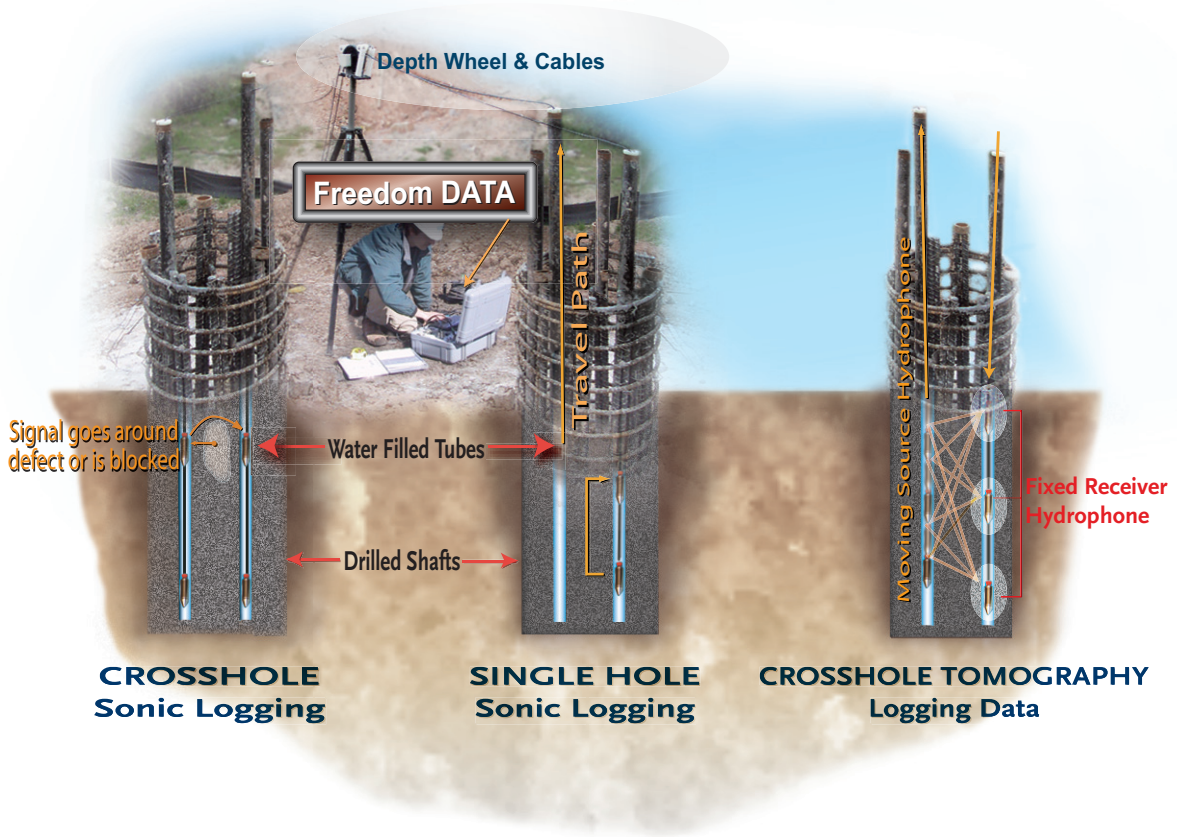
FREEDOM DATA PC™

CROSSHOLE SONIC LOGGING

System Reference Manual 2006



CSL2 Version 3.4
Windows Version

OLSON
INSTRUMENTS

NOTICES

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1.0 INTRODUCTION

The Olson Instruments Crosshole Sonic Logging (CSL) system is used for quality assurance testing of a variety of concrete foundations and slurry walls as shown below. The basic requirement for any structure to be testable by this system is that some form of access (such as cast-in-place tubes or boreholes) for the transducers must be provided. When used for quality assurance testing on drilled shafts, slurry walls, etc, the sonic logging system is a powerful, state-of-the-art tool in verifying concrete integrity, locating defects, and evaluating repair effectiveness.

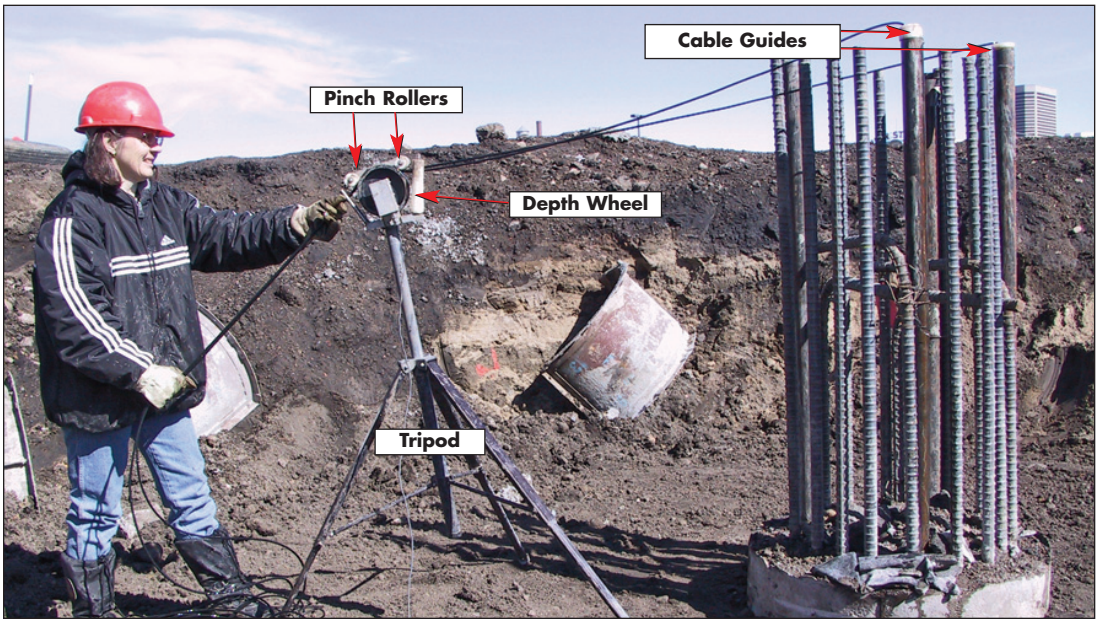


Figure 1 - Crosshole Sonic Logging performed on a concrete shaft

The Crosshole Sonic Logging system (CSL-1) consists of 4 basic components for most testing applications:

1. Freedom Data PC with high-speed data acquisition card, Windows based CSL acquisition and analysis software, installed
2. CSL Pulser and Input Modules, installed
3. Depth Measurement Wheel Assembly
4. Interchangeable source/receiver hydrophones (2). CSL-2 option for 3rd hydrophone for two simultaneous logs

These components are interconnected with cables to form a complete system (see page 27). This manual covers hardware setup and use for the Olson Instruments Freedom Data PC CSL-1 and CSL-2 systems. Details of the hardware and its usage are included in SECTION 2.0.

The Windows CSL software included in the system is a real time display program. This includes real time displays of waveform, first arrival time log, velocity plot, time and energy log and waterfall plot.

1.0 INTRODUCTION

It acquires the data for 1 (CSL-1 system) or 2 channels (CSL-2 system) simultaneously. The software can also be used to perform tomographic data acquisition to image defects (with purchase of TOMO-1 option). This manual covers step-by-step data acquisition, data analysis, and report generation (or output generation for tomography that links the summary report and CSL logs directly to a Microssoft Word document). If a TOMO-1 system is purchased, an additional manual is available for details on tomography data collection and processing. The system is designed/manufactured to be in accordance with ASTM D6760-02 Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing.

1.1 ORGANIZATION AND SCOPE OF MANUAL

This operation manual for the Olson Instruments Crosshole Sonic Logging System includes all required instructions for the use of the software and hardware included with the system. Also included is a troubleshooting guide for the system to help overcome any problems experienced or answer any questions.

If any problems with the system appear that are not covered in this manual, please call Olson Instruments at 303-423-1212. Training in the use of the system by Olson Instruments personnel is strongly recommended for the most effective operation of this system.

1.2 SYSTEM REQUIREMENTS AND COMPONENTS

The Crosshole Sonic Logging system can only be purchased with the Olson Freedom Data PC, as the pulser and input modules are custom designed for this system. When the system is purchased, Olson Instruments personnel will properly set up the computer. Each computer setup is based on the customer's option requests.

1.3 TEST METHODOLOGY

Crosshole Sonic Logging (CSL) – The CSL test relies on propagation of ultrasonic waves between two or more **water-filled** access tubes to measure the velocity and signal strength of the propagated waves. The testing can be performed on any concrete foundation provided two or more access tubes or coreholes capable of holding water are present in the foundation. CSL can also be used to check the integrity of underwater concrete piers and foundations by strapping access tubes to the sides. Crosshole Tomography can be performed to image critical anomalies found in CSL tests as discussed.

A companion of the CSL test is the Singlehole Sonic Logging (SSL) test, which can be performed in one access tube or corehole to check the integrity of the concrete foundation around the tube in a fashion similar to Gamma-Gamma nuclear density tests.

CSL tests are typically performed on concrete, particularly concrete drilled shafts. Other materials, which support transmission of ultrasonic waves, can be tested, such as:

■ slurry ■ rock ■ grout ■ water saturated media ■ cemented radioactive wastes

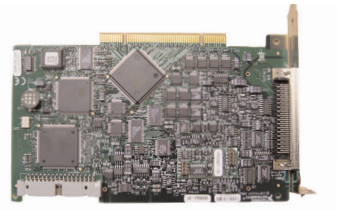
2.0 FREEDOM DATA PC HARDWARE

Main Components of Freedom DATA PC

1. Case Latches
2. Backlight Switch Control
3. External Power Supply Jack
4. CRT, LAN, USB (2), COM, and Parallel Port location
5. Lithium Ion Battery location with cover in place
6. Input Module location
7. POWER ON/OFF Buttons and Battery Condition Indicator Lights
8. Pulser Module location
9. Mouse Buttons
10. Pressure Relief Valve

Before the computer is turned on, verify that the correct Input (6) and Pulser Module (8) are in the computer for the test method you will performing. Each test will have its own set of modules that come pre-installed by Olson Instruments, Inc. Should you ever have a need to remove/replace the modules, the Input Module is installed in the top pocket and the Pulser Module in the bottom pocket.

2.0 Freedom Data PC Hardware Component List

Component Name	QTY	Description
 **Olson Instruments, Inc.** **Freedom DATA PC** (National Instruments A/D Data Card)	1	12" Diagonal LCD Transflective Screen (1024x768) for Sunlight/Night Viewing, Windows XP based low power 1.1 GHz Intel Pentium M Processor, 512 MB DRAM, 40 GB Hard Drive with External CD-RW, 10/100MB LAN, USB, CRT, Serial and Parallel Ports
 **Input Module (top right slot)** **Newer models will not have rings on thumbscrews**	1	Olson Instruments built electronic unit configured for system method purshased. Mounts into the Freedom Data PC top right slot. Module Sample Shown: 1 Channel (for CSL-1) or 2 Channel (for CSL-2) hydrophone signal amplification and filtering circuits with internal interface cable to data acquisition card
 **Pulser Module (bottom right slot)**	1	Olson Instruments built electronic unit configured for system method purshased. Mounts into the Freedom Data PC bottom right slot. NOTE: Not all systems will have a pulser module. If this is the case, a blank cover plate is substituted into the slot
	1	Internal, shock-mounted National Instruments 1.25 MHz, 16 Bit, 16 channel PCI Data Acquisition M-Series Card Standard, Optional Cards Available
 **External Power Supply/Charger**  **12 VDC Automobile Adapter**	1	110/220 VAC 50-60Hz autoswitching power supply for Freedom Data PC plus 12 volt DC Automobile Adapter
 **Lithium Ion Batteries**	2	Shown with cover removed from top, exposing 2 - Internal Lithium Ion Batteries, ~ 8 to 10 hrs of operation You will need to install the batteries when your Freedom Data PC arrives from the manufacturer. Refer to Section 2 for instructions

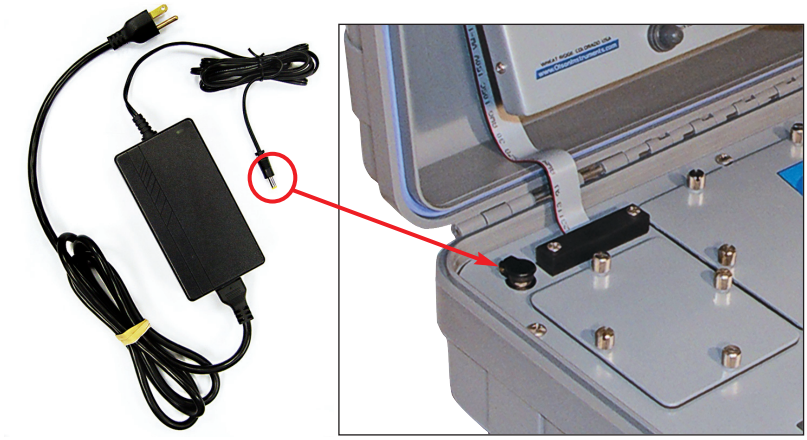
2.0 FREEDOM DATA PC HARDWARE

2.2 HARDWARE SETUP

The hardware connection steps are illustrated below. Please refer to these figures and the test during connection of the components. A step-by-step procedure for connecting the various system components is included below.

1. Lay the instrument case and Freedom Data PC down on a flat, stable surface. Unlock the case if locked. Next, open the Freedom Data PC case. The location of the Freedom PC should be within 15 m (50 ft) of the subject/material to be tested.

2. Next, if desired, connect the Freedom Data PC to the external power supply from the 115/120 VAC Power Supply/Charger. The external power supply/charger automatically switches between 115/230 Volts AC.



This computer should not be exposed to heavy rain. However, the computer is designed to be resistant to light rain or other moisture.

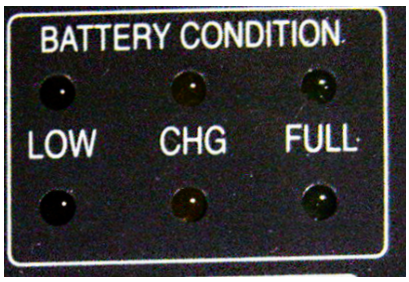
3. BATTERY INSTALLATION

The Freedom Data PC is shipped without the batteries intalled. Remove the battery cover as shown. Insert both batteries with the (+) polarity to the right (photo below)

Opening Battery Cover

Insert Batteries with (+) on right side

The internal batteries, if fully charged, should power the Freedom DATA PC system for 8-10 hours depending on whether the backlight is used. The Freedom Data PC can also be powered from an automobile cigarette lighter socket using the supplied 12 VDC adapter. This may drain a weak car battery in a few hours if the engine is not running.



BATTERY CONDITION INDICATOR LIGHTS

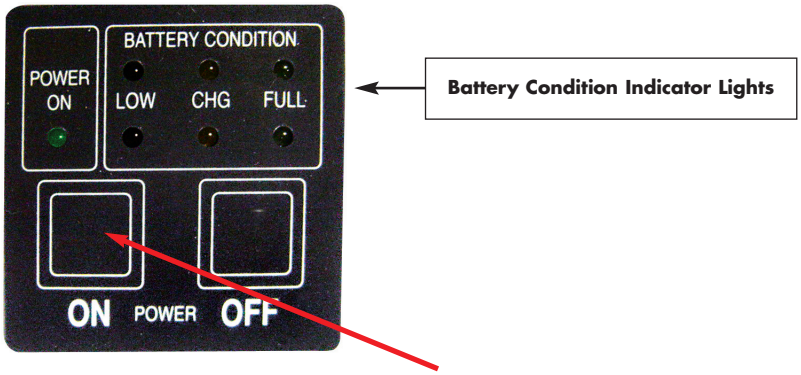
Green Light =	Batteries are fully charged and stays on
Yellow Light =	Charging status
Red Light =	Low Battery, ~15 minutes usage left, put external power charge on at this point

2.0 FREEDOM DATA PC HARDWARE

2.3 HARDWARE OPERATION

After the Freedom Data PC /CSL hardware is properly set up, operation is straightforward and primarily involves the use of the Freedom Data PC and the installed modules. The operation of each of the controls on the Input Module and CSL Pulser Module are described in this section.

1. Power



Power on the Freedom Data PC by pressing the "ON button" as shown.

If the battery LED is ***red***, do not try to operate the computer, as the batteries are very low. In this case, the system should be run on external power rather than off the batteries. Charging of the batteries will begin once external power is attached. A running automobile outputs approximately 14.2 VDC, which will charge the batteries to around 85% of full charge. To achieve 100% charging power, use the 16 VDC AC p owered external power supply that is shipped with your instrument.

When operating the computer on external power with partially or fully discharged batteries, a "Fault" light may appear after a period of time. This is normal, and is due to the combined current drain of the computer operation and the battery charge current. The batteries will charge normally if the power supply is connected with the computer power shut off (such as overnight). Totally drained batteries will require 12 - 13 hrs for full charging.

2.3.1 FREEDOM DATA PC OPERATION NOTES

The Freedom Data PC is a self contained data conditioning, collection, and processing platform usable for a number of types of NDE Geophysical and Vibration measurements as well as general data acquisition. The data acquisition tasks for which the Freedom Data PC is capable, depends on the modules installed (up to two at a time) and system(s) purchased.

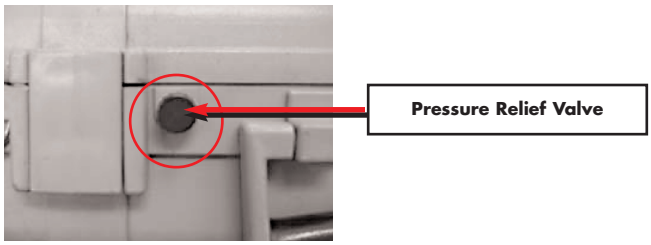
The following sections discuss the basics of the hardware operation of the Freedom Data PC, including:

1. General Maintenance and Usage
2. Battery Charging and Usage
3. Removing and Replacing Batteries and Modules

2.3.1.1 GENERAL MAINTENANCE AND USAGE

The Freedom Data PC is a ruggedized unit designed for field conditions. It is normally water and air tight when closed and latched, which will protect it in most storage and transportation conditions.

The unit may be difficult, if not impossible to open if the unit is shipped to a lower altitude while closed, due to the change in air pressure. If this happens, simply unscrew the pressure relief valve on the front of the unit near the handle (photo below). When the valve is unscrewed all the way, air should be heard flowing into the unit until the pressures stabilize. At this point, the cover can be opened and the valve replaced.



While the Freedom Data PC is water-tight when closed and the bleed air valve is closed, it is water resistant (not water-tight) when open or operating. Thus, rain or other normal moisture should not bother the unit, but it should NOT be submerged or sprayed at high pressure. Also, water should not be allowed to collect or pond on the face of the computer unit.

Never expose the external power supply/charger to rain or moisture. The other components of most systems can all be freely exposed to rain, etc. (depth wheel, transducers, cables)

2.0 FREEDOM DATA PC HARDWARE

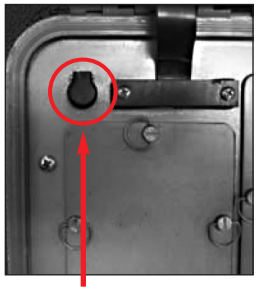
CLEANING THE FREEDOM DATA PC

When used in a field environment, the Freedom Data PC should be expected to get dirty. If this happens, simply wipe the unit with a damp (not wet), clean towel. Do not allow water to flow into any of the components, and do not wipe the plastic film covered screen with a dry or dirty towel.

The screen is subject to damage if impacted or pressed on

2.3.1.2 BATTERY CHARGING AND USAGE

The batteries inside the Freedom Data PC consist of 2 sealed units, each of which is 12 VDC, 11 Ampere-Hours. Depending on the usage, these batteries should last for 8-12 hours of continuous use, depending on the state of the backlight switch. After this, the batteries should be recharged or switched out with a fully charged pair. The batteries used are Lithium Ion batteries with internal protection circuitry. There is no memory effect, so batteries can be used freely with only a partial charge.



External Power Supply Jack

Opening Battery Cover

Cover Removed, Exposing 2 Lithium Ion Batteries

Charging the Batteries

1. Turn off "POWER" to the Freedom Data PC
2. Plug in the external power supply/charger into the jack in the upper left-hand corner on the front panel of the unit (top left photo). The yellow "CHARGE" lights will come on for each battery for the bulk of the charge cycle. At 85% of capacity, the green "FULL" lights will light, with all lights out when the battery is completely full. Always charge the batteries in a protected environment, at normal room temperatures. The batteries "charge" light indicates that the batteries are nearly fully drained and need recharging.

2.0 FREEDOM DATA PC HARDWARE

To prolong battery life, always recharge the batteries IMMEDIATELY after use

Do not disassemble, incinerate, short out, or otherwise abuse the batteries as there would be a possible risk of FIRE or EXPLOSION!

If power is available at the field site (110/220 VAC), the external power supply/charger can be used to power the Freedom Data PC with or without batteries installed. The external power supply/charger will run the unit and start to charge the batteries if installed. A 12 VDC adapter can also be used to power the unit off of a car battery.

The Freedom Data PC should be turned OFF before connecting or disconnecting the external power supply/charger. Disconnecting the power supply/charger during operation may cause the Freedom PC to reboot and lose data in memory, especially if the batteries are very low. If it does reboot, turn off power, then turn on again for normal operation.

Maximizing Battery Life

The following can help maximize the run-time of the batteries:

— Turning off the screen backlight (only use the backlight indoors or in the dark)

— Turning off the computer if not used (when moving or setting up other equipment)

— Use external power when easily available

— Recharge the batteries immediately after each use to preserve capacity

2.0 FREEDOM DATA PC HARDWARE

2.3.1.3 REMOVING/REPLACING BATTERIES AND MODULES

The batteries and Input/Pulser Modules on the Freedom Data PC are field replaceable. They all use thumbscrew fasteners for securing.

Removing the Modules:

1. Turn off "POWER" to the Freedom Data PC
2. Disconnect all cables from the module
3. Loosen the thumbscrews counterclockwise (see Figure "Module Thumbscrews")
4. Pull up firmly and evenly on the screws to remove the module

Step 2: Disconnect all cables

Note: Newer models will not have the rings as shown.

Step 3: Module Thumbscrews

Replacing the Modules:

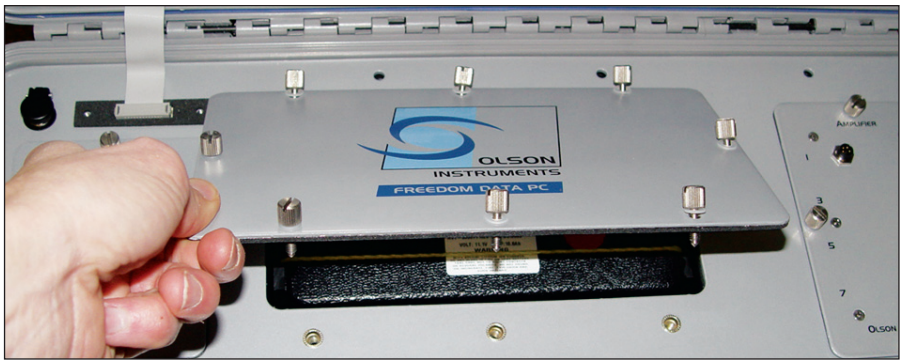
1. Simply press the module fully into the slot and tighten the thumbscrews clockwise

2.3.1.3 REMOVING/REPLACING BATTERIES AND MODULES *continued*

Replacing the Batteries

Replacing the batteries in the Freedom Data PC is a similar operation to removing/replacing the modules from their slots.

1. Unscrew the 8 thumbscrews (photo below)
2. Lift off the battery cover, it should lift up freely
3. Lift the batteries out by the lifting cord
4. Install new batteries by dropping them into the compartment
   Note: They are keyed for polarity and cannot be inserted wrong
5. Replace battery cover
6. Press and hand-tighten each of the 8 thumbscrews



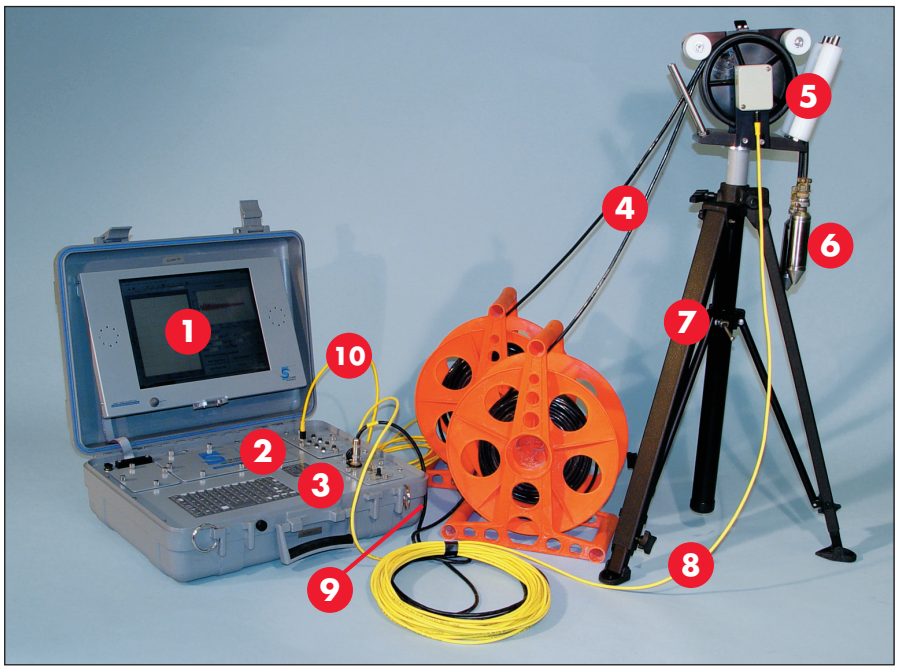
Steps 1-2: Loosen the 8 thumbscrews, lift cover off entirely to remove batteries

Step 3: Lift batteries out by the yellow cords

3.0 CSL HARDWARE SETUP

EQUIPMENT LIST FOR CROSSHOLE SONIC LOGGING (CSL)

(1) - 1 Olson Freedom Data PC
(2) - 1 CSL Input Module (1 Channel High Pass)
(3) - 1 CSL Pulser Module
(4) - 2 Orange Reels of CSL Cable (3 Pin MS to Phone Plug)
(5) - 1 Depth Wheel
(6) - 2 Hydrophones
(7) - 1 Tripod
(8) - 1 Depth Wheel Cable (Yellow Cable, 3 Pin Adapter)
(9) - 1 CSL Source Cable (Phone Plug to Phone Plug)
(10) - 1 CSL Receiver Cable (Phone Plug to 4 Pin Adapter)



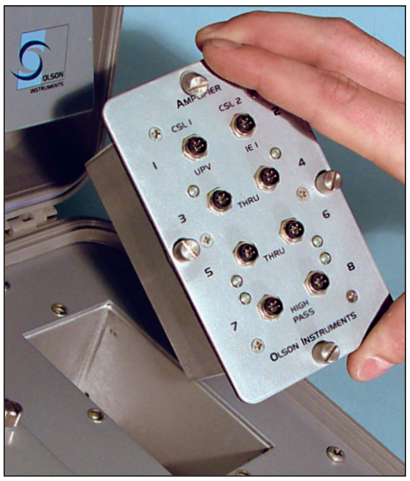
* Equipment/Software Required for Testing Not Shown in Photo:

- 1 Tape Measure
- Latest CSL2 Software
- Field Notebook & Pen

STEP-BY-STEP GUIDE

CROSSHOLE SONIC LOGGING (CSL) HARDWARE SETUP

1. After opening the Freedom Data PC, insert the input module into the top module pocket if not already present. This pocket is reserved for the input module.



2. Next insert the CSL Pulser module into the bottom right module pocket if not already present. This pocket is reserved for the pulser module.

3. Now that the modules for this test are resting in their appropriate module pockets, hand-tighten the screws on each module to secure them into the Freedom Data PC. The screws must be properly aligned with the holes in the Freedom Data PC.

3.0 CSL HARDWARE SETUP

4. SETTING UP THE TRIPOD:

a. Open tripods legs by loosening the locking lever connected to the center of the tripod and pulling the legs in the outward direction.

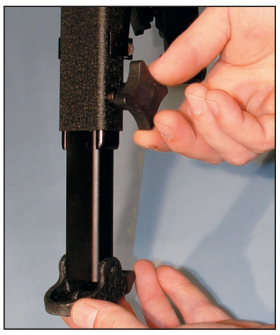
b. Set the tripod to the desired height and tighten the locking lever by hand.

c. Loosen and tighten the thumbscrew at bottom of each leg to adjust the legs of tripod.

d. The center of tripod can be raised or lowered by adjusting knob at the top of tripod.

4a

4b

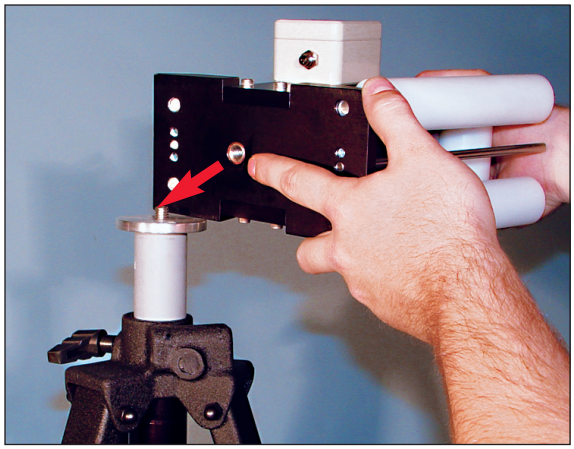


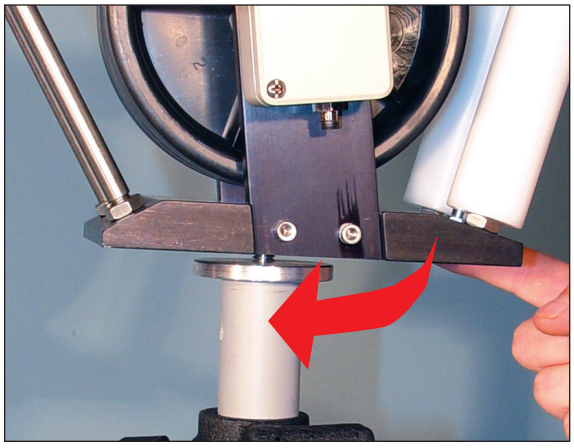
4c

4d

5. ATTACHING DEPTH WHEEL TO THE TRIPOD:

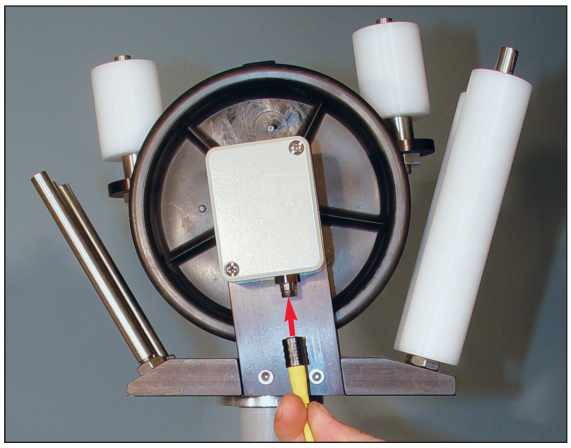
a. Carefully screw the depth wheel onto the tripod by aligning the screw with the hole in the bottom of the depth wheel. Rotate clockwise and hand-tighten.

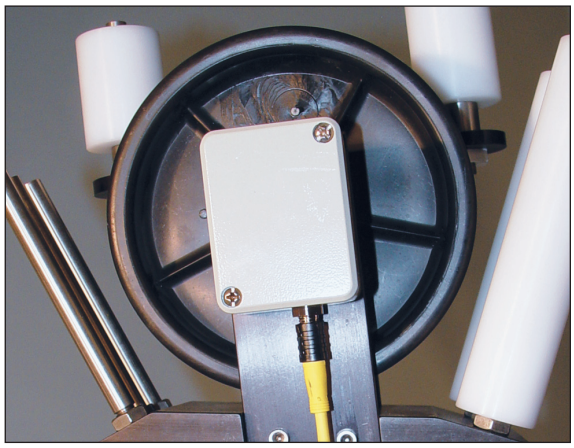




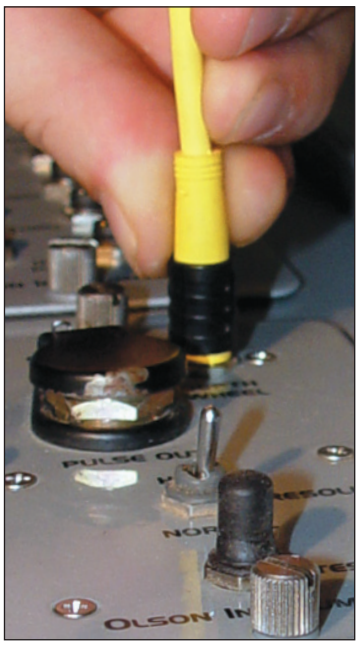
6. **CONNECTING THE DEPTH WHEEL TO THE FREEDOM DATA PC:**

a. Attach the yellow three-pin depth wheel cable to the encoder on the depth wheel. This is done by pulling back on the small black sleeve at the end of the cable and carefully lining up the three holes on the cable with the three pins on the encoder.



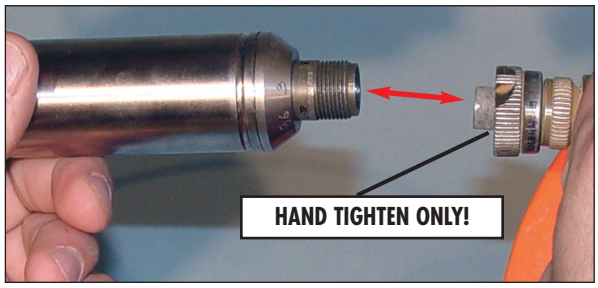


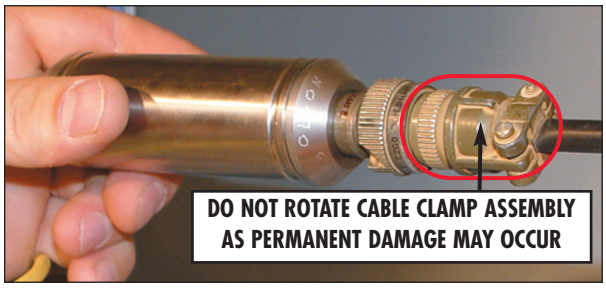
b. The other end of the yellow cable will then attach to the pulser module on the computer. Attach the cable to the input port on the pulser module labeled "DEPTH WHEEL" by aligning the three pins with their appropriate holes.



3.0 CSL HARDWARE SETUP

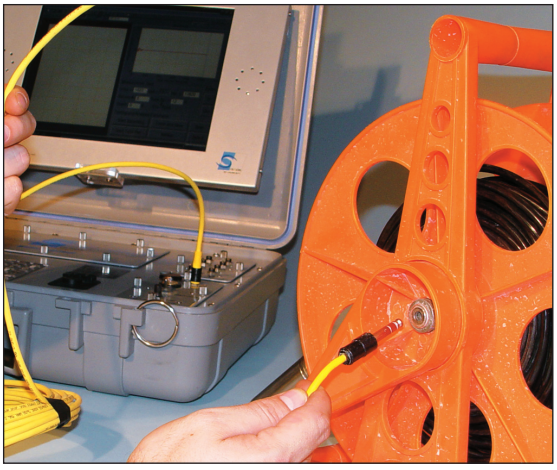
7. Attach a hydrophone to one of the orange reels of CSL cable (3 pin MS to phone plug). Attach the hydrophone to the CSL cable by aligning the three pins of the hydrophone with the three holes on the 3-pin MS end of the CSL cable and carefully hand-tighten the hydrophone to the cable as you push the connector in. Reverse the step to remove the hydrophone(s).



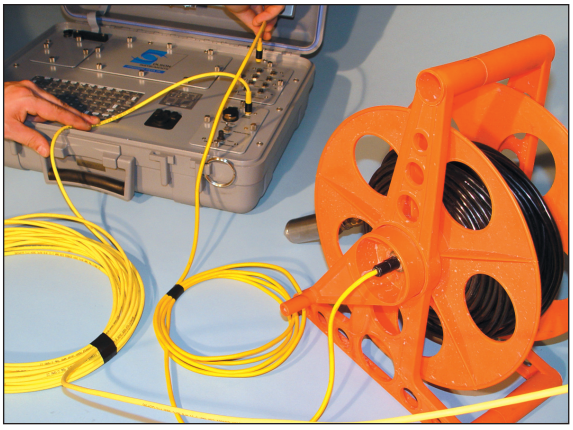


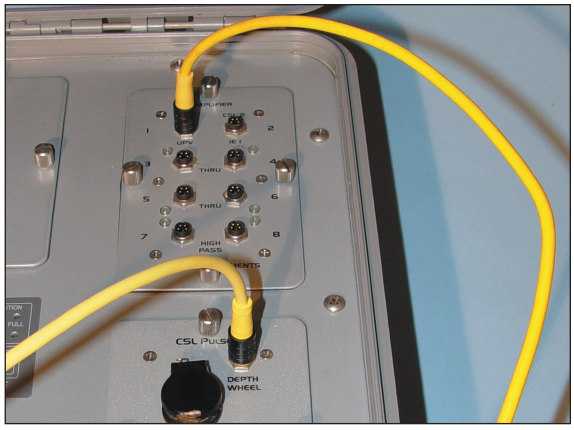
The transducers are subject to damage if impacted. NEVER drop a transducer, or allow one to swing on a cable end and impact any hard object. Olson Instruments DOES NOT WARRANTY transducers from physical damage.

8. Next attach a yellow phone plug to 4-pin adapter cable to the side of an orange reel of CSL cable. The phone plug can simply be inserted into the side of the orange spool by pushing it in; alignment is not necessary. The yellow cable will have a four-pin connection on the other end of it to connect to the pulser module on the Freedom Data PC.

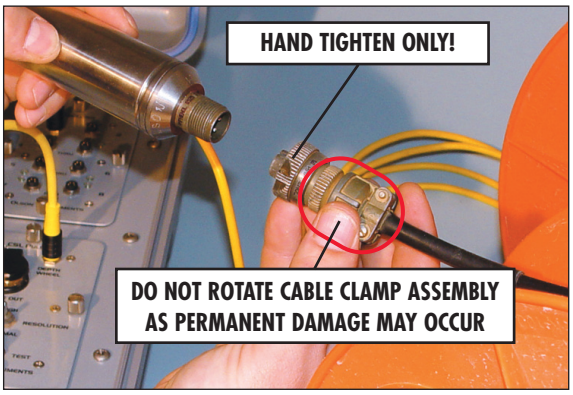


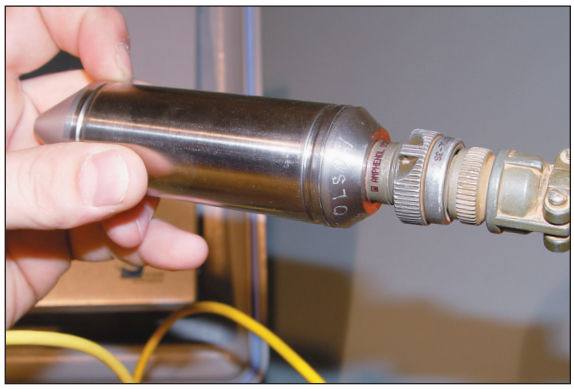
9. Once the phone plug has been securely attached to the orange spool, the four-pin adapter can be attached to the computer. This can be done by pulling back on the small black sleeve at the end of the cable and carefully lining up the four holes on the cable with the four pins on the input module.





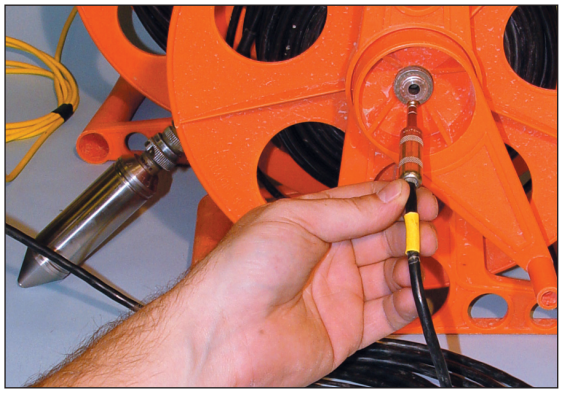
10. Next you will need to attach the other hydrophone to the other orange reel of CSL cable (3-pin MS to phone plug). Attach the hydrophone to the CSL cable by aligning the three pins of the hydrophone with their three corresponding holes and carefully hand-tighten



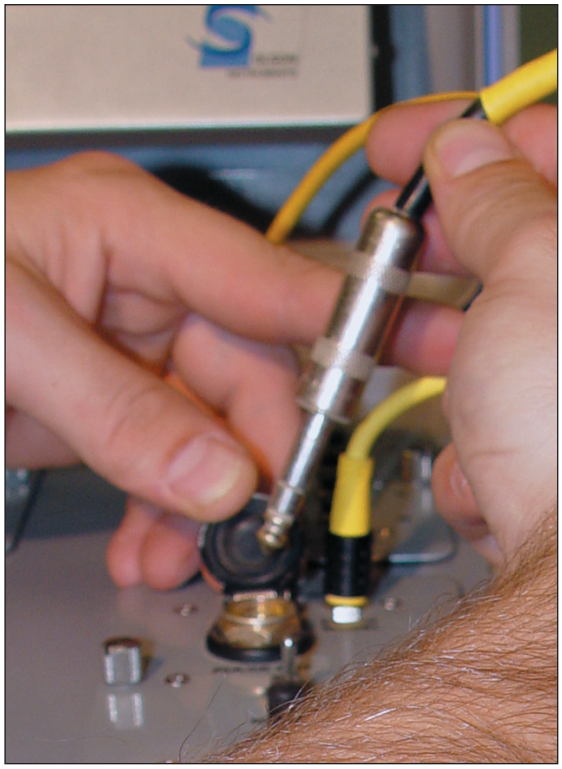


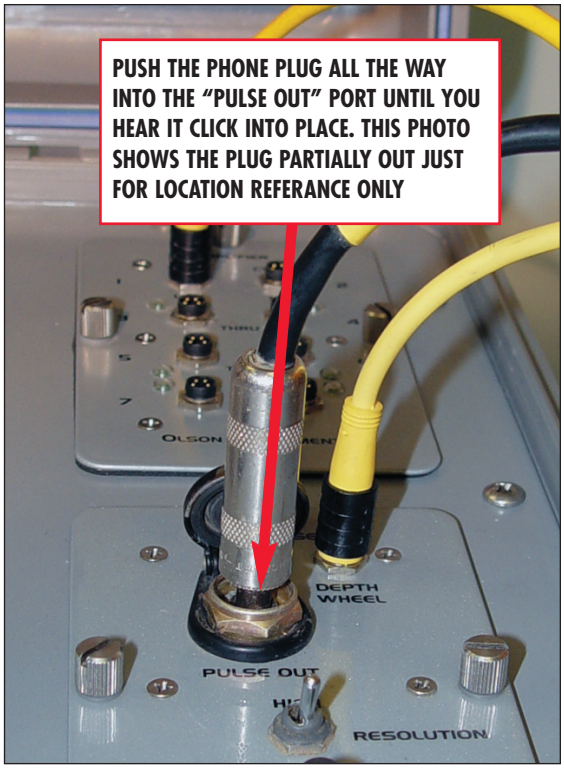
3.0 CSL HARDWARE SETUP

11. Attach the black phone plug cable to the side of the 2nd orange reel of CSL cable. This plug can simply be inserted into the side of the orange reel by pushing it in; alignment is not necessary. Both ends of the cable have phone plug adapters.

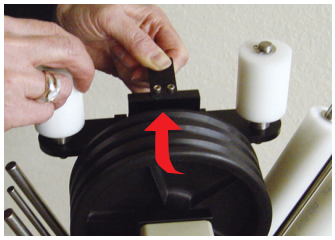


12. Once the black phone plug has been securely attached to the other orange reel, the other side can be attached to the pulser module on the computer. Insert the phone plug into the pulser module where the words "PULSE OUT" appear. Lift the black cover and insert the phone plug fully until you hear it click.

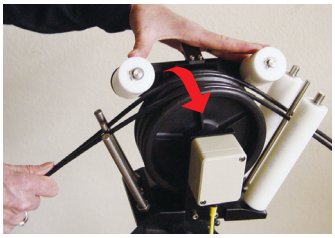




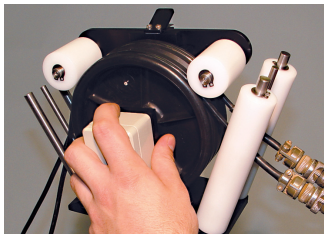
13. The Depth Wheel requires the downhole cables to be placed in the grooves of the wheel for accurate depth measurements. Refer to the following steps:



13a - *Squeeze latch spring and rotate pinch rollers at the same time as shown*

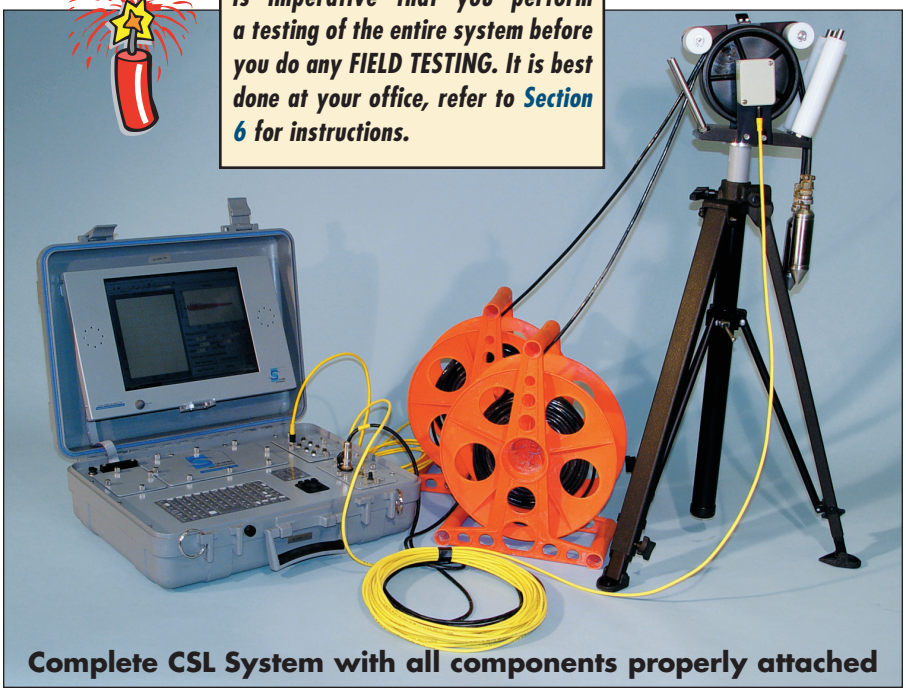


13b - *Holding wires, rotate pinch rollers back to LOCK position*



13c - *Slack adjusted in cable, rollers in LOCK position*

1. Squeeze the pinch roller latch spring with one hand and with your other hand, rotate the pinch roller assembly until it can go no further (photo 13a).
2. Place downhole cables in outer grooves of depth wheel. You will not use the center groove for the CSL-1 test. Pull cables enough to remove any slack in the downhole cable, leaving the hydrophones at bottom of tubes.
3. While holding slack from cables, rotate pinch roller assembly back to it's LOCK position. (photo 13b and photo 13c).
4. It is now OK to let go of the cables as the one way clutch in the depth wheel prevents cables from going slack.



After setting up both Freedom Data PC and CSL hardware components, it is imperative that you perform a testing of the entire system before you do any FIELD TESTING. It is best done at your office, refer to Section 6 for instructions.

Complete CSL System with all components properly attached

4.0 FIELD TEST PROCEDURES

4.0 CSL Field Test Procedures

At this stage, we assume that you have performed the "Test Overall System Operation" as outlined in **Section 6** of this manual, and have verified that the equipment is running properly. You are now ready to begin Field Testing Procedures using CSL.

The following are the simplified steps that need to be followed in order to collect data in the field:

1a. Set up the equipment at the test site as described in the CSL Hardware Setup, **Section 3**.

1b. Place the depth wheel stand 3 - 6 feet (1 - 2m) away from the shaft and ensure the depth wheel is higher in elevation than the tops of the test tubes. Failure to properly elevate depth wheel will result in slippage and improper depth measurements.

2. Assign tube number to each of the test tubes, starting with 1 (one) and increasing in a clockwise order. If testing more than one shaft, it is recommended to have tube 1 on all shafts oriented in the same direction (i.e. northernmost tube).

3. Measure tube spacing for all tube pairs (center of tube to center of tube).

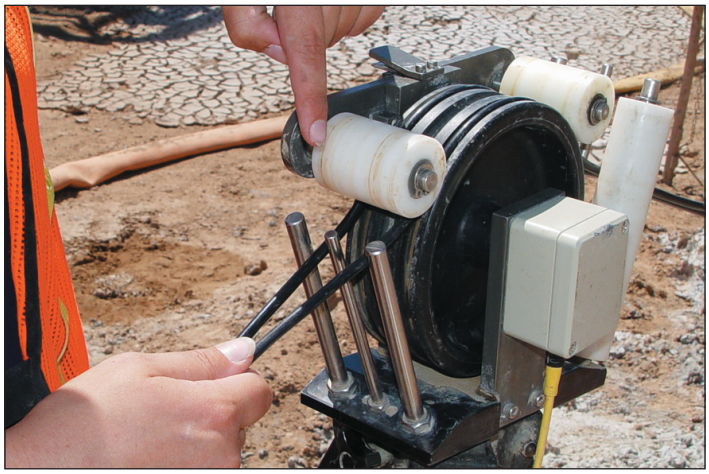
4. Set up **data acquisition** as described in **Section 7**.

5. Lower hydrophones in the first tube pair (1-2) and ensure cable guides are properly inserted. Inserting the cable guides will prevent abrasion of the cables. Failure to insert the cable guides will decrease the life of the hydrophone cables.

4.0 FIELD TEST PROCEDURES

6. Ensure that the tips of the hydrophones are gently resting at the bottom of the test tubes. The hydrophones should be within 3-6 inches (7.5 - 15cm) apart in elevation in order to collect accurate data. The bottom can be felt by removing all slack in the cables and gently raising and lowering the hydrophone several inches (cm).

7. Once hydrophones are at the proper elevation, lock the cables into the depth wheel to prevent slippage.



8. Test signal as described in **Section 6**. If a strong signal is displayed, proceed to step 9. If the signal is weak (requiring too high of a gain) or not seen at all, check all connections and re-adjust hydrophone elevations to ensure they within 3-6 inches (7.5 - 15cm) in elevation from each other and not laying on their sides. Test signal and repeat if necessary.

9. Start **acquisition** as described in **Section 7** of the manual.

10. Raise both of the hydrophones, at same time, at a rate of no faster than 2 ft/second. (0.6m/s). When the hydrophones reach the top of the test tubes, make sure that the hydrophones are within 6 inches (15cm) or less in elevation of each other. If the elevation difference is greater than 6 inches, (15cm), repeat Steps 4-9 for the same tube pair. If the tubes are of different lengths, repeat the log and measure the cables for the source and receiver hydrophones to lower them to the depth of the shortest tube.

4.0 FIELD TEST PROCEDURES

11. If the hydrophones are within six inches in elevation of each other, **Finish and Save** the data set for this tube pair, see **Section 8, Step 2**.
12. Place hydrophones and cable guards in the next tube pair. It is strongly recommended to unlock the depth wheel before moving the hydrophones in order to prevent knocking over the equipment.
13. Repeat Steps 5 - 12 until all tube pairs have been tested.
14. **Finish and save** the complete data set for all tube pairs tested, see **Section 8, Step 2**.

Photo showing field testing setup and procedure

5.0 SOFTWARE

The software for the CSL Systems is pre-installed and thoroughly tested at the manufacturer. If for any reason you need to reinstall/uninstall, the steps are included in this manual.

5.1 CSL2 SOFTWARE INSTALLATION

Prerequisite software (NIDAQ 7.4) prior to installing the CSL software (version 3.0 and higher) can be located in the enclosed CD or downloaded at:

http://digital.ni.com/softlib.nsf/websearch/90b60d5899bcccdb86256fc700581b89

If retreiving files from the web, download the two(2) files named NIDAQ740CD1.ZIP and NIDAQ740CD2.ZIP. Unzip the files and install the NIDAQ program.

Failing to install the prerequisites will result in an error when running the CSL software

Installing the CSL Software:

1. Uninstall the previous version or delete "c:\program files\olsoninstruments\csl2\csl2.exe" if the older file exists
2. Run "Setup.exe" from the Olson Instruments install CD
3. Type any numbers for the serial number
4. Follow the default setup
5. After finishing the installation, the "CSL2.exe" file will be found on: drive C:\Program Files\Olson Instruments\CSL2\
6. Make a shortcut of the program folder and paste it into your desktop location
7. Copy "default.prm" file from the CD to the root directory (C:\) in the Freedom Data PC™ hard drive

Failing to uninstall or delete the previous version of CSL will prevent the installation of the new version

Updating the CSL2 Software:

1. For updates to software, the only file that is necessary is the "CSL2.exe" file. This file must be installed in the drive c:\Program Files\Olson Instruments\CSL2 directory. If not, the shortcut on the desktop references the old version of CSL2. Simply replace the existing "CSL2.exe" by copying and pasting the new version into the directory.
2. Verify the default.prm file is located in the directory listed below;

   c:\program files\olsoninstruments\CSL2

   otherwise a parameter file error will pop up during the initial execution of the software. The default parameter file will be created after "Save Data Parameters" is clicked under the "Acquisition" tab.

5.2 PRINTER DRIVER INSTALLATION

1. For Windows 98 Users
   a. Go to the dos prompt, go to directory c:\windows\system>
   b. Type: regsvr32 nireports.dll
2. For Windows 2000 Users
   a. Type: regsvr32 c:\winnt\system32\nireports.dll (in the Run Command line)
3. For Windows XP Users
   a. Type: regsvr32 c:\windows\system32\nireports.dll (in the Run Command line)

If you fail to do the driver installation, all the printing commands will not work

5.3 MICROSOFT WORD SETUP

CSL software version 3.0 or higher allows users to link the CSL logs and reports to the MS Word program (version 2002 or higher.) Instructions on how to set up the MS word software to accommodate the CSL software are described in this section:

1. Open the MS Word program
2. Set the margin of MS Word program by going to File/Page Setup. Select the Margin option and set the left margin of 1" (25.4mm) and right margin of 0.8" (20mm). Finally, click on the "Default" button to save the new setup values into the default file. Failure to do this step will result in misalignment of logs and the picture of the shaft template.
3. Set the picture's text wrapping property to be "in front of text" by going to Insert/Picture/From File. Then select any picture in the PC. Click on the picture and go to Format/Picture. Select the "Layout" option, click on "in front of text" option, then select OK. Finally, save the main document onto doc1.dat. Failure to do this step may result in misalignment of logs and the picture of the shaft template.

5.0 SOFTWARE

5.4 SETUP COMPANY LETTERHEAD FOR AUTOMATICALLY GENERATED CSL REPORT

CSL software version 3.4 or higher allows users to add company letterhead to the top of the front page of the CSL report. The letterhead is required to be in a bitmap format (.bmp) with a maximum height of 1.15 inches. Rename the letterhead file to "letterhead.bmp" and move this file to c:\program files\olson instruments\CSL2\.

5.5 CSL2 SOFTWARE UNINSTALL

1. Click on Start/Settings/Control Panel
2. Select "Add/Remove Programs"
3. Highlight CSL2, select "Remove"

The uninstall process will begin automatically, removing all installed components including shortcuts.

5.6 FIRST TIME RUNNING THE CSL2 SOFTWARE

1. Double click on the **"Launch CSL.EXE"** icon on the desktop

2. An error message "OlsonKey.dat is not found" will appear on the screen for the first time running the software. Click ok to proceed to the next step.

3. The tomography option will be disabled without the correct software key registered in the PC.

4. To register the software key in the PC, enter any directory in the "Project Name" field, then click on "CSL" button.

5. The main menu will appear on the screen. Go to "Test New Shaft" option.

6. For the first time running the CSL2 software and the default parameter file (default.prm) does not exist on the system, a applet for data acquisition card selection will appear on the screen. The user MUST select one type of National Instruments data acquisition card (E or M) for the Freedom Data PC. This information will affect the gain control. In general a Freedom Data PC with Transmeta CPU comes with an E card and a Pentium M system comes with an M card. Note that either M or E card can be selected for the processing PCs.

7. A template error will appear on the screen for the first time running the CSL2 software. Once the program detects that a template file does not exist, it will automatically generate and save the template file.

8. The Shaft Information screen will appear on the screen. Go to Help/Software Key and enter the 9 digit number attached on the CSL installation CD case. Failure to register the software key on the PC will result in an error message every time the CSL software is executed.

5.0 SOFTWARE

5.7 START CSL2 SOFTWARE

1. Locate the "CSL2.exe" file or it's shortcut
2. Double click on either the "CSL2.exe" file or the shortcut you created on the desktop
3. The following dialog box should appear on the screen:

Tomography button disabled if TOMO-1 software was not purchased

Perform the following steps:

1. Enter the desired project name in the top entry. This name will be used to create a new directory (if the directory does not already exist). If the directory already exists, you can also click on the **Browse** button to select the existing directory.
2. Check the date in the bottom entry. The correct testing date should appear on the entry. If the date is wrong, enter the correct date. Correct the clock on the Freedom PC if necessary.
3. If the user needs to perform a zero offset Crosshole Sonic Logging (the standard horizontal log which will be referred as CSL for the rest of the text), press the **Enter** key or click at the button 

then go to Section 4.1. If the user needs to perform tomography tests, click at the button 

then, go to Section 4.1. Please note that this tomography button will be **disabled** unless the additional TOMO-1 software is purchased.

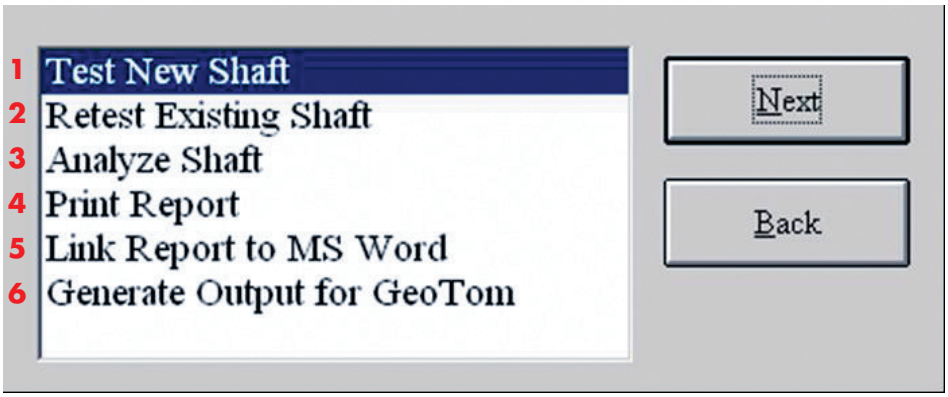


Figure 2: CSL Options from Main Menu

The user will see the following six options appear on the screen as shown in Figure 2:

1. **Option 1** — **Test New Shaft**

   Allows users to acquire the data or perform the CSL test on new shafts. If this option is selected, please continue to **Section 5.8**.

2. **Option 2** — **Retest Existing Shaft**

   Allows users to continue testing on previously tested shafts. If this option is selected, please continue to **Section 8.1**.

3. **Option 3** — **Analyze Shaft**

   Allows users to analyze data in the office that was previously acquired in the field. If this option is selected, please continue to **Section 9.1**.

4. **Option 4** — **Print Report**

   Allows users to prepare the automated CSL final report. This option will let user customize the report (whether full report printing or just logs printing). If this option is selected, please continue to **Section 10**.

5. **Option 5** — **Link Report to MS Word (optional software feature)**

   Allows users to link the automatically generated CSL report directly to MS Word If this option is selected, please continue to **Section 10**.

6. **Option 6** — **Generate Output for GeoTom Crosshole Tomograhy Analysis**

   Allows users to export CSL data (zero offset data) to be processed using 3-D imaging software.

The first and second options "Test New Shaft" and "Retest Existing Shaft"allow users to acquire and post-process the data right after data collection in the field. The remaining options "Analyze Shaft" and "Generate Report" do not allow data acquisition.

5.0 SOFTWARE

5.8 TEST NEW SHAFT

If this is the first time executing the CSL software and the default.prm file does not exist, the dialog box saying "default.prm file not found" will appear twice on your screen as a warning, simply click OK to clear the message.

Then the program automatically generates a default parameter file called default.prm. This file will be saved in c:\program files\olson instruments\CSL2\. These parameter values can be changed by going to Acquisition/Parameter Setup and can be saved for future use by going to Acquisition/Save Parameter Setup (or F10).

The "Test New Shaft" option allows users to perform CSL data collection. The figure below should appear on the screen:

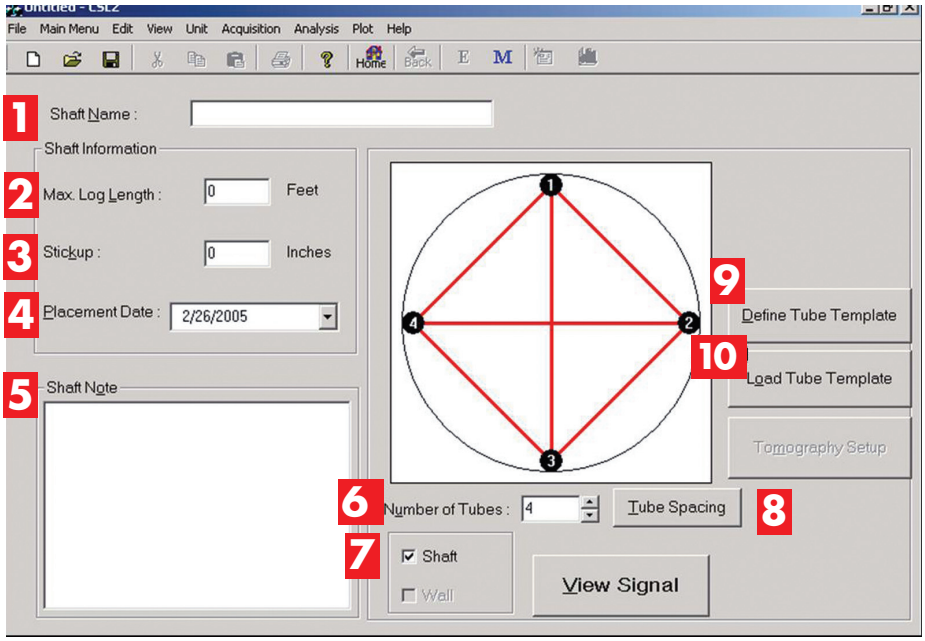


Figure 4: Shaft Information Screen

5.9 SHAFT INFORMATION SETUP

The following 12 steps will need to be completed as shown in Fig. 4, previous page:

1. Enter the name of the shaft to be tested in Entry 1. This name will be used as a filename saved in the previously created directory. **This field input is mandatory**.
2. Enter the estimated concrete shaft length in Entry 2. This field is not required. If this field is not filled, an estimated length of 40 ft (or 12.19 Meter) will be assumed. This shaft length will be used in a real time first arrival time scanning. After the logging process is completed, the actual shaft depth will be calculated based on the depth wheel calibration and the actual number of records collected (see Fig.14, Section 7).
3. Enter an average measured tube stickup height above concrete in Entry 3. This field in not required. This stickup will be used in real time first arrival time scanning only. This data can be changed after the data collection is complete.
4. Check the placement date in Entry 4. The default placement date will be a day before the testing date. Correct this date if it is incorrect. **This field is mandatory if the report generation option is desired.** However, this placement date can be changed later in the analysis.
5. Enter any comments the user might notice during data collection in the Shaft Note box (Entry 5) such as cracked concrete, water below tops of tubes, etc. To move to the next line in Entry 5, press "Ctrl+Enter". This field is not required.
6. Change the number of access tubes in Entry 6. **This field is mandatory and cannot be changed later in the analysis.**
7. In Entry 7, the user can select two types of CSL test setup; Shaft or Wall setup. NOTE: Wall geometry setup is currently under construction as of this writing.
8. Click on 

to enter the measured center to center spacing between tube pairs. This option is not mandatory during the data collection, but **strongly suggested** since some of the scanning parameters are calculated from tube spacing. If they are not entered correctly during data collection, a spacing value of 12 inches will be assumed between each tube pair and the calculated velocity during real time data collection will not be correct. In addition, the real-time scan may not be clear due to the assumed parameters.
9. The CSL software version 2.14 and higher supports user-defined tube templates. The tube template can be defined, saved and loaded. To define the tube template, click on "Define Tube Template" button. An applet as shown in Figure 5 (next page) will appear on the screen. Users can add/remove tube-pairs from the pre-defined template. The user-defined template can be saved by clicking on "Save Template" button.

5.0 SOFTWARE

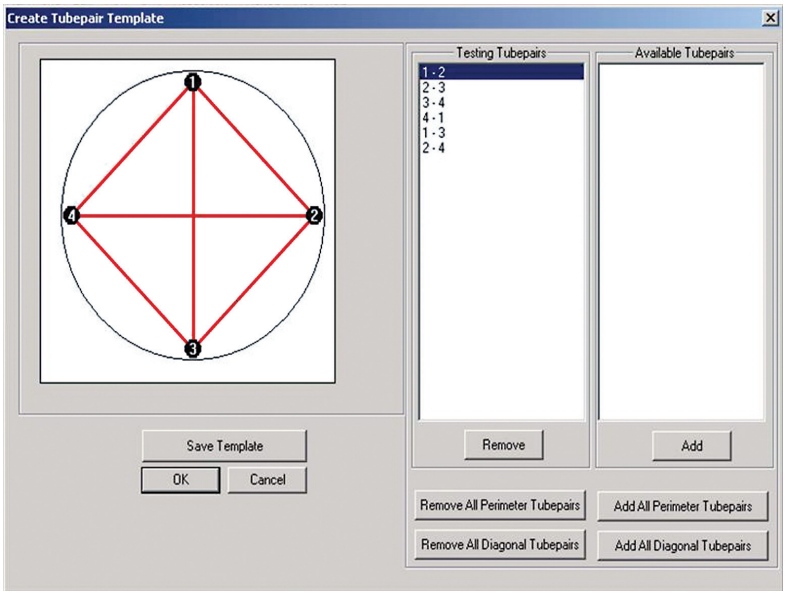


Figure 5: User-Defined Tube Template

10. The software will be loaded up with the last used tube template. However, the software allows users to recall any pre-defined tube template by clicking on "Load Tube Template" button. The following screen is an example of shaft information input. In this case, only diagonal tubepairs were selected in the user-defined tube template:

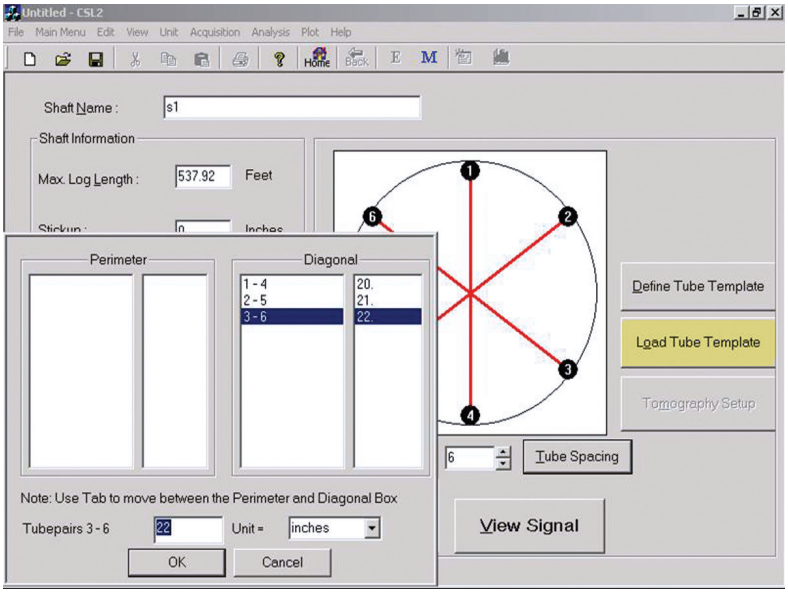


Figure 6: Shaft Information Input

11. The pre-defined tube template can be loaded by clicking on "Load Tube Template". An applet shown in Figure 7 will appear on the screen. After selecting the desired saved tube template, the screen will be updated according to the selected file.

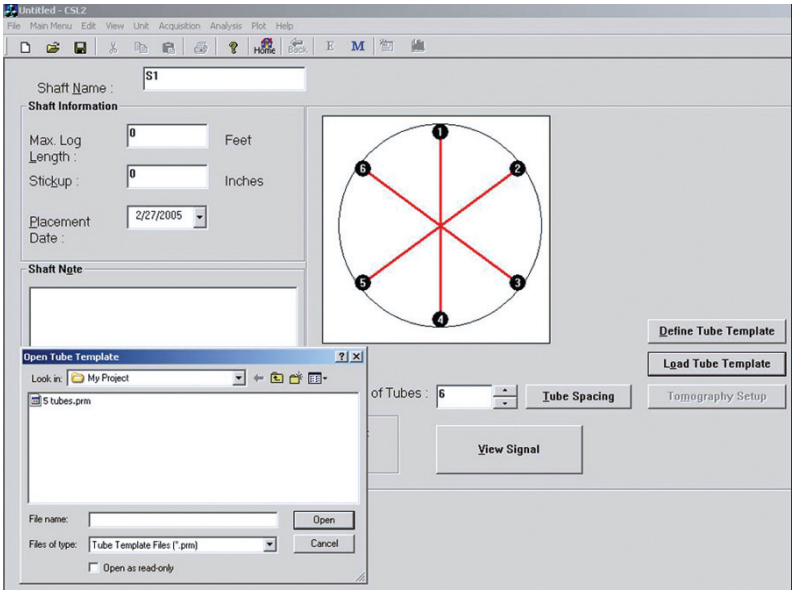


Figure 7: Loading Tube Template

12. After completing the necessary information, click View Signal on to proceed to the data collection procedure. The following screen in Figure 8 should appear to confirm the filename. **It is highly recommended to use the input shaft name as a filename.** Then, click Save to save the shaft information and proceed to the next screen. Note that if the name entered is the same as a previously saved file name, the user will be prompted to overwrite the data.

Figure 8: Filename Confirmation

5.0 SOFTWARE

5.10 NUMBER OF CSL RECEIVERS

The CSL system comes with 2 options; 1 receiver (CSL-1) and 2 receivers (CSL-2). The CSL system with 1 source and 2 receivers allow for faster data collection by simultaneously acquiring data from two tubepairs at the same time. This option can be selected by going to "Acquisition/Number of Receivers". Then an applet shown in Figure 9 will appear on the screen. Select "Different Tube" option if the two transducers will be inserted into two different tubes to speed up the CSL test process. However, if the angled CSL test is to be performed, both receivers can be inserted into the same tube with a pre-defined transducer spacing. In this case, if the receiver from Ch1 is below the receiver from Ch2, a negative transducer spacing will be entered in the applet. If the receiver from Ch1 is above the receiver from Ch2, a positive number of transducer spacing will be used.

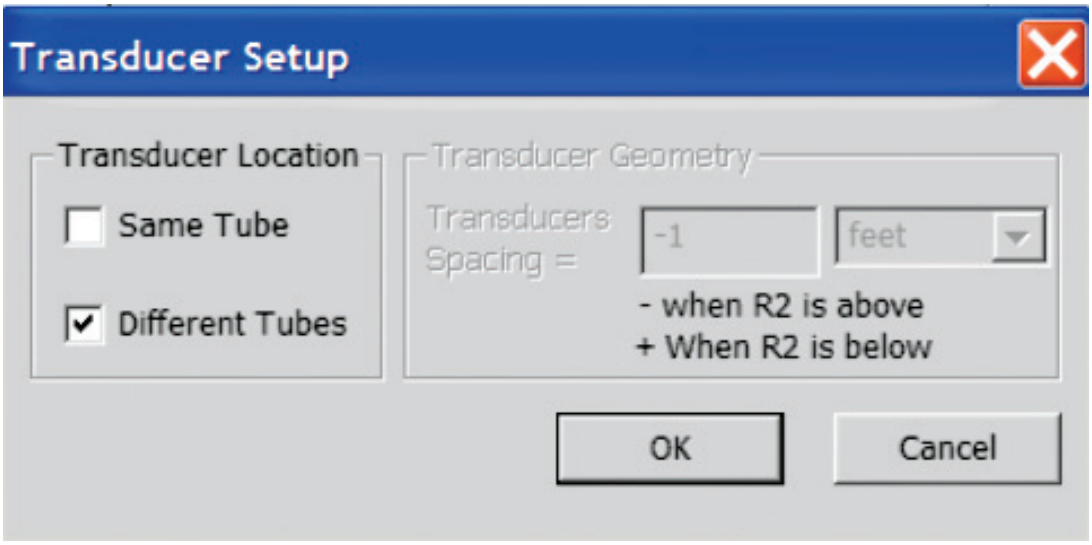
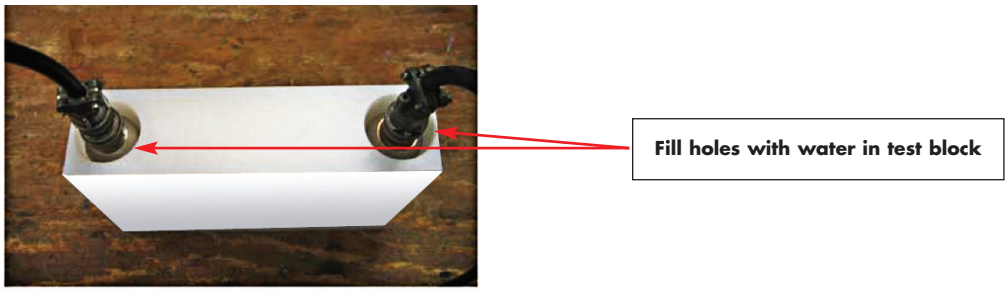


Figure 9: Number of Receivers

If this is the first time executing the CSL software and the default.prm file does not exist, a dialog box saying "Value must be positive" will appear on the screen. Click OK and go to main menu, select "Acquisition/Parameter Setup". Adjust these values to the right data parameter (Fig. 10) and click OK. Then, go to the main menu and select "Acquisition/Save Parameter". Now the default.prm file should exist on your C drive. Click on "View Signal" button to proceed to the next step.

6.0 TESTING OVERALL SYSTEM OPERATION

The CSL system can be easily tested for proper operation before going into the field. A test block is included with each system (see figure below). Connect the transducers as outlined in **Section 3.0, Step 7** and follow **Section 5.0, CSL Sofware Setup**. Use a generic filename, i.e. Test, for testing the system. Follow the steps outlined in this section to verify the Input Module, Pulser Module, and all (2 or 3) transducers are working correctly before going into the field. Make sure the test block holes (2) are filled with water so the signal is coupled through the test block.



CSL Test Block filled with water

1. **Input Module**

   The system is tested using the "VIEW" mode described in **Section 5.8**, Figure 4. This will allow viewing of test signals, gain setting, etc.

2. **Pulser Module**

   Press the TEST switch temporarily on the Pulser Module to test the system connections and operation. With the TEST switch pressed, and the data acquisition/analysis software in the "VIEW" mode, a typical received ultrasonic pulse should appear on-screen when:

   1. the data collection parameters have been properly set
   2. the TEST button is depressed

CSL Pulser Module Test Switch

TESTING OVERALL SYSTEM OPERATION

If a wave does not appear, verify that the computer is taking data and is triggering, and verify that all connections are made properly, switches are as described, and the unit has power. Once the unit is displaying the signal properly, the auto gain function should operate automatically (unless a manual gain has been set), and will set the gain at x1 to x4 to give about 6 V Peak signal amplitude. Note that if the gain increases to higher than x10, then it is likely that either the holes are not filled with water, or one of the transducers is bad. Switch the interchangeable source/receiver hydrophone transducers to confirm both are working properly.

NORMAL SYSTEM OPERATION:

After testing the operation of the Amplifier and Pulser Modules of the Freedom Data PC and the operation of the data collection software and data acquisition card, release the TEST switch and set the RESOLUTION switch on the Pulser Module to position "Normal", which is about 6.0 cm/point.

For closer spaced vertical tests, set the RESOLUTION switch to "High", which is approximately 1.5cm/point in addition to changing the the software setting under "Acquisition" to a "High" setting as well.

TESTING SYSTEM OPERATION

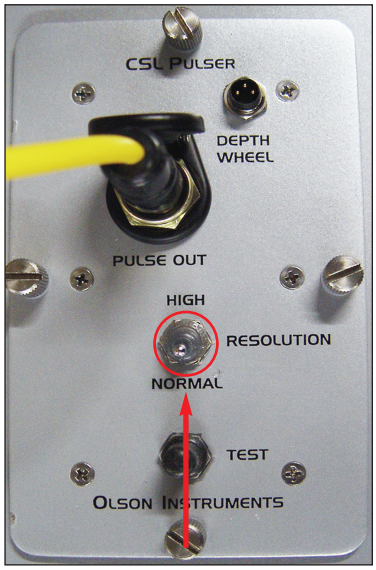
The pulser is tested as part of the overall system test above.
If the system test fails, then check the pulser independently as follows:

1. Set the RESOLUTION control to "Normal". If the transducer is not in a tube, listen for a clicking sound from the transducer when the depth wheel is turned by hand or the TEST button is pressed.

2. If no clicking is heard, check the wiring (make sure you are listening to the source transducer). If clicking is still not heard, verify again that all connections are made properly, and then follow the procedures in the troubleshooting guide, **Section 11**.

NORMAL SYSTEM OPERATION:

Set the RESOLUTION switch to the "Normal" position for testing



Pulser Module Resolution Switch

7.0 SETUP FOR DATA ACQUISITION

Following the steps in Section 6.1 for testing an actual shaft, this section will explain the setup for Data Acquisition. Once "View Signal" is selected on the shaft information screen, a screen similar to Figure 10 will be displayed.

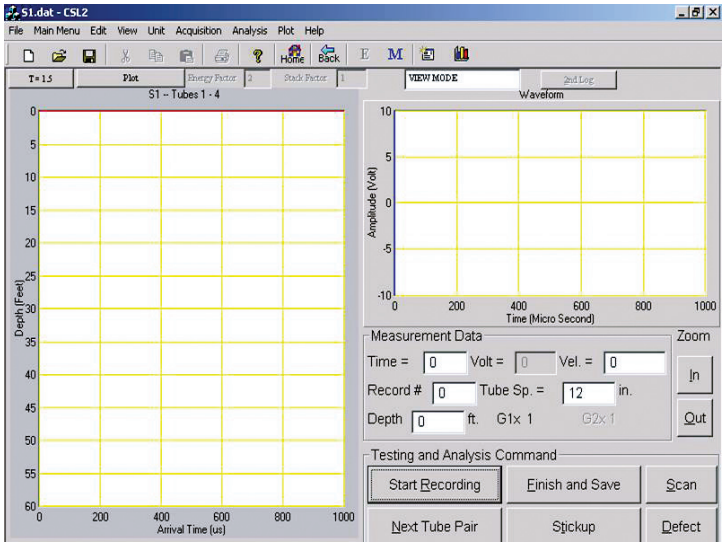


Figure 10: Data Acquisition Screen

If this is the first time executing the CSL software and the default.prm file was just created by the user, there might not be tick mark on the X scale (arrival time) on the log plot (left plot). The user also needs to set the graph scale for the CSL log by clicking on  in the toolbar area or go to Plot/Log Plot/Change Scale.

The dialog box in Figure 11 should appear on the screen for the user to setup the log scale. Note that if you want the program to remember all the settings, you should save the parameters by going to Acquisition/Save Parameter Setup to "c:default.prm".

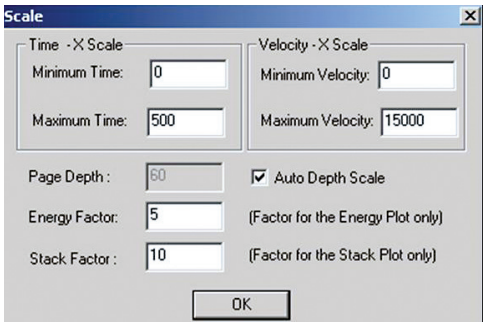


Figure 11: Scale Setup for CSL Log

7.0 SETUP FOR DATA ACQUISITION

Once the data collection screen appears on the screen, it will be in "VIEW MODE". In "VIEW MODE", the program will let the user view the signal (for the purpose of gain setting or auto gaining) without recording the data. When viewing the signal, the waveform will appear on the Waveform Screen (right plot in screen) as shown below:

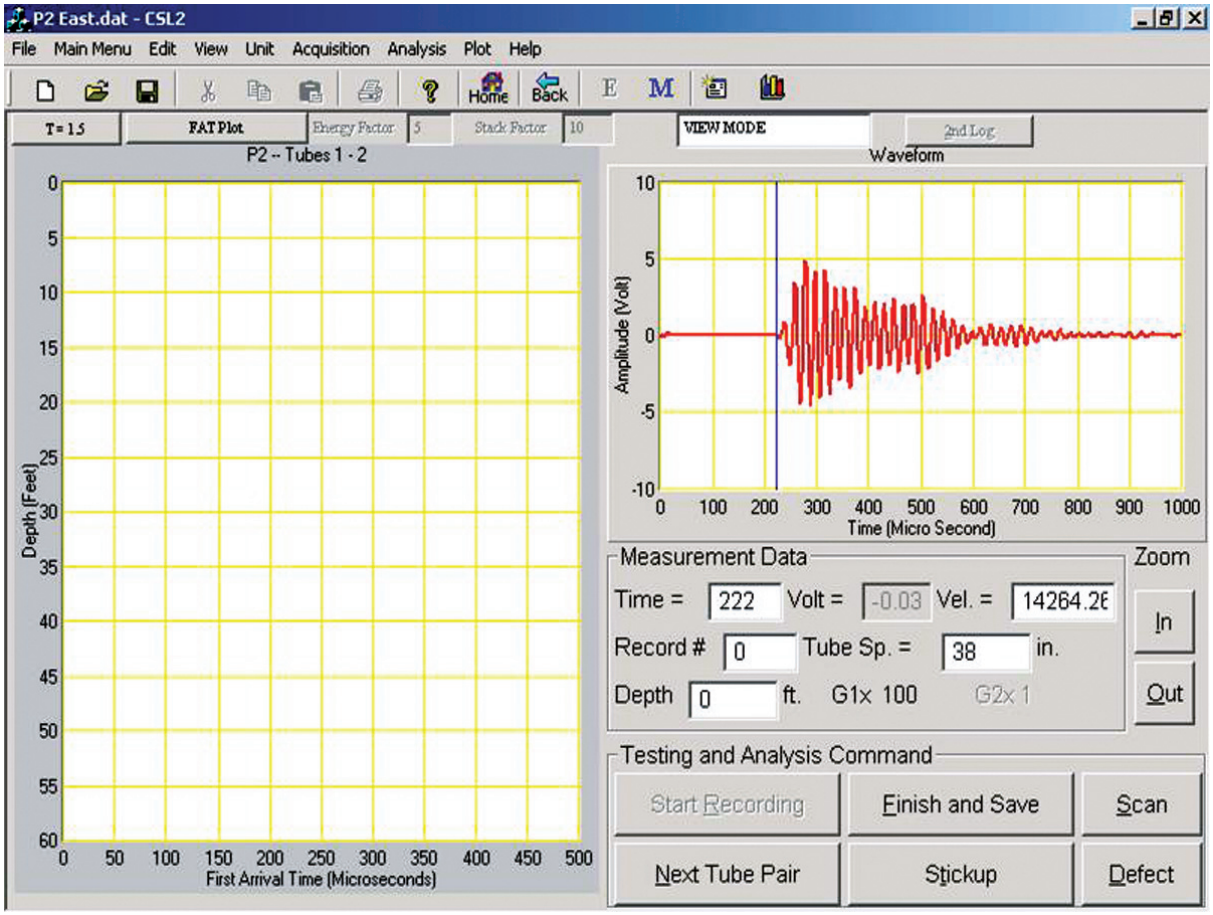


Figure 12: Data Acquisition Screen with Example Signal in View Mode

7.0 SETUP FOR DATA ACQUISITION

Before collecting the data, there are few things that the user should know. This is not mandatory, but it is useful knowledge. The software will reload the default data collection parameters from the file "c:default.prm" on program start-up, and then will automatically adjust the scan time parameter based on previous input (such as tube spacing).

A.) How do you setup data acquisition parameters?

Once the CSL program is loaded, the acquisition parameter will be recalled from the file "c:default.prm". If the user desires to change the data parameters, go to the main menu, select Acquisition, select Data Parameter (or press F4) and the dialog box in Figure 13 should appear on the screen:

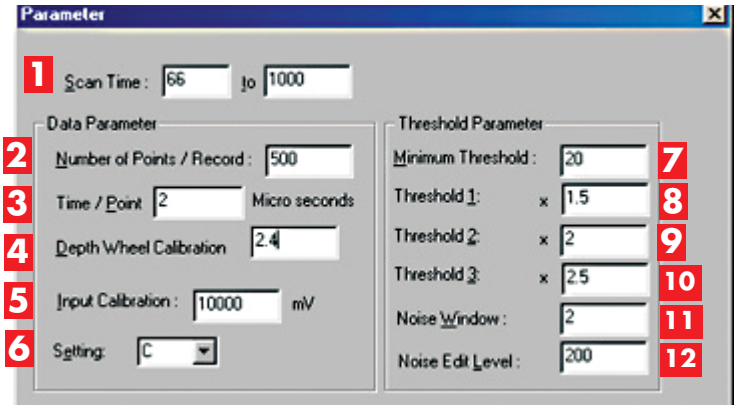


Figure 13: Data Parameter Setup

The data parameter dialog box should appear with the default settings. The parameters in the box on the left hand side associate with the data collection setup, and the parameters in the box on the right hand side are for the first arrival time scanning routine. The first parameter on the left side is scan time. The initial value of scan time start will be calculated from the input tube spacing (with an assumed faster concrete velocity of 15,000 ft/sec or 4570 meter/sec) and the stop scan time will be 1000 microseconds unless changed by the user.

Data Parameter Setup (Refer to Fig. 13 above)

1. Number of Points / Record is number of sampling points for each waveform. The higher this value, the more data acquired in each waveform (also dependent on Time/Point).
2. Time/Point is the sampling rate. In this case, the default was set at 2 microseconds. This means the system will acquire data at 2 microsecond intervals. For the CSL-2 system with 2 transducers, the minimum Time/Point is 2 microseconds and for the CSL-1 system, the minimum Time/Point is 1 microsecond.
3. Depth Wheel Calibration is a calibration number for each depth wheel. In this case, the depth wheel calibration is 2.4. This means that the CSL system will produce a pulse every 2.4 inches (6 cm) at Setting C "Normal". **The default depth wheel calibration is**

7.0 SETUP FOR DATA ACQUISITION

always set for Setting "Normal". The depth wheel calibration number will not change for other settings such as Setting "High". The program will adjust the number for other settings.

4. Input Calibration is the full-scale setting of the data collection hardware. This should be left at 10,000 millivolts for standard CSL-1 and CSL-2 systems.
5. The Depth Wheel Pulse Setting for the Freedom NDT Data PC and our new Freedom Data PC:

   — Freedom NDT Data PC can be set to 4 different pulse interval options:
   1. A (1.5 cm),
   2. B (3 cm)
   3. C (6 cm)
   4. D (7.5 cm)

   — Freedom Data PC can be set to 2 different pulse interval options:
   1. Normal (C – 6 cm)
   2. High (A-1.5 cm)

The recommended setting for a regular CSL test is Setting C or "Normal"

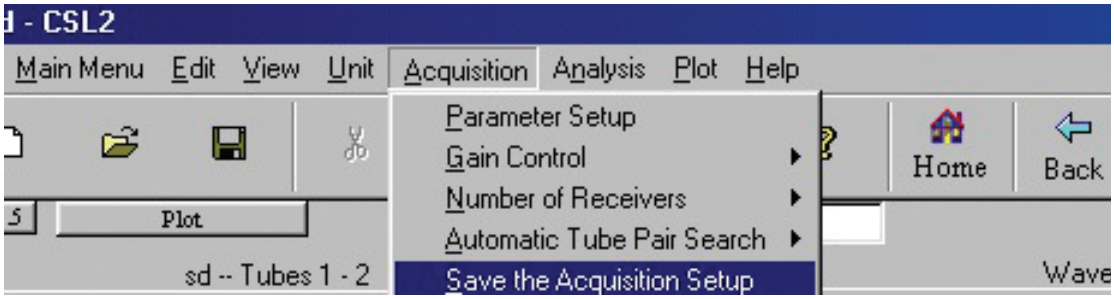
Threshold Parameter Setup (Refer to Fig. 13, previous page)

7. Minimum Threshold is the minimum voltage level that can be accepted as a CSL signal arrival in millivolts (mV).
8. Threshold 1 is the multiplier that is multiplied times the maximum background noise in the Noise Window (see below) to set the threshold for each record that the signal must be greater than (positive or negative) to pick the signal arrival time. Threshold 1 must be less than Threshold 2 and a typical value might be 1.5 (range from 0.8 to 2 depending on signal).
9. Threshold 2 is the second multiplier threshold and it must be greater than Threshold 1 and less than Threshold 3.
10. Threshold 3 is the third multiplier and it must be greater than Threshold 2.
11. Noise Window is a divisor that is used to define the Noise Window preceding the CSL signal. The Noise Window is defined as being between the Start Scan time divided by the Noise Window input to the Start Scan Time.
12. Noise Edit Level is the signal voltage level at which if a noisy signal (from hydrophone receiver bouncing) exceeds this value in mV, then the CSL log is marked with a dark line at the proceeding signal arrival time. A typical value is 1000 mV, while setting this value to 10000 mV turns off the automatic Noise Edit Level feature.

7.0 SETUP FOR DATA ACQUISITION

After the data parameters are set, the user should save the parameter in "c:default.prm" file by clicking on Save to "c:default.prm" or go to main menu and select the "Acquisition/Save the Acquisition Setup" as shown below:

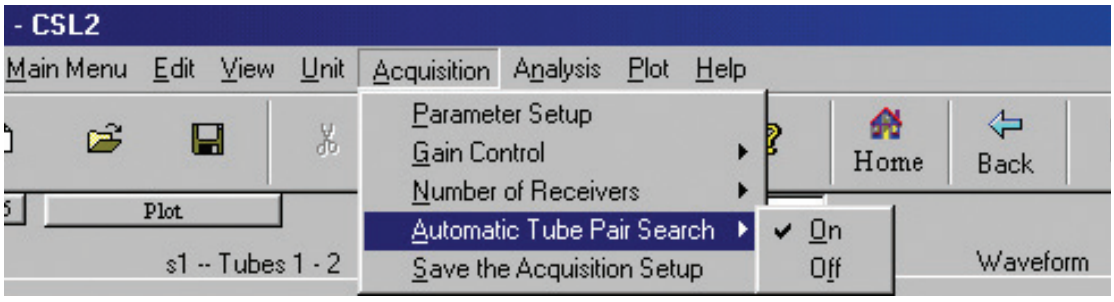
The default.prm file contains acquisition parameter setup and unit setting (English or Metric)



B.) Automatic Tube Pair Search Option

The software runs in either automatic channel search mode or manual mode. Go to the main menu, select "Acquisition", select "Automatic Tube Pair Search". If this option is on, the program will automatically search for an appropriate next tube pair (in clockwise order starting from Tube Pair 1 - 2 after the current test is complete. If this option is off, the user must manually input the tube numbers.

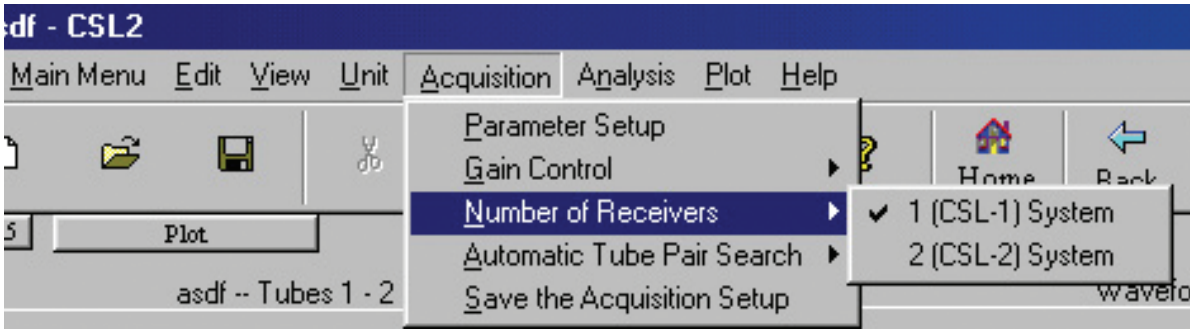
Note that if this parameter is turned off, the user will not be able to turn it back on for the current shaft. To turn off the automatic tube pair search feature, simply press F5.



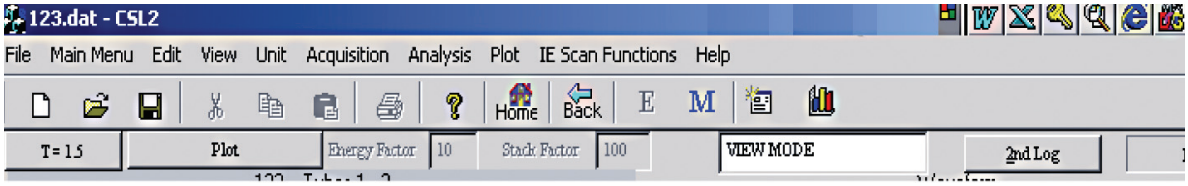
7.0 SETUP FOR DATA ACQUISITION

C.) CSL-2 Systems

The CSL-2 system allows the user to simultaneously acquire data with 2 channels (2 receivers and 1 source). Go to the main menu, select "Acquisition", select "Number of Receivers", select "CSL-2 System". For the CSL-2 system, only the manual mode is allowed to input the tube pairs.



For the CSL-2 system (with 2 channels), a toggle button (2nd Log) will be used to switch between the first and second log that were acquired simultaneously:



D.) What is gain control?

In "VIEW MODE", the CSL system automatically adjusts the gain of the amplifier until the peak signal amplitude is between 4 – 8 volts. The software also allows the user to manually adjust and set the gain by going to the main menu and select "Acquisition/Gain Control/Manual Gain" (or simply press F2). In the manual gain dialog box, use the mouse to slide the gain control slide bar or press "Alt+I" to increase and "Alt+D" to decrease the gain. To restore auto gain mode, press F3.

8.0 DATA COLLECTION

After the Data Acquisition parameters are entered correctly, data collection can begin. The following steps outline the necessary procedures for proper data collection.

1. In the VIEW mode, with the Freedom Data PC, pushing the "Test" button on the CSL Pulser module automatically sets the gain. The signal amplitude will stabilize after a few seconds. This can be set at the bottom of the shaft if it is sound, or higher up if there is a soft bottom. Automatic or Manual Gain is also accessed under Acquisition and under Gain Control or by pressing F3 or F2, respectively.

   To record the CSL log, simply click on [Start Recording] (or press Key "Alt+R"). The word "Recording Data" should appear on the top of the screen. Now the system is ready to acquire and record the data and the user can start pulling the CSL cables.Note that there are four modes of log display allowed for the real time log display. This includes first arrival time, velocity, time and energy, and waterfall plots. While the user is logging the data, the real time CSL log (as defined by users) and real time wave form display as shown in Figure 14.

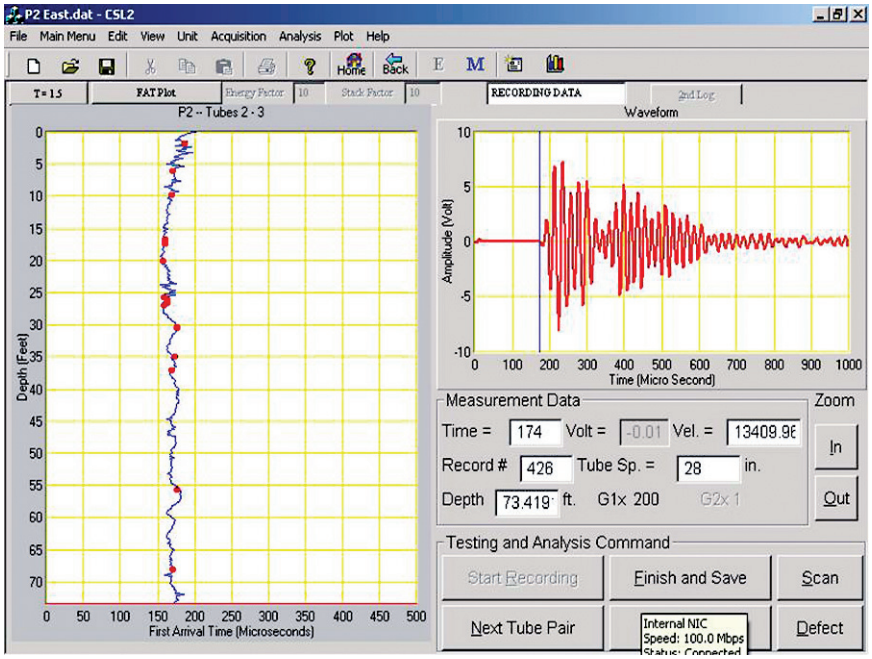


Figure 14: Real-Time First Arrival Time Scanning

8.0 DATA COLLECTION

2. After the CSL logging process is finished for the current tube pair, simply click on Finish and Save (or press Key "Alt+F") to recalculate the actual logging depths and save the data. Remember that the shaft depth in Figure 4 is just an estimate maximum depth for real-time first arrival time scanning purposes. The actual depths will be calculated after the logging is completed. This step is not mandatory but strongly suggested. If the user does not save the data for the current test tube pair, the data can still be saved later after testing the next tube pair for the same shaft. It is recommended to save the file after finishing each test of each tube pair to prevent accidental lost of data.

3. To continue the CSL test on the next tube pair, click (or press Key "Alt+N").

— In the manual tube pair search mode, the dialog in Figure 15 should appear on the screen (for CSL-1 system). The user can enter the desired tube number for the source and receiver. In CSL-1, source and receiver tubes can be switched.

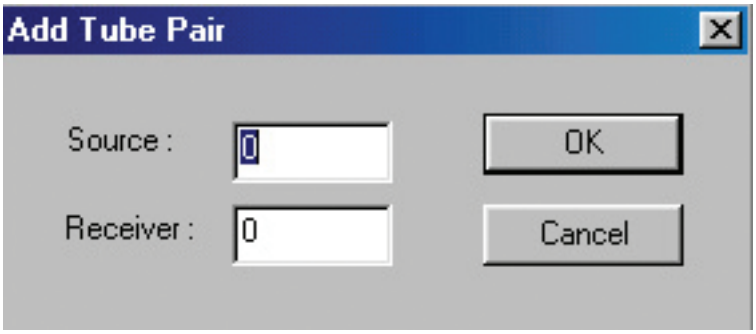


Figure 15: Add Tube Pair Dialog Box

— In the automatic tube pair search or default mode, the program will enter a new screen allowing the user to display untested tube pairs, tested tube pairs, and designate the next tube pair to be tested.

Graphical View of the Tested or Untested Tube Pairs

The CSL2 program with version 2.21 and higher was designed to have a graphical view of the tested/untested tube pairs when the user proceeds to the next test (by clicking on "Next Tube Pair"). The dialog box as shown in Figure 16 will appear on the screen:

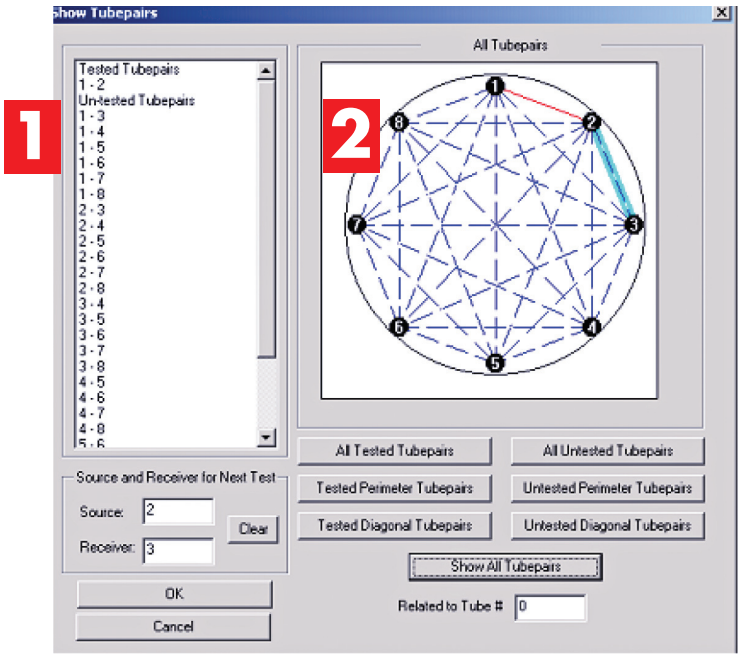


Figure 16: Tube Pair Selection Screen

The text of tube pairs is listed on the left side of the dialog box (1) and the graphical image of the tested/untested tube pairs is shown on the right side of the dialog box (2).

In the graphical display shown in area "2" above, the following are represented with various line shapes:

A. Solid red line (——): represents the tested tubepair

B. Dotted blue line (-----): represents the untested tubepair

C. Heavy solid light blue line (——): represents the next tubepair to be tested

8.0 DATA COLLECTION

There are 7 options that the user can set as shown in Figure 16. The program remembers the last option in the parameter default file (go to the main menu/Acquisition/Save Parameter Setup) if the user wants the selected option for the future tests. In this case, the graphical image shown in the dialog box has the option of "Show All Tube Pairs". Figure 17 below shows the same graphical image with a different option (Untested Perimeter Tube Pairs that relate to all tubes):

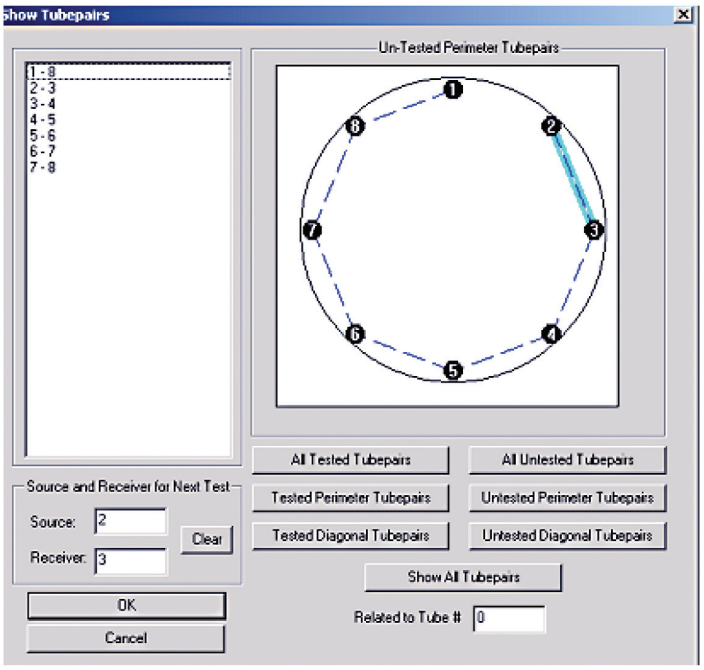


Figure 17: Untested Perimeter Tube Pairs has been selcted. Bright blue line indicates next tube pair to be tested.

The user can also change the source and receiver of the next test. In this case, the next tube pair to be tested is tube Pair 2-3. The user can also select to see only the tube pairs that related to a certain tube by entering the number of the tube in "Related to Tube# ….". If this value is 0, it means that it will show all the tube pairs that fit one of the seven options the user selected.

4. After completing the CSL tests for all necessary tube pairs in the shaft, either click on 

(or press Alt + "M") or go to main menu, click on "File/New" to go back to the main menu screen (see Fig. 4 in Section 4.1).

8.1 RE-TESTING EXISTING SHAFT

This option allows the user to perform CSL data collection on the previously tested shaft. In order to use this option, the file has to exist. This option will load the existing file and allow the user to re-test the tubepairs or add more tests in the shaft.

1. The dialog in Figure 18 should appear on the screen to let the user select the existing shaft (or file). Select the shaft needed to be re-tested and click "open".

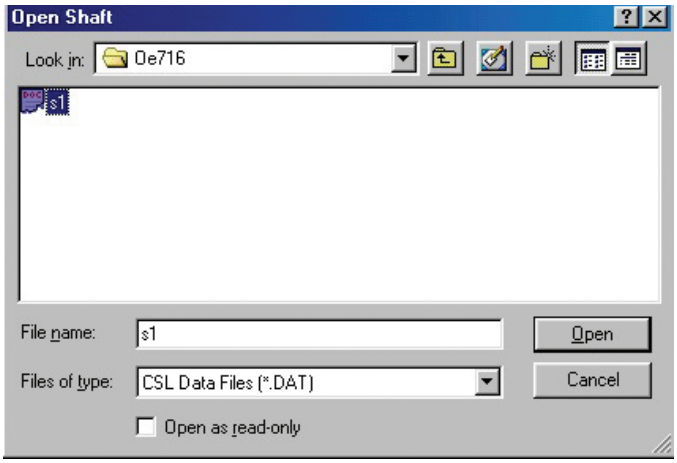


Figure 18: Open Shaft Dialog Box

2. The program will load the data from the selected shaft and the screen in Figure 4 should appear with the saved information (such as shaft name, length, stickup, number or tubes, etc.).

3. Follow the instruction in Section 4.1. If the selected tube pair has been tested, the program will load the plots with the saved data. If the selected tube pair has not been tested, the plot will appear blank and is ready for data acquisition. For re-testing the tube pair, simply view the signal until the gain is properly set and click on 

to start the testing.

   Please note that the user can simply click 

until the desired tube pair appears on the screen.

9.0 PROCESSING

This section will walk the user through the steps necessary for processing of collected CSL data. The first step is to select Analyze Shaft on the opening menu (refer to Fig. 3, Section 4).

9.1 ANALYZE SHAFT

This option will allow the user to analyze the CSL data. This option **will not allow** the user to re-record the raw waveform. The user can change and resave the processed data (such as time of arrival, energy, etc.), but the waveform data cannot be changed. The following are simple steps to the analysis procedure:

1. The dialog box in Figure 19 should appear on the screen to let the user select the existing shaft (or file). Select the shaft needed to be analyzed and click "open".
2. The program will load the data from the selected shaft and the screen in Figure 4, Section 4 should appear with the saved information (such as shaft name, length, stickup, number of tubes, and tube spacings etc.). The user is allowed to change any information except the number of tubes (these entries will appear disabled with gray color on the screen).
3. Correct the necessary information (such as tube spacings) and proceed to the next screen by clicking View Signal

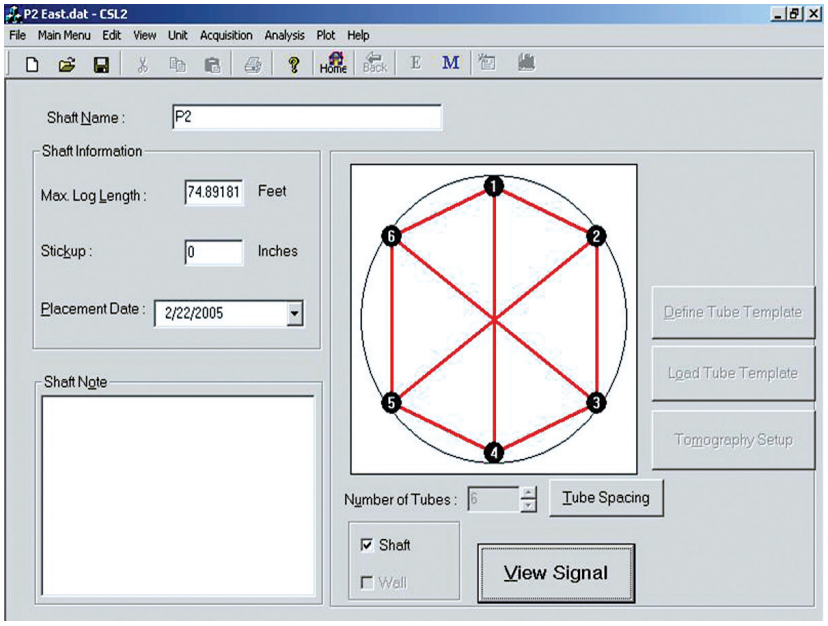


Figure 19: Recalled Shaft Information

9.2 DATA ANALYSIS FUNCTIONS

9.2.1 KEYSTROKE:

The screen in Figure 20 should appear with a signal of the last record on the right plot and first arrival time log on the left plot.

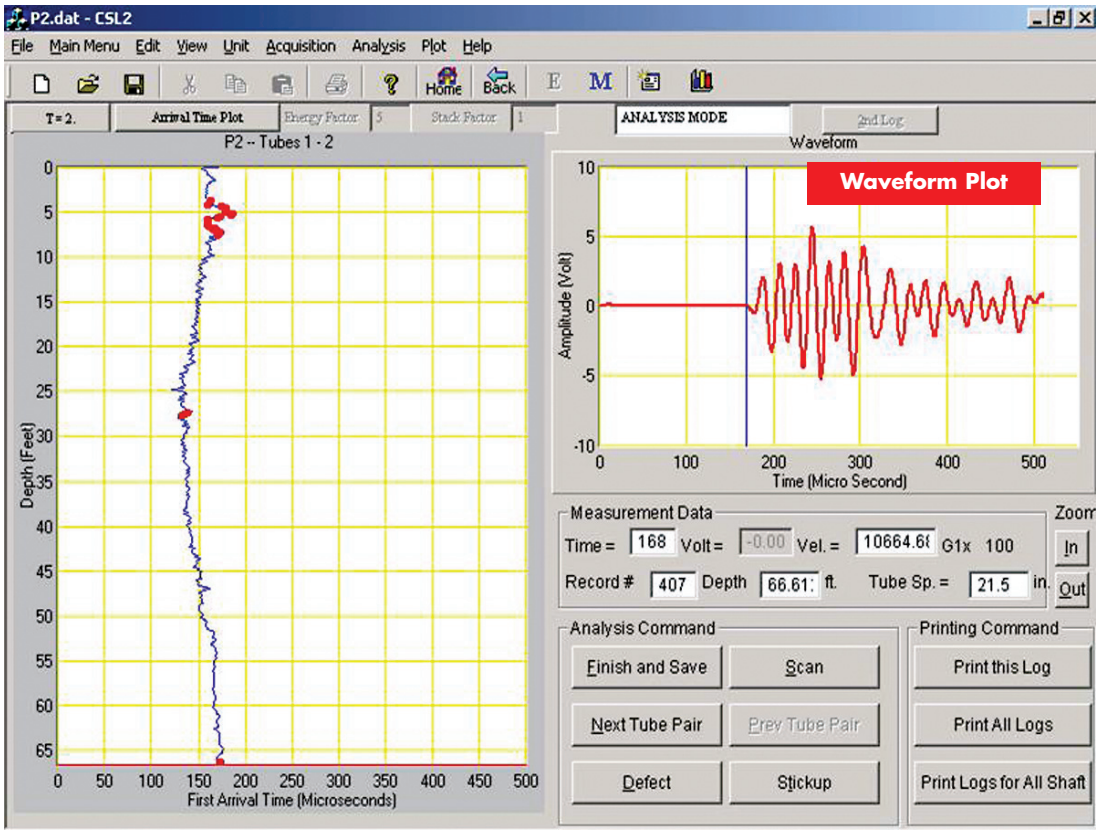


Figure 20: Data in the Analysis Mode (First Loaded Data)

Simply use "Alt + Arrow Keys" (Up and Down) or mouse (click approximately at the trace on the plot) to move the cursor to the desired record. If users desire to move faster, use "Alt + Home" to go to the top record, use "Alt + End" to go to the bottom record, use "Alt + Insert" to move 12 records up and use "Alt + Delete" to move 12 records down. Note that the cursor is designed to snap to the line plot so the mouse click has to be at (or close to) the line. The waveform plot (the right plot) shows the current record according to the cursor in the left plot (see Fig. 21).

9.0 PROCESSING

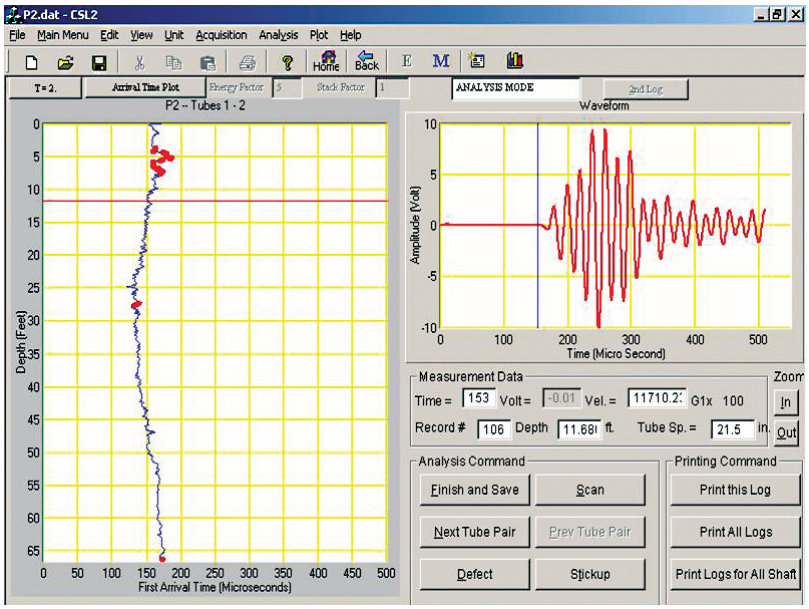


Figure 21: Data in the Analysis Mode (showing Waveform of Fig. 20)

9.2.2 SCANNING PARAMETER

If the scanning parameters (such as Scan Time, Threshold Level, Noise Edit Level, etc.) need to be adjusted, go to main menu, select "Acquisition/Parameter Setup". The dialog box similar to Figure 13, Section 6 will appear on the screen. The user can change any of the analysis (scanning) parameters, but is not allowed to change the saved acquisition parameter (such as Time Per Point and Point Per Record). Click Scan to rescan the first arrival time. After changing **ANY** of the scanning parameters, the user must rescan the data to take into account of the new parameters.

9.2.3 MANUAL PICK OF ARRIVAL TIME:

If the automatic scanning routine results in an incorrect pick, the user can simply correct the pick in the waveform plot by moving the blue cursor (left click on the current position and drag to the correct position). If the automatic scanning routine yields numerous bad picks, the user might want to change the scan time. If manual pick has been made, a small red dot will appear on the record (on the left plot). If the red dot appears on the record without the manual pick, it means the waveform has high noise (higher than NSE) and the scanning routine will automatically use the data from the previous record.

9.2.4 STICKUP

Click Stickup to input the stickup length of the tested tubes. The dialog box in Figure 22 should appear on the screen. Users can type stickup length into the entry field. Note that the unit of the stickup is either in "inches" or "cm". After inputting the stickup length, the user has the option of either showing the stickup or hiding the stickup. If the "show stickup" option is selected, the plot will be zeroed at the bottom of the stickup and the stickup portion is shown in a negative depth zone. If the "hide stickup" option is selected, the plot will be zeroed at the bottom of the stickup and the stickup portion will not be shown. This stickup value can also be copied to other tubepairs by clicking on "Copy Stickup Value to Other Tubepairs".

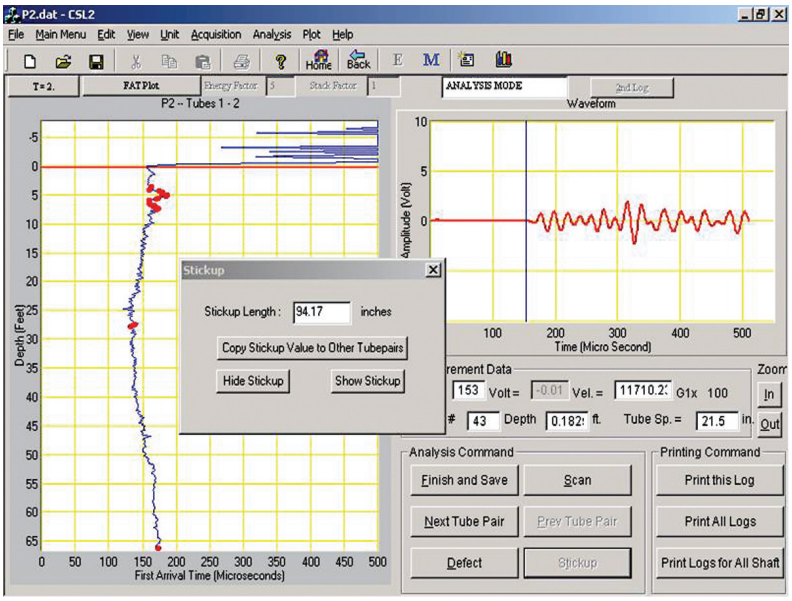


Figure 22: Stickup Dialog Box

9.2.5 DEFECT ANALYZER

Click Defect to automatically analyze for defect zones in the shaft. This step is optional. However, if the user wants to use the automated report generation option (see Section 9.0) that comes with the program, this step is required. At this point, Figure 23 should appear on your screen. In this dialog box, the user can click on Auto Defect Analyzer to let the program look for the defect zones. The defect analyzer function was designed to automatically detect the anomalies including debonding, soft bottom and any low velocity zones in the tubepair. When performing "Auto Defect Analyzer", the program simply calculates the average velocity of the entire log and then searches for data points that have a velocity reduction of more than 10%, starting from top to bottom of the tubepair. Once the program finds the location with low velocity, it goes back up to look for the starting location of this anomaly by looking for the first encountered location that has a velocity of at least the average velocity. Then the analyzer starts from the detected low velocity zone and goes down to find the end of this anomaly by looking for the first location that has a velocity of at least the average velocity.

Therefore, the starting and ending locations for the defect might be slightly off the actual locations. In this case, the "Manually Added Defect" feature can be used to correct the locations. The program automatically calculates the velocity reduction by looking for the data point with lowest velocity in the defect zone and computes the velocity reduction based on the mean velocity. When the user manually adds a defect, the velocity reduction can be calculated by using left mouse click on the log plot directly at the point that has lowest velocity in the defect zone. The user can add and delete defects to and from the list. After the defect analyzing process is complete, click Done to save the defects and go back to the previous screen.

9.0 PROCESSING

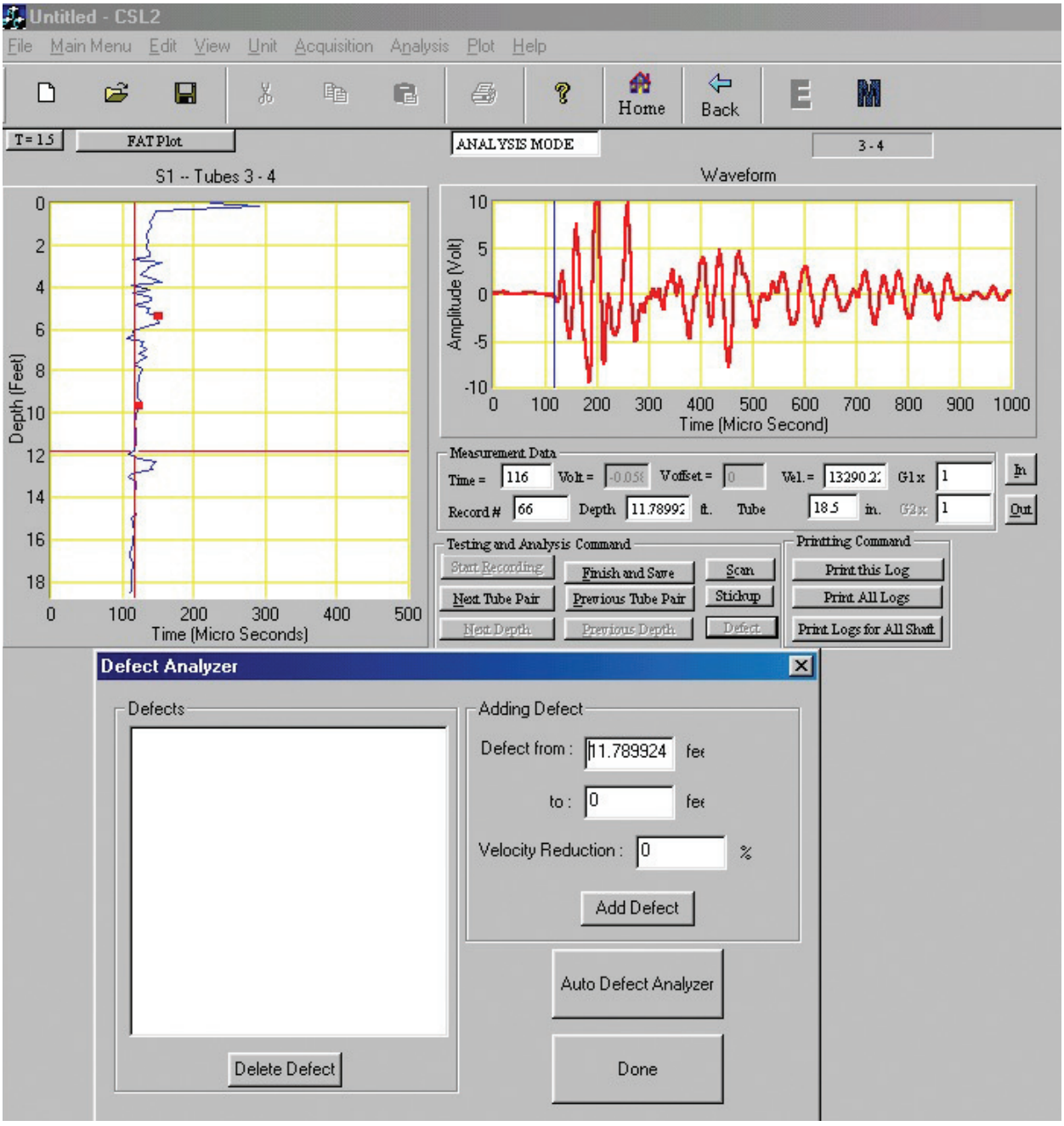


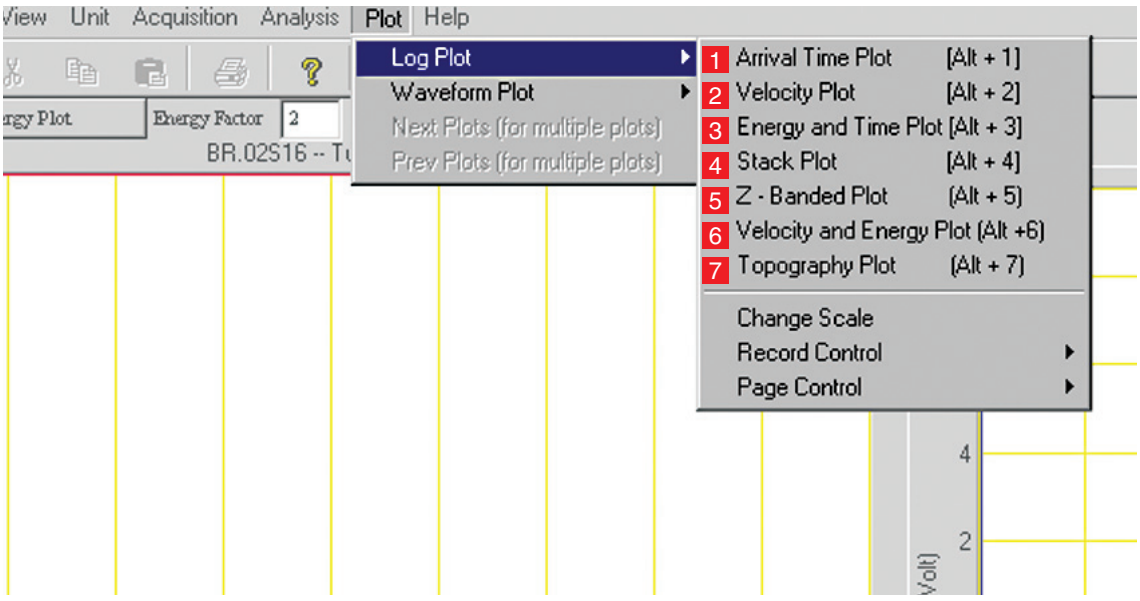
Figure 23: Defect Analyzer Option

After the analysis of the current tube pair is complete, click Finish and Save (or press Key "Alt+F") to save the processed data. To proceed to the next tube pair, click Next Tube Pair (or press Key "Alt+N"). To go back to the previous tube pair, click Previous Tube Pair (or press Key "Alt+P").

9.2.6 DISPLAY OPTIONS

There are currently 7 different plot options the user can display: (screen image 11 below)

1. First Arrival Time (FAT) plot: Alt + 1 or Plot/Log, Plot/Arrival, Time Plot (see Fig. 21)
2. Velocity Plot: Alt + 2 or Plot/Log, Plot/Velocity Plot (see in Fig. 24)
3. Energy and FAT Plot: Alt + 3 or Plot/Log, Plot/Energy, and Time Plot (see Fig. 25)
4. Stack Plot: Alt + 4 or Plot/Log, Plot/Stack Plot (see Fig. 26)
5. Waterfall or Z Banded Plot: Alt+5 or Plot/Log, Plot/Z Banded Plot (see Fig. 27)
6. Velocity and Energy Plot: Alt+6 or Plot/Log, Plot/Velocity and Energy Plot (see Fig. 28)
7. Topography Plot: Alt + 7 or Plot/Log, Plot/Topography Plot (see Fig. 29)



11: Plot Options Dialog Box

9.0 PROCESSING

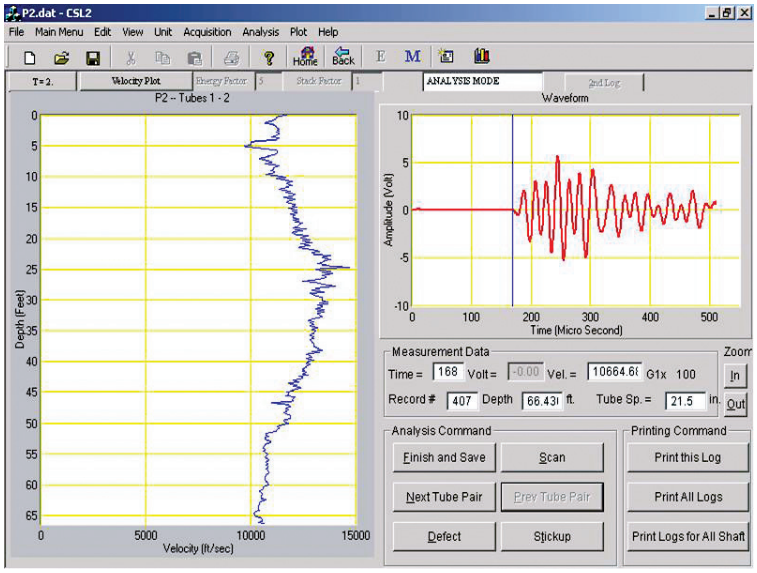


Figure 24: Velocity Plot

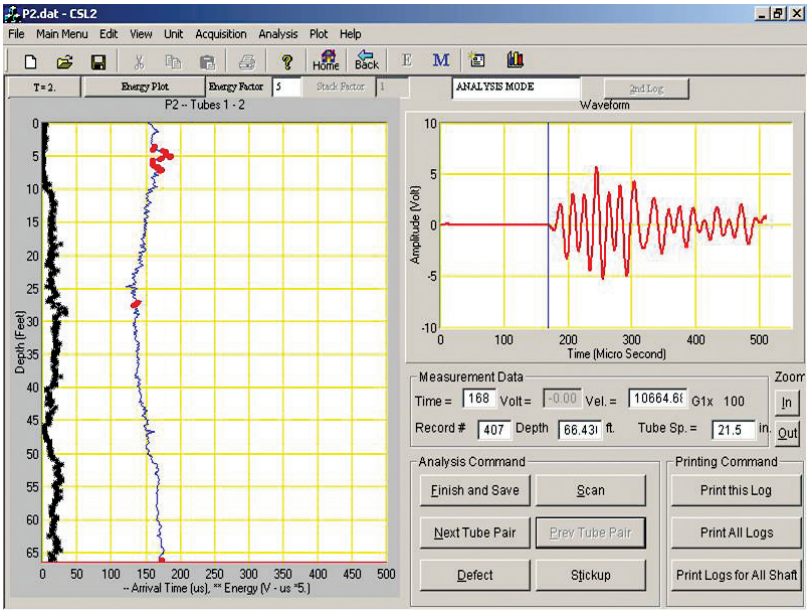


Figure 25: Energy and Time of Arrival Plot

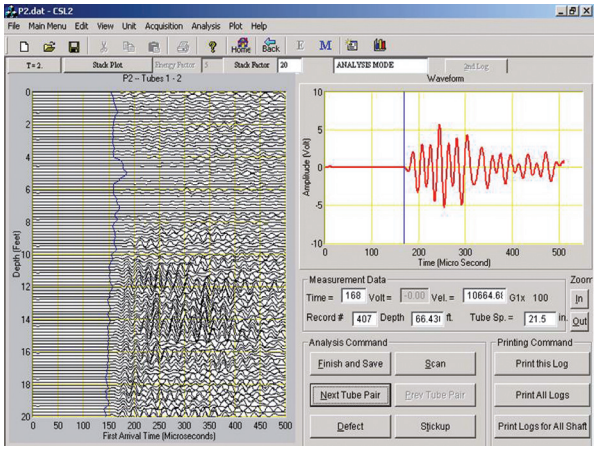


Figure 26: Stack Plot

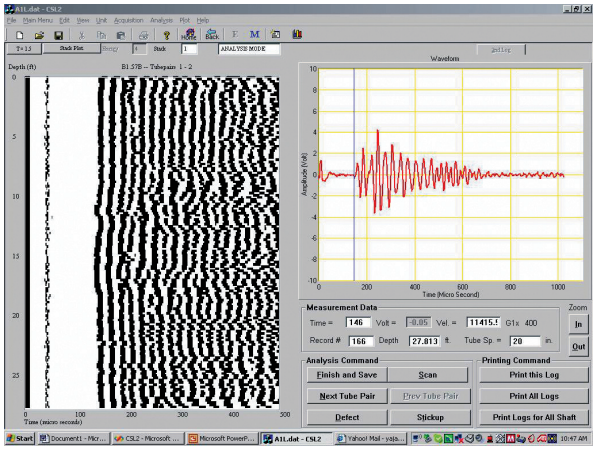


Figure 27: Waterfall or Z-Banded Plot

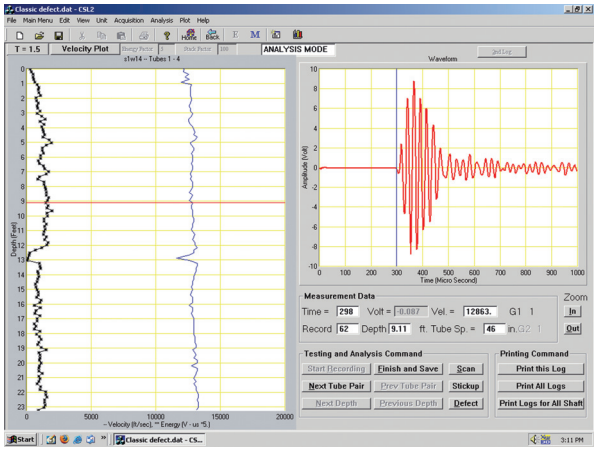


Figure 28: Velocity and Energy Plot

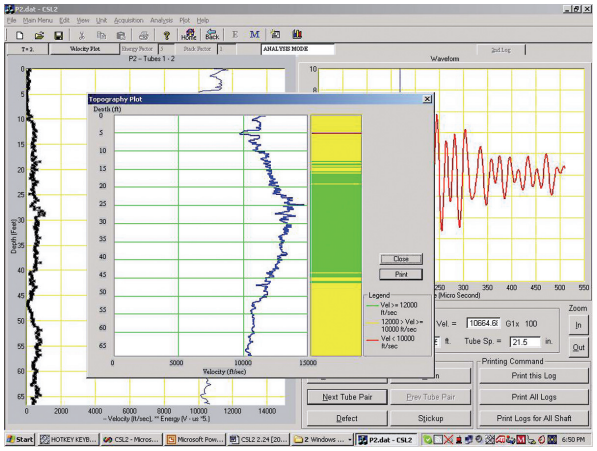
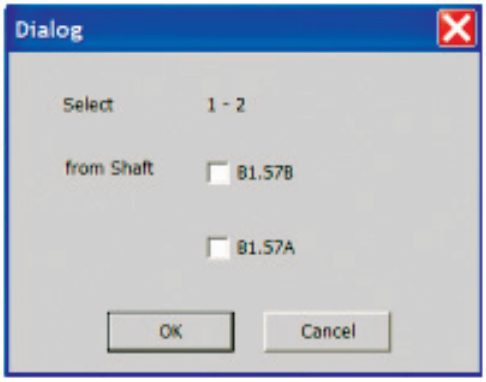


Figure 29: Topography Plot

9.0 PROCESSING

9.2.7 ADD CSL LOGS FROM ANOTHER FILE TO THE CURRENT CSL FILE

The CSL program allows users to add or merge CSL logs from a separate file to a current CSL file. Go to Analysis/Add CSL Log(s) then select the filename whose CSL logs to be added/merged to the current CSL file. If the CSL software detects the same tubepair in both files, the program will prompt an applet (shown in Figure ??) for users to select the file that the user wish to keep the data from the repeated tubepairs



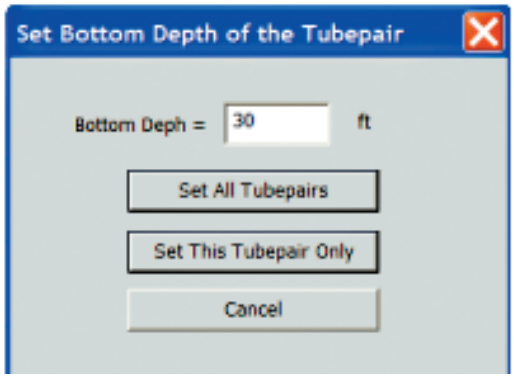
Applet for Tubepair Selection

9.2.8 DELETE CURRENT LOG

The current log can be deleted in the analysis mode by going to Analysis/Delete Current Log. The CSL log on the screen will be permanently deleted. This action can not be reversed if the file is saved after deleting a log.

9.2.9 SET BOTTOM DEPTH

The bottom depth of the CSL logs can be set by going to Analysis/Set Bottom Depth. Then an applet shown in Figure ? will appear on the screen. Users can set the bottom depth of the current log or all the logs in the file. Note that the depth of the log will be re-calculated if the scan function is engaged (users click on "Scan").

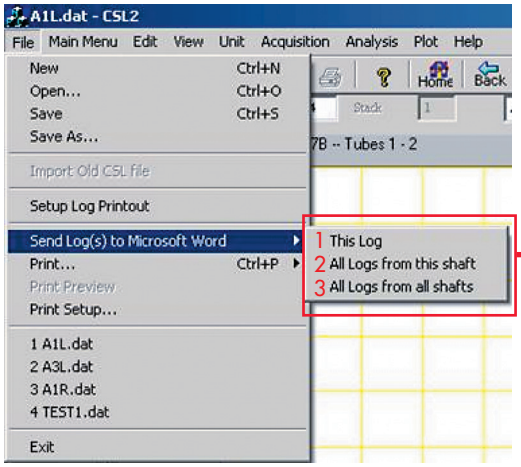


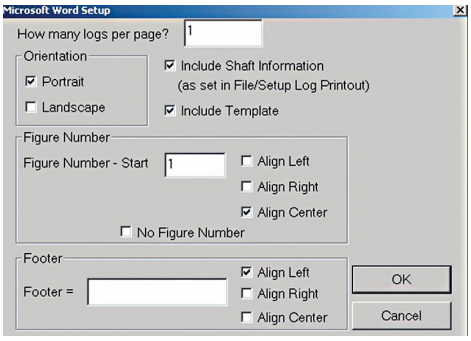
Set Bottom Depth

10.0 REPORT GENERATION

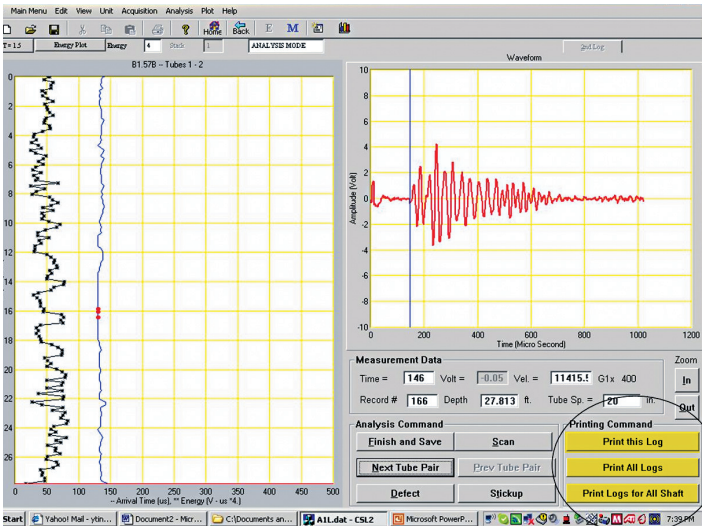
10.1 LINK CSL LOGS TO MS WORD

There are two ways to export CSL logs from the software: sending CSL logs to MS Word and printing the logs directly to the default printer. To send the logs to MS Word go to File/Send Log(s) to Microsoft Word and there are three options: sending only this log, sending all logs from this shaft or sending all logs from all the tested shafts.





Select one of the three options shown in left figure and the dialog box above will appear on the screen. The program allows up to 3 logs per page to be linked to MS Word. If more than 1 log per page is set, shaft information and template cannot be included in the print-out (no space). Select "OK and the software will open up MS Word and send the log(s) to the program.



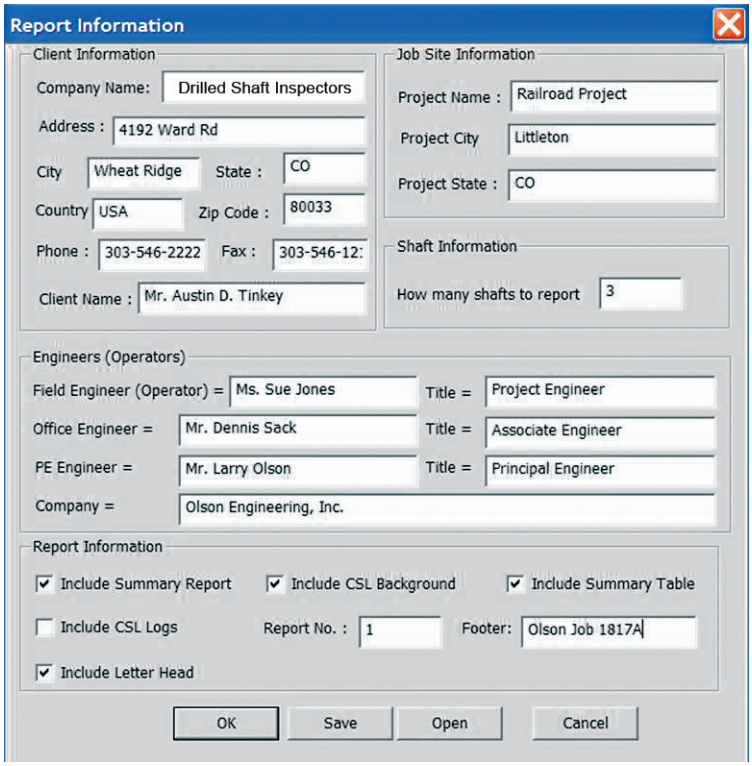
10.2 PRINTING FUNCTIONS

To print log(s) directly to the default printer, simply click on one of the three printing commands on the main screen as shown in the figure at left.

10.0 REPORT GENERATION

10.3 LINK AUTOMATICALLY GENERATED CSL REPORT TO MS WORD

This option allows user to link the automatically generated CSL report directly to Microsoft Word (version 2002 and higher). It uses the client information database incorporated into the CSL program. The dialog box below should appear on the screen. Users can enter all the required information and save this information in a client file that can be reloaded in the future.



The software automatically generates a CSL summary report, CSL background, a summary table and CSL logs. In addition, company letterhead can be automatically inserted in the report if the "letterhead option" is selected.

Click on "Open" to open the shafts to be included with the report. The summary report includes basic client information and a summary of the conditions of the tested foundations including number of defects, locations of each defect, the affected tubepairs as well as the maximum percentage of velocity reduction.

The CSL background included in the report is a standard CSL brief written by Olson Engineering, Inc. A summary table included in the report lists the conditions of the shaft (as analyzed and saved in the Defect Analyzer). After the shafts are selected, the CSL software opens the Microsoft Word application and sends the selected report option to the program. The report can then be saved in MS Word format by the user.

11.0 TROUBLESHOOTING

This section will allow the user to check the CSL system to verify everything is working properly. If the recommendations do not solve the problem, or if the particular problem is not covered, please contact Olson Instruments.

11.1 HARDWARE SYSTEM CHECK

There are several procedures which can be used to check the operation of the system prior to data collection, or if problems are encountered during data collection. These procedures are described in the following sections. Note that not all procedures apply to all systems.

11.1.1 INPUT Module Test

The primary way to test the Input Module unit is to set the gain to a high level with a transducer attached, and then go into the 'View Signal' mode in the data collection submenu. Press the test switch on the pulser module and observe the screen. If a transducer is connected to the source and the receiver, and the two transducers are near each other (or horizontally opposed in a water bath or concrete shaft), a signal should appear on-screen. If no pulser transducer is connected (or it is suspected that the pulser is not functioning), the receiver signal on-screen should show noise or other signals on-screen (gain=8000). Tapping the transducer while holding the test button on the module should result in a large signal on-screen. If not, check the signal connections, raise the gain on the amplifier, and make sure that the transducer cables at the cable reel and amplifier module are fully connected (kicking or pulling on the short transducer interface cable may pull it part way out of the socket on the cable reel). If all else checks out, but the test signal is still not visible, contact Olson Instruments at 303.423.1212.

11.1.2 PULSER Module Test

Testing the Pulser Module involves one simple test. This test will also verify the functionality of a cable and transducer pair. The test is performed by connecting a transducer to the high voltage output and listening for a clicking sound in the transducer when it pulses. To do this, first connect the transducer to a cable, and then the cable to the high voltage output. Next, connect the box to power (power light should be on). When the TEST switch is depressed, the transducer should click at 2-20 clicks/second.

If no clicking is audible from the transducer, first verify that the computer is turned on and the pulser module firmly seated. If this does not result in the clicking being heard, retest the system with another transducer and/or cable to verify that the problem is not in either of these units. If no combination of cables and transducers produces the clicking sound, then the Pulser Module is suspect and Olson Instruments should be contacted.

A final check of both the Pulser and the Input Modules can be made with the two transducers lowered into a water bath. Submerge the source and receiver transducer in water about 30 to 60 cm apart (this must be measured) and check that the velocity of water is measured for the known spacing and water temperature. Typical water velocity at 21 degrees C is 1,493 meters per second.

FREQUENTLY ASKED QUESTIONS

? I cannot follow the tube combination order when I perform the CSL tests. What should I do?

A If you know from beginning that you will not be able to follow the tube combination order, turn the Automatic Tubepair "off" in the menu as shown in **Section 7.0, B**. If you turn this feature off before you get into the data acquisition screen, you will be able to input tubepair manually from the first test. If you realize this after you get in the data acquisition screen, you can turn this feature off anyway. Then click on "Next Tube Pair" or Alt + N to input the test manually. Remember that once you turn this feature off, you can not turn it back on again.

? My Freedom Data PC reboots itself (due to batteries or other circumstances) before I finish testing the shaft. How do I finish the test on the shaft?

A Hopefully you have been saving your data often. You can finish testing by entering "Retest Existing Shaft" from the main menu and recall the filename. Click "View Signal" or Alt +V to proceed to data acquisition screen. The software will start from your first test in "Analysis Mode". Keep hitting "Next Tube Pair" or Alt + N until you reach your tubepair you wish to test. If there is no data in the tubepair, the program will switch to "View Mode". If you wish to retest the tube pair you already tested (appear in "Analysis Mode"), you can simply click "Start Recording" or Alt +R to retest.

? I need to set up all the acquisition parameters and unit every time I run the program. Why?

A If you wish to automatically reload your acquisition parameter setup and unit setting every time you run the program, you need to save these parameters by going to the menu and clicking on "Acquisition/Save Parameter Setup". These parameters will be saved in "default.prm" on your root directory in hard drive C. (C:\)

? I accidentally put my test in the wrong tube pair. How do I fix this?

A Go ahead and finish your test. You can change tubepair name in the analysis mode. In the analysis mode, please click on "Next Tube Pair" until you are in the tube pair you wish to change name. Go to the menu and Click on "Analysis/Change Tube Pair Name". Note that you can not rename your tube pair after an existing tube pair. If you want to switch between Tube 1 – 2 and 2 – 3, you need to go in to Tube 1 – 2 and change name to "6 – 1" (if you do not have 6 – 1 in your test). Then go into Tube 2 – 3 and change name to Tube 1 – 2. Finally you have to go back to Tube 6 – 1 and change it to Tube 2 – 3. It seems a bit awkward, but it guarantees that you will not need to repeat the tube pair.

? When I record the data and pull the cables up, I do not see a line on the screen. What did I do wrong?

A If you do not see the log on the screen when you acquire the data or after you scan the data, it is possible that the scan time was set wrong. Press F4 to bring out the parameter setup dialog box and change the first Scan Time to a number less than the actual arrival time. Then close the dialog box by hitting Enter. Finally, press Alt +S or click on "Scan" to rescan the data. You should see a log on the left plot.

? I tried to print a log with "Print this Log" and the depth reading appeared on the log was at the bottom of the shaft. How do I change it?

A Command "Print this Log" will print out "What you see" on the plot. You can set your cursor at the desired depth and it will read data from the cursor position to the printer. The cursor was set at the bottom of the shaft as default. Command "Print All Logs" will automatically print all the logs in the shaft and read data at of depth of 2 ft (or lower). If there is debonding at that depth, the software will keep reading the next depth until it finds a good reading.

APPENDIX A

Example CSL Specification

APPENDIX A

A1.0 CROSSHOLE SONIC LOGGING (CSL) OF DRILLED SHAFT FOUNDATIONS

The completed drilled shaft foundations shall be tested with the nondestructive testing (NDT) method called Crosshole Sonic Logging (CSL) after at least 1 day (24 hours) of curing time has elapsed to allow the concrete to harden sufficiently. The Engineer may specify a longer minimum time if special retarders, mix designs, or other factors result in slower-setting concrete. All CSL testing must be completed within 45 calendar days of concrete placement for steel access tubes, or 10 days for PVC access tubes (PVC tubes can debond from the concrete above the water table for larger shafts at more than 10 days of age). The choice of PVC versus steel tubes should be made in consultation with the CSL testing firm, and will depend on shaft size, testing schedule, and other factors. The CSL tests shall be undertaken by an experienced and approved independent testing organization.

The CSL test measures the time it takes for an ultrasonic pulse to travel from a signal source in one access tube to a receiver in another access tube. In uniform, good quality concrete, the travel time between equi-distant tubes will be relatively constant and correspond to a reasonable concrete pulse velocity from the bottom to the top of the foundation. In uniform, good quality concrete, the CSL test will also produce records with good signal amplitude and energy. Longer travel times and lower amplitude/energy signals indicate the presence of irregularities such as poor quality concrete, void, honeycomb and soil intrusions. The signal will be completely lost by the receiver and CSL recording system for the more severe defects such as void and soil intrusions.

A1.1 DRILLED SHAFT FOUNDATION PREPARATION

A number of tubes, typically between 2 to 6, shall be installed in each shaft to permit access for CSL. The number of tubes installed will be as designated on the design drawings for each foundation. If the number and placement of the tubes are not specifically called out on the drawings, then the general guidelines in the table below should be followed.

Shaft Diameter	Recommended Number of Tubes	Tube Spacing
$D \leq 2.5$ ft	2 minimum	180°
$2.5 < D \leq 3.5$ ft	3 minimum	120°
$3.5 < D \leq 5.0$ ft	4 minimum	90°
$5.0 < D \leq 8.0$ ft	6 minimum	60°
$D < 8.0$ ft.	8 minimum	45°

The tubes shall be 1.5 to 2.0 inch inside diameter schedule 40 steel or PVC pipe. The pipes shall have a round, regular internal diameter free of defects or obstructions, including any at pipe joints, in order to permit the free, unobstructed passage of 1.35 inch or smaller diameter, typically 6 to 10 inches long, source and receiver probes. The tubes shall be watertight and free from corrosion with clean internal and external faces to ensure passage of the probes and to ensure a good bond between the concrete and the tubes.

APPENDIX A

The pipes shall each be fitted with a watertight shoe on the bottom and a removable cap on the top. The pipes shall be securely attached to the interior of the reinforcement cage with a minimum cover of 3 inches. The pipes may be attached to exterior of the cage if approved by the Engineer and if the minimum cover requirements are maintained. The tubes shall be installed in each shaft in a regular, symmetric pattern such that each tube is spaced the maximum distance possible from each adjacent tube, with a spacing in degrees around the perimeter of the cage to correspond to the design drawings or that called out in the table above for the selected number of tubes. The tubes are typically wire-tied to the reinforcing cage every 3 feet or otherwise secured such that the tubes stay in position during placement of the rebar cage and concrete placement. The Contractor shall submit to the Engineer his selection of tube material and size, along with his proposed method to install the tubes, prior to construction. The tubes shall be as near to vertical and parallel as possible. The tubes shall extend from ? foot above the shaft bottoms to at least 3 feet above the shaft tops. Under no circumstance should the tubes be allowed to rest on the bottom of the drilled excavation. If the shaft top is subsurface, the tubes shall extend at least 2 feet above the ground surface. Any joints required to achieve full length tubes shall be made watertight. Care shall be taken during reinforcement installation operations in the drilled shaft hole not to damage the tubes.

After placement of the reinforcement cage, the tubes shall be filled with clean water as soon as possible (immediately before or after concrete placement - no later than 4 hours after placement) and the tube tops capped or sealed to keep debris out of the tubes. Care shall be exercised in the removal of caps or plugs from the pipes after installation so as not to apply excess torque, hammering, or other stresses which could break the bond between the tubes and the concrete.

Upon completion of the CSL testing, all water shall be removed from the access pipes and any other drilled holes. The pipes and holes shall then be completely filled with an approved grout.

A1.2 CSL TEST EQUIPMENT

The CSL equipment consists of the following components:

- A microprocessor based CSL system for display of individual CSL records, analog-digital conversion and recording of CSL data, analysis of receiver responses and printing of CSL logs

- Ultrasonic source and receiver probes for 1.5 or 2 inch I.D. pipe, as appropriate
- An ultrasonic voltage pulser to excite the source with a synchronized triggering system to start the recording system

- A depth measurement device to determine record depths

- Appropriate amplification and cable systems for CSL testing

A1.3 CSL LOGGING PROCEDURES

Information on the shaft bottom and top elevations and/or length, along with construction dates should be provided to the testing organization before or at the time of the CSL tests. CSL tests shall be conducted between pairs of tubes, with the determination of which pairs to be tested to be made as part of the testing contract. Typically, perimeter and/or major diagonal tube pairs are tested. Additional logs may be conducted in the event any anomalies are detected in the specified logs. The full depth of all pipes shall be used for conducting CSL tests unless approved otherwise by the engineer. Should an access tube be blocked, the Engineer shall determine what action should be taken in response.

The CSL tests shall be carried out with the source and receiver probes in the same horizontal plane unless test results indicate potential anomalies/defects in which case the questionable zone may be further evaluated with angled tests (source and receiver vertically offset in the tubes). CSL measurements shall be made at depth intervals of 0.2 feet or less, and shall be done from the bottom to the top of each shaft. The probes shall be pulled simultaneously, starting from the bottoms of the tubes, over the depth measuring device. Any slack shall be removed from the cables prior to pulling to provide for accurate depth measurements in the CSL records. Any anomalies/defects indicated by longer pulse arrival times and significantly lower amplitude/energy signals should be reported to the Engineer on-site and any further tests carried out as required to evaluate the extent of such anomalies/defects. Additional NDT methods which could be used include Angled Crosshole Sonic Logging, Crosshole Tomography, Singlehole Sonic Logging, Gamma-Gamma Nuclear Density Logging, and/or Sonic Echo and Impulse Response tests.

A1.4 CSL RESULTS

The CSL results shall be presented in a report. The test results shall include CSL logs with analyses of:

- Initial pulse arrival time or compression wave velocity versus depth
- Pulse energy/amplitude versus depth

A CSL log shall be presented for each tube pair tested with any anomaly/defect zones discussed in the report as appropriate.

APPENDIX A

A1.5 ACCEPTANCE OF COMPLETED DRILLED SHAFT FOUNDATIONS

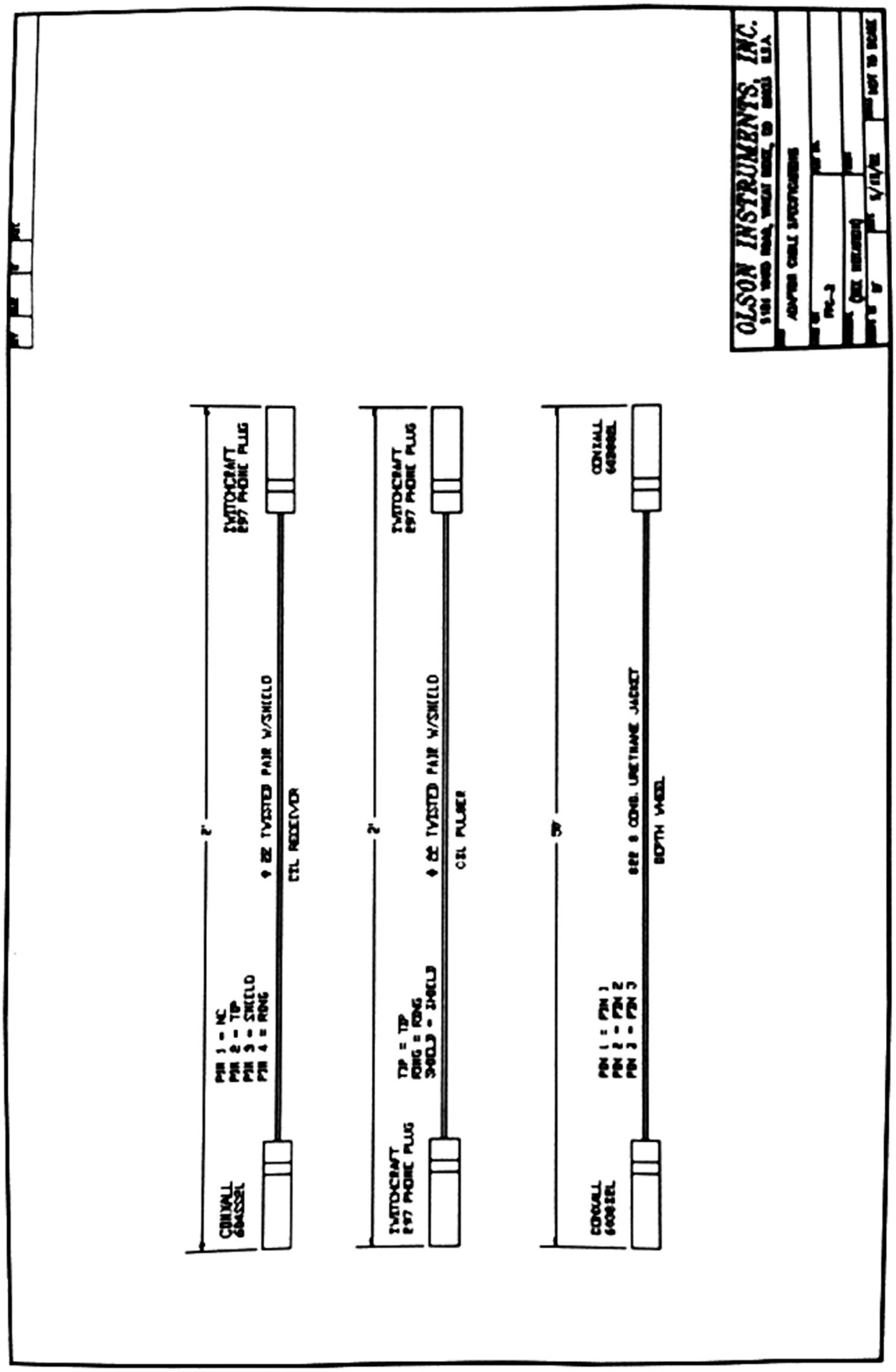
The acceptance of each drilled shaft shall be the decision of the Engineer, based on the results of the shaft integrity testing report(s) and other information on the shaft placement. Rejection of a shaft based on the shaft integrity testing shall require conclusive evidence that a defect exists in the shaft which will result in inadequate or unsafe performance under service loads. If the NDT records are complex or inconclusive, the Engineer may require coring or excavation of the shaft to verify shaft conditions. If a defect is confirmed, the Contractor shall pay for all coring or excavation costs. If no defect is encountered, the State shall pay for all coring or excavation costs, including grouting of all coreholes.

In the case that any shaft is determined to be unacceptable, the contractor shall submit a plan for remedial action to the Engineer for approval. Any modifications to the foundation shafts and load transfer mechanisms caused by the remedial action will require calculations and working drawings stamped by a registered professional engineer for all foundation elements affected. All labor and materials required to perform remedial shaft action shall be provided at no cost to the State and with no extension of the contract time.

In the event the equipment or software is functioning incorrectly these are some steps to use to identify why the problem is occurring or what is causing the problem, i.e. bad cable.

APPENDIX B

Schematic of Cables



For the Cable Spools, the connections are as follows, A – tip, B – ring, and C – shield. If the user desires to test the Cable Spools, please call Olson Instruments, we will be happy to assist you in verifying the cable is working properly.

APPENDIX C

Tube Pair Order

as set in the default template

NOTE: The order of the tube pair can be changed in the template

This combination will be generated and saved in “template.prm”. However, the combinations can be removed, added and resaved in the same filename.

1) One Tubes:	Tube 1 - 1
2) Two Tubes:	Tubes 1 – 2
3) Three Tubes:	Tubes 1 – 2, Tubes 2 - 3, Tubes 3 – 1
4) Four Tubes:	Tubes 1 – 2, Tubes 2 – 3, Tubes 3 – 4, Tubes 4 – 1, Tubes 1 – 3, Tubes 2 – 4
5) Five Tubes:	Tubes 1 – 2, Tubes 2 – 3, Tubes 3 – 4, Tubes 4 – 5, Tubes 5 – 1, Tubes 1 – 3, Tubes 1 – 4, Tubes 2 – 4, Tubes 2 – 5
6) Six Tubes:	Tubes 1 – 2, Tubes 2 – 3, Tubes 3 – 4, Tubes 4 – 5, Tubes 5 – 6, Tubes 6 – 1, Tubes 1 – 4, Tubes 2 – 5, Tubes 3 – 6
7) Seven Tubes:	Tubes 1 – 2, Tubes 2 – 3, Tubes 3 – 4, Tubes 4 – 5, Tubes 5 – 6, Tubes 6 – 7, Tubes 7 – 1, Tubes 1 – 4, Tubes 1 – 5, Tubes 2 – 6, Tubes 3 – 7

8) Eight Tubes:
Tubes 1 – 2,
Tubes 2 – 3,
Tubes 3 – 4,
Tubes 4 – 5,
Tubes 5 – 6,
Tubes 6 – 7,
Tubes 7 – 8,
Tubes 8 – 1,
Tubes 1 – 5,
Tubes 2 – 6,
Tubes 3 – 7,
Tubes 4 – 8

9) Eight Tubes:
Tubes 1 – 2,
Tubes 2 – 3,
Tubes 3 – 4,
Tubes 4 – 5,
Tubes 5 – 6,
Tubes 6 – 7,
Tubes 7 – 8,
Tubes 8 – 9,
Tubes 9 – 1,
Tubes 1 – 5,
Tubes 1 – 6,
Tubes 2 – 7,
Tubes 3 – 8,
Tubes 4 – 9

10) Ten Tubes:
Tubes 1 – 2,
Tubes 2 – 3,
Tubes 3 – 4,
Tubes 4 – 5,
Tubes 5 – 6,
Tubes 6 – 7,
Tubes 7 – 8,
Tubes 8 – 9,
Tubes 9 – 10,
Tubes 10 – 1,
Tubes 1 – 6,
Tubes 2 – 7,
Tubes 3 – 8,
Tubes 4 – 9,
Tubes 5 – 10

11) Eleven Tubes:

Tubes 1 – 2,
Tubes 2 – 3,
Tubes 3 – 4,
Tubes 4 – 5,
Tubes 5 – 6,
Tubes 6 – 7,
Tubes 7 – 8,
Tubes 8 – 9,
Tubes 9 – 10,
Tubes 10 – 11,
Tubes 11 – 1,
Tubes 1 – 6,
Tubes 1 – 7,
Tubes 2 – 8,
Tubes 3 – 9,
Tubes 4 – 10,
Tubes 5 – 11

12) Twelve Tubes:

Tubes 1 – 2,
Tubes 2 – 3,
Tubes 3 – 4,
Tubes 4 – 5,
Tubes 5 – 6,
Tubes 6 – 7,
Tubes 7 – 8,
Tubes 8 – 9,
Tubes 9 – 10,
Tubes 10 – 11,
Tubes 11 – 12,
Tubes 12 – 1,
Tubes 1 – 7,
Tubes 2 – 8,
Tubes 3 – 9,
Tubes 4 – 10,
Tubes 5 – 11,
Tubes 6 – 12

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