOPES (HILBERT TRANSFORMS)
OF A SUITE OF NARROW-BAND FILTERED TRACES.
THE CURSOR MARKS INDICATE ANALYST TIME PICKS

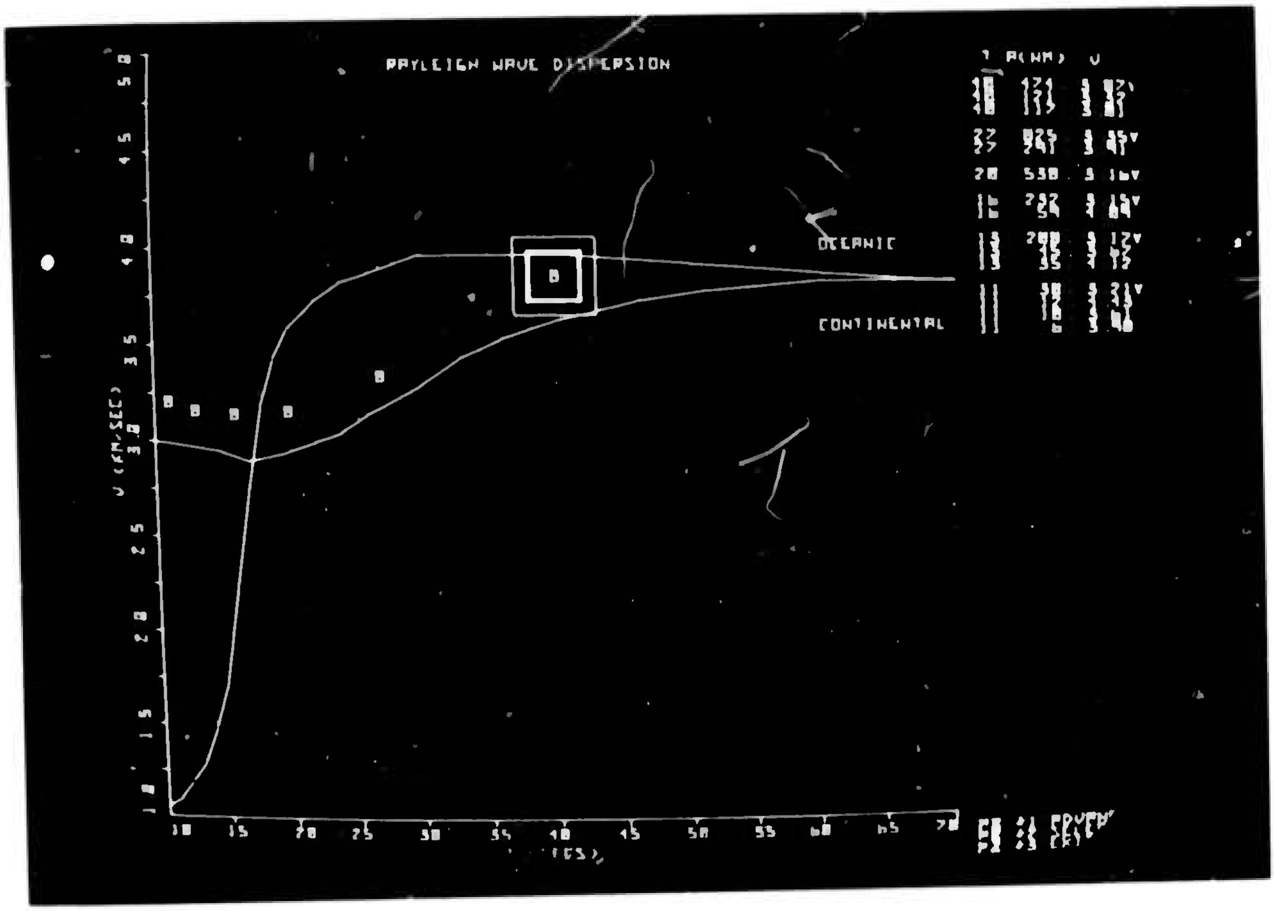


FIGURE III-11

CONSTRUCTION OF A GROUP VELOCITY CURVE VIA THE INTERACTIVE DISPLAY

A total of 10 events (specified in Table III-1) were processed. All of these events occurred during January of 1973. Only 6 VLPE stations were operating reliably during this period (stations number 2, 5, 6, 8, 9 and 11); consequently, the processing was restricted to those stations. Only the vertical component of each station was analyzed in this study.

In order to conduct a realistic experiment, we included in the processing all the options of ILPPS that could reasonably be expected to be used in an actual surveillance system. Typically, each station waveform was processed as follows:

- Extract the station waveform from the Event Data File on Disk.
- Select a time window for processing that includes the predicted arrival of the Rayleigh wave train in a 2.5-3.9 km/sec velocity window. For stations of epicentral distance less than 60 degrees, a time window of 1024 seconds is usually selected; otherwise, a 2048 second time window is used.
- Perform bandpass filtering with a 0.020-0.060 Hz filter.
- Perform linear chirp filtering with chirp window lengths selected by the analyst using the bandpass above. Typically, 5-10 different chirp lengths are tried.
- Perform reference waveform filtering using a fixed and previously selected event as a reference. (See Table III-1).
- Compute magnitude M_s on the bandpass filtered trace. (If no signal was detected, this will be a "noise magnitude" which is useful as an upper bound on the actual station magnitude.)

TABLE III-1

LIST OF PROCESSED EVENTS

*** PROCESSED EVENTS ***

EV#	EVENT NAME	ORIG DATE	TIME	LAT	LON	MB	STATION CODES
1	LX+CENAP+ 11	1/03/73	15.05.16	39N	72E	4.8	101000100001111
2	LX+CENAN+ 12	1/03/73	17.04.43	34N	72E	3.8	101000100001111
3	LX+CENAN+ 37	1/12/73	17.35.49	38N	70E	3.7	101000100001111
4	LX+CENAP+ 55	1/18/73	06.47.28	34N	99E	4.6	101000100001111
5	LX+CENAP+ 59	1/19/73	15.10.02	32N	68E	5.0	101000100001111
6	LX+CENAN+ 6[illegible]	1/19/73	18.42.41	35N	71E	3.6	101000100001111
7	LX+CENAN+ 65	1/20/73	14.31.54	31N	67E	4.0	101000100001111
8	LX+CENAL+ 67	1/21/73	03.23.53	41N	71E	4.3	101000100001111
9	LX+CENAP+ 71	1/23/73	11.31.48	40N	91E	4.9	101000100001111
10	LX+CENAP+ 75	1/24/73	03.20.20	41N	82E	5.1	101000100001111

*** REFERENCE EVENTS ***

EV#	EVENT NAME	ORIG DATE	TIME	LAT	LON	MB	STATION CODES
M1	LX+CENAP+ 6	1/02/73	22.25.57	31N	88E	5.2	101000100001111
M2	LX+CENAP+ 10	1/03/73	14.31.04	39N	71E	5.5	101000100001111

Explanation:

Station codes: (Stations 1 to 15):	0	: Data available
	1	: No data available
Orig Date/Time:	Event origin date and time; GMT	
LAT-LON:	Epicentral latitude and longitude (degrees)	
EV#:	Event number of processed events (1-10)	
	M1 is a master event used for Station 6	
	M2 is a master event used for Stations 2, 5, 8, 9, 11	

- If a signal was detected, compute the AR discriminant on the bandpass filtered trace (Brune et al., 1963).
- Compute RMS noise and signal-to-noise ratio for:

  - the unfiltered trace
  - the bandpass filtered trace
  - the "best" chirp filtered trace (only if the event was detected)
  - the master filtered trace (only if the event was detected).

- If a detection/no-detection decision is questionable, go back to process the full event trace (4096 seconds) to get a better visual indication of noise versus signal characteristics.
- Store event parameters on disk together with data quality and detection indicators set by the analyst.

2. Results

Table III-2 gives a breakdown of the processing times in minutes for the station data analyzed. The time required to process one component has a relatively wide range (from 3 to 8 minutes if faulty data channels are disregarded). The most typical values are 3 or 4 minutes for one trace, with an average processing time of 4 minutes for good channels. As anticipated, the longest time was spent in processing components with marginal detections.

In Table III-3 we present a breakdown of the time required to process the individual subtasks that together form the complete processing of one waveform. These times are all estimated "typical" times, and add up to about 3 to 7 minutes for best and worst case, respectively. The following observations may be made:

TABLE III-2

PROCESSING TIME IN MINUTES BY EVENT AND STATION

Event Number	Station Number						Average
	2	5	6	8	9	11	
1	7	5	5	4	3	7	5.2
2	3	3	4	4	4	3	3.5
3	4	3	4	2*	4	4	3.5
4	6	1*	7	8	8	2*	5.3
5	5	3	3	5	5	2*	3.8
6	3	6	2*	4	5	4	4.0
7	3	3	1*	4	4	2*	2.8
8	3	3	1*	3	4	3	2.8
9	3	1*	5	4	1*	3	2.8
10	5	1*	5	7	1*	5	4.0
Average	4.2	2.9	3.7	4.5	3.9	3.5	

*: Faulty data channel (i. e. no data, spikes or calibration pulses)

TABLE III-3

BREAKDOWN BY PROCESSING SUBTASK OF TIME REQUIRED TO ANALYZE A TYPICAL WAVEFORM

Type of Operation	Total Time (including CPU time)	Estimated CPU Time
Selection of waveform segment	20-30 sec	5 sec
Bandpass filtering (512 pts or 1024 pts)	10-20 sec	3-6 sec
Chirp filtering (scanning of 5-10 chirp lengths)	1-3 min	15-45 sec
Reference waveform filtering	20-30 sec	10-15 sec
Parameter measurements	30-60 sec	5-10 sec
Selection and filtering of "long trace" (not usually performed)	60 sec	20 sec

"Total Time" includes:

- CPU time
- Computer wait time (e.g., for disk data retrieval)
- Time required for analyst entry of numbers or commands
- A reasonable (although short) time for the analyst to judge the results.

- CPU time (i. e., time used for actual computations by the Central Processing Unit of the PDP-15 computer) constitutes approximately 25 percent of the total time actually spent on processing an event.

- The single subtask requiring the most time is the chirp filter scanning (1-3 minutes).

- Both the selection of waveform segments (20-30 seconds) and the parameter measurements (30-60 seconds) consume a substantial amount of time especially relative to the corresponding CPU time utilized, which is on the order of 5 seconds in each case.

It is clearly of considerable interest to examine possible ways to speed up routine processing. This problem will be addressed in detail in Subsection III-C.

We proceed to present the actual data analysis results from the evaluation experiment. Since our primary purpose was not to evaluate the VLPE network as such or the filtering techniques applied; but rather the interactive analysis concept, the actual processing results are of secondary interest. However, we still include these results for completeness and to verify that the interactive procedure produces results of acceptable quality.

Table III-4 presents the effects on detection/no-detection decisions when examining matched filter output traces instead of conventional bandpass-filtered data. As expected, the matched filter makes only a marginal difference in the number of detections. Out of the 34 station-events that were not detected with bandpass filtering, two had a chirp filter detection.

TABLE III-4

DETECTION INFORMATION FOR EVENTS AND STATIONS PROCESSED

Event Number	Station Number					
	2	5	6	8	9	11
1	2-2-2	ND	2-2-1	ND	ND	0-1-0
2	ND	ND	ND	ND	ND	ND
3	ND	ND	ND	-	ND	ND
4	2-2-2	-	ND	0-2-1	1-2-2	-
5	2-2-2	ND	ND	2-2-2	2-2-2	-
6	ND	2-2-2	-	ND	ND	ND
7	ND	ND	-	ND	ND	--
8	ND	ND	-	ND	ND	ND
9	2-2-2	-	2-2-2	ND	-	2-2-2
10	2-2-2	-	2-2-2	2-2-2	-	2-2-2

Nomenclature:
- 0 : No detection
- 1 : Marginal detection
- 2 : Clear detection
- x-y-z : Detection code for bandpassed, chirp filtered and master filtered data, respectively
- ND : No detection by any method
- \- : Faulty data channel

One additional event improved from a marginal detection to a clear detection when applying a chirp filter. The results of master waveform filtering were slightly inferior to the chirp results; probably due to the application of a fixed master waveform in all cases rather than trying to determine an optimum reference trace.

We would like to point out that our criteria for declaring detection were very conservative in this evaluation; i.e., we required a clearly visible dispersion pattern in order to accept a detection on band-passed data, and a matched filter detection was only declared if a clear peak was observed in the expected signal arrival window.

Matched filter detection performance in this study is somewhat inferior to that determined by Strauss (1974) using a more extensive data base of central Asian events recorded by the VLPE network. We attribute this difference to the slightly less strict detection criteria applied in his study.

The gains in signal-to-noise ratio (SNR) for the matched filtered waveforms relative to the bandpassed traces are shown in Table III-5 for all waveforms with a detection. Note that the SNR values of the bandpassed traces represent maximum zero-to-peak value of the signal relative to the root-mean-square (RMS) value of the noise; thus in a sense they are biased high. However, the chirp and master filtering gains are true values, based upon compatible processing in each case.

The following observations may be made:

- Chirp filter gains vary from less than 1 dB to more than 6 dB, with an average value of 2.7 dB.

TABLE III-5

MATCHED FILTERING GAINS
FOR DETECTED EVENTS

Event Number	Station Number	Distance (degrees)	SNR (bandpass) dB	Chirp Gain dB	Master Gain dB	Chirp Length Seconds
1	2	30.9	8.8	2.2	2.9	280
4	2	16.1	19.5	1.6	3.8	75
5	2	30.8	16.1	1.5	2.7	280
9	2	22.7	15.1	0.5	1.4	100
10	2	26.4	29.0	5.0	2.0	230
6	5	30.8	14.1	0.6	0.5	200
1	6	43.5	9.6	2.8	3.0	120
9	6	51.9	14.7	0.8	1.6	320
10	6	47.1	23.1	2.1	6.8	450
4	8	87.4	9.3	4.5	0.7	900
5	8	110.1	19.8	5.9	2.2	790
10	8	96.3	17.4	3.5	4.5	900
4	9	106.0	11.4	2.9	3.3	1630
5	9	112.2	23.2	6.4	5.5	1600
1	11	51.5	9.6	2.1	-	200
9	11	36.7	10.4	2.7	3.0	250
10	11	43.1	18.9	0.7	-1.6	450

Average gains: Chirp : 2.7 dB

Master : 3.0 dB (excluding station 11)

- Master waveform filtering gains have about the same range as the chirp gains, except for station 11, which had a master waveform with a poor signal-to-noise ratio. The average gain for master waveform filtering, not including station 11, is 3.0 dB.

- As expected, matched filter gains are generally highest for the most distant stations (which, of course, usually have the most dispersed waveforms.)

- In several cases, there was a significant difference (up to $\pm$ 5 dB) between master filtering gain and chirp filtering gain.

Table III-5 also shows that the length of the best linear filter varies considerably even within narrow epicentral distance ranges. This implies that it would be difficult to predict the optimum chirp filter length for a given event, therefore, fairly extensive calibration data would be necessary in order to cut down on the number of iterations necessary to determine the best linear chirp.

The Rayleigh wave magnitudes of the processed events are listed in Table III-6. In those cases where no detection was declared, the number listed indicates the "noise magnitude," which is an upper bound for the actual event magnitude at the station. The "network magnitudes," averaged over all detecting stations for each event, are also included in the table.

The low noise magnitudes of station 5 (EIL) and the poor detection performance of this station indicate a discrepancy in the amplitude response of the vertical component of this station for the processed events. This assertion is supported by the fact that the radial component of this station was found to have more detections and substantially higher magnitudes than the vertical component.

TABLE III-6

RAYLEIGH WAVE MAGNITUDES
OF PROCESSED EVENTS

Event Number	m_b	M_s for Station Number						Average M_s
		2	5	6	8	9	11	
1	4.8	3.2	(2.9)	3.5	(3.8)	(3.9)	3.5	3.4
2	3.8	(2.9)	(2.5)	(3.1)	(3.4)	(3.5)	(3.8)	-
3	3.7	(3.0)	(2.2)	(3.6)	-	(3.9)	(3.6)	-
4	4.6	3.3	-	(4.5)	3.2	3.4	-	3.3
5	5.0	3.5	(2.5)	(3.8)	4.0	4.1	-	3.9
6	3.6	(2.6)	3.1	-	(3.5)	(3.5)	(3.2)	3.1
7	4.0	(3.3)	(2.7)	-	(4.0)	(3.6)	-	-
8	4.3	(2.9)	(2.6)	-	(3.4)	(3.5)	(3.1)	-
9	4.9	3.3	-	3.9	(3.7)	-	3.3	3.5
10	5.1	4.0	-	4.4	3.9	-	3.9	4.1

Note: Values in parantheses represent "noise magnitudes" for stations that did not detect.

C. DISCUSSION

The evaluation experiment described in the preceding subsection demonstrates that the ILPPS system provides processing results of a quality comparable to those obtained by conventional methods. In addition, interactive processing of an event may be completed in a considerably shorter time span than is possible with batch processing, and with significantly improved convenience for the analyst.

However, the time factor still remains the most fundamental question when one considers the application of ILPPS in a potential seismic surveillance system. At an average processing time of 4 minutes per station, about 1 1/2 hours would be required per event in a hypothetical 25 station network, and considerably more time would be expended if processing of both Love and Rayleigh waves were required. These requirements seem prohibitive for routine analysis of all detected events, but might be acceptable for processing events of special interest in a surveillance system.

In this context, it is important to remember that the processing times presented in the ILPPS evaluation are based upon event analysis in a fully interactive mode. By this we mean that the analyst has specifically selected each option and each parameter setting in each particular processing case. Clearly, it would be possible to obtain a significant reduction in time requirements by adapting a more automated analysis procedure with analysis intervention only at a few specific decision points. An example of such a semi-automated processing system could be as follows:

- Initially, the full waveform (2048 points) is displayed, and the analyst selects either a "manual" processing mode (as described previously) or an "automated" mode, which is described in the following.

- The expected signal arrival window is extracted, and the following traces are displayed automatically.
  - The original trace
  - The trace filtered with a standard bandpass filter
  - The trace filtered with a default chirp filter (based upon regional information)
  - The trace correlated with a reference waveform taken from a library.
- The analyst then has the option to request additional processing but presumably in most cases he will make a detection/no detection decision based upon the displayed data.
- A parameter measurement routine is then invoked. All measurements are automated, but with an analyst override capability.
- After each component is processed, control passes automatically to the next data channel by direct disk access.

A procedure as outlined above would probably make it feasible to reduce processing time to less than 1 minute in the 'standard' cases (i.e., if no analyst override action occurs). Although this type of standard processing might be somewhat inferior to the fully interactive procedure (since no iteration on chirp filter lengths would normally be performed), it might still be adequate in most cases. Clearly, the full interactive processing machinery would always be available to ensure optimum processing of events of special interest.

The semi-automated capability outlined above is not available in the initial implementation of the ILPPS system. However, the inclusion of such an option would not require a very large programming effort, and should be considered in future applications of the system.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The purpose of the ILPPS experiment was to investigate the feasibility of using interactive graphics for processing long-period data in an operational seismic surveillance system. It is felt that the following features of the interactive approach have been definitely demonstrated:

- High quality of results
- Convenience to the analyst
- Minimal intermediate hard copy output
- Short turn-around time compared to batch processing.

The one major question not fully answered is whether interactive signal analysis is efficient enough for the large-scale routine processing required in a surveillance system. The average processing time for one station component during the ILPPS evaluation was 4 minutes, including time for event selection, bandpass and iterative matched filtering and interactive computation of several event parameters. This processing time is probably prohibitive for routine analysis in surveillance mode. However, it is possible to reduce the average ILPPS processing time significantly by the following approach:

- Establish a semi-automated interactive system, in which a fairly extensive default processing may be performed automatically if the analyst so wishes.
- Retain an option to perform extensive interactive analysis of difficult cases or events of special interest.

- Improve computer efficiency by various means (e.g., extensive use of direct access disk operations to reduce wait time).

The time required for this type of a routine processing could probably be reduced to about 1 minute per station component. This processing time would seem to satisfy the real-time requirements of a large scale surveillance system, while the indicated approach still retains the desired flexibility to perform extensive analysis of interesting events.

It is therefore recommended that further development of ILPPS be directed toward establishing a semi-automated processing capability to supplement the already existing fully interactive system. The addition of such a capability would probably not require a major software effort.

Also, improving efficiency in the computer operations and in providing more analyst conveniences such as hard copy output from CRT should be given high priority.

Finally, several additional options may be included in the system at relatively low cost, such as:

- The capability to process short-period data.
- Techniques for data quality control and spike removal.
- Additional processing techniques, such as beamforming, three-component processing, complex cepstrum and multichannel filtering.
- The capability to interface directly with a remote seismic data mass storage, in the event such a system is established.

The implementation of some or all of the above options can be expected to provide more insight into areas within the seismic event detection problem which are well suited to the application of interactive graphics. This information will be valuable both for seismic data processing techniques in general and also for the possible future operation of a global seismic surveillance network.

SECTION V

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