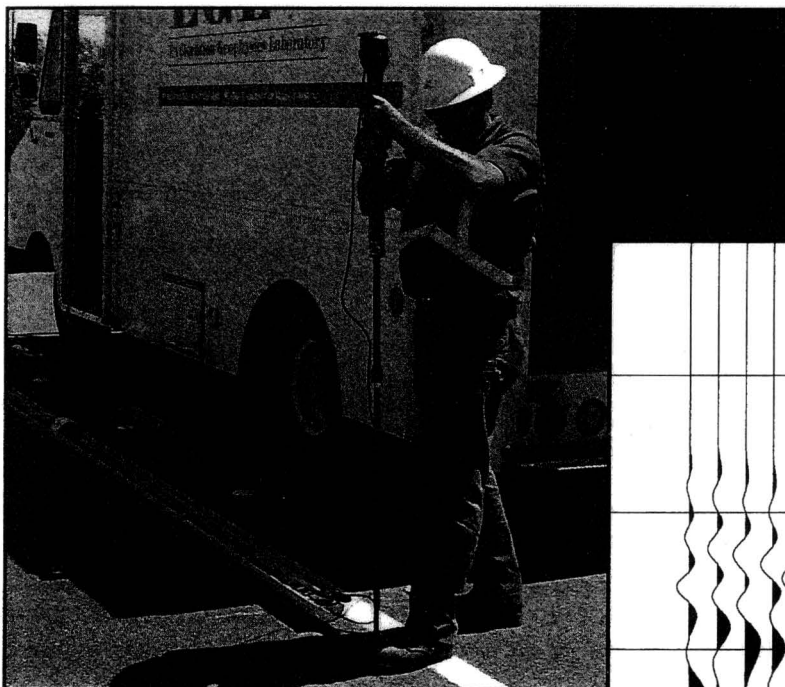


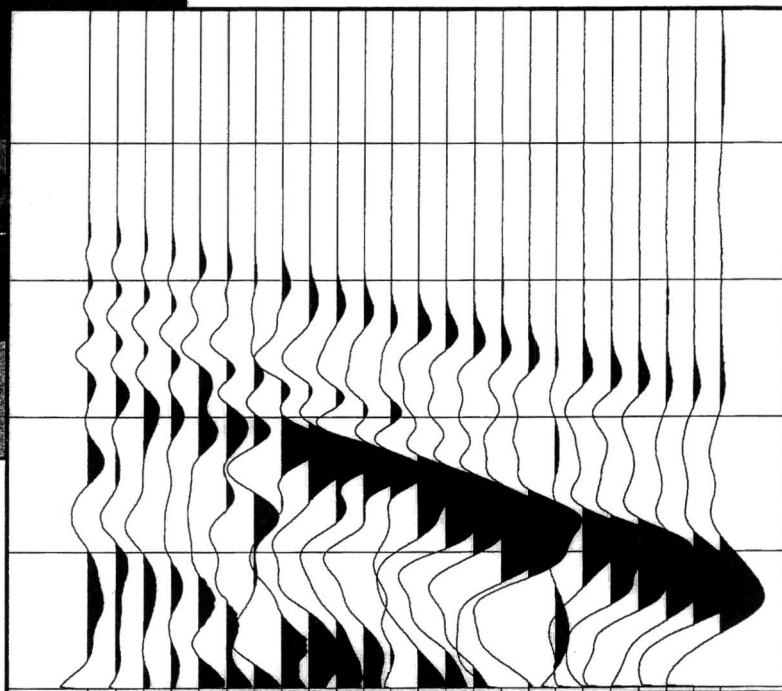
Estimating Depth to Bedrock Beneath Pavement Using The SRBA Prototype

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by

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INTRODUCTION

This manual describes the setup and operation of the prototype Seismic Refraction Bedrock Analyzer (SRBA) and the analysis of data acquired with the instrument. The SRBA prototype (fig. 1) was constructed at the Bureau of Economic Geology to aid in the estimation of bedrock depths and seismic velocities beneath paved surfaces. It employs a fixed array of ground-motion detectors (geophones) and a movable seismic source to acquire seismic refraction data that can be analyzed to produce two-layer, planar models of seismic velocity changes in the near surface. The instrument was designed and constructed during studies completed for TxDOT to determine whether existing geological data could be used to estimate bedrock depth to allow better analysis of falling-weight deflectometer data (Paine, 1999; Paine and Murphy, 2000). To test the concept

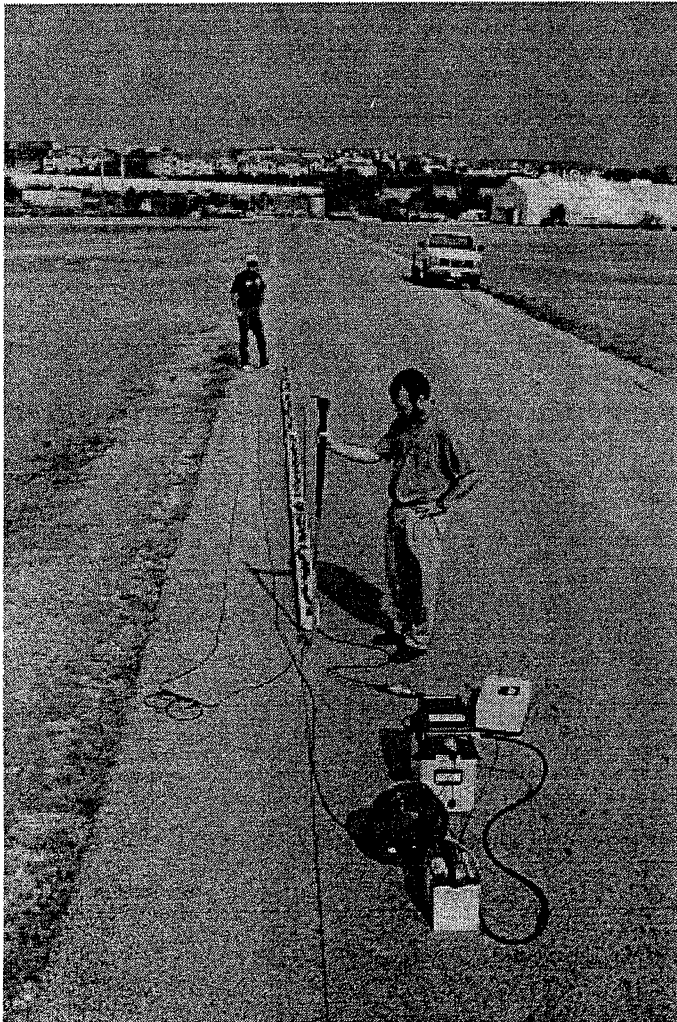


Figure 1. SRBA seismograph, geophone array, power supply, and seismic source deployed and ready to acquire data.

of acquiring usable refraction data on pavement, we deployed standard seismographs and detectors with variable detector spacings at various test sites. These studies indicated that seismic refraction data could be acquired on asphalt pavement, but that the acquisition system was cumbersome to deploy. The SRBA prototype, with its fixed and stowable geophone array, aluminum tripod geophone bases, custom geophone spacing, and fixed seismic source locations, is the first version of a refraction system optimized for use on pavement.

The basic workflow consists of (1) laying out the geophone array at the chosen location, (2) connecting the geophone array to the seismograph, (3) setting up the seismograph to record for the proper duration and sample interval, (4) attaching the trigger switch on the seismic source to the seismograph to provide an accurate zero-time for the seismic record, (5) moving the source to one of at least two and normally five different locations, (6) firing the seismic source and recording ground motion sensed by the geophones, (7) verifying that the seismic records contain coherent, analyzable data, (8) moving the source and acquiring refraction data at all remaining source locations, (9) downloading seismic files to a computer for analysis, (10) interpreting the first arrival times on each seismic record, and (11) selecting simple one- or two-layer seismic velocity models that best fit the actual, observed arrival times evident on the seismic records from within a custom spreadsheet. Parameters that can be varied to fit the chosen arrival times include the compressional wave velocities of up to two subsurface layers (assumed to represent compacted material beneath the pavement that has a relatively low seismic velocity, and an underlying, higher velocity layer representing consolidated bedrock), the dip of the underlying layer, and the depth to bedrock (or thickness of the upper layer).

COMPONENTS

The principal components of the SRBA prototype are (1) a Geometrics SmartSeis seismograph, (2) a recording array housing 24 geophones, (3) a seismic source, and (4) a power supply. The seismic source (fig. 2) produces impact energy when the downward-sliding weight strikes a

vertical rod that is in contact with the pavement. An electromechanical switch mounted on top of the sliding weight closes at the moment the weight strikes the rod, sending an electrical signal through a cable attached to the seismograph. This signal triggers the seismograph to begin recording ground motion.

The recording array (fig. 3) consists of 24 geophones mounted at fixed 0.5-m intervals along four segments of PVC pipe. The geophones are connected by seismic cable with a single connector at one end of the array that can be connected to the seismograph or to an extension cable to reach farther distances from the seismograph. There are six geophones on each segment, allowing the array to be folded for stowage or transport or deployed end-to-end while acquiring data. The geophones have moderately high natural frequencies of 40 Hz and have a relatively flat natural response to frequencies of about 400 Hz.

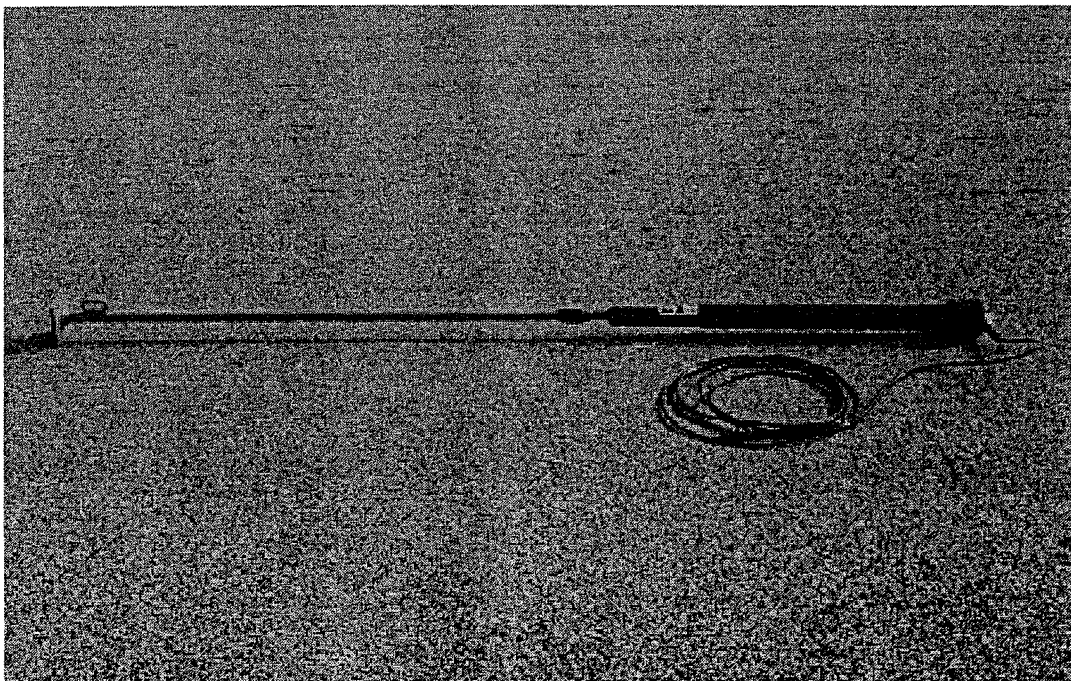


Figure 2. Sliding-weight assembly used as portable seismic source. Trigger switch and cable are attached to the top of the sliding weight. The blue rod is threaded tightly into the slide assembly to prevent thread stripping.

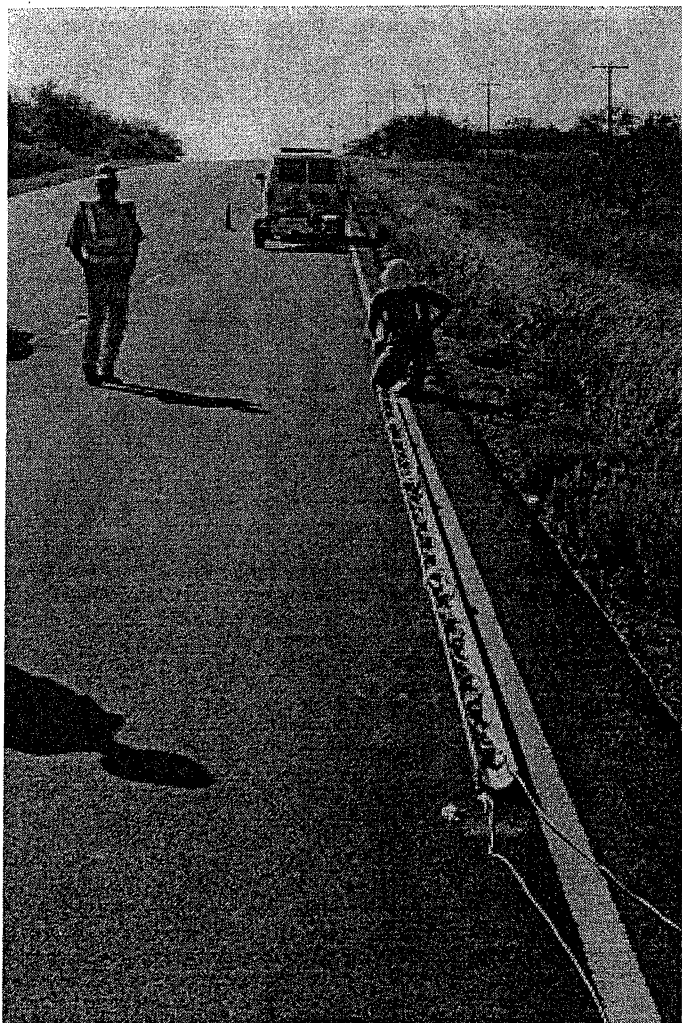


Figure 3. The geophone array, unfolded and deployed on asphalt pavement.

The Geometrics SmartSeis seismograph (fig. 4) is a commercially available, general-purpose seismograph used mostly in seismic refraction and reflection surveying. It operates on 12-volt power provided by a battery or power supply. It has its own display and printer, and includes built-in software that allows the user to configure the instrument for a wide variety of survey types. The user can select the number of recording channels, the length of time to be recorded, the time interval between samples on each channel, the frequency of low-pass and high-pass filters, and the geometry of the receiver array and seismic source location. As a dedicated component of the SRBA, the instrument parameters can be set once to a configuration that will be adequate for most pavement investigations. These parameters are retained by the instrument between surveys and need not be re-entered for each site.



Figure 4. Geometrics SmartSeis seismograph. Power cable, geophone array cable, and trigger link spool cable are attached to seismograph.

The seismograph stores seismic data as files conforming to the Society of Exploration Geophysicists' SEG-2 standard format (Pullan, 1990). The PC-compatible computer built into the seismograph stores the files on an internal hard drive. Data can be transferred to floppy disk for subsequent analysis either from the program that operates the seismograph or within the version of Microsoft's DOS operating system that controls the computer. Work outside of the integrated seismic software requires the use of an keyboard and monitor.

INSTRUMENT SETUP

Steps necessary to acquire refraction data on pavement include (1) connecting the seismograph to the trigger, geophone array, and power cables, (2) deploying the geophone array on the pavement, (3) connecting the seismic source, and (4) setting or verifying the seismograph acquisition parameters.

Connecting the Seismograph

Power can be supplied to the seismograph either from a heavy-duty 12-volt battery (fig. 4) or a 12-volt power supply. Depending on the choice, connect either the battery post clamp cable segment or the pigtail cable segment to the power cable, then plug the 3-socket connector at the end of the power cable into the large, 3-pin connector labeled "12V DC" on the back of the seismograph (fig. 5). Connect the battery or power supply to the power cable.

Connect the trigger extension cable (the thin, 100-m long cable on the orange reel, fig. 6) to the small, 3-socket connector labeled "START" on the back of the seismograph. Being careful not to strain the connection at the seismograph, unspool enough line to reach the shotpoint farthest from the seismograph. The other end of the cable will connect to the trigger switch cable lead from the seismic source (fig. 2).

Connect one end of the jumper cable (a 10-m long cable with a large, 61-socket connector at one end and a 61-pin connector at the other end, fig. 7) to the 61-pin connector labeled "SIGNAL 1-24" on the right side of the seismograph (fig. 8). For a secure connection, align the connectors, push them together as far as they will go, then turn the connector collar until it locks in place.

The instrument can be left in this configuration when traveling from site to site to reduce setup time for subsequent surveys.

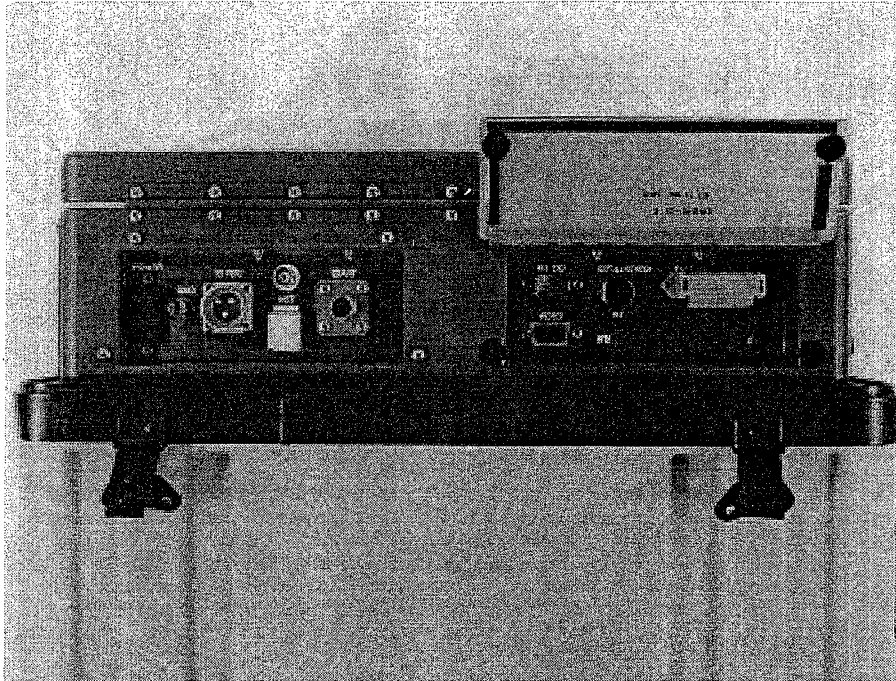


Figure 5. Back panel of the Geometrics SmartSeis seismograph. At left are the on/off switch, the power receptacle, and the trigger receptacle. At right are the RS-232 serial port, the external video port, and the external keyboard port.

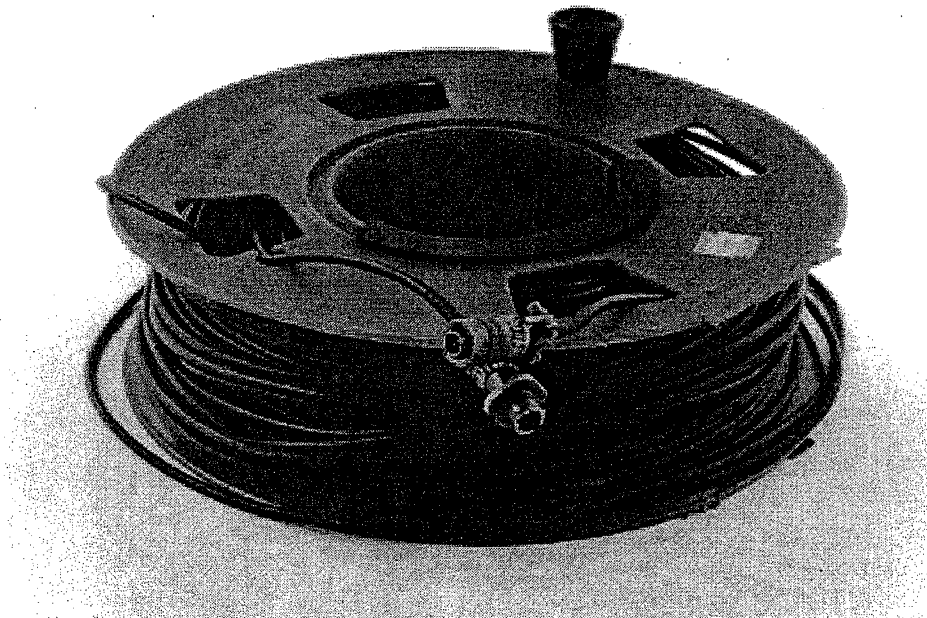


Figure 6. Trigger extension cable, a 100-m long cable connecting the seismograph (lower connector) with the trigger (upper connector).

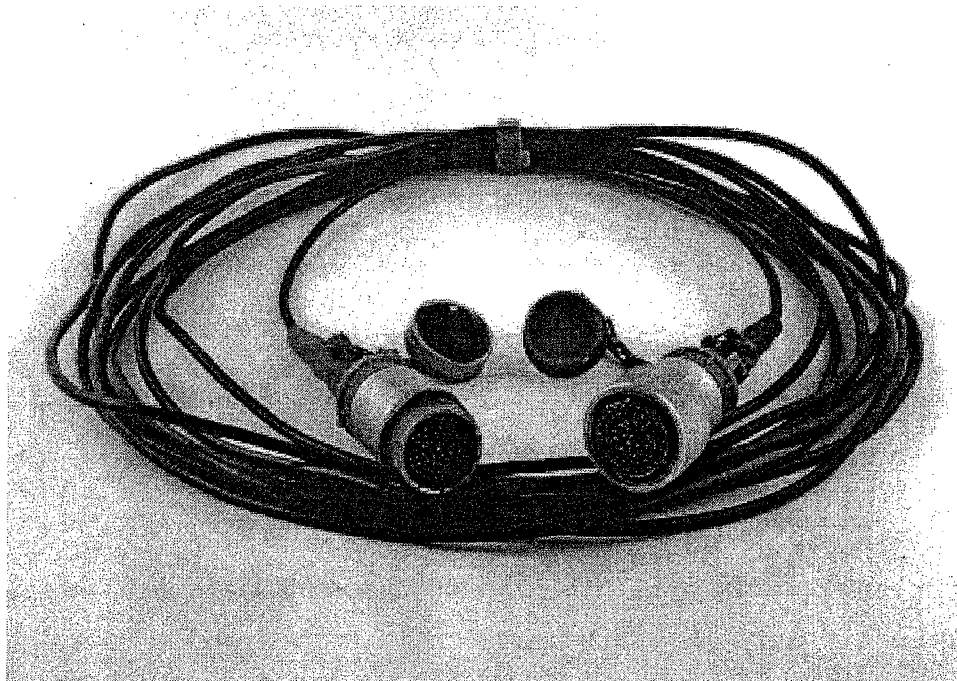


Figure 7. Extension (jumper) cable, a 10-m long cable connecting the geophone array to the seismograph.

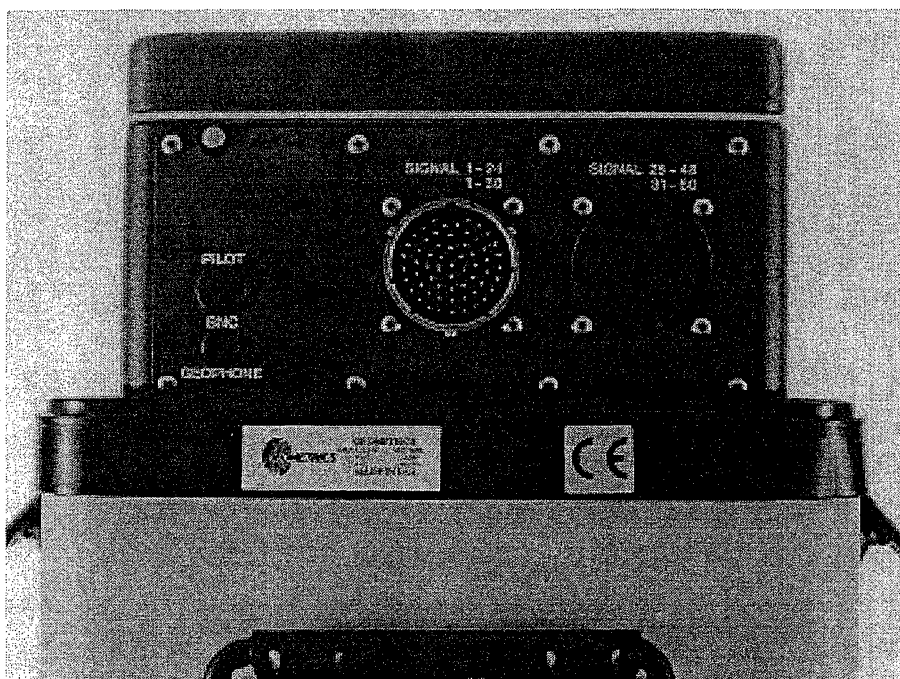


Figure 8. Seismograph right-side panel that includes a 61-pin connector that joins to either the jumper cable or directly to the geophone array cable.

Deploying the Geophone Array

Using the provided slats, one at each end of the folded array (fig. 9), two persons can carry the geophone array to the desired location on the pavement. Unsnap and remove the slats, then carefully unfold the four segments of the geophone array to its full length. Ensure that the segment with the cable connector is closest to the seismograph location. Align the segments in a reasonably straight line, fitting the end of one segment into the coupler on the adjacent segment to preserve the proper geophone spacings across the joins. Check to ensure that each geophone is vertical and that the aluminum geophone base is in full contact with the pavement. Connect the 61-pin connector at the end of the 10-m jumper cable to the 61-socket connector on the geophone array.

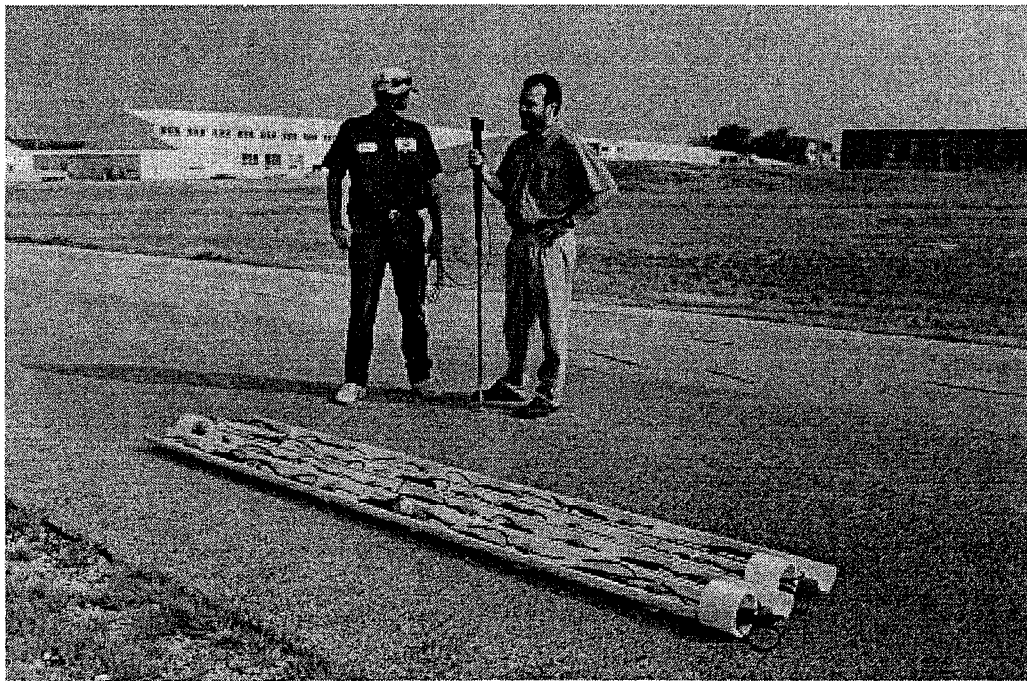


Figure 9. Geophone array folded for transport.

Connecting the Seismic Source

Thread the rod and baseplate assembly onto the threaded end of the sliding hammer securely, then tighten the nut to ensure a snug fit that will not loosen during operation. While in use, check the tightness of the nut periodically to prevent stripping the mating threads. Mount a trigger switch atop the sliding hammer assembly. The switch can be either clamped or taped onto the hammer, but must be oriented properly (follow the manufacturer's instructions) and fastened securely to the top of the hammer such that a downward blow will activate the switch and begin recording at the seismograph.

Use the source-positioning cable (the plastic coated steel cable with snap rings at each end, fig. 10) to properly position the source for the end and far shots. To begin the survey, connect the last snap ring on the two-ring end of the source-positioning cable to the hole at the front (the end with the geophone cable connector) of the geophone array. For the end shot, the seismic base

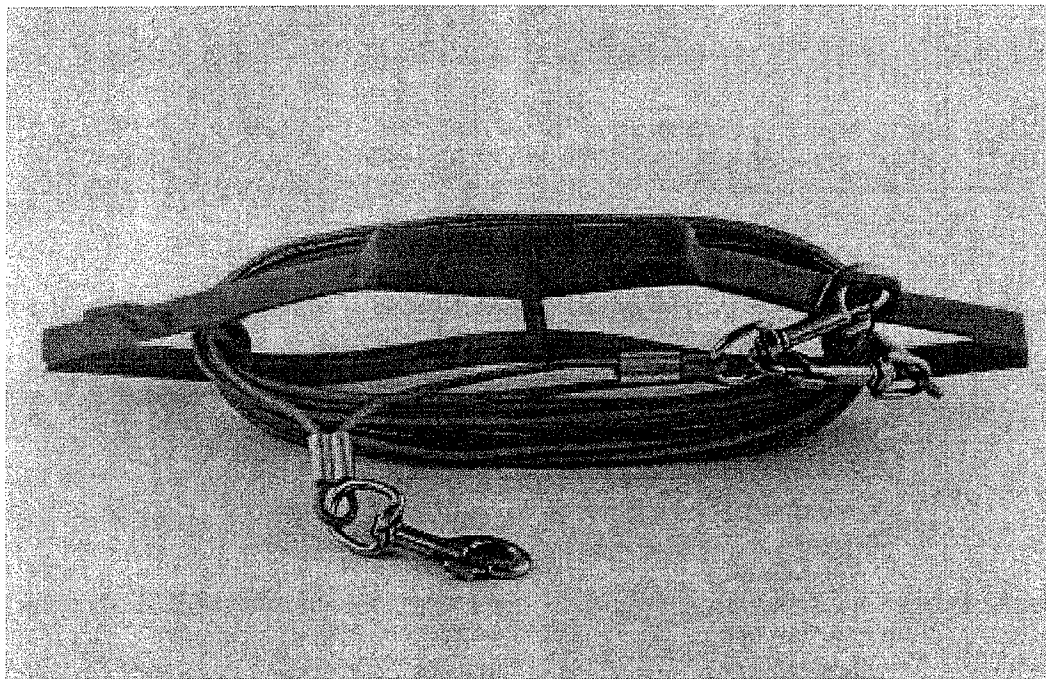


Figure 10. Source-positioning cable connecting the geophone array and seismic source assembly. Metal snap connectors are spaced for proper end- and far-shot locations.

attaches to the snap ring nearest the array. For the far shot, the seismic base attaches to the snap ring at the end of the source-positioning cable.

Configuring the Seismograph

The Geometrics SmartSeis provided as part of the SRBA is a full-featured, 24-channel seismograph that has a variety of uses. Once configured, its numerous setup options chosen from the menu-driven seismograph software s12.exe (App. A) need not vary from site to site. It retains the instrument settings from its last use, so once it is properly set up an operator need only verify the proper settings, choose a directory and filename for data recording, and proceed with data acquisition.

The seismograph must be configured properly to acquire seismic data. The menus below (reached by pressing the MENU button on the top of the seismograph, or the F1 key on the optional keyboard) are used to check or change the instrument settings before the survey commences. Once these parameters are set, no further changes to the seismograph settings are required. Previous settings are retained for the next survey even when the seismograph is shut down between surveys.

To configure the instrument to properly acquire shallow refraction data, follow the following steps:

1. Verify that 12-volt power is being supplied to the instrument and turn the instrument on. The seismograph program s12.exe automatically launches, displaying the seismograph screen.
2. Use the touchpad arrow keys to highlight "USE LAST SETTINGS" and press ENTER.
3. Using the MENU button and arrow keys, highlight the GEOMETRY menu (App. A), ensuring that item 1 (SURVEY MODE) is set to REFRACTION. Item 3, PHONE INTERVAL, is the spacing between the geophones and should be set to 0.5 (meters). If any of these settings are incorrect, simply navigate to the item using the arrow keys and press

ENTER to edit. Item 4, SET PHONE & SHOT LOCATIONS, should be examined by pressing ENTER. The ensuing display should indicate channel 1 at position 100 (by convention), channel 2 at position 100.5, and so on to channel 24 at position 111.5. Shotpoint (seismic source) location can be changed to represent the first shot location, which in this case will be 12.5 m from geophone 1, or position 87.5. Item 5 (PHONE INCREMENT) and item 6 (SHOT INCREMENT) should be set to 0. Press the CLR button to return to the seismograph display.

4. Press the MENU button and navigate to the ACQUISITION menu (App. A). Item 1, SAMPLE INTERVAL, should be set small enough to allow seismic arrivals at adjacent geophones to be distinguished. The choices range from 31.25 to 500 us (0.00003125 to 0.0005 s), but 125 us (0.000125 s) is a good compromise between resolution and file size. For a wave propagating along the pavement at 2000 m/s, this wave travels half the geophone spacing between samples acquired at 125 us.

Item 2, RECORD LENGTH, represents how long the instrument will record ground motion after the source triggers the instrument to begin recording. This duration should be long enough to examine first seismic arrivals at the longest source to receiver spacings. The longest offset occurs where the source is at the far position and the geophone is at the opposite end of the array, which is about 24 m distant. At very low propagation velocities in overburden of perhaps 400 m/s, the time required for a compressional wave to travel from the source to the last geophone is about 60 ms (0.060 s). To err on the safe side a record length of 128 ms is usually adequate. A shorter recording time can be used where bedrock has high velocities and is within a meter or so of the surface.

Item 3, DELAY, is the delay time between the source trigger and the onset of seismograph recording. It should be set to 0.

Items 4 (FILTER 1) and 5 (FILTER 2) allow the operator to filter the seismic data to remove low- or high-frequency noise. Both should normally be set to "OUT," which indicates that no filter is applied.

Item 6 (STACK MODE) should be set to AUTOSTACK, which means that multiple seismic source shots at the same spot will be automatically added to previous shots to produce a higher signal-to-noise ratio for that shot location.

Item 7 (STACK POLARITY) should be set to POSITIVE.

Item 8 (ACTIVE CHANNELS) should be set to ALL. Because the current setting is not displayed, the operator should select this option to ensure that data are being recorded on all 24 channels.

After all parameters in this menu have been set, press CLR to return to the seismograph display.

5. Press the MENU button and navigate to the FILE menu (App. A). This menu controls the reading and writing of data files to storage devices and directories.

Item 1 (CHANGE DRIVE) indicates the storage volume to which the acquired data will be written. The choices are A: (the floppy drive) and D: (the built-in hard drive). In most cases, the D: drive is the correct choice.

Item 2 (MAKE DIR) will create a new directory on the drive selected in item 1. Use this command to create a new directory for each site or data set, if desired. Without a keyboard attached to the seismograph, only numeric characters can be entered as directory names.

Item 3 (SET FILE NAME) indicates the name of the next data file to be written. The chosen name always carries a .DAT suffix and is automatically incremented by 1 each time a data file is saved.

Item 4 (AUTO SAVE) allows the instrument to automatically save a file after a selectable number of stacks. Because the optimal number of stacks varies from shotpoint to shotpoint, AUTOSAVE should be OFF.

Item 5 (CHANGE DIR) indicates the current directory and allows the operator to select other existing directories where files may be saved or retrieved.

Remaining FILE menu items 6 through 8 (READ, TRANSFER TO FLOPPY/DELETE, AND FORMAT) are used during or after data collection and are not part of the seismograph configuration.

6. Navigate to the DISPLAY menu (App. A). These menu items allow the operator to control the appearance of the data on the screen, but do not affect data acquisition. Typical settings are shown in appendix A.

The instrument is now properly configured and can be used to acquire seismic refraction data on pavement. With the exception of specifying directories and filenames, most of the seismograph settings will not change from one site to the next.

ACQUIRING DATA

A complete seismic refraction survey at a site consists of data recorded with the source at five different locations and the geophones at their original locations. At sites where bedrock is very shallow, one shot located at the center of the spread might be sufficient to record seismic arrivals from material above bedrock (fill) and from bedrock, which would provide enough information to estimate bedrock depth. At sites where bedrock is deeper, the seismic source must be placed far enough from the recording array such that the seismic wave traveling along the interface between fill and bedrock arrives before the wave traveling only in the fill at enough geophones to get a good estimate of the seismic velocity of bedrock. Shots should be located

symmetrically at both ends of the geophone array to allow the operator to detect bedrock that may be dipping toward one end or the other.

A standard survey consists of five shot locations (fig. 11 and table 1): (a) two “far” shots, the forward one located 12.5 m from the front end of the geophone array (at station 87.5) and the reverse one located 12.5 m from the trailing end of the array (at station 124); (b) two “end” shots, the forward one located 0.5 m from the front end of the array (at station 99.5) and the reverse one located 0.5 m from the trailing end (at station 112); and (c) one “center” shot, located between geophones 12 and 13 within the array (at station 105.75). These shotpoints and spacings were chosen to optimize the survey procedure for typical bedrock depths of 6 m or less.

The number of shots at each shot point depends on local conditions. In seismically quiet places, a single source blow would be sufficient to accurately pick a first arrival for that data record. In practice, vehicular traffic, wind noise, and crew movement all contribute noise to the seismic record. The signal-to-noise ratio can be improved by “stacking” shots at each shotpoint, or adding data from multiple shots at the same shot and geophone locations. Successive shots augment the wanted seismic signal by partly canceling the seismic noise that is practically random, but the degree of signal-to-noise improvement is progressively smaller above a certain number of shots. Practice has shown that 8 shots at the far locations and 4 shots at the end and center locations are rapidly acquired and commonly sufficient to render interpretable first arriv-

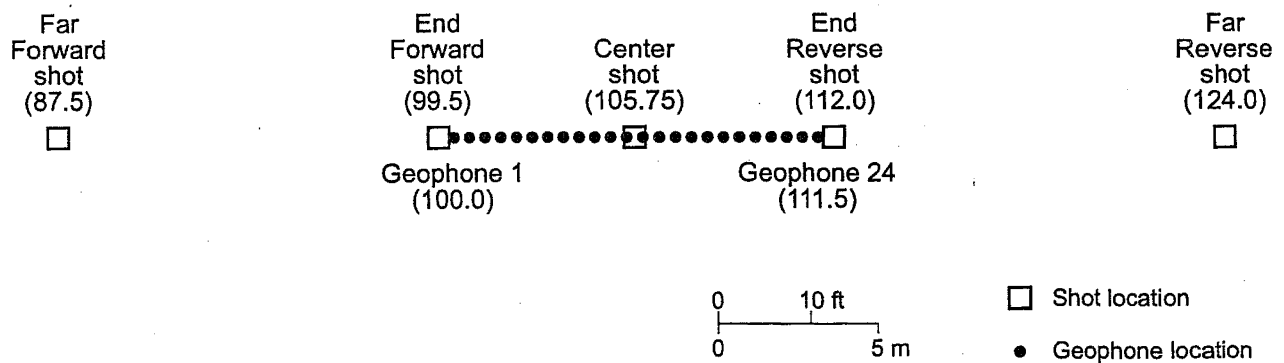


Figure 11. Sketch map showing the five shot locations (far forward, end forward, center, end reverse, and far reverse) and 24 geophone locations used to determine depth to bedrock.

Table 1. Shot position, name, and recommended number of shots at each shotpoint.

Shot position	Shot name	Recommended number of shots
87.5	Far forward	8
99.5	End forward	4
105.75	Center	4
112	End reverse	4
124	Far reverse	8

als. The seismograph operator monitors the record quality during data acquisition and has the option to accept or reject additional shots and determine how many shots are sufficient to produce a good seismic data record.

Once the setup and deployment procedures described above have been completed, acquisition is controlled from the DO_SURVEY menu (App. A) on the seismograph. To minimize confusion, we recommend that the five shots be acquired in order from the front of the array to the trailing end, progressing from the far forward shotpoint at 87.5, to the end forward shotpoint at location 99.5, to the center shotpoint at 105.75, to the end reverse shotpoint at 112, to the far reverse shotpoint at 124 (fig. 11 and table 1). Once the directory and file names have been selected, the seismograph automatically increments the file name for each shotpoint.

Far Forward Shot

1. Using the source-positioning cable (fig. 10) attached to the front end of the geophone array, position the seismic source at the end snap ring at position 87.5. Before acquiring shot data, ensure that the source-positioning cable is not taut and does not pull on the geophone array during source operation.
2. On the DO_SURVEY menu, select item 2, SHOT LOCATION, and enter 87.5. Return to the main seismograph display.

3. Acquire 8 successive shots from the seismic source, waiting a few seconds between each shot to ensure good data were collected and to allow the seismograph to ready itself for the next shot. After the first shot, press MENU, select the DO_SURVEY menu, and select item 5, AUTO SCALE TRACES, to properly scale the display. The seismograph will automatically return to acquisition mode once this item is selected.
4. Repeat step 3 if necessary until coherent and interpretable data have been acquired (fig. 12a). If data are re-acquired, be sure to select DO_SURVEY menu item 1, ERASE, before acquiring another set of shots. If coherent seismic traces are observed on each of the 24 traces, with initial wave-arrival times increasing with distance from the source, then select item 6, SAVE, to save the data and automatically increment the file name. PRINT the record if you wish to retain a copy for reference.
5. Select DO_SURVEY menu item 1, ERASE, to clear the Far Forward shot data from active seismograph memory.

End Forward Shot

1. Move the seismic source to the snap ring located 0.5 m from the front of the geophone array (position 99.5).
2. On the DO_SURVEY menu, select item 2, SHOT LOCATION, and enter 99.5. Return to the main seismograph display.
3. Acquire 4 shots from the seismic source. Select the AUTO SCALE TRACES item on the DO_SURVEY menu to ensure that data quality is acceptable, that data are coherent from trace to trace, and that first arrivals are reasonably clear (fig. 12b).

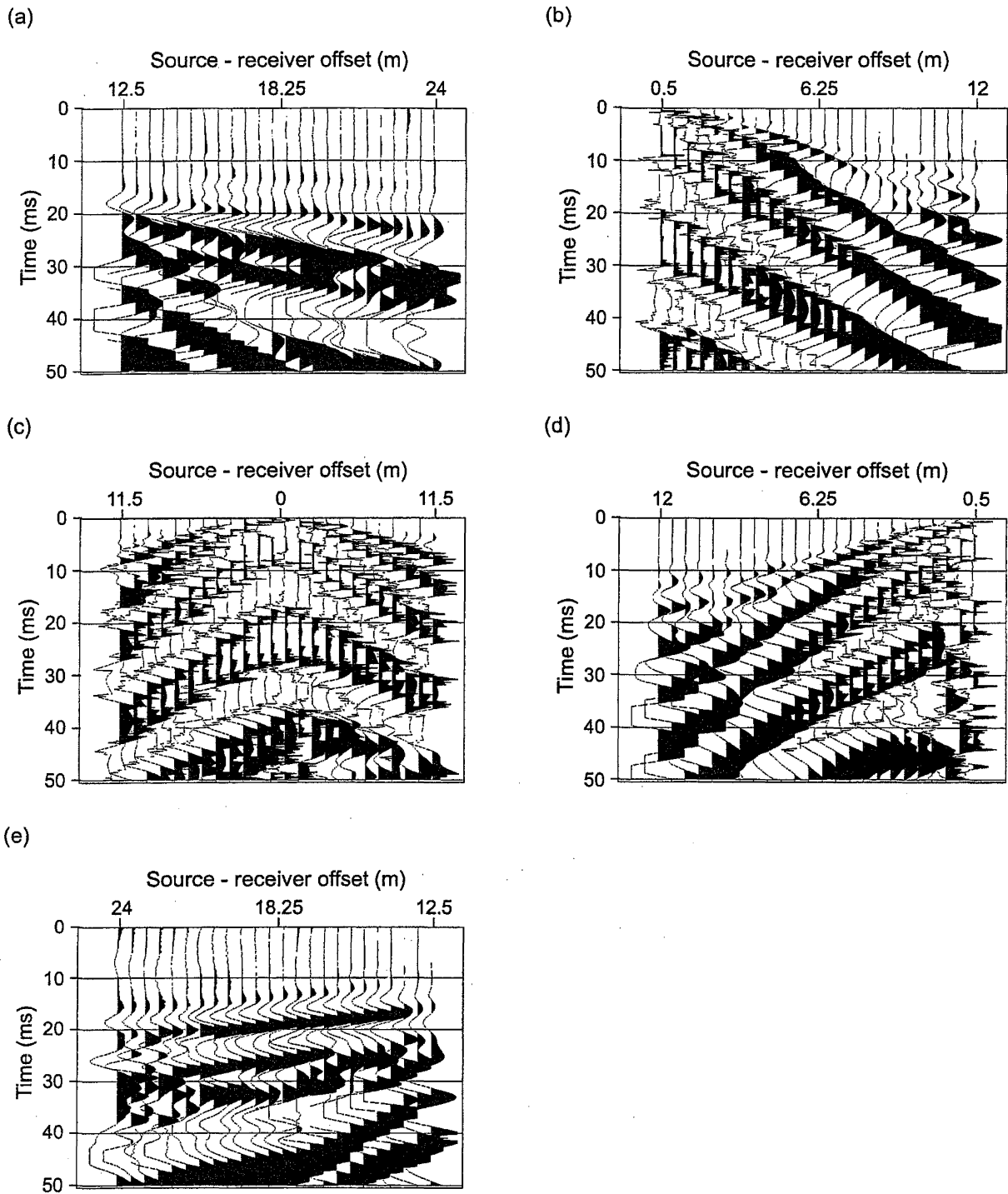


Figure 12. Far, end, and center shot examples. Ground motion detected by the 24-sensor geophone array during the first 50 ms following source impact at a point (a) 12.5 m from the forward end of the recording spread (far forward shot, location 87.5); (b) 0.5 m from the forward end of the recording spread (end forward shot, location 99.5); (c) at the center of the recording spread (center shot, location 105.75); (d) 0.5 m from the trailing end of the recording spread (end reverse shot, location 112); and (e) 12.5 m from the trailing end of the recording spread (far reverse shot, location 124). Data acquired along U.S. 290 in western Travis County, Texas.

4. Repeat step 3 if necessary until acceptable data have been acquired. Select DO_SURVEY menu item 6, SAVE, to save the data and automatically increment the file name. PRINT the record if you wish to retain a copy for reference.
5. Select DO_SURVEY menu item 1, ERASE, to clear the End Forward shot data from active seismograph memory.

Center Shot

1. Move the seismic source to a point adjacent to the center of the geophone array and midway between geophones 12 and 13. To prevent unwanted noise, be careful not to let the seismic source touch the array during operation.
2. On the DO_SURVEY menu, select item 2, SHOT LOCATION, and enter 105.75. Return to the main seismograph display.
3. Acquire 4 shots from the seismic source. Select the AUTO SCALE TRACES item on the DO_SURVEY menu to ensure that data quality is acceptable, that data are coherent from trace to trace, and that first arrivals are reasonably clear (fig. 12c).
4. Repeat step 3 if necessary until acceptable data have been acquired. Select DO_SURVEY menu item 6, SAVE, to save the data and automatically increment the file name. PRINT the record if you wish to retain a copy for reference.
5. Select DO_SURVEY menu item 1, ERASE, to clear the End Forward shot data from active seismograph memory.

End Reverse Shot

1. Move the seismic source positioning cable to the trailing end of the recording array, attaching the end snap ring (at the two-snap-ring end of the cable) to the hole in the recording array frame. Move the seismic source to the snap ring located 0.5 m from the end of the geophone array (position 112).
2. On the DO_SURVEY menu, select item 2, SHOT LOCATION, and enter 112. Return to the main seismograph display.
3. Acquire 4 shots from the seismic source. Select the AUTO SCALE TRACES item on the DO_SURVEY menu to ensure that data quality is acceptable, that data are coherent from trace to trace, and that first arrivals are reasonably clear (fig. 12d).
4. Repeat step 3 if necessary until acceptable data have been acquired. Select DO_SURVEY menu item 6, SAVE, to save the data and automatically increment the file name. PRINT the record if you wish to retain a copy for reference.
5. Select DO_SURVEY menu item 1, ERASE, to clear the End Forward shot data from active seismograph memory.

Far Reverse Shot

1. Move the seismic source to the end snap ring located 12.5 m from the end of the geophone array (position 124).
2. On the DO_SURVEY menu, select item 2, SHOT LOCATION, and enter 124. Return to the main seismograph display.

3. Acquire 8 shots from the seismic source. Select the AUTO SCALE TRACES item on the DO_SURVEY menu to ensure that data quality is acceptable, that data are coherent from trace to trace, and that first arrivals are reasonably clear (fig. 12e).
4. Repeat step 3 if necessary until acceptable data have been acquired. Select DO_SURVEY menu item 6, SAVE, to save the data. PRINT the record if you wish to retain a copy for reference.

Transfer Data

The SAVE item on the DO_SURVEY menu saves the data in active memory to the current file name in the current directory on the selected disk volume. It is good survey practice to transfer a copy of the data files to a floppy disk after data have been acquired at each site. Navigate to the FILE menu (App. A), select item 7, TRANSFER TO FLOPPY/DELETE, and insert a 3.5-inch floppy disk into the drive bay at the left side of the seismograph. Follow the prompts to copy the data files from the seismograph to the floppy disk. Files need not be deleted from the original volume during this operation.

PICKING FIRST ARRIVAL TIMES

The only part of the seismic record that is used in refraction analysis is the arrival time of the first coherent ground motion at each geophone. Close to the seismic source, the first arrival is usually the direct wave, or the compressional wave that originates at the source and travels a more or less linear path to the geophones. Because it travels in the shallowest layer, this wave typically has relatively low seismic velocity. It is overtaken at some point by compressional waves that travel a longer but faster path. At a point called the crossover distance, the critically refracted wave that traveled downward until it encountered high-velocity bedrock, then traveled along the top of the bedrock surface before returning to the ground surface becomes the first

arrival. The time that these waves require to reach the geophones, along with the distances they traveled, are the basis for determining the layer depths and velocities in refraction analysis.

First-arrival picking and basic refraction analysis can be carried out using the seismograph's built-in software that is available under the ANSWERS menu (item 1, PICK FIRST BREAKS, and item 2, SOLVE REFRACTION), but better first-arrival picks are commonly obtained using the separate program FIRSTPIX available from Interpex. The instructions below assume that either (a) the operator has loaded FIRSTPIX onto the seismograph following the instructions in the separate FIRSTPIX manual, and has attached a monitor, keyboard, and mouse to the seismograph, or (b) the operator has loaded FIRSTPIX onto some other PC-compatible computer with suitable accessories and has transferred the raw seismic data files to that computer for analysis. Analysis on another computer is recommended because the seismograph computer is relatively slow.

Run FIRSTPIX

FIRSTPIX employs a software key for copy protection. When FIRSTPIX is installed, the key can be kept on the original floppy disk or transferred to the computer that will be running FIRSTPIX. If the key is left on the original disk, the disk must be in the drive when FIRSTPIX is launched.

Assuming the seismograph computer is being used for analysis, the operator must exit from the seismograph program (s12.exe) that automatically launches on startup to the DOS operating system. This is accomplished by navigating to the OTHER menu (App. A) and selecting the last item, EXIT TO DOS. Within DOS, navigate to the FIRSTPIX directory on the C: drive and type FIRSTPIX.EXE to launch FIRSTPIX. During launch, the program will check for a valid software protection key and will present a window with nine menus, namely EDIT, INPUT, OUTPUT, PRINT, SHOW, VIEW, PLOT, PROCESS, and EXIT (App. B). Although all menus can be used, items in the EDIT, OUTPUT, PROCESS, and EXIT menus are the only ones required to pick

first arrivals. The following steps are required to produce a text file containing the first arrival times at each geophone for the five shot locations. The text file is subsequently imported into a custom Excel workbook for refraction analysis.

Load Seismic Data Files

Locate the raw data files for input into FIRSTPIX. To do this, navigate to the EXIT menu (App. B), select the SET (new) DIRECTORY item, and follow the prompts to locate the directory where the raw data files have been saved.

Navigate to the EDIT menu (App. B) to load the data files into the program and create the spread geometry. Select the CREATE (new) SPREAD item, enter an appropriate name for the spread, and type the default data file extension (which is DAT for the SmartSeis). Press the <Alt> and <G> keys simultaneously to display the available files in the chosen directory, choosing the five files corresponding to the far, end, and center shots for the site being analyzed. If the files are not visible in the list of available files, ensure that the correct directory was specified in step 1. At this point, FIRSTPIX queries the operator regarding site information. Most of the fields are not used during analysis, but it is important that the G spacing (geophone spacing) be set to 0.5 m. After the site information entry is complete, FIRSTPIX will display geophone locations for all loaded files. Check that geophone 1 is located at position 100 for all records and that there is a 0.5-m spacing between each geophone. Next, FIRSTPIX displays the shot parameters. Ensure that each data file shows the correct shot location (table 1).

Adjust the screen display. Navigate to the VIEW menu (App. B), selecting the VIEW SHOT (data) item. Select one of the data files to view and make the appropriate parameter choices (table 2).

Table 2. Recommended display parameter choices while using FIRSTPIX to pick first arrivals.

Item	Setting
Plot traces from	1 to 24
Variable area plot	YES
Overlap (no. traces)	1
Clip (no. traces)	1
Start time (ms)	0
End time (ms)	60
Low pass filter	NO
Apply AGC	NO
AGC gate length (%)	30
AGC amplitude	1024

Pick First Arrivals

Let FIRSTPIX automatically pick the first arrivals for each shot as a starting point in the iterative process of first arrival analysis. Navigate to the PROCESS menu and select the AUTO PICK (all records) item. FIRSTPIX will automatically choose the first arrivals for each of the records loaded into the spread.

Manually adjust the first arrival picks on each record until realistic and consistent picks have been made (fig. 13). Unless the field records are very clear, the automatic picks will not be sufficiently accurate or consistent, but they provide a starting point for manual adjustment. To adjust the picks, navigate to the PROCESS menu and select the EDIT PICKS item. FIRSTPIX will display a graph showing lines connecting time picks for each of the five shot locations on the same screen. If the picks are well chosen, the time picks should gradually increase with distance from the shot for that particular data file. Additionally, the forward and reverse far shot picks should appear as mirror images of each other, as should the forward and reverse end shots. For all shots, similar times should be chosen for similar source-geophone distances. Individual picks can be adjusted from this screen by using the mouse to select a pick that appears to be in the wrong position. That seismic trace will be displayed, along with several adjacent traces, that

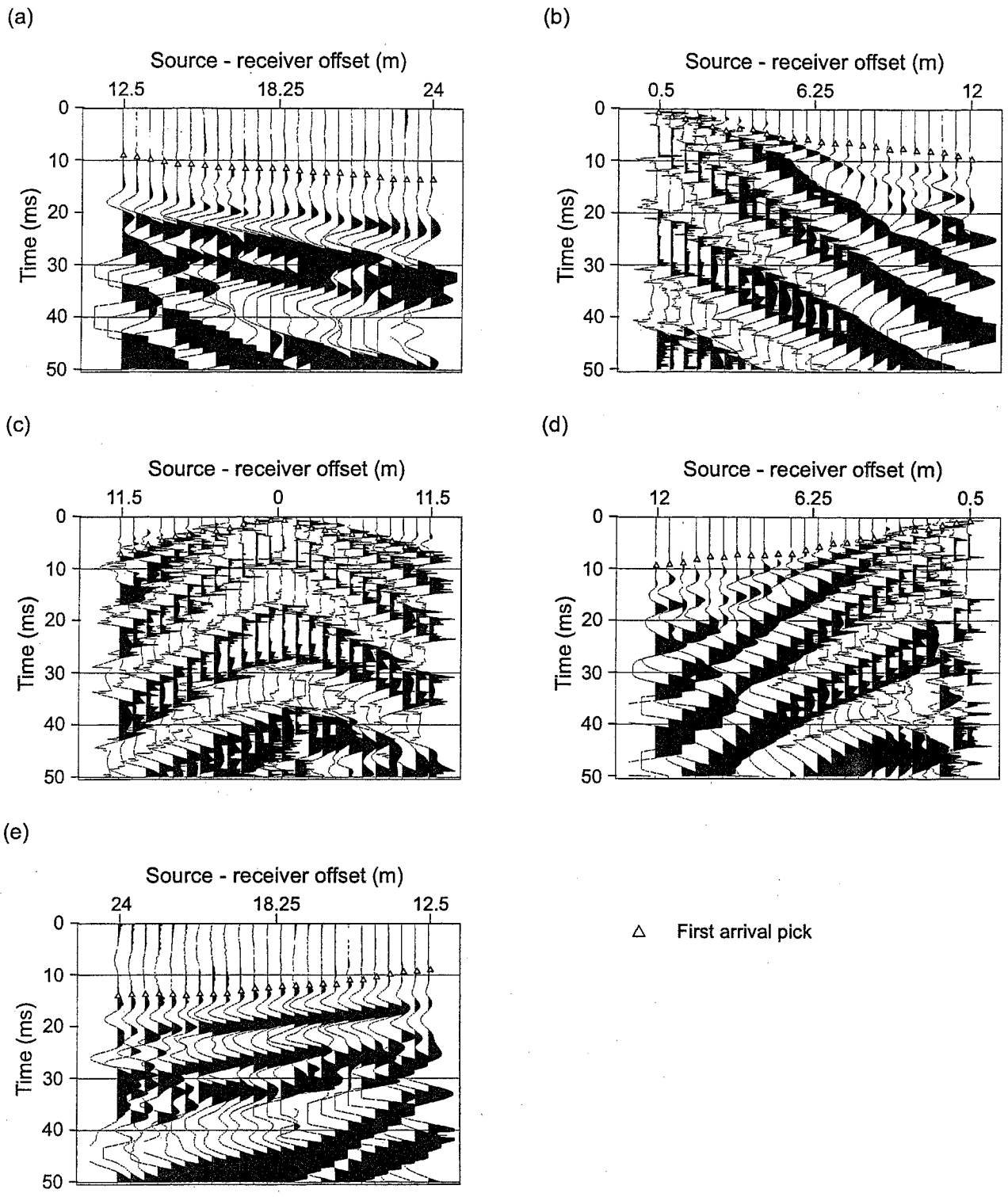


Figure 13. First-arrival picks for the (a) far forward; (b) end forward; (c) center; (d) end reverse; and (e) far reverse shots. Data acquired along U.S. 290 in western Travis County, Texas.

will allow a consistent pick to be made. Commonly, a good first arrival cannot be picked on an individual trace, yet good arrivals are visible on adjacent traces. Rather than leave the trace unpicked, simply choose a time that fits within the context of the adjacent traces.

It is a good practice to begin the analysis with the far shots, where the first arrivals are commonly more obvious (fig. 13a and e). At the longer source-receiver offsets on these records, the first arrival is commonly the refraction from the bedrock surface that, because of its higher velocity, has separated itself in time from other seismic phases. Beginning with the traces farthest from the source, select arrival times progressively toward the source until the arrival time has been picked for the trace closest to the source on the far shots, which should be 12.5 m distant from the source. Next move to the end and center shots (fig. 13b, c, and e), making sure that the arrival at the most distant geophone on the end shots (at 12 m from the source) is consistent with the chosen arrival at the closest geophone on the far shots (at 12.5 m from the source). In most cases, those arrival times should be within one or two milliseconds of each other. Continue following the first arrival on the end shots toward the source location, keeping in mind that at some point the bedrock refraction will not be the first arrival. From the source position out to a distance that is proportional to the bedrock depth, the first arrival will be either the wave traveling directly from the source to the geophone in the pavement or fill layers, or a minor refraction along some thin rigid layer below the pavement. Because of the presence of multiple, complex seismic phases close to the source, it is commonly difficult to pick the direct arrival and therefore necessary to estimate the first arrival times for the direct wave. The direct wave will commonly be visible, but may not always be the first arrival. The best approach is to use typical compressional wave velocities in fill material of 400 to 800 m/s to guide the arrival estimates on the inner parts of the end records and on the center shot record. To calculate the approximate arrival time, divide the source to receiver distance by 500 m/s, then pick the arrival that is close to that estimated arrival time. Ensure that the direct arrivals are consistent in both the forward and reverse directions.

Export the First Arrival Picks for Velocity and Depth Analysis

Navigate to the EXIT menu and select the COMMAND item. Type PRINTER IS picks.txt (or some other name for a text file) to prepare a text file for FIRSTPIX output. Type MENU to return to the menu mode in FIRSTPIX. Navigate to the PRINT menu and select PRINT DATA (values). FIRSTPIX will now write all first arrival picks to the text file name chosen above (fig. 14). The file will be written in the directory from which FIRSTPIX was launched. The picks contained in the text file will be imported into the custom Excel spreadsheet for layer thickness and velocity analysis.

US290JP							PAGE 1
OBSERVED TRAVEL TIMES (msec)							
STATION No.	ELEVATION (m)	SHOT- 1 1	SHOT- 2 2	SHOT- 3 3	SHOT- 4 4	SHOT- 5 5	
175.00	0.0	SHOT					
199.00	0.0	SHOT					
200.00	0.0	9.00	0.75	7.25	9.37	14.00	
201.00	0.0	9.37	1.62	6.50	9.12	13.75	
202.00	0.0	9.87	2.00	5.50	8.87	13.75	
203.00	0.0	10.25	2.37	4.62	8.12	13.62	
204.00	0.0	10.75	3.50	3.87	7.62	13.75	
205.00	0.0	10.75	4.25	3.50	7.75	14.00	
206.00	0.0	11.00	3.87	2.87	7.25	13.62	
207.00	0.0	11.37	4.00	2.87	7.37	13.75	
208.00	0.0	11.37	4.75	2.25	7.37	13.62	
209.00	0.0	11.50	5.62	1.50	7.12	13.12	
210.00	0.0	11.50	5.75	1.12	7.12	12.62	
211.00	0.0	11.50	5.87	0.75	6.37	12.50	
211.50	0.0	SHOT					
212.00	0.0	11.50	6.37	0.75	5.75	12.25	
213.00	0.0	12.00	6.62	1.87	5.12	12.12	
214.00	0.0	12.25	6.50	2.25	5.00	12.00	
215.00	0.0	12.37	7.00	2.62	4.37	11.75	
216.00	0.0	12.37	7.25	3.25	4.12	11.87	
217.00	0.0	12.75	7.75	3.37	3.87	11.00	
218.00	0.0	12.75	7.62	3.50	3.00	11.00	
219.00	0.0	13.25	8.00	4.12	2.50	10.37	
220.00	0.0	13.62	8.12	4.75	2.25	9.87	
221.00	0.0	13.62	8.37	5.75	1.62	9.37	
222.00	0.0	13.62	9.00	6.37	1.12	9.25	
223.00	0.0	13.62	9.62	7.25	0.75	9.00	
224.00	0.0	SHOT					
248.00	0.0	SHOT					

Figure 14. Text file exported from FIRSTPIX containing first arrivals for the U.S. 290 data set (fig. 13).

ESTIMATING VELOCITIES AND BEDROCK DEPTH

A custom Excel workbook is used to interactively estimate fill velocity and bedrock depth and velocity based on the first arrival picks exported from FIRSTPIX. The steps involved are (1) importing the first arrival text file into the appropriate rows and columns in Excel, (2) assigning layers to each of the arrival times (direct or refracted), (3) adjusting the layer 1 velocity to best match the direct-wave first arrivals, (4) adjusting the layer 2 velocity to match the slope of the refracted first arrivals, (5) adjusting the layer 1 thickness (bedrock depth) to minimize the difference between refracted first arrivals and predicted layer 2 arrivals, and (6) making final adjustments to the bedrock (layer 2) dip, layer 1 thickness, and layer 2 velocity to minimize the error between the actual and predicted first arrivals.

The Excel workbook contains several worksheets that are used to analyze refraction data and estimate bedrock depth. The first worksheet, named vars (fig. 15), is where users enter site

	A	B	C	D	E
1	uc290	spread			
2	5/1/2002	date			
3					
4	Synthetic			Total error	
5		607 Velocity, layer 1 (m/s)		12.50	layer 1, ms
6		1814 Velocity, layer 2 (m/s)		39.38	layer 2, ms
7		1.07 Thickness at 105.75, layer 1 (m)		51.88	total, ms
8		0.2 Dip angle (degrees forward)			
9					
10	Shot Locations (m)	Title	Label	longitude	latitude
11	50.5	Far shot forward (FF)	FF		
12	88.5	End shot forward (EF)	EF		
13	105.75	Center shot	cen		
14	112	End shot reverse (ER)	ER		
15	124	Far shot reverse (FR)	FR		
16					
17		Calculated			
18		0.003490699 Dip angle, radians			
19		0.473361545 Critical angle, layer 1 to layer 2 (radians)			
20					
21		Geophone locations		Depth_m	
22		100 Geophone 1 (west end)		1.06	
23		100.5		1.06	
24		101		1.06	
25		101.5		1.06	
26		102		1.06	
27		102.5		1.06	
28		103		1.06	
29		103.5		1.06	

Figure 15. The “vars” worksheet from the Excel refraction workbook, where site information is entered, seismic layer values are adjusted to fit observed first arrivals, and bedrock depths are calculated.

information and adjust layer velocities and bedrock depth and dip to produce a seismic model that best fits the observed first arrivals. The second worksheet, named `xs_chn` (fig. 16), displays a cross section of depth to bedrock beneath the geophone locations using the current seismic model in `vars`. The next five worksheets, named `dat_ff`, `dat_ef`, `dat_cn`, `dat_er`, and `dat_fr`, are where shot information and first arrival picks are transferred from the exported `FIRSTPIX` data. The final five worksheets, named `ff_chn`, `ef_chn`, `cen_chn`, `er_chn`, and `fr_chn`, graphically depict how well the current model matches the observed first arrivals from the far forward, end forward, center, end reverse, and far reverse shots. Consult these charts to see how well the chosen model parameters fit the observed data, and how to adjust the model to make a better fit.

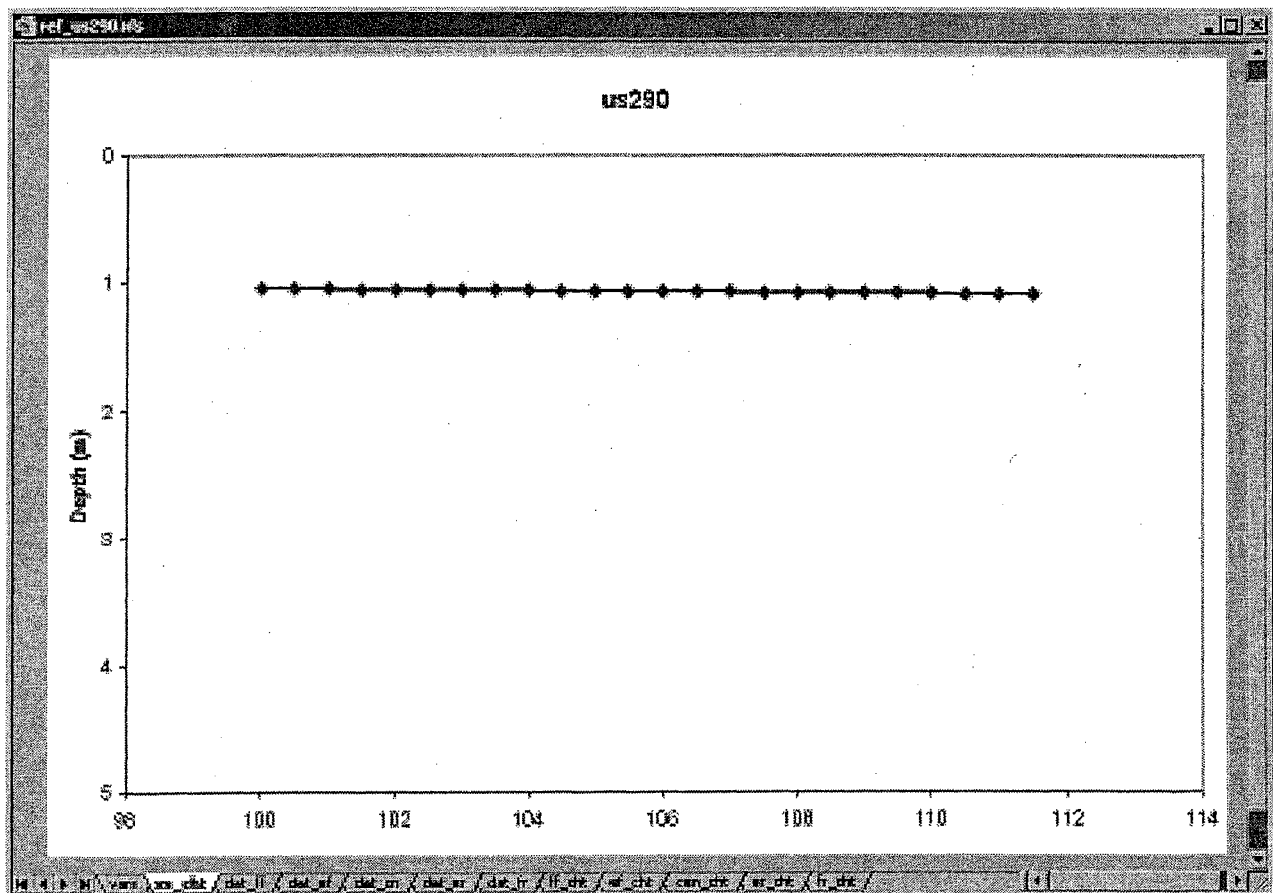


Figure 16. The “`xs_chn`” chart from the Excel refraction workbook, where a cross section displays depth to layer 2 beneath the geophone array using the current seismic model entered in the “`vars`” worksheet.

Importing First Arrival Picks

The final step in the first arrival analysis was to export the arrivals from FIRSTPIX into a text file (fig. 14). Rather than entering the 120 first arrivals manually into the Excel refraction analysis workbook, the text file can be imported into Excel by opening the file and indicating that the file is space delimited. FIRSTPIX exports the arrival times in columns corresponding to the shot location, facilitating import into the Excel shot worksheets dat_ff, dat_ef, dat_cn, dat_er, and dat_fr (fig. 17). The SHOT rows in the imported file should be deleted before the appropriate arrival-time columns are copied and pasted into the leftmost yellow column on the corresponding shot worksheets. Ignore the layer column (the rightmost yellow column) in the shot worksheets until first arrivals from all shots have been copied from the imported file and pasted.

Shot	File	Location	Source	Slacks	Station	Time (ms)	Layer	Smith_ms	layer1_error	layer2_error	total_error
8	100.00				100.00	0.75	1	0.80	0.15	NA	0.15
9	100.50				100.50	1.02	1	1.21	0.41	NA	0.41
10	101.00				101.00	2.00	1	1.81	0.19	NA	0.19
11	101.50				101.50	2.37	1	2.42	0.05	NA	0.05
12	102.00				102.00	3.50	1	3.02	0.48	NA	0.48
13	102.50				102.50	4.25	1	3.63	0.62	NA	0.62
14	103.00				103.00	4.97	2	4.30	NA	0.32	0.32
15	103.50				103.50	4.00	2	4.48	NA	0.48	0.48
16	104.00				104.00	4.75	2	4.75	NA	0.00	0.00
17	104.50				104.50	5.02	2	5.02	NA	0.59	0.59
18	105.00				105.00	5.75	2	5.91	NA	0.44	0.44
19	105.50				105.50	5.97	2	6.29	NA	0.38	0.38
20	106.00				106.00	6.37	2	6.88	NA	0.51	0.51
21	106.50				106.50	6.62	2	6.14	NA	0.48	0.48
22	107.00				107.00	8.50	2	6.42	NA	0.08	0.08
23	107.50				107.50	7.00	2	6.70	NA	0.30	0.30
24	108.00				108.00	7.25	2	6.97	NA	0.28	0.28
25	108.50				108.50	7.75	2	7.25	NA	0.00	0.00
26	109.00				109.00	7.82	2	7.52	NA	0.00	0.00
27	109.50				109.50	9.00	2	7.81	NA	0.18	0.18
28	110.00				110.00	8.12	2	8.08	NA	0.04	0.04
29	110.50				110.50	8.37	2	8.36	NA	0.01	0.01
30	111.00				111.00	9.00	2	8.64	NA	0.38	0.38
31	111.50				111.50	9.02	2	8.92	NA	0.70	0.70

Figure 17. The “dat_ef” worksheet from the Excel refraction workbook, where end forward shot data are entered and arrival times are pasted from the first arrivals text file (fig. 14). The dat_fr, dat_cn, dat_er, and dat_fr worksheets for the other shots are similar.

Assigning Arrivals to Layers 1 or 2

Once the far forward, end forward, center, end reverse, and far reverse arrival times have been imported into the corresponding Excel shot worksheets, a layer is chosen for each arrival time. Because the refraction analysis is based on a two-layer model, arrivals will be assigned to either layer 1 (the slower, direct wave that is the first arrival near the seismic source) or layer 2 (the faster, critically refracted wave along the bedrock interface that overtakes the direct wave at some distance from the seismic source and becomes the first arrival). By inspecting the slopes of the arrival times on the Excel charts ff_chn, ef_chn, cen_chn, er_chn, and fr_chn (fig. 18; ignore the synthetic lines for now) for each of the shots, assign the arrivals on the dat_ff, dat_ef, dat_cn, dat_er, and dat_fr worksheets (fig. 17) to either layer 1 or layer 2, filling in the rightmost yellow

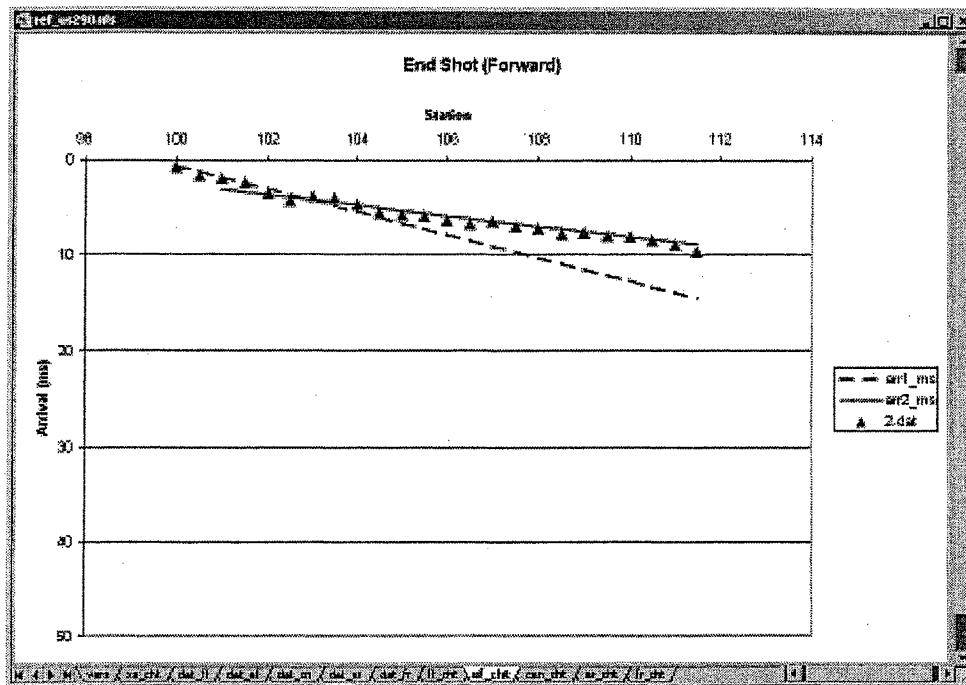


Figure 18. The “ef_chn” chart from the Excel refraction workbook, where the actual first arrival times for the end forward shot are displayed, as well as the arrival times for the direct and refracted waves predicted from the seismic model entered on the “vars” worksheet. If the model fits the data well, the actual arrival times should coincide with the predicted times for the layer to which the individual arrival has been assigned on the “dat_” worksheets. The ff_chn, cen_chn, er_chn, and fr_chn charts show similar information for the far forward, center, end reverse, and far reverse shots.

column with the appropriate number on each of the shot worksheets. There should be a break in slope on the arrival-time charts where the bedrock refraction overtakes the direct wave.

Adjusting Layer 1 Velocity

When all of the arrivals for each of the shots have been assigned to either layer 1 or layer 2, the seismic velocity model on the vars worksheet (fig. 15) can be adjusted to provide the best fit to the observed first arrivals. This process begins with selecting a velocity for layer 1 (the top cell in the yellow area representing the synthetic seismic model) because changes in the other parameters (layer 1 thickness, layer 2 velocity, and dip) do not change the fitting error for layer 1 velocity.

Where layer 1 represents pavement and compacted fill layers above bedrock, typical values to use for layer 1 velocity range from about 400 to 800 m/s. Through the interactive process of entering a value for layer 1 velocity on the vars worksheet, examining the change in layer 1 fitting error displayed on the same worksheet row, and examining the arrival time charts (especially the near-source charts ef_cht, cen_cht, and er_cht, fig. 18) for a good visual fit between the synthetic layer 1 arrivals and the actual first arrivals, a velocity corresponding to a minimum layer 1 fitting error can be selected. Once the minimum layer 1 error has been achieved, no further adjustment of layer 1 velocity is required.

Adjusting Layer 2

The layer 2 fitting error displayed on the vars worksheet (fig. 15) is affected by changes in all other parameters, including layer 1 velocity, layer 1 thickness, layer 2 velocity, and layer 2 dip angle. As such, it is important to fix the layer 1 velocity first and then make changes in the layer 2 parameters. As a starting point, a good approach is to pick a reasonable layer 2 velocity such as 2000 m/s, a reasonable layer 1 thickness for the site, and a dip angle of 0 degrees.

Once the starting model has been entered, adjust the layer 2 velocity until the layer 2 fitting error is as small as only changes in the layer 2 velocity can make it. Examine the arrival-time charts (especially the relatively far-offset charts ff_cht and fr_cht) to make sure that the slope of the layer 2 synthetic line reasonably matches the slope of the actual layer 2 first arrivals. Because the layer 1 thickness and dip have not yet been adjusted, the layer 2 synthetic arrivals may be offset from the actual first arrivals by a constant time shift.

Adjusting Layer 1 Thickness

Adjusting the layer 1 thickness (identical to layer 2, or bedrock depth) on the vars worksheet will shift the predicted layer 2 arrival times earlier (if layer 1 is thinned) or later (if layer 1 is thickened) to better match the actual arrival times. The fitting error for layer 1 will not change, but the layer 2 and total fitting errors displayed on the vars worksheet will change. Continue adjusting the layer 1 thickness until the layer 2 fitting error has been minimized. Unless layer 2 is a dipping layer, the arrival-time charts should show relatively good agreement between actual and synthetic first arrival times.

Final Adjustments: Dip, Layer 1 Thickness, Layer 2 Velocity

Final adjustments can be made to the dip angle, layer 1 thickness, and layer 2 velocity to further improve the agreement between the actual and synthetic first arrivals and reduce the total fitting error displayed on the vars worksheet (fig. 15). The error represents the cumulative root-mean-square difference between the actual and predicted arrival times for all of the five shots (120 different arrival times). Good fits are generally those that are less than 120 ms, or less than 1 ms per arrival time pick. Most good final solutions have total fitting errors of 50 ms or less.

For the sample data set shown here, the total fitting error (fig. 15) was 51.9 ms. Actual first arrivals for the direct and refracted waves match the modeled arrivals relatively well for each of

the shot locations (fig. 19 a to e). Modeled velocities were 827 m/s for layer 1 and 1814 m/s for layer 2 (bedrock). Depth to bedrock at this site is estimated at 1.07 m.

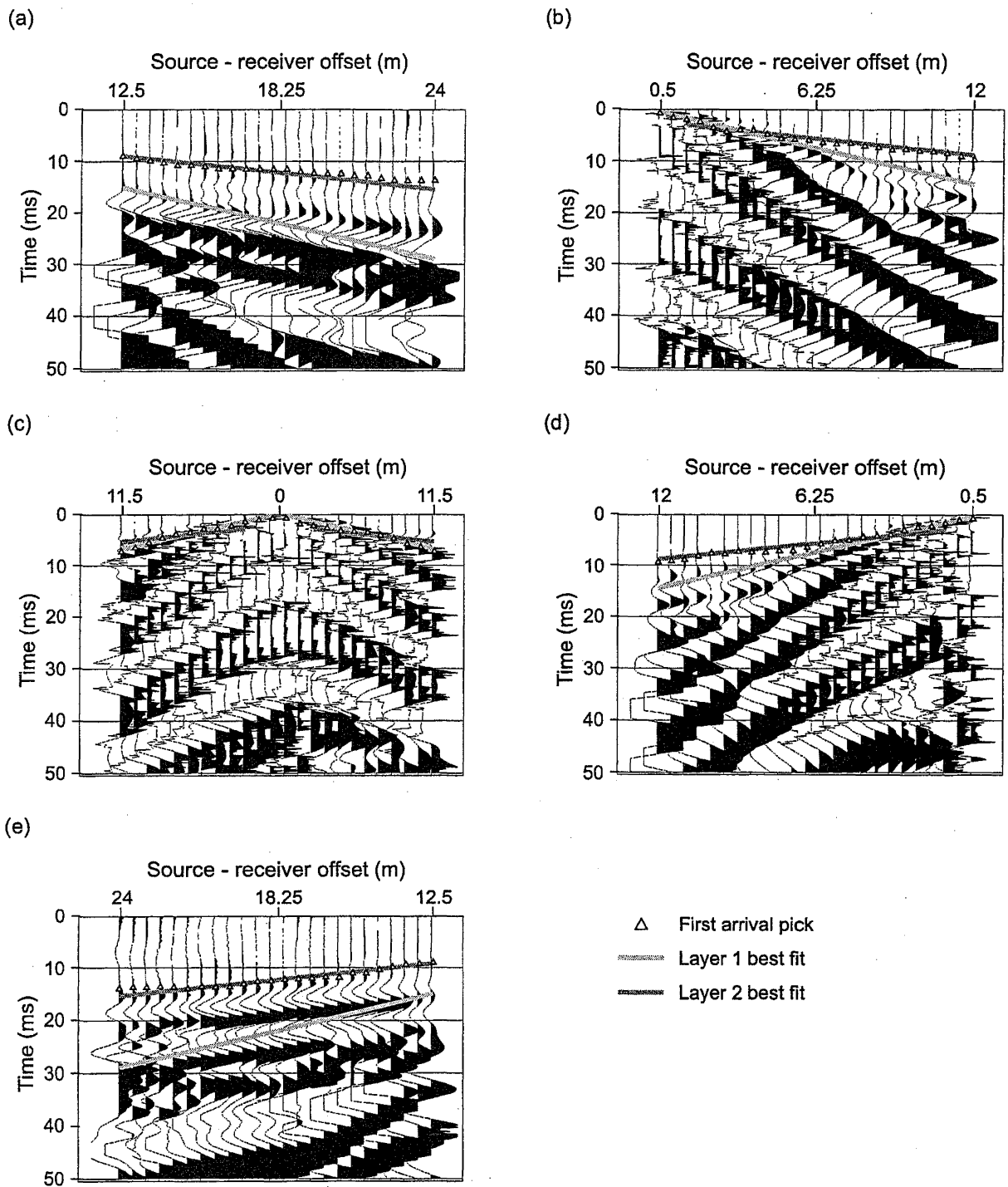


Figure 19. Seismic data records, first-arrival picks, and synthetic first arrivals for the (a) far forward; (b) end forward; (c) center; (d) end reverse; and (e) far reverse shots. Data acquired along U.S. 290 in western Travis County, Texas.

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APPENDIX A. SEISMOGRAPH MENUS

The Geometrics SmartSeis seismograph includes integrated software (s12.exe) that operates the seismograph. Upon startup, the program s12.exe automatically launches, putting the seismograph directly into data acquisition mode. The following menus, reached using the MENU button on the display or the F1 key from an optional keyboard, control data acquisition and display. Detailed instructions on the operation of the seismograph are included in the manufacturer's manual.

ACQUISITION Menu

The items within the ACQUISITION menu control the seismograph settings such as sample interval, record length, and stack mode. The settings listed below are appropriate for most pavement surveys.

Item Number	Item Name	Setting/Function
0	QUICK ACQ SETUP	Blank; select to set all items
1	SAMPLE INTERVAL	125 us
2	RECORD LENGTH	64 or 128 ms
3	DELAY	0
4	FILTER 1	OUT
5	FILTER 2	OUT
6	STACK MODE	AUTO STACK
7	STACK POLARITY	POSITIVE
8	ACTIVE CHANNELS	Blank; select to change active channels (should be all)

GEOMETRY Menu

Items in the GEOMETRY menu are used to define the geometry of the refraction survey, including shot location and geophone locations and spacing. The settings listed below are appropriate for pavement surveys.

Item Number	Item Name	Setting/Function
0	QUICK GEOMETRY SETUP	Blank; select to set all items
1	SURVEY MODE	REFRACTION
2	LINE NUMBER	Not required
3	PHONE INTERVAL	0.50
4	SET PHONE & SHOT LOCATIONS	Blank; select to set locations
5	PHONE INCREMENT	0.00
6	SHOT INCREMENT	0.00

FILE Menu

The items within the FILE menu control the seismograph settings such as the destination drive and directory for acquired data files, the file names, and the automatic file saving option.

Item Number	Item Name	Setting/Function
0	QUICK FILE SETUP	Blank; select to set all items
1	CHANGE DRIVE	D:
2	MAKE DIR	Blank; select to create new data file directory
3	SET FILE NAME	Select to change next file name
4	AUTO SAVE	OFF
5	CHANGE DIR	Displays and changes current data file directory
6	READ	Blank; select to read file into active memory
7	TRANSFER TO FLOPPY/DELETE	Blank; transfer files to floppy disk
8	FORMAT	Blank; format blank disk

DISPLAY Menu

The items within the DISPLAY menu control the appearance of the data on the screen, but do not affect data acquisition. Typical settings are listed below.

Item Number	Item Name	Setting/Function
0	QUICK DISPLAY SETUP	Blank; select to set all items
1	TYPE	CLIPPED & SHADED
2	AGC	FIXED GAIN
3	TIME SCALE	NORMAL
4	PRINT TIME SCALE	COMPRESS BY 2
5	TRACE SIZE	Blank; select to modify trace size
6	DISPLAY CHANNELS	Blank; select to verify all channels are displayed
7	FILTER 1	OUT
8	FILTER 2	OUT
9	BACK LIGHT	ON or OFF, depending on lighting

DO_SURVEY Menu

Items in the DO_SURVEY menu are used during acquisition of seismic data.

Item Number	Item Name	Setting/Function
1	ERASE	Erases data in active memory
2	SHOT LOCATION	Displays shot location; select to change
3	NOISE DISPLAY	Blank; select to display current ground motion
4	TRACE DISPLAY	Blank; select to display traces
5	AUTO SCALE TRACES	Blank; select to scale all traces
6	SAVE	Displays current data file; select to save data to displayed file
7	PRINT	Blank; select to print seismic data in active memory
8	FREEZE	Blank; select to prevent addition of more data to active memory
9	ROLL CHANNELS	Blank; unused in refraction survey
-	UNSTACK	Blank; select to remove last shot from active memory

APPENDIX B. FIRSTPIX MENUS

FIRSTPIX is a commercially available, menu-driven or command-driven program for picking first seismic first arrivals for refraction analysis. It is published by and available from Interpex (www.interpex.com) in Golden, Colorado. Below is a listing of menu items and a brief description of their relevance. Many of the menu items are not required in SRBA data analysis. **Highlighted items** are those that are used routinely. More detailed explanations can be found in the FIRSTPIX user's manual.

EDIT Menu

Items in the EDIT menu are used to load seismic data and define spread geometry.

Item Name	Function
CREATE (new) SPREAD	Creates a new data set (spread), loads seismic data, and verifies spread geometry
EDIT DATA PARAMETERS	Edits previously entered spread data
EDIT SHOT (parameters)	Edits shot locations
EDIT (spread) LAYOUT	Edits layout geometry
EDIT ELEVATIONS	Edits shot or geophone elevations
DELETE SHOT (record)	Deletes unnecessary shots
DELETE SPREAD	Deletes entire spread

INPUT Menu

Items in the INPUT menu are used to change working directory and load existing data set.

Item Name	Function
SET (new) DIRECTORY	Selects data file directory
GET (existing spread)	Loads existing data set
APPEND (files to) SPREAD	Adds seismic data files to existing spread
LOAD SPREAD	Loads existing data set into new spread file
LOAD SEGPI	Loads elevation data
LOAD ELEVATIONS	Loads elevation data from text file
READ PLATE	Loads existing specifications for plate output

OUTPUT Menu

Items in the OUTPUT menu are used to save files for analysis using other commercial software. These items are not used in SRBA data analysis.

Item Name	Function
SAVE (new GREMIX file)	Saves data set for refraction analysis using GREMIX
REPLACE (existing GREMIX file)	Saves data set for refraction analysis using GREMIX
WRITE (GREMIX ascii file)	Saves data set for refraction analysis using GREMIX
WRITE PLATE (window parameters)	Saves custom plate output parameters
WRITE SEG2 (files)	Saves data set in industry-standard SEG-2 format
WRITE SEGY (files)	Saves data set in industry-standard SEG-2 format

PRINT Menu

Items in the PRINT menu are used to obtain print or digital output from a SRBA data set.

Item Name	Function
PRINT (long output)	Prints entire data set
PRINT DATA PARAMETERS	Prints the data set parameters
PRINT SHOT (parameters)	Prints the shot parameters
PRINT DATA (values)	Prints the first arrival picks
PRINT RECORD (list)	Prints a list of field records
PRINT FIELD (record header)	Prints field record parameters

SHOW Menu

Items in the SHOW menu are used to display textual data on screen. These items are not required for SRBA data analysis.

Item Name	Function
SHOW DATA PARAMETERS	Displays data parameters
SHOW SHOT (parameters)	Displays shot parameters
SHOW DATA (values)	Displays first arrival picks
SHOW RECORD (list)	Displays a list of field records
SHOW FIELD (record header)	Displays field record parameters

VIEW Menu

Items in the VIEW menu are used to display data graphically on screen.

Item Name	Function
VIEW SHOT (data)	Selects and displays seismic data
VIEW TRAVELTIME (curve)	Displays first arrival picks
VIEW (spread) LAYOUT	Displays shot and geophone locations
VIEW (common/long) OFFSET DATA	Selects and displays seismic data and arrival picks
VIEW SHOT PLATE	Displays seismic shots in plate format
VIEW TRAVELTIME PLATE	Displays traveltime plot in plate format
VIEW (common/long) OFFSET PLATE	Displays data and picks in plate format

PLOT Menu

Items in the PLOT menu are used to print data graphically on a printer or plotter. These items are not required for SRBA data analysis.

Item Name	Function
PLOT SHOT (data)	Selects and plots seismic data
PLOT TRAVELTIME (curve)	Plots first arrival picks
PLOT (spread) LAYOUT	Plots shot and geophone locations
PLOT (common/long) OFFSET DATA	Selects and plots seismic data and arrival picks
PLOT SHOT PLATE	Plots seismic shots in plate format
PLOT TRAVELTIME PLATE	Plots traveltime in plate format
PLOT (common/long) OFFSET PLATE	Plots data and picks in plate format

PROCESS Menu

Items in the PROCESS menu are used to automatically and manually select first arrival times.

Item Name	Function
PICK (first breaks)	Manually pick first arrivals for each data file
AUTO PICK (all records)	Automatically pick first arrivals for all files
EDIT PICKS (with traveltime display)	Displays all picks simultaneously for editing
MERGE (adjacent records)	Combines adjacent seismic records
COMBINE (opposite polarity records)	Combines opposite polarity traces

EXIT Menu

Items in the EXIT menu are used to set the working directory, enter the command mode, and exit to DOS.

Item Name	Function
COMMAND (revert to command mode)	Enters command-line mode
SET (new) DIRECTORY	Selects data file directory
SET (new) PLOTTER	Selects new hardcopy device
EDIT (plot) COLORS	Selects plotting colors
EDIT (plot) LABELS	Edits plot axis labels
EDIT (screen) ATTRIBUTES	Edits display parameters
ABOUT FIRSTPIX	Displays information about FIRSTPIX
SHELL (dos command shell)	Enters DOS command shell within FIRSTPIX
EXIT (return to system)	Exits FIRSTPIX to DOS