Chapter 9
Single Beam Acoustic Depth Measurement Techniques

9-1. General Scope and Applications

Single beam acoustic depth sounding is by far the most widely used depth measurement technique in USACE for surveying river and harbor navigation projects. Acoustic depth sounding was first used in the Corps back in the 1930s but did not replace reliance on lead line depth measurement until the 1950s or 1960s. A variety of acoustic depth systems are used throughout the Corps, depending on project conditions and depths. These include single beam transducer systems, multiple transducer channel sweep systems, and multibeam sweep systems. Although multibeam systems are increasingly being used for surveys of deep-draft projects, single beam systems are still used by the vast majority of districts. This chapter covers the principles of acoustic depth measurement for traditional vertically mounted, single beam systems. Many of these principles are also applicable to multiple transducer sweep systems and multibeam systems. This chapter especially focuses on the critical calibrations required to maintain quality control in single beam echo sounding equipment. These criteria are summarized in Table 9-6 at the end of this chapter.

9-2. Principles of Acoustic Depth Measurement

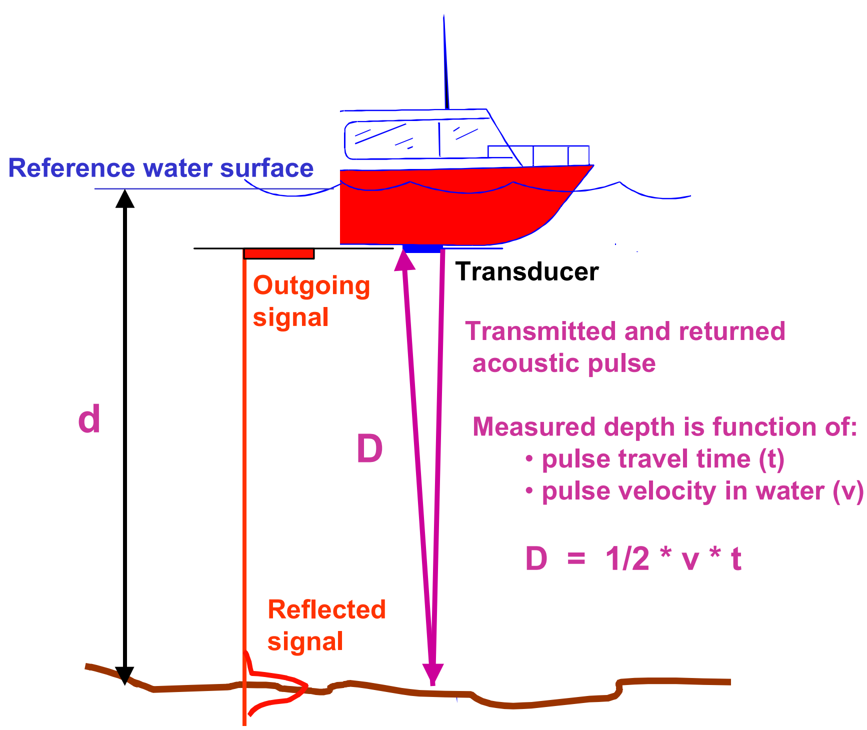


Figure 9-1. Acoustic depth measurement

a. Basic principle. Acoustic depth measurement systems measure the elapsed time that an acoustic pulse takes to travel from a generating transducer to the waterway bottom and back. This is illustrated in Figure 9-1 where the measured depth (D) is between the transducer and some point on the acoustically reflective bottom. The travel time of the acoustic pulse depends on the velocity of propagation (v) in the water column. If the velocity of sound propagation in the water column is known, along with the distance between the transducer and the reference water surface, the corrected depth (d) can be computed by the measured travel time of the pulse. This is expressed by the following general formula:

Depth corrected to referenced water surface $d = \frac{1}{2} (v \cdot t) + k + d_r$ (Eq 9-1)

where:

d = corrected depth from reference water surface
v = average velocity of sound in the water column
t = measured elapsed time from transducer to bottom and back to transducer
k = system index constant
d_r = distance from reference water surface to transducer (draft)

The parameters v, t, and d_r cannot be perfectly determined during the echo sounding process, and k must be determined from periodic calibration of the equipment. The elapsed time, t, is dependent on the reflectivity of the bottom and related signal processing methods used to discern a valid return. The shape, or sharpness, of the returning pulse shown in Figure 9-1 will play a major role in the accuracy and detection capabilities of depth measurement.

b. Velocity of sound in water. Determining the sound velocity, v, is perhaps the most critical factor in using acoustic depth sounders. The sound velocity varies with the density and elastic properties of the water. These properties are, for typical river and harbor project depths, primarily a function of the water temperature and suspended or dissolved contents, i.e., salinity. Due to these effects, the velocity (v) can range from 4,600 to 5,000 ft/sec. Since most river and harbor projects can exhibit large variations in temperature and/or salinity with depth, the velocity of the projected sound wave will not be constant over the distance from the boat's transducer to the bottom and back. The effect of this variation is significant. A temperature change of 10 deg F will change the velocity by as much as 70 ft/sec, or 0.8 ft in 50 ft of water. A 10-ppt salinity change can vary the velocity by some 40 ft/sec, or 0.4 ft in 50 ft. For practical single beam echo sounding work in shallow water, an average velocity of sound is usually assumed (by calibration). Use of an average sound velocity may not be valid in coastal projects subject to freshwater runoff nor will it be constant over the entire project area surveyed. If large variations in velocity occur over the water column, the average sound velocity used should be that at or near the average project survey depth, not over the entire water column. The sound velocity may be measured directly using a velocity probe or indirectly by a bar check calibration. The velocity probe can measure sound velocities at each point in the water column (e.g., every foot). These data can be used to compute an average velocity over the entire column, or use the velocities at each increment to correct depths. The bar check measures actual depths relative to the recorded depths on the echo sounder with an assumed average velocity. Sound velocity determination is much more critical on multibeam systems--especially on the outer beams. Thus, more frequent and accurate sound velocity measurements using probes are required for multibeam systems.

c. Transducer draft and index constant. The transducer draft and index constant must be applied to the reduced time distance to obtain the corrected depth from the reference water surface. The index constant contains any electrical and/or mechanical delays inherent in the measuring system, including return signal threshold detection variations. It also contains any constant correction due to the change in velocity between the upper surface level and that used as an average for the project depth range. For this reason, the apparent "draft" setting or reading on a digital or analog record is *not* necessarily the actual draft of the transducer, as would be obtained by physical measurement between the water surface and transducer. Also, the vessel draft is not the same as the transducer draft because the vessel draft may be measured relative to skegs or other points on the hull. The only effective method of determining the combined constants in Equation 9-1 is by a bar check calibration.

d. Other corrections to observed depths. The depth in Equation 9-1 must subsequently be corrected for short-term vessel draft variations due to loading changes, squat, settlement, heave, pitch, roll, etc. The reference water surface must then be reduced to the local vertical datum based on real-time river/lake stage, pool, or tidal observations. The various corrections required in an acoustic depth measurement are generalized in the sketch shown in Figure 9-2 and are discussed in subsequent sections in this chapter.

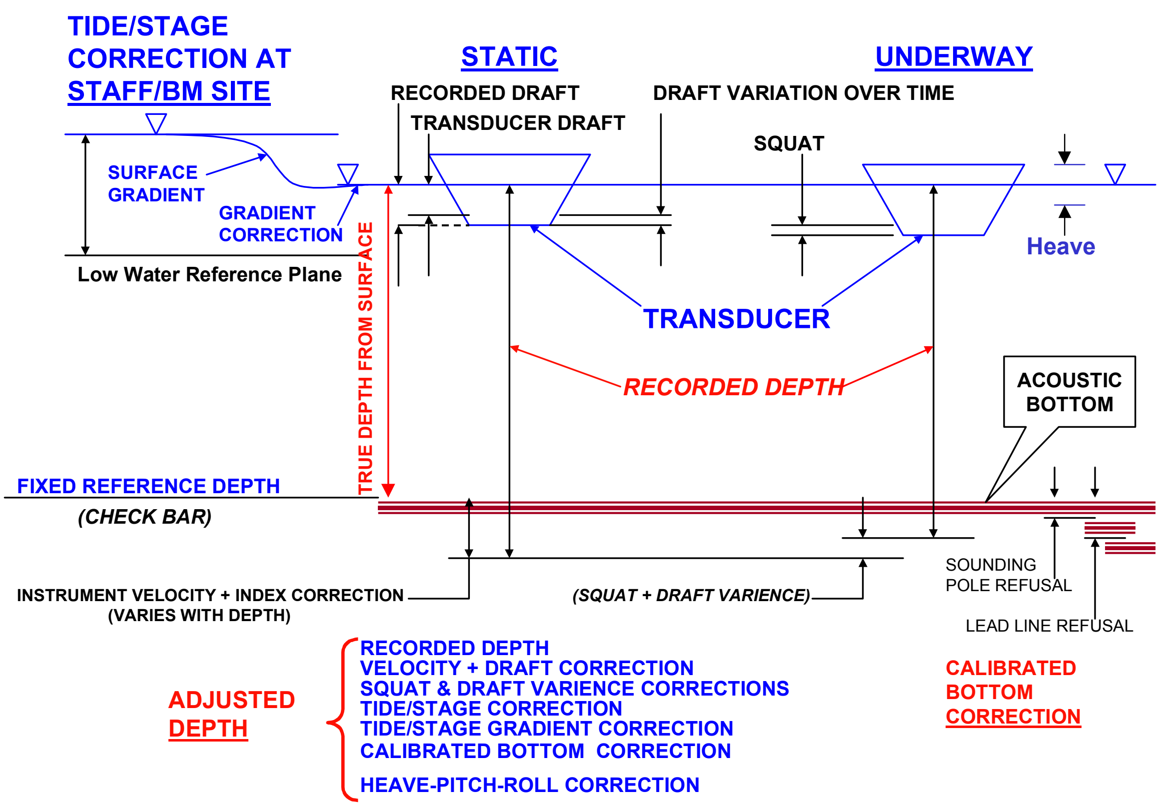


Figure 9-2. Corrections to observed echo soundings

e. Sounding instrument accuracy. The travel time of the sound pulse is measured either electronically in a depth digitizing device or mechanically (graphically) on an analog recording type instrument. The accuracy of the absolute time measurement generally varies with depth. This is due to signal attenuation, noise, and the ability of the measurement circuitry to correlate the outgoing and incoming pulses. In addition, the acoustic reflectivity characteristics of the target, i.e., size, shape, orientation, material, etc., can significantly impact the returning pulse. Variations in return signal strength and sharpness will affect the depth measurement accuracy. The irregularity of the reflected pulse causes uncertainty in the overall time measurement process. There is no practical calibration process for minimizing this error. The *nominal* accuracy of echo sounding time measurement is usually rated by manufacturers at ±0.1 ft plus 0.1 to 0.5 percent of the depth. This equates to a precision range of ±0.15 to ±0.35 ft in 50 ft and is independent of the acoustic reflection characteristics. Digitally measured elapsed times are more accurate than those performed on older mechanical recording devices.

9-3. Transducer Frequency Specifications

A transducer converts electronic energy to acoustical pulses and vice versa. The type of transducer used is a major determining factor in the adequacy of a depth measurement. The optimum transducer frequency is highly project- or site-dependent. Throughout USACE river and harbor projects, a variety of frequencies have been used. These frequencies generally range between 20 kHz and 1,000 kHz. Each frequency/transducer has physical characteristics that particularly suit it to an individual application or project site. The response (i.e., sounding) of the transducer is dependent on the frequency, project conditions, array gain, and beam pattern as is generalized in Figure 9-3. Sensitivities are measured at the - 3 dB half-power points. In general, higher frequency transducers (100 kHz to 1,000 kHz) will provide more precise depth measurement, due to both the frequency characteristics and more-concentrated (i.e., narrow) beam widths. Narrow beam transducers (i.e. less than 8 deg) may require roll and pitch correction since the more-focused beam will measure a slope distance at non-vertical points. However, the side lobes shown in Figure 9-3 could provide a vertical return in shallow water. Narrow beam transducers should be obtained with minimum side lobes. Lower frequency transducers (below 40 kHz) tend to have larger beam widths, which can cause distortion and smoothing of features in irregular bottoms or on side slopes. However, lower frequencies are less subject to attenuation, which allows greater depth measurement and penetration of suspended sediments. Although greater depth measurement is not required for river and harbor projects, the ability to penetrate suspended sediment is a decided asset, especially in performing surveys for dredging projects. A major disadvantage of higher frequency transducers is that there is high signal attenuation with depth, and low specific gravity suspended sediments (fluff) or bottom vegetation will readily reflect the signal. High frequency transducers are not recommended in areas where suspended sediment layers commonly occur, or where bottom vegetation may obscure the desired "pay" grade. In such areas, frequencies ranging between 20 kHz and 50 kHz are typically employed for payment determination.

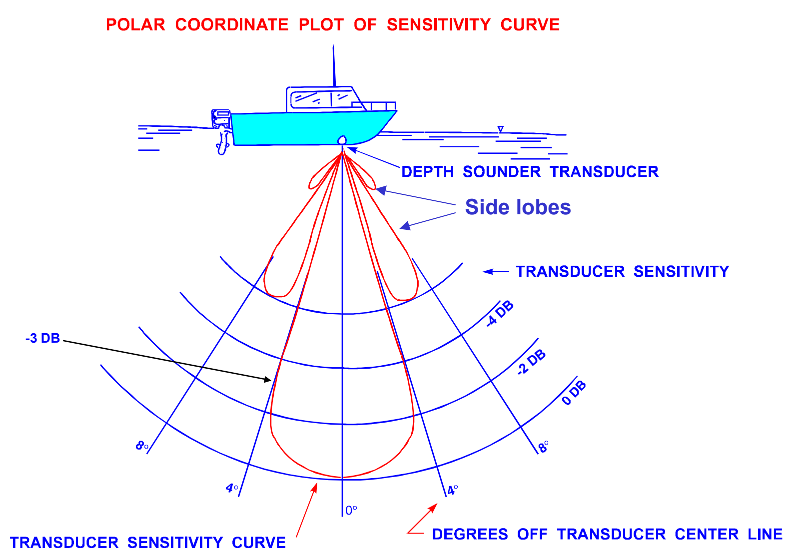


Figure 9-3. Transducer beam angle

a. Ensonification coverage. Each transducer ping ensonifies an area of the bottom. The size of this ensonified area is a function of the transducer beam width and transducer characteristics (i.e., side lobes). The narrow beam transducers used in the Corps ensonify a smaller area of the bottom; resulting in less distortion or smoothing of bottom features within this area. However, only a small portion of a channel is ensonified by narrow beam transducers. The approximate bottom footprint size of a transducer can be computed as follows:

$$\text{Linear coverage (ft)} = 2 \cdot D \cdot \tan(a/2)$$

$$\text{Footprint area coverage (sq ft)} = 3.14 \cdot D^2 \cdot \tan^2 (a/2) \qquad \text{(Eqs 9-2)}$$

where,

D = Depth in ft
a = Beam width in deg

Table 9-1 illustrates the lineal coverage for typical USACE transducers. Table 9-2 computes the resultant area footprint coverages.

Table 9-1. Approximate lineal coverage for different beam width transducers

		BEAM WIDTH		
Project depth	1.5 deg	3 deg	8 deg	20 deg
10 ft	0.3 ft	0.5 ft	1.4 ft	3.5 ft
25 ft	0.7 ft	1.3 ft	3.5 ft	9 ft
50 ft	1.3 ft	2.6 ft	7 ft	18 ft
75 ft	2 ft	4 ft	10 ft	26 ft

Table 9-2. Approximate footprint coverage for different beam width transducers

		BEAM WIDTH		
Project depth	1.5 deg	3 deg	8 deg	20 deg
10 ft	< 1 sq ft	< 1 sq ft	< 2 sq ft	10 sq ft
25 ft	< 1 sq ft	< 2 sq ft	10 sq ft	60 sq ft
50 ft	< 2 sq ft	5 sq ft	40 sq ft	250 sq ft
75 ft	3 sq ft	10 sq ft	90 sq ft	550 sq ft

Table 9-2 clearly indicates that bottom coverage is small for narrow beam transducers. Thus, when cross-section surveys are performed, only a very small portion of the channel is ensonified. The total amount of ensonified coverage for typical cross-section surveys at 100-ft and 200-ft spacings is shown in Table 9-3.

Table 9-3. Approximate percent bottom coverage for cross-section surveys

	100-ft Cross-Sections			200-ft Cross-sections		
Project depth	1.5 deg	3 deg	8 deg	1.5 deg	3 deg	8 deg
10 ft	0.3%	0.5%	1.4%	0.1%	0.2%	0.7%
25 ft	0.7%	1.3%	3.5%	0.3%	0.6%	2%
50 ft	1.3%	2.6%	7%	0.6%	1%	4%
75 ft	2%	4%	10%	1%	2%	5%

Table 9-3 indicates that only 1% to 5% of a channel bottom is typically ensonified by single beam cross-section surveys. From this small data sample, shoaling conditions are projected and material quantities are estimated using end area projection methods. In effect, quantity take-off computations and shoaling estimates are "extrapolated" over 95-99% on the channel that is not surveyed. These estimates have normally been adequate for engineering and construction purposes; plus they were deemed practical given the high cost of data collection per cross-section. In the past this rationale was valid; however, multi-transducer sweep systems and multibeam systems can now easily collect 100% bottom coverage.

b. Single beam roll and pitch correction. The transducer measures depth from the first echo return. The wider the beam, the less effect vessel roll or pitch will have since the transducer beam width falls within the vertical. For narrow beam transducers a slope rather than vertical distance is measured. If roll and pitch is severe--e.g., a 10-15 deg roll--the recorded depth will be a longer slope distance. This measurement should either be rejected due to excessive roll/pitch or corrected for slope-to-vertical given the observed roll/pitch angle from a motion sensor. Processing software such as HYPACK provides pitch/roll slope-to-vertical depth correction in addition to correcting for the positional (X-Y) eccentricity or the transducer relative to the positioning antenna.

c. Shoal or object strike detection. Far more complex is the effect of frequency on the detection of certain-size objects on the bottom. Detection of blasted rock fragments or other hazardous objects above project grade is a difficult process with traditional echo sounders, regardless of the frequency used. Generally, lower-frequency, wider-beam transducers may be more suited for strike detection than higher-frequency, narrow-beam transducers. However, the sounding system's threshold detection settings, gate settings, display methods, etc., are also critical to strike detection. Vertically mounted, narrow-beam transducers (either single hull-mounted or boom "sweep" systems) may not be the best configuration for providing optimum energy return from small underwater strikes; notwithstanding their small acoustical footprint. Side-looking multibeam systems and side-scanning sonar may provide better returns from such objects. In addition, many "charting" type echo sounders used in USACE are not designed (or optimized) for strike detection work.

d. 200 kHz standard frequency. The most commonly employed transducer frequency in USACE river and harbor navigation projects is 200-208 kHz. Transducers operating at this frequency are usually narrow-beamed (between 1.5 deg and 8 deg at the -3 dB points) to provide more accurate bottom detailing. Narrower beams are recommended for projects with relatively hard, smooth grades, such as rock cuts or sand bottoms. A 3 deg transducer will provide a slightly higher depiction of small bottom features. The 200-208 kHz (± 10%) frequency is *not* a mandatory USACE frequency standard, nor is any particular beam width. Lower or higher frequency transducers, ranging between 20 kHz and 1,000 kHz, and with varying beam widths, are allowable for any class of survey or type of acoustic measurement system (e.g., single, sweep, or multibeam systems). Local conditions and unique project requirements will dictate the optimum type of survey system and frequency to be used. However, for navigation and dredge payment surveys, the acoustic survey system and/or transducer frequency should be constant throughout the project duration--and clearly identified in construction specifications. Multiple frequency systems may be used for analyzing sediment layers of varying densities-- typically using 200 kHz and 28 kHz dual frequency sounders.

e. Single beam transducer mounting. The transducer for a single beam echo sounder should be mounted nearly amidships and as near as possible to the vessel's fore and aft center of rotation. The transducer should be permanently located in a frame or transducer well adjacent to the vessel's keel. Over-the-side, bow, and stern mounts are permitted only if heave-pitch-roll roll motion and location eccentricities are compensated. The positioning system's antenna should preferably be located directly over the transducer--any X-Y-Z offsets must be accurately measured and input into processing software.

9-4. Single Beam Echo Sounding Equipment and Procedures

Prior to the 1970s, most districts employed mechanical analog depth recorders. The most common models used were Bludworth and Raytheon 719. These devices marked the continuous depth profile on a pre-printed graph paper using a rotating stylus mechanism. The speed of the rotating mechanical stylus was a function of water depth and velocity of sound. Unfortunately, the rotational velocity of the mechanical recorders was often unstable and required constant calibration and alignment. Few of these mechanical analog recording systems are still used in the Corps. Figure 9-4 depicts an older Raytheon DE 719 along with a typical cross-section record. In the 1970s, districts began to acquire digital depth recording systems. These systems marked analog (profile) depths directly on blank thermal recording paper; thus eliminating most of the errors in mechanical recorders. Digital depth data could also be sent to a data logging device where it was correlated with positioning data input. Newer generation systems record data on disc or WORM drives for real-time screen viewing and/or off line printing. All modern depth measurement systems can be configured to output measured depths to data recording devices, where they can be time tagged with position and motion sensing data.

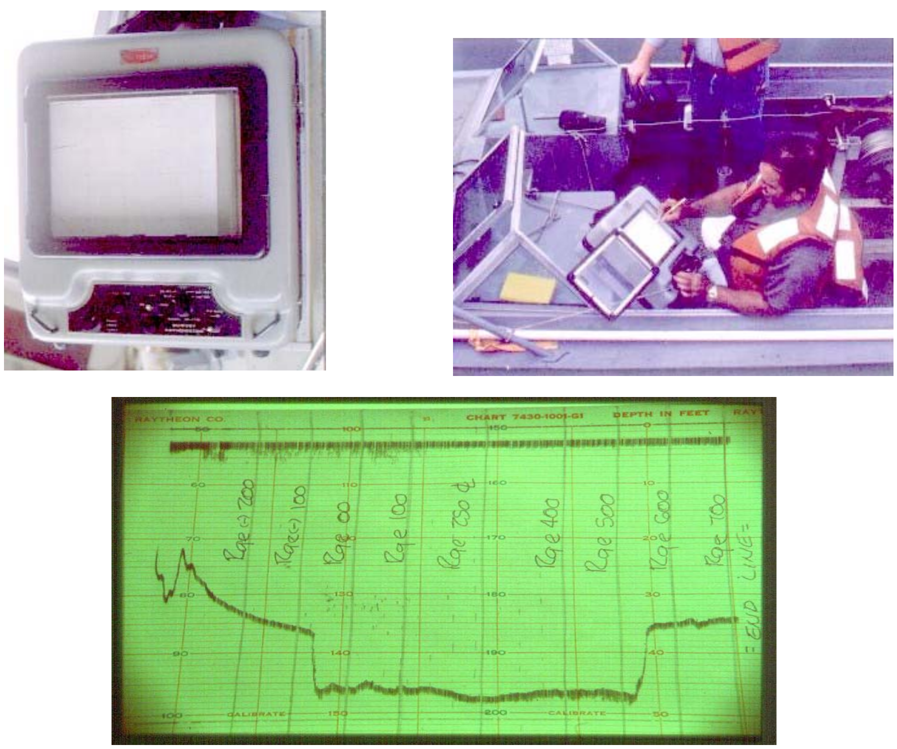
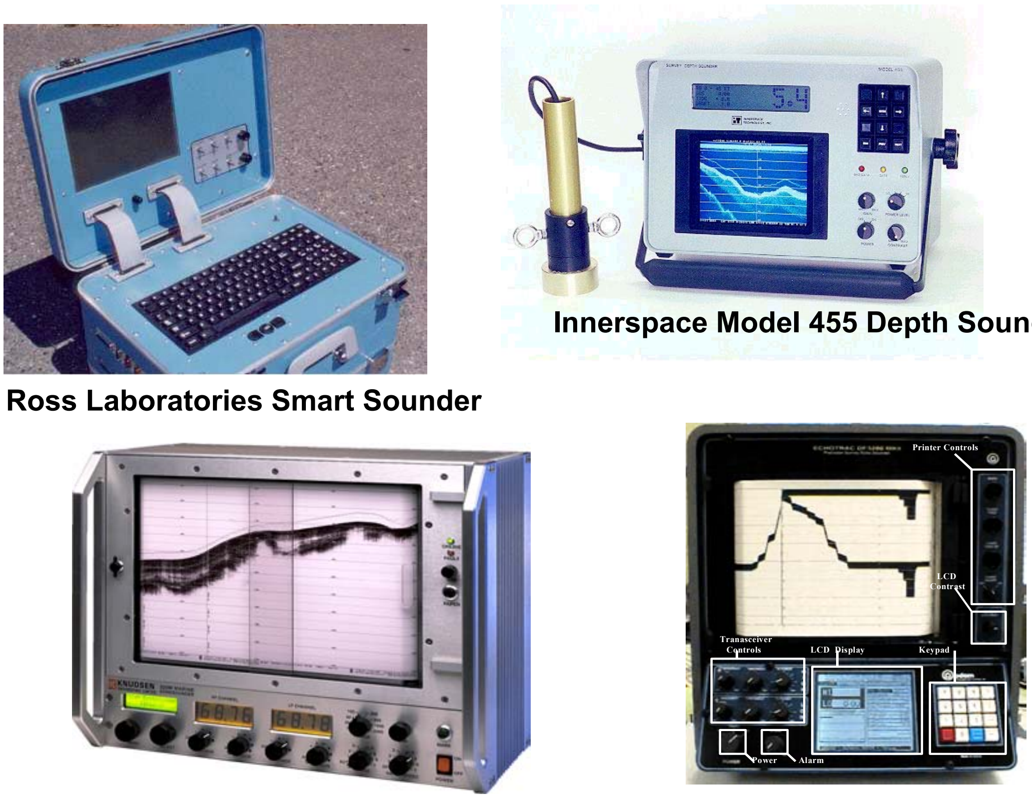


Figure 9-4. Raytheon DE 719 analog-recording portable echo sounder (Jacksonville District)

a. Single beam echo sounders. Figure 9-5 depicts some of the more common digital sounding units currently used by Corps districts. A brief description of the specifications for some of these units follows. These specifications were obtained directly from the manufacturer's operating manuals and/or other literature--see the references at the end of this chapter for more details.



Innerspace Model 455 Depth Sounder

Ross Laboratories Smart Sounder

Knudsen 320M Echosounder

Odom Echotrak DF3200 Mk II

Figure 9-5. Typical single beam echo sounders used in Corps

(1) Innerspace Technology, Inc. Model 455 and Model 448. The Model 455 shown in Figure 9-5 provides analog and digital depth on separate high resolution LCD display screens. The small, lightweight, portable unit is designed for use on reconnaissance vessels and small workboats. Optionally, analog screens can be printed on a computer printer or stored internally for future reference or hard copy printout. The menu is controlled via up / down, left / right arrows; no numerical entries are required. The analog LCD provides a continuous, high-resolution, bottom profile with alphanumerical annotation of pertinent information. Significant features include:

- Range gated autotracking digitizer
- Variable speed-of-sound adjustment (feet & meters)
- Power output adjustment (four level)
- VGA, parallel, serial (three), floppy, keyboard ports
- VGA, transflective monochrome LCD with contrast control (daylight readable) optional-color LCD TFT VGA 500NIT with index filtering for daylight viewing
- Resolution, 0.1 feet or 0.01 meter, digital and analog
- Audible shallow depth alarm

- Mission storage of charts on 48 MB solid state flashRAM; two days of continuous screen capture
- Analog chart files are in PCX format for color presentation on standard computer equipment
- 40 character chart annotation from external computer
- GPS input for latitude/ longitude chart annotation.
- Built in multiplexer. Digital depth and GPS position can be internally multiplexed then outputted as a single NMEA data string to a single port, data logging computer
- Complete transducer and GPS antenna mounting accessories for small boats

The Innerspace Model 448 Thermal Depth Sounder Recorder (not shown in Figure 9-5) is used in some 18 Corps districts. The 448 provides survey precision, high resolution depth recordings using solid state thermal printing. The lightweight, portable unit is designed for use in small boat surveying as required for engineering surveys, harbor and channel maintenance, pre and post dredge surveys, etc. Some of the features of the 448 advertised by Innerspace Technology include:

- Thermal Printing fixed head - no stylus to replace-no carbon residue-no rotating stylus-no arcing-odorless operation - no burned paper
- Large viewing area with sliding window
- Large chart - high resolution
- Blank Paper is high contrast black on white
- Portable and lightweight for small boat operation
- Microprocessor controlled
- Scale selected is the only one printed
- Feet or meters operation - switch selectable
- Thumbwheel settings for speed of sound, tide and draft
- Annotation of all parameters appear on recordings in chart margin Speed-of-sound, Tide, Draft, Event, Time and Mode of operation
- TVG (time varied gain) minimizes gain adjustments
- Internal micro controlled depth digitizer
- No adjustments for zero line or cal line are required
- Motion compensation interface

(2) Knudsen Engineering Limited Model 320M or 320M/P Echosounder. Models 320M or 320 M/P are single or dual-frequency recorders. Using either the high or low frequency channel, or both simultaneously, the 320M and M/P produce a high resolution record accurately depicting bottom profiles and sediment layers with 32 shades of gray. The thermal printer uses 8.5 inch plastic film for permanent, high-quality archival records. The annotated depth grid is printed with reverse shading for clarity.

- Digitized water depths is shown on two large 4-digit LCD displays, visible in direct sunlight and backlit for night operation. Serial RS232 depth data is continuously available in NMEA format as well as user-defined string formats, and in operator-selectable time and position tagged formats.

- A LCD menu display with 2-button control provides access to parameters such as sound velocity, draft, TX blanking, serial port assignment, time and date setting, and testing features. All settings are retained in non-volatile memory and recalled on power-up.

- Three RS 232 ports support communication with personal computers, NMEA input and output devices, GPS receivers, sound velocity sensors, heave sensors, remote depth display, and survey data loggers. An optional upgrade allows the 320M or 320 M/P to be operated remotely through the built-in SCSI interface and Windows application software. This SCSI interface provides the ability to transfer the entire gray scale image data (32 gray scales) as well as the binary files to disc for future archive.

- Technical specifications (selected). Frequencies: 3.5 kHz to 250 kHz (12, 24, 26, 28, 30, 33, 38, 40, 41, 50, 100, 120, 150, 200, 208, and 210 kHz). Units: meters, feet, or fathoms. Weight: 40 lbs. Power: 12 or 24 VDC nominal. Resolution: 1 cm over 0-100 meter range.

- The 320M series provides a depth range capability from extremely shallow (12 inches or less) to full ocean depth, depending on frequency/transducer options.

(3) Odom Hydrographic Systems, Inc. Echotrac Model DF3200 MKII. The Echotrac MKII Recorder/Digitizer/Transceiver utilizes highly integrated digital and analog circuitry, display technology, and thermal printing techniques. System response is achieved by employing techniques such as digital signal processing, task sharing, asynchronous event processing, and multiple scan buffering.

- Dual Frequency Operation: Two frequencies are selectable from the following: Low (12 kHz to 50 kHz), High (100 kHz to 1 MHz), Standard frequencies are 24 kHz and 200 kHz.

- Printer mechanism: The high-resolution thinfilm thermal print head (216 mm (8.5") wide, 8 dots per mm (203/in.)) prints up to 16 gray shades.

- Display: Film Super Twisted Nematic (FSTN) Dot Matrix LCD Module (320 x 200 pixels, 0.38 mm x 0.52 mm dot pitch), Six inch (156.4 mm) diagonal measure, on board controller and Fluorescent Back Lighting (CFL). The paper white display has visibility in all light conditions--from bright sun to darkened wheel house.

- Remote Operation: All system controls are accessible to a remote computer via one of the three serial ports. The sounder in completely interactive with motion and positioning systems and provides unlimited header and event annotation input capability generated either internally or by the computer.

- Keypad: The 16 key Nema 12 sealed unit has full travel and tactile feel. The keypad is used by the operator for direct parameter entry and functional control of the unit from the front panel.

- Receive: The system incorporates both TVG and AGC Sensitivity and AGC are continuously variable by front panel mounted potentiometers. Automatic gain control can be disabled by setting the front panel mounted potentiometer to the minimum detect position. The TVG curve is internally accessed.

- Transmit: Transmit frequencies are digitally synthesized and based on the stable frequency characteristics of a crystal controlled clock oscillator. Transmitted power for both high and low channels is individually adjustable via front panel mounted controls. Power is adjustable from the minimum of less than 20 watts in high frequency shallow water applications to over 1600 watts in low frequency deep water versions. Transmit Pulse Width is variable either automatically (actual value dependent on frequency and depth) or manually by keypad entry.

(4) Odom Hydrographic Systems, Inc. HYDROTRAC. The Hydrotrac is a single frequency, Recorder/Digitizer/Transceiver and is a highly integrated digital and analog sounder packaged into a small, waterproof housing. The thermal printer is identical to that used in the Echotrac MKII sounder.

Many of the features in Echotrac are carried over into the Hydrotrac including; digital signal processing, task sharing, asynchronous event processing, and multiple scan buffering.

- Single Frequency Operation: The frequency agile Hydrotrac allows connections to a variety of transducers ranging between 33 kHz and 200 kHz.
- Printer Mechanism: The high-resolution thin film thermal print head (216 mm (8.5") wide, 8 dots per mm (203/in.) prints up to 16 gray shades. Help instructions are printed on the chart and standard fax paper can be used in emergencies.
- Display: Backlit dot matrix LCD module with scrolling menu for parameter setting and large character "depth" reading. All settings are stored in non-volatile internal memory.
- Keypad: The sealed, 10 key, tactile feel keypad is waterproof and used by the operator for direct parameter entry and functional control of the unit from the front panel.
- Remote Operation: All system controls are accessible to a remote computer via one of the two serial ports. The sounder in completely interactive with motion and positioning systems as described for the Echotrac MKII.
- Receive: The system incorporates both Sensitivity and TX Power controls on the front panel.
- Transmit: Transmit frequencies are digitally synthesized and based on the stable frequency characteristics of a crystal controlled clock oscillator.
- System upgrades: Remotely installed in flash memory via the Internet.
- DGPS Receiver: (Optional) Incorporated inside the waterproof housing of the Hydrotrac, provides XYZ chart annotation and combined NMEA output string.

(5) Odom Hydrographic Systems, Inc. Echotrac Model DF3200 MKIII. The Echotrac MKIII Recorder/Digitizer/Transceiver utilizes Multiple DSP and RISC technology to provide a portable, dual frequency sounder that is mission configurable. With an interchangeable chart panel, the surveyor can elect to have a standard paper chart recorder or a paperless, full color LCD presentation. In either case, data, parameter settings, sensor input, etc. are stored on a removable PCMCIA card for later playback or chart printing on the recorder or directly on a computer.

- Dual Frequency Operation: Frequency and Impedance agile to match a variety of transducers ranging in frequency from 24 to 210 kHz.
- Printer Mechanism: Interchangeable, high-resolution thin film thermal print head (216 mm (8.5") wide, 1600 dots per scan, printing up to 32 gray shades. Standard fax paper can be used in emergencies.
- Display: Active matrix, high intensity color LCD (1500 NITS) for data, setup, and graphical user interface.
- Remote Operation: All system controls are accessible to a remote computer via one of the three serial ports. The sounder in completely interactive with motion and positioning systems

and provides unlimited header and event annotation input capability generated either internally or by the computer.

- Keypad: The 16 key Nema 12 sealed unit has full travel and tactile feel. The keypad is used by the operator for direct parameter entry and functional control of the unit from the front panel. All operator settings are stored in non-volatile internal memory.

- Storage Media: Removable PCMCIA memory card – compatible to PCMCIA readers for direct download to computer or other Echotrac units – with 10 hour logging range.

- Receive Section: Incorporates both Sensitivity and AGC controls via the front panel.

- Transmit Section: Frequencies are digitally synthesized and based on a crystal controlled clock oscillator. Transmitted power and pulse width for both high and low channels are individually adjustable via front panel mounted controls.

- Communications: Four Serial RS232 ports plus USB port for analog feed to computer for real-time chart display on monitor.

- Power Agile: AC or DC power supply.

(6) Ross Laboratories Series 850 Smart Sounder. It is a paperless recorder (all electronic) which automatically stores a Sonogram to operator-selected media on the data collection computer. This is used for playback and for editing purposes. The sonograms are also archived on a Zip drive or CD ROM. Hard copies may be printed out on a color printer also. The display is a high visibility (900 NIT) active matrix TFT display.

- Hardcopy. The 850 can print the analog signal levels graphically in color or gray scale, in real time or post-survey. Printing after the survey is accomplished by connecting a printer to the 850 or transferring the analog data to a computer for printing.

- Heave Correction. Direct serial communication with the TSS Heave Compensator is standard. The heave is placed in scale anywhere on the analog display. Heave corrected depth data can be superimposed as a line on the color display.

- Serial Output. Custom NMEA-0183 output string includes feet and meters, and if connected, heave corrected depth in both feet and meters.

- Digital Data Logging. Digital depth can be logged to a file on any one of the 850's disk drives. This text file can be exported to a spreadsheet or any other application that reads comma delimited text files.

- Color Display. The display shows the digitized signal levels in different colors. The color display provides enhanced bottom and sub-bottom detail using active TFT color display, which is effective in bright sunlit applications. The entire sonogram (received echo) is stored on magnetic or optical media for future playback and printing. The playback of the data can be done on the 850 or using an MS-DOS based personal computer. Playback software is used for display and editing of the soundings. The transfer of the data to a second computer is done by floppy or removable ZIP drive. The recording time of the data varies--the storage of the entire sonogram is typically 1.7 megabytes per hour for a 200 kHz system on a 50-foot range. This varies due to bottom dynamics and depth range.

- Model 850C. The 850C is the basic machine that includes a standard 3.5 inch floppy drive and a software compression utility (pkzip.exe) for the transfer of the sounding data to a PC compatible computer. The 850C also has a removable ZIP drive for large data transfers and backup storage of the sounding data.

- Model 851C. The 851C can permanently archive the sounding data on a removable optical media. This optical media is intended to be the legal record of the survey.

b. Single beam surveying methods. Single beam surveys are run either normal to (i.e., cross-sectioned) or longitudinal with the channel alignment. Cross-sections for dredge payment surveys are usually spaced between 50 and 200 ft, depending on the bottom consistency between sections and need for shoal or strike detection. Cross-sections are extended up the channel sides. Condition survey lines are typically run longitudinal with the channel alignment--inside the channel toes. The spacing of lines is typically between 50 and 250 ft, again depending on project-dependent channel shoaling patterns.

c. Marking position events on hard-copy depth profile records. Horizontal positioning event marks (or fixes) are made on analog or digital hard-copy recorders. When channel cross sections are run, the position fixes may be keyed to specific channel offset ranges. Position fixes may also be keyed by time or distance traveled along a cross-section. The horizontal fix events should be spaced at close intervals so that positions can be accurately interpolated between event marks. A fix should be taken at channel toe ranges. The vertical event line in the recorded profile may be manually “fixed” or automatically generated from the positioning system. On older mechanical systems (e.g., Raytheon 719) excessive stylus wobble during an event must be prevented. Fully automated survey systems that tag each recorded depth with a position can be configured to annotate periodic event marks on the analog record. This period will be much longer than the digitized depth sample rate. Special care must be taken to ensure that the event corresponds exactly with the position update. Otherwise, severe systematic latencies due to electrical and/or mechanical delays can result. These latencies are exhibited by apparent shifts on alternately run cross sections.

d. Retention of hard-copy depth records. Real time, hard copy depth profile records of navigation and dredging surveys are still used in the field to visually evaluate project condition and clearance. This may be done using hard-copy (paper) depth recordings or digital play-back recordings. Retention of real-time (or near real-time) profile depth records is still required for contract measurement and payment surveys since these analog records contain bar check calibration data as a continuous part of the record. These data can be retained either in hard-copy form or on a "write-once" type of digital record that cannot be edited. Recording to rewritable discs is optional for project condition surveys.

9-5. Depth Collection Density and Bottom Coverage

Single beam echo sounders typically collect depth data at a rate of 5 to 20 soundings per second. Data acquisition systems can be set to acquire some or all of these data points each second. If continuous bottom coverage along the cross-section is required, then the update rate should be adjusted such that each portion of the cross-section is ensonified. This update rate is a function of the average or project depth, vessel speed, and transducer beam width. An approximate computation of this update rate can be made from the following equation:

$$\text{Update rate (milliseconds)} = 1185 \cdot (D / v) \cdot \tan(a/2) \qquad \text{(Eq 9-3)}$$

where

D = Average or project depth
v = Velocity in knots
a = Transducer beam width

Since all these parameters can vary during a survey, the minimum practical update rate should be used. For example, given a project depth of 43 ft and an 8-deg transducer, the required update rate would be 400 millisecs at 5 kts, and 200 millisecs at 10 kts. Thus, a 200 millisec rate (i.e., 5 depths/sec) would be adequate for all speeds less than 10 kts. However, if the project depth were only 20 ft, a 100 millisec collection rate would be needed to obtain full along section coverage if the vessel runs up to 10 kts. In general, a 100 millisec update will be adequate for most surveys. Setting too large an update rate could leave data gaps. Higher densities (i.e., every 50 to 100 milliseconds) might be collected in rock-cut channels to give a more accurate representation of the bottom and to detect strikes above grade. A high density of depths may also be needed to confirm multiple hits on strikes. Data collection software allows input of the desired depth collection rate. As high-density depth data is recorded, it is time tagged to interpolated positions taken at a lower update rate. Dredging contracts should specify depth data collection density used in payment computations, and distinguish the process by which depths are thinned or generalized for plotting purposes (i.e., sorting, binning, or gridding techniques).

9-6. Effects of Vessel Heave, Roll, Pitch, and Yaw on Single Beam Systems

Correcting observed depths for the superimposed effects of vessel roll, pitch, yaw, and heave was once perhaps the most difficult aspect of hydrographic surveying. Along with tide/stage, these effects are a major error component in hydrographic surveying. Vessel heave is the major error component of the four listed motions. Since the mid 1990s, affordable and accurate motion compensation instruments have significantly reduced these errors. Many districts have now incorporated motion compensation into single beam systems. Since vessel roll, pitch, yaw, and heave conditions can occur simultaneously and at different periods, either visual or automated interpretation of a single beam analog profile record to reduce these errors is an imprecise process, at best. Motion compensation (heave-pitch-roll) is mandatory on critical dredging measurement and payment surveys and strongly recommended for all other surveys where adverse sea conditions can affect the quality of the recorded data.

a. Interpretation of single beam recorded depths without motion compensation. The impact of lateral vessel roll and fore-and-aft pitch of the vessel are more pronounced when narrow-beam transducers are employed because the sounding cone becomes non-vertical and measures a longer slope distance. Up and down vertical heave reflects the wave height. Heave is superimposed with roll and pitch on the observed depth. Heave values typically can range up to 2 to 4 ft whereas roll/pitch depth errors are much smaller--e.g., less than 1 ft. Interpretation of the effects of all three potential motions on an analog recording requires skill and experience with the vessel motion at the time of the survey. The apparent smoothing of undulations on the graphical record are not always interpolated correctly, depending on the vessel's course relative to the seas, vessel size, vessel characteristics, and wave height. On an irregular bottom, it is extremely difficult to separate vessel motions from the bottom undulations. Digitally recorded depths do not allow for any human interpretation or smoothing of undulations due to heave, pitch, and roll.

(1) Unless reliable heave-pitch-roll (HPR) motion compensation devices are used, the only practical method of minimizing vessel motion effects is to limit the maximum allowable sea states under which a particular type of survey may be performed. Such limitations are highly subjective and can have significant economic impacts, due either to delayed survey work or to inaccurate payment when a survey is performed under adverse conditions. Maximum sea state limitations must also factor in the size and relative stability of

the survey vessel, along with the effects of the prevailing wave direction relative to the survey lines or cross sections. Procuring larger vessels to minimize roll, pitch, and heave is likewise no longer economically justified given the small cost of HPR compensators. Thus, a simple maximum allowable wave height criterion is difficult to definitively specify.

(2) An on-site assessment of the potential data adequacy must be performed since so many variables are involved. If the effects of vessel motion appear to be degrading the desired (and acceptable, from a contract performance measurement standpoint) survey quality after the on-site assessment is performed, the on-site survey party chief should make the decision to postpone the survey. Such a decision should be made with the concurrence of the government's Contracting Officer Representatives (COR) and/or contractor representatives present aboard the survey boat, or as otherwise defined in the contract provisions.

(3) A subjective judgment on the effects of excessive vessel motion to a survey's adequacy must also consider the type of survey. One-half-foot seas may be the maximum tolerable limit for performing a final acceptance survey or sweep on high-unit-price rock excavation work, whereas 1-ft seas or larger might have been tolerable for the initial pre-construction survey of this same project. Any workable sea state may be tolerated for an intermediate progress payment survey of this project. No maximum sea state limits need be imposed on performing less critical non-navigation surveys--the only tolerance to be considered is the ability of the vessel, equipment, and personnel to collect reliable data.

(4) Based on the above discussion, use of HPR motion compensation instruments for single-beam surveys is recommended in order to maximize data quality and production.

b. Motion stabilization for single beam systems. To best minimize the adverse effects of vessel motion, single beam systems used for dredging and navigation surveys in rough sea states should be equipped with automated heave sensors, and also pitch and roll sensors. Motion compensation should be required if the effects of heave, roll, or pitch generate depth errors exceeding ± 0.2 ft. Yaw compensation may or may not be required. Motion compensation may not be necessary in confined, calm waters, such as inland rivers or reservoirs; presuming these corrections are less than ± 0.2 ft. Motion compensation systems are configured to operate in line directly with depth recorders or independently as a real-time input to the survey data acquisition and processing system. Nearly all systems display heave, pitch, and roll information in real-time; allowing for operator assessment of the data quality. Motion compensation is then applied either in real-time or during post-processing of data. Raw observed data can be independently corrected for heave (e.g., Figure 9-6), roll, and/or pitch, depending on the magnitude of these correctors.

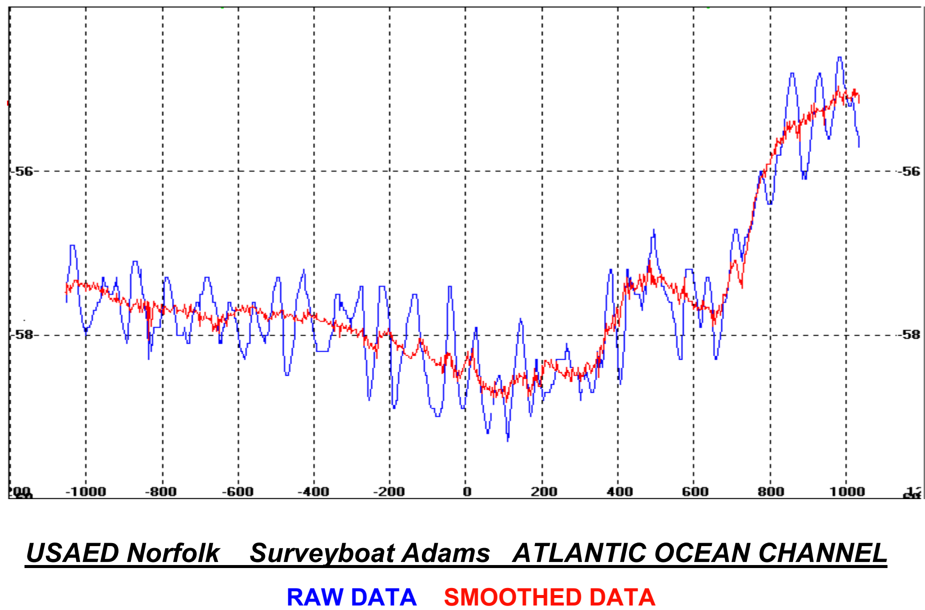


Figure 9-6. Heave compensation on typical offshore channel (Norfolk District)

c. Heave compensation. The major depth error component is heave--the long-period up and down motion of the vessel due to wave motion, other vessel wakes, etc. Heave is basically a function of wave swell and period. Heave errors are normally excessive at coastal entrances and on offshore approach channels--large 65-ft survey boats can typically work in swells up to 3 or 4 feet. Modern heave compensators can effectively record heave movement and smooth out these effects. Heave compensators require internal alignment and stabilization calibrations specified by the manufacturers. Since heave compensators can be subject to constant drifts, continuous monitoring during surveys is required.

d. Roll and pitch compensation. Excessive roll and pitch can introduce bias error in depth, resulting in a deeper reading over a level bottom. Excessive roll and pitch can also inject position errors in the measured depth. This is caused by the motion of the positioning system antenna relative to the transducer. If the distance between the units is large, roll and/or pitch displaces the transducer. This is usually not significant for most applications but can be corrected with roll/pitch and antenna-transducer offset data.

(1) Roll-pitch effects. On larger vessels--i.e., greater than 26 ft--roll and pitch are usually not excessive under normal working conditions--typically less than 5 deg . However, on smaller vessels (e.g., less than 26 ft) roll or pitch can easily approach or exceed 10 deg in rough seas. The correction for roll and pitch varies with the angle of rotation and depth--see Figure 9-7. However, the beam width of the transducer may be greater than the overall roll or pitch, resulting in the first return still being near vertical. Figure 9-8 shows a starboard roll (looking from aft). Rotation is about the point "O". The transducer is rotated slightly higher relative to the reference surface. In theory, the measured depth without roll--"D_0"--would be slightly less than that measured at the indicated roll-- "D_1". If the roll angle is within the beam width, as shown, then the correction would be negligible. However, if the roll is excessive--say greater than 10 deg-- then observed depths would be greater. Corrections for roll-pitch should be applied for high frequency narrow beam transducers--similarly to that applied to narrow beams formed by multibeam arrays.

ROLL/PITCH ERROR ON NEAR-VERTICAL BEAM

Roll/Pitch	Error at Depth 10 ft	25 ft	50 ft
0 deg	0 ft	0 ft	0 ft
1	0	0	0.01
5	0.04	0.10	0.19
10	0.15	0.39	0.77
15	0.35	0.88	1.76
20	0.64	1.6	3.2

MAXIMUMLALLOWABLE ROLLL/PITCH ANGLE TO MAINTAIN +/- 0.2 FT ERROR

Project Depth	Max Angle
10 ft`	11 deg
25 ft	7 deg
50 ft	5 deg
75 ft	4 deg

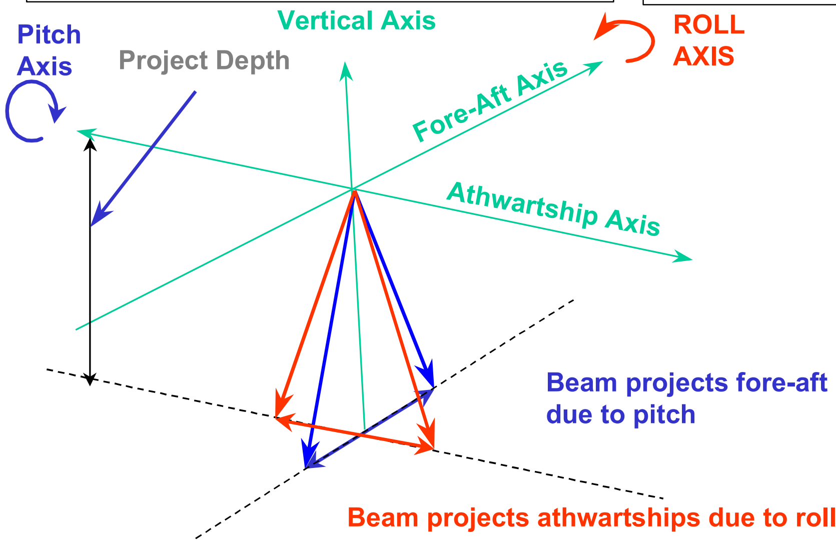


Figure 9-7. Roll and pitch effects on a single beam depth

(2) Roll-pitch position displacement correction. Single beam processing systems (e.g., HYPACK) correct for depth and position variations due to roll or pitch. Using roll-pitch data, HYPACK does allow correction of the depth's X-Y position due to rotation of the antenna-transducer axis, and optionally to compute the X-Y coordinate of the center of the projected (i.e., steered) beam on the bottom--point D_1 in Figure 9-8. On a large survey vessel with an antenna located 30 ft above the transducer subject to a 10 deg roll or pitch, this would amount to a 5 ft horizontal displacement of the transducer. In a 30-foot project, the center of the beam on the bottom would also be displaced by another 5 ft (approximately) relative to the transducer. The total horizontal displacement of the depth relative to the antenna would then be about 10 ft. A displacement of this magnitude (3 m) is outside the 2 m RMS positional tolerance for dredging and navigation surveys, so it should be applied to all observed depths. A smaller survey boat would normally have a much smaller antenna height (< 10 ft) so the horizontal displacement between the antenna and beam-steered bottom depth would be smaller. If cm-level RTK DGPS positioning is being observed, then the antenna-depth displacement is especially significant and should be applied on all work. In shallow draft projects (< 15 ft) using meter-level code-phase DGPS positioning, this displacement correction is usually not significant and need not be applied as long as the displacement does not exceed 1 meter.

(3) Roll-pitch slope to vertical depth correction. In addition to the antenna-transducer-bottom depth positional displacement correction, the slope-to-vertical correction to depth may also be computed and applied to the observed depth. The slope-to-vertical depth correction is usually small for typical roll-pitch conditions. As indicated in Figure 9-7 it is generally insignificant (i.e., < 0.2 ft) for project depths less than 20-25 ft. Full roll and pitch corrections are performed in HYPACK processing software at ADVANCED READ PARAMETERS\MRU\STEER SOUNDING BEAM.

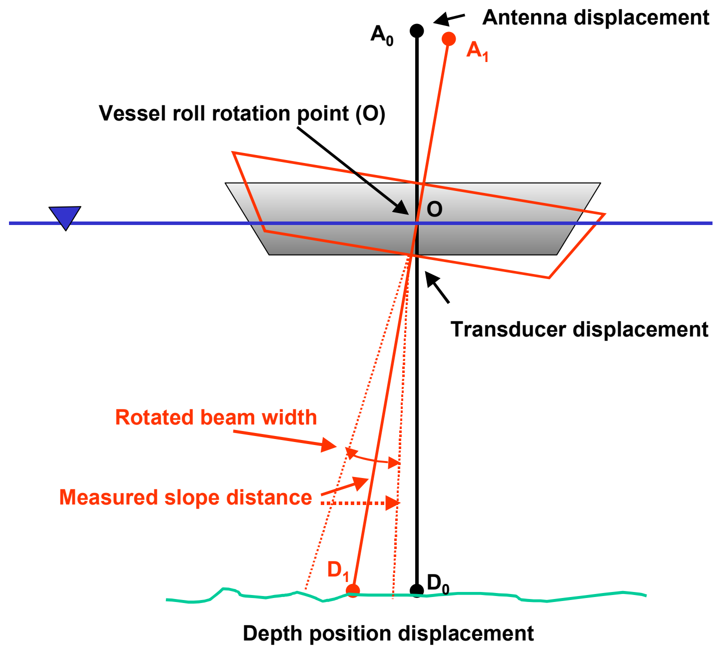


Figure 9-8. Depth correction due to roll (starboard roll viewed from aft)

(4) Constant pitch bias test and gyro stabilized transducers. Transducers are mounted vertically in a vessel at rest trim. When underway, excessive vessel roll and pitch can deflect the transducer from vertical. A constant forward pitch offset angle could be induced if a vessel's trim changes while underway--causing all depth to be measured over slope ranges rather than vertically. Given the typical beam width of a transducer, this misalignment is usually not significant unless pitch exceeds the beam width, which could occur for an extremely narrow beam transducer. A constant pitch bias can be checked similar to that for multibeam systems--i.e., running two pairs of reciprocal lines run over a slope at two different speeds. The important characteristic of pitch offset is that the along-track displacement caused by pitch offset is proportional to water depth. Thus, the deeper the water, the larger the offset. If a constant pitch bias is indicated in a single beam transducer, then a slope-vertical correction might be required. (Refer to the chapter on Multibeam Systems for more details on the pitch bias test). Alternatively, the transducer could be realigned to point vertical at typical sounding speeds. Gyro stabilized transducers can also be utilized to correct for these errors if work must be performed in heavy seas.

(5) Roll-pitch tolerances for single beam systems. Ideally, roll-pitch depth errors should be kept within tolerable limits--say not greater than 0.2 ft. As indicated in Figure 9-7, this can be achieved if maximum allowable roll or pitch is kept less than 10 deg when using a typical 8 deg beam width transducer. On critical deep-draft projects, 5 deg roll-pitch limits would be recommended. In general, roll-pitch exceeding 10 deg is a degraded working environment and overall acoustic data quality is marginal. The table in Figure 9-7 also indicates that roll-pitch slope-vertical corrections are insignificant on project depths of less than 20-25 ft; thus, slope-vertical depth corrections would (usually) only be significant on deeper draft projects.

(6) Testing roll-pitch magnitudes. For a particular beam width transducer, the effect of roll and pitch can be roughly tested to determine if roll-pitch slope-vertical corrections are necessary or significant. A pole-mounted transducer can be hung over the side by hand in deep (i.e., typical project

depth), smooth-bottom water. Rotate the transducer and observe the rough angle where the recorded depth begins to increase. If relatively large rotations are required to detect significant depth increases, then slope-vertical corrections with this transducer's beam width are probably not justified. If relatively small angular deflections cause discernible increases in depth, then this narrow beam transducer should have full roll-pitch corrections applied.

e. Yaw. Yaw (or vessel heading) rotation error is not significant for vertical single beam systems if the transducer and positioning system antenna are co-located vertically. If these units are not located vertically, then offset corrections must be applied using vessel heading information. This translates the position to the transducer--it has no effect on the measured depth. A variety of techniques can be used to measure real-time heading: magnetic fluxgate compasses, fiber optic gyro compasses, inertial systems, and carrier-phase DGPS. Refer to the chapter on multibeam systems for more details on yaw/heading offset corrections.

9-7. Calibration of Single Beam Echo Sounders

Calibration of acoustic sounding instruments is absolutely critical (and mandatory) in maintaining quality control of depth measurements. This is primarily due to instabilities or variances in the water column, or to a lesser extent, in the equipment. All navigation and dredging surveys for contract measurement and acceptance require, *as a minimum*, twice daily calibration at the project work site. Failure to perform adequate calibrations, including documentation/certification thereof, can lead to total unacceptance of the survey and any payment associated with it. This section describes the various methods used to calibrate single beam depth measurement equipment. The calibration procedures in this section also apply to multiple transducer sweep systems and, to a lesser extent, multibeam systems. Independent quality assurance procedures are also detailed.

a. Bar check calibration. The primary depth calibration procedure used in USACE is the "bar check." The bar check is recognized throughout the Corps and dredging industry as the standard reference system for acoustic depth measurements. The bar check is a quality control procedure. It is not a quality assurance procedure. The bar check is a flat bar or plate suspended by two precisely marked lines to a known depth below the water surface and under the transducer. A series of depth intervals are observed during a bar check, down to the project depth. Any difference between the reference bar depths and the recorded depths represent corrections to be made to any subsequently recorded soundings. The bar check represents the only recognized check on the quality of a depth recording system. In reality, the bar check may not exhibit the same acoustic properties as the bottom; however, in practice, any such differences are ignored. This primary reference device is also used to periodically check secondary calibration devices, such as a velocity meter and a ball check. Figure 9-9 characterizes the operation of suspending the bar a known distance below the waterline using calibrated chains. Both a single line calibration plate and a dual line (full beam) bar check device are shown. Bar checks correct for velocity variations, draft variations, and index errors in the echo sounding system--reference Equation 9-1. The effect of a varying velocity of sound propagation is measured by performing a bar check. The actual velocity need not be computed as part of a bar check. The bar check must be taken at sufficient intervals to develop the variation. Normally intervals of 5 to 10 feet are adequate, unless the velocity of sound is highly variable. If a bar check were performed at 1-ft increments throughout the water column, a correction would be available for any observed depth falling within that those 1-ft intervals. Draft and index variations are also compensated through the use of a bar check calibration. It is again emphasized that a bar check will not correct for variations in acoustic reflectivity, either between the bar and bottom material or between different bottom materials within a project area. The bar check is also not a totally independent reference in that it may contain errors within itself--e.g., water surface smoothing, line markings.

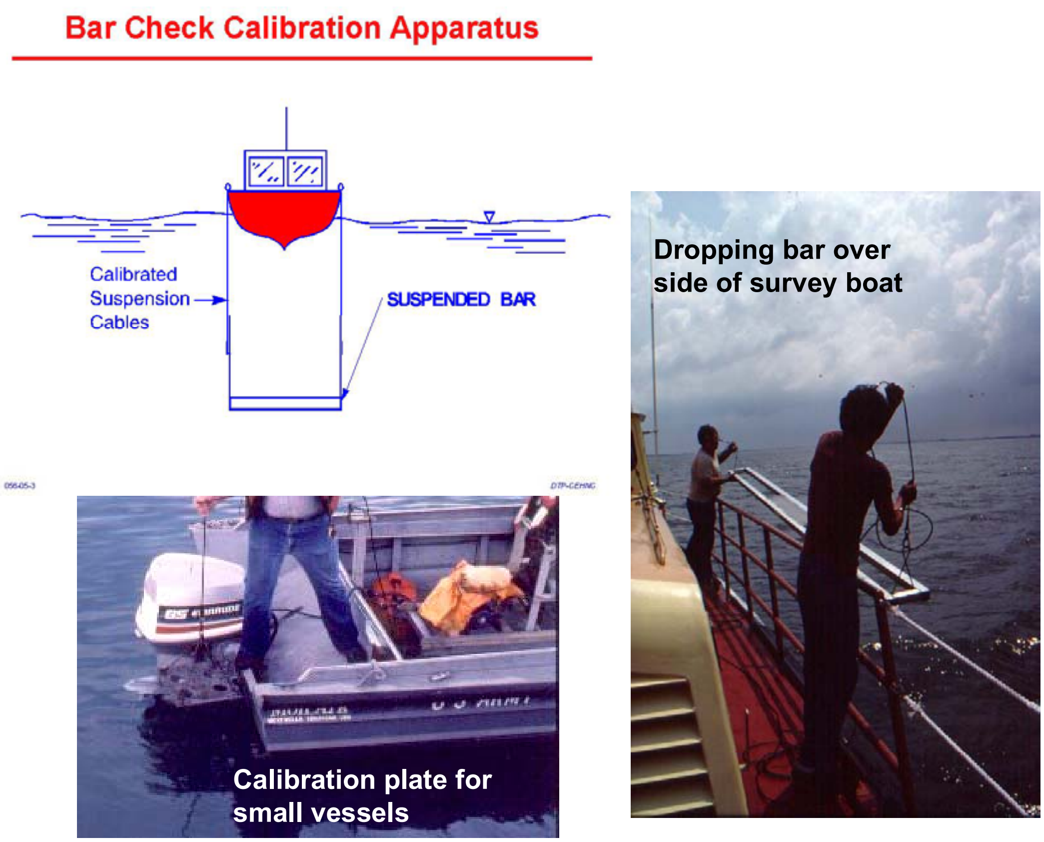


Figure 9-9. Bar check calibration (Jacksonville District)

b. Ross ball check. As a substitute to a full-beam bar check, many districts use a center-mounted, spherical calibration ball with a flat top in lieu of a calibration bar. This device was designed and developed by Wayne Ross of Ross Laboratories. The ball is suspended on a cable from the interior of the boat by a hand crank-lock mechanism. The line is marked and calibrated in a manner similar to that used for a bar or lead line; however, the reference water surface is not. Therefore, any index error or draft line variation must be calibrated using a standard bar check method. An interior water level gage may also be used to measure/monitor the line indexes. Details regarding installation and operation of this calibration device can be obtained from the manufacturer (Ross Laboratories, Inc.). See Figure 9-10.

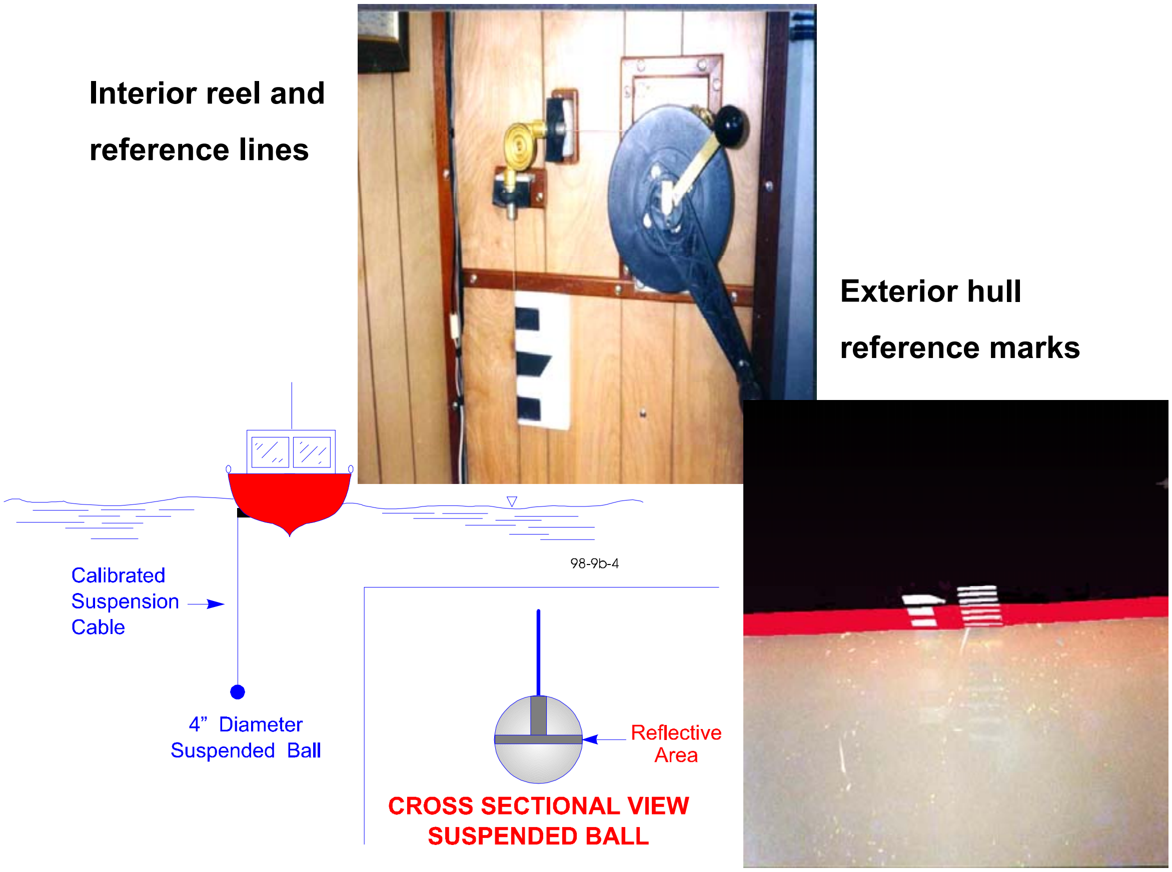


Figure 9-10. Ross Ball Check (Surveyboat Adams, Norfolk District)

c. Velocity probe calibration. In lieu of a bar check calibration, the velocity of sound may also be directly measured using a velocity probe instrument. A velocity probe measures the speed of sound at various depth intervals. A velocity probe must still be periodically calibrated, both internally and externally. A bar check is necessary to perform the external calibration, since a velocity probe measurement will not determine the constant terms in Equation 9-1.

9-8. Bar or Ball Check Calibration Procedures

The bar check effectively measures for the following systematic errors inherent in depth recording systems: instrumental errors—index, mechanical, and electrical; velocity of sound errors due to temperature, salinity, or other suspended or dissolved sediment variations; and static draft fluctuations resulting from varying vessel displacement caused by fuel and personnel loads.

a. Bar check apparatus. The suspended bar is constructed of flat stainless steel or aluminum plate welded or bolted to any standard supporting crosspiece section. The plate should be of sufficient width (typically 8 to 12 in.) to provide an adequate return down to project depth. The bar should be approximately 1 ft longer than the vessel beam (on the measuring deck). The reflecting plate need not extend the full length of the bar. Both ends of the bar are rigged with universal-type swivel joints to attach the supporting lines. Each line is zero-referenced from the top of the plate and is marked at either 1- or 5-ft increments. The top surface of the bar plate may optionally be coated with foam, rubber, or other like material that better simulates the acoustic reflectivity properties of the channel bottom. A small

(12-in.-diam) steel plate can be used to calibrate over-the-side mounted transducers. The plate is suspended by a standard single bar check line or lead line. Calibration and/or adjustment is performed in a manner identical with that used for bar check. Special caution must be taken not to change the vessel draft when performing a check on one side or end of the boat.

b. Bar weight. The weight of the bar will be dependent on the types of currents experienced, project depths, and beam of the vessel. A typical bar will range between 40 and 100 lb. In deep-draft projects with large currents, a heavy bar is essential because subsurface currents will pull too light a bar away from the transducer's vertical plane, causing loss of acoustic return or slope error in the check lines. Provisions for adding additional weight to the bottom base of the bar ends may also be needed in strong currents. Increased bar weight may necessitate additional personnel to perform the bar check.

c. Bar check procedures. On a larger vessel, the bar is usually deployed off the bow and each end walked aft until abeam of the transducer. Both lines are held at the desired fixed depth increment (visually meaning vessel and water surface motion), and the depth recorder is simultaneously observed, annotated, and/or recalibrated. Vessel alignment must be held toward the sea to minimize roll. Under adverse wind and current conditions, coupled with a narrow-beam transducer, maintaining vertical alignment of the bar and lines becomes extremely difficult, especially at greater bar depths. In such cases, the skill and experience of the boat operator to maneuver the vessel over the suspended bar becomes critical to the process. On smaller vessels, personnel movement during a bar check may affect the nominal (underway) trim of the boat. Care must be taken to ensure that this variation is minimized.

d. Calibration increments. Static bar comparisons should be taken at 5-ft intervals throughout the project or dredging excavation range. If the recorder is adjusted to display actual bar depths, subsequent bar check readings need to be taken only at the upper, intermediate, and lower project levels to verify stability. A sample bar check is shown in Figure 9-11.

e. Data corrections. Stage/tidal corrections, vessel squat corrections, draft loading variances, calibration line graduation errors, or any other correction should never be “dialed” into the depth recording device. These corrections are always applied off-line (manually or automatically) or in data reduction software on an onboard processor. Recorded depth data must be “original” relative to the calibration process. Adding other time/speed variable corrections makes reconstruction of original survey data difficult and indefensible in the case of a contractual dispute or claim over the data adequacy.

f. Frequency of bar check. For critical navigation and dredging support surveys, two bar checks are required each day--one before work and one after completing a day's activity. Additionally, if a mechanical analog recorder that does not contain a zero/calibration event line(s) is turned off, or the paper or stylus is replaced, a new bar check must be performed before proceeding with the survey.

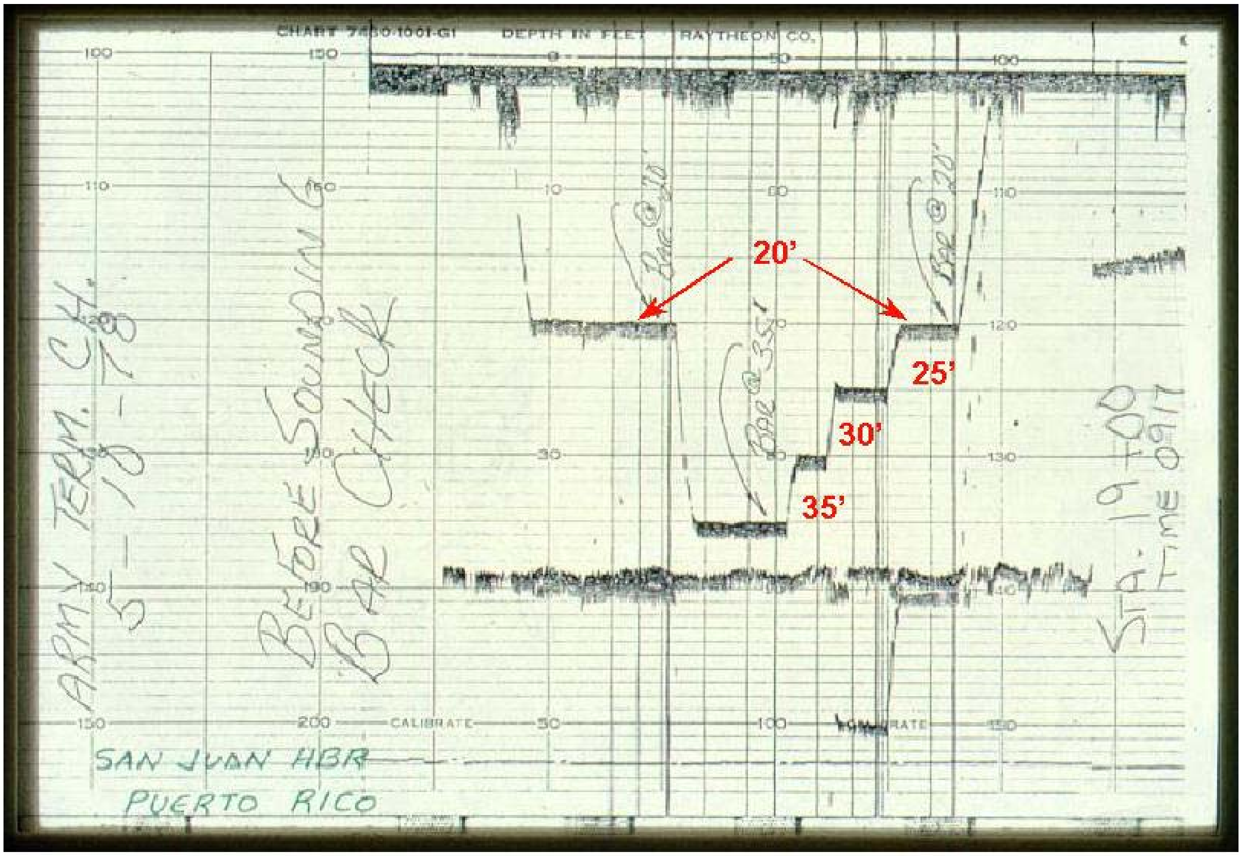


Figure 9-11. Example of bar check in deep-draft navigation project (Jacksonville District)

g. Location of bar checks. Due to the high potential for local temperature and/or salinity variations in typical USACE river and harbor projects, the resultant effect on the velocity of sound must be measured directly at the work site. This is a mandatory requirement for payment surveys. Failure to perform a bar check calibration within the project area will be sufficient reason for rejection of the survey. If an area is known to be subject to extreme temperature/salinity variations, additional bar checks in these areas may be warranted. In extremely adverse conditions where it is physically impossible to perform a bar check at the project site (due to high winds, currents, and/or sea states), a velocity probe may be used to determine the sound velocity at the project site--see paragraph 9-10. However, on critical projects, both a bar check and velocity probe should be simultaneously performed in a protected area near the project vicinity. The velocity derived from the bar check should agree within 5 fps with the probe's average velocity in the protected area. The echo sounder draft would be set from the bar check and the velocity would be readjusted based on the probe velocity measured later at the actual project site.

h. Bar check recording. Bar check data for digital data shall be recorded in a standard field survey book or on a form. Bar check data are obviously visible on analog hard copy recording media and must be immediately adjacent (on the graphical record) to the actual survey. For dredging payment surveys in which analog backup recordings must be maintained, digital bar check data may be recorded on the analog record for comparative purposes. When no analog recorded is used, digitally recorded bar checks shall be recorded on a write-only type of media. It is a recommended practice to maintain a continuous record of all bar check calibrations in a bound survey field book. This record should include draft and velocity settings, along with other instrumentation calibration and alignment records. Figure 9-12 shows pre-sounding and post-sounding calibrations in which both a bar check and velocity probe are performed simultaneously.

SURVEY VESSEL "PAJ" - DAILY REPORT OF ON-LINE OPERATIONS

PRESOUNDING CALIBRATION CHECK:	POSTSOUNDING CALIBRATION CHECK:
Bar Check at 0922 hours	Bar Check at 1311 hours
Digibar Velocity Reading 4778 FPS	Digibar Velocity Reading 4776 FPS
Recorder Velocity Set at 4778 FPS	
Bar at 30.0 feet	Bar at 30.0 feet
Monitor Reads 30.1 / 30.0 feet	Monitor Reads 30.0 / 30.1 feet
Sounder Trace Reads 30.1 / 30.0 feet	Sounder Trace Reads 30.0 / 30.1 feet
Sounder Digitizer Reads 30.1 / 30.0 feet	Sounder Digitizer Reads 30.0 feet
Bar at 20.0 feet	Bar at 20.0 feet
Monitor Reads 20.1 / 20.0 feet	Monitor Reads 19.9 / 20.0 feet
Sounder Trace Reads 20.1 / 20.0 feet	Sounder Trace Reads 19.9 / 20.0 feet
Sounder Digitizer Reads 20.0 feet	Sounder Digitizer Reads 20.0 feet

Figure 9-12. Bar check and velocity meter records (Detroit District)

i. Agreement between successive bar checks. The two bar checks for a work day must be compared for excessive differences. Adjustments are *never* made to the final (end-of-day) bar check. Results are logged at the same check increments used during the initial calibration. Any known draft variation due to loading should be applied to the final readings before comparison. Otherwise, the draft variation may be taken from markings on the vessel hull. Failure to obtain consistent agreement between successive bar check calibrations may be due to any number of physical or electronic causes and must be located. The frequency of calibration may have to be increased. The mean value of the calibrations may be used to correct the recorded data. Differences exceeding the limits shown in Table 9-6 may be grounds for rejection of the survey.

j. Calibration of bar check lines. The bar check suspension lines must be periodically checked to ensure the accuracy and stability of the graduated marks on the lines. The frequency of this independent calibration is indicated in Table 9-6. Periodic calibration data shall be recorded on a worksheet or in a standard field survey book. Any errors in the graduated marks must be physically corrected (removed) at the time of calibration.

9-9. Depth Corrections Based on Bar Check Data

There are several methods of performing bar checks and arriving at corrections to apply to observed depths. Three methods are commonly used in USACE and are described below. Each of these methods is acceptable on any type of survey. Typical results of a bar check calibration are shown in Table 9-4 below. The differences between the bar depth and recorded depth indicate the presence of both a constant index error and a velocity error in the recorded data. The velocity change is exhibited by the increasing differences below 20 ft where a change in the water's sound velocity has occurred. The constant 0.2-ft index error indicates that the presumed 3.0-ft draft measurement must be independently checked. Three different methods for correcting soundings are described below.

Table 9-4. Sample results of a bar check calibration

Initial velocity set at 5,100 ft/sec	Initial draft = 3.0 ft		Project depth range: 20 to 40 ft
Depth of Bar (ft)	Recorded Depth (ft)	Difference (ft)	Notes
5	5.2	0.2	0.2 ft index error indicated
10	10.2	0.2	
15	15.2	0.2	
20	20.2	0.2	
25	25.3	0.3	Change in water column velocity occurs
30	30.4	0.4	
35	35.5	0.5	
40	40.6	0.6	
45	45.7	0.7	
50	50.8	0.8	

a. Incremental bar check readings and correction formula. Recorded depths may be directly and individually corrected mathematically without making any adjustments to the draft or velocity settings on the recording device. All recorded depths are adjusted according to the bar check data, such as that recorded in Table 9-4. This reduction can be made on-line when an automated data acquisition system is used or off-line during the post-processing phase. The results of a sample calibration shown in Table 9-4 are used directly for this process; however, a table combining the before and after survey bar checks may also be used. A corrected depth is then computed by:

$$d_c = [[(bar_i - bar_{i+1}) \div (rec_i - rec_{i+1})] \cdot (d_0 - rec_i)] + bar_i \quad \text{(Eq 9-4)}$$

where:

d_c	=	corrected depth
d_o	=	any observed/recorded depth to be corrected for speed of sound and index error
bar_i	=	bar depth at checkpoint i
bar_{i+1}	=	bar depth recorded at point i+1
rec_i	=	recorded depth at bar depth i
rec_{i+1}	=	recorded depth at point i+1
i, i+1	=	any two successive calibration depth points and $rec_i > d_o < rec_{i+1}$

An observed depth is corrected between its closest range of calibration data. For example, if a 43.5-ft sounding is recorded, it is corrected relative to the calibration data in Table 9-4 at the 40- and 45-ft levels.

From the calibration table:

bar_i	=	40	rec_i	=	40.6
bar_{i+1}	=	45	rec_{i+1}	=	45.7

From Equation 9-4,

$$d_c = \frac{(40 - 45)}{(40.6 - 45.7)} \cdot (43.5 - 40.6) + 40$$

$$d_c = \frac{(-5)}{(-5.1)} \cdot (2.9) + 40$$

$$d_c = 0.9804\ (2.9) + 40 = 2.8 + 40 = \underline{42.8}$$

Given a bar check calibration table, all subsequent observed depths may be corrected using the above-described procedure. Such a procedure may be performed either on-line or in an off-line mode. Correcting non-digital depth data by this method is obviously not very practical unless that data can be digitized into a database. The Correction Table/Formula method works well in areas of salt wedges or places where the water has distinct temperature differences.

(1) This method may be preferred in the vicinity of power plants where the plant cooling water effluent has a much higher temperature than the surrounding water. This will cause the speed of sound to increase slightly if the water is turbulent and thoroughly mixed. In most cases the effluent will not thoroughly mix with the surrounding water. This will cause the temperature to be different through the depth layers. The result to the surveyor will be a significant increase in the speed of sound in these depth layers (shallow soundings). If the bar check table does not reflect this phenomenon, the survey may erroneously indicate extreme shoaling in the area of the power plant outfall. A separate bar check should be recorded in these areas.

(2) Since the speed of sound is normally fairly stable over most river and harbor projects, it is usually desirable and more practical to base the above-described correction over a wider interval than 5 ft. Given the sample project data in Table 9-4 with excavation depths ranging between 20 and 40 ft, a single correction factor may be computed over that range, since the differences over that 20 to 40-ft range in Table 9-4 are linear.

For example:

bar_i	=	20	rec_i	=	20.2
bar_{i+1}	=	40	rec_{i+1}	=	40.6

From Equation 9-4,

$$d_c = \frac{(20 - 40)}{(20.2 - 40.6)} \cdot (d_0 - 20.2) + 20$$

$$d_c = 0.9804\ d_0 + 0.2$$

The above factor may be used to correct any depth ranging between 20 and 40 ft and may be practically extended to a range of 15 to 45 ft. Such a correction procedure is valid as long as the calibration data are linear over this range.

(3) The constant term (0.2 ft) represents the index correction. The ratio (0.9804) represents a velocity correction between that set in the recorder (5,100 ft/sec) and that actually occurring in the water medium over this range, or approximately (0.9804) · (5,100 ft/sec) = 5,000 ft/sec. Readjusting the recorder to 5,000 ft/sec and modifying the draft line to 2.8 ft (3.0 - 0.2 ft) will *not* graphically correct the depths over this range.

b. Graphical bar check calibration method (Jacksonville District). The computational method described above may not always be suitable in practice, since the displayed depth cannot readily be related (i.e., on-site) to a required excavation grade. Performing the computations and then applying other required corrections (squat, draft loading variances, and stage/tide corrections), requires automated processing capabilities. Such equipment may not always be available aboard small work boats. Since most construction payment/acceptance work depends on immediate on-site assessment of the recorded data, the computations must be minimized. This is accomplished by changing the velocity and draft settings in the analog/digital recording device so that the recorded depth equals that calibrated during the bar check. In essence, the recording mechanism is reoriented and rescaled by appropriate adjustment of the velocity and index/draft. This procedure is performed *only* during the initial bar check of the day, *never* during the final check. The procedure for making these adjustments is described below and graphically illustrated in Figure 9-13.

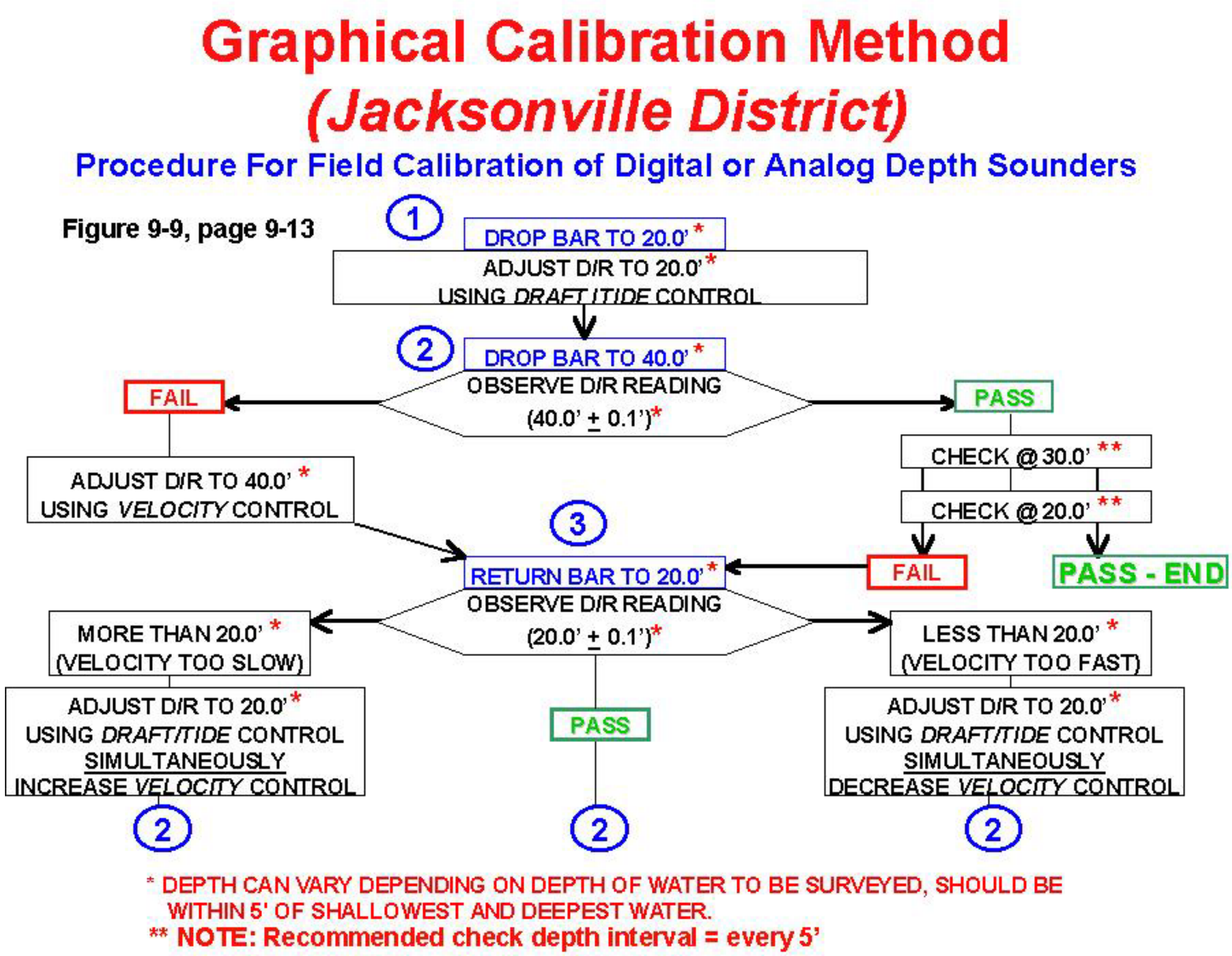


Figure 9-13. Jacksonville District calibration method

> Calibration is a sequential process performed by trial and error so that the index/draft and the sound velocity errors are simultaneously minimized. Two depths, for example, 20 and 40 ft, are chosen that correspond to the maximum and minimum project depths. The bar is lowered to the lesser depth, and the depth recorder display is adjusted with the index controls to read that depth value. The bar is then lowered to the greater depth, and the reading is adjusted to that depth using the speed of sound control only. When the bar is returned to the first depth, the reading is observed. If the display reads low (i.e., 19.9 ft), velocity is too high. The display should be adjusted to the proper reading (20 ft) with the index control while simultaneously decreasing the speed of sound control. Reverse the adjustments for a high reading (i.e., 20.1 ft). The entire process is then repeated by lowering the bar to the greater depth, then back to the first depth for inspection of the display until the correct reading is produced at all three steps (within ±0.1 ft). Intermediate readings should then be checked to compare displayed value with the known length of bar lines.

Once set, the velocity and draft settings will usually remain fairly stable for a given project area. The primary advantage of the method described above is that a recorded depth can be easily referenced to a required excavation grade. If the velocity of sound is not relatively constant throughout the working depth range, it will not be possible to adjust the instrument so that it reads equal to the bar check at each depth increment. In such cases, the data will have to be corrected by linear interpolation as described previously.

c. Modified graphical bar check calibration method (Norfolk District). This method is similar to the graphical method except that the draft setting on the recorder is not modified. The bar is placed close to the maximum project depth (40 ft in this example), and *only* the speed of sound control is adjusted so that the observed bar equals the actual bar depth. The bar is then raised at 5-ft intervals throughout the range of project depths, and observed bar readings are recorded. Any significant variation will be corrected in the office data-processing program using the computational procedures described previously. This method only minimizes the error near the lower level at which the sound velocity control was adjusted. The recorded values at other depths will be proportionately in error. In the sample data from Table 9-4, at the 20-ft bar check level the recorder will read 19.9 ft, a 0.1-ft error. Near the project excavation grade the instrument is adequately calibrated. However, this is not true up the side slopes.

9-10. Velocity Meter Calibration Method

A velocity meter is a portable, hand-deployed instrument that directly measures sound velocity. A velocity meter may be used to correct sounding data for dredging payment surveys provided independent external/internal calibrations are periodically conducted using a traditional bar check--see paragraph 9-8g for recommended procedures. Velocity measurements are always taken at the project work site. Two types of velocity meters are shown in Figure 9-14.

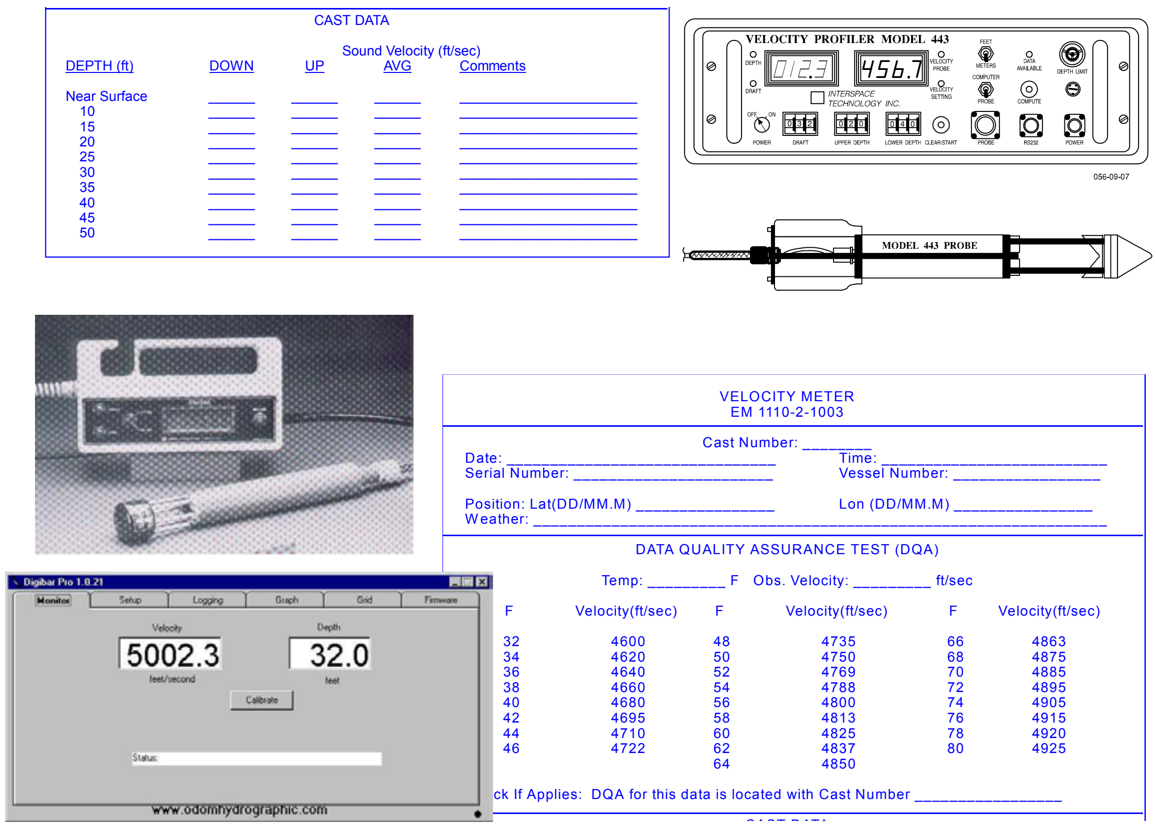


Figure 9-14. Innerspace Technology Model 443 and Odom DigiBar Velocity Profilers

a. General description of velocity meters. Velocity meters generally consist of a probe attached by cable to a waterproof, hand-held control unit powered by internal batteries. The cable is numerically labeled at 5-m intervals and marked in 1-m intervals, or labeled at 10-ft intervals and marked at 5-ft (or more frequent) intervals. Some models use a pressure sensor for depth determination, thus minimizing cable slant range errors. Velocity meter output is typically speed of sound as a function of water depth. Sound velocities should be recorded at 1 to 5 ft depth intervals. Readings should be made to the nearest 1 foot per second (fps). Where velocity of sound is not constant over the water column (e.g., Table 9-4) a correction table should be developed in processing software. This is especially critical for multibeam systems where velocity variations can refract outer beams. Software processing systems, such as HYPACK (PROCESSING\SOUND VELOCITY), provide a sound velocity correction table based on velocity readings at incremental depths (Figure 9-15). It is absolutely essential that velocity meter data be periodically checked with a standard bar check. The following paragraphs describe some of the basic specifications of two velocity meters. Additional information can be obtained directly from the manufacturers listed at the end of this chapter.

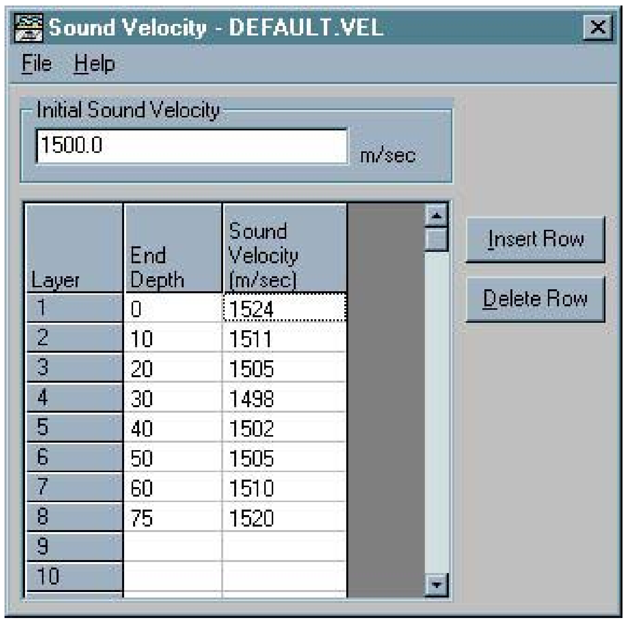


Figure 9-15. HYPACK sound velocity correction

(1) Innerspace Model 443. The Model 443 Velocity Profiler (Figure 9-16) measures and records an accurate speed-of-sound for each foot of the water column automatically as the probe is deployed. It then computes and displays sound speed and draft values for use in the depth sounder for calibration. Since depth is determined by a sensor in the underwater probe, the length or angle of the cable paid out is unimportant, thus enabling the sampling of data while underway. Since the Innerspace 443 provides precise speed-of-sound for each foot of the water column, this data can also be used to correct acoustical transmissions from any underwater ranging device, such as transponders used in oil exploration and other devices such as multibeam sonar. Via the RS232 front panel connector, the speed-of-sound/depth values can be sent to a computer for further analysis of the water column speed-of-sound gradient. For multibeam sounding, an acoustic speed-of-sound can be logged for each foot of the water column. This information can be sent to a computer where it can then be used to apply different speeds-of-sound to different segments of the water column for more accurate velocity corrections when processing multibeam sonar data. The Innerspace Model 443 additionally computes and displays the average sound velocity over the measured water column and the draft/index corrections. This process effectively provides a correction equation for speed of sound in the water column.

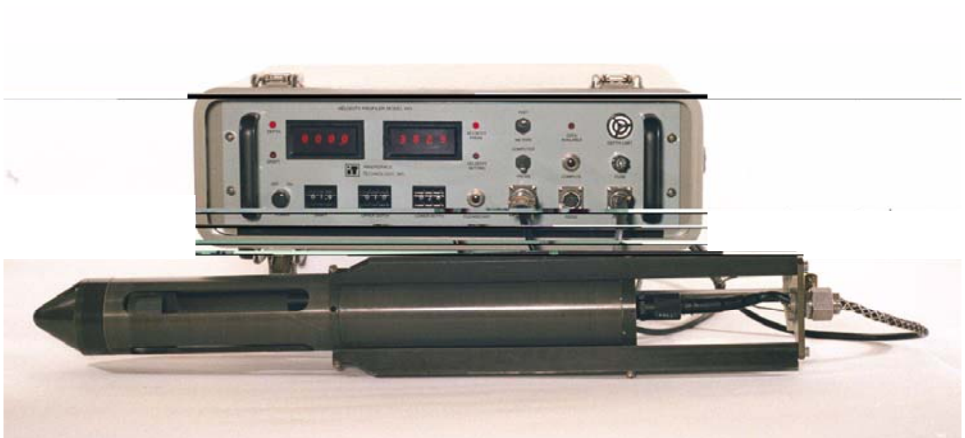


Figure 9-16. Innerspace Model 443 velocity profiler

(2) Odom Digibar Pro velocity meter. DIGIBAR-PRO (Figure 9-17) is a velocimeter that employs the sing-around method of sound velocity determination. Mounted near the end of the sampling probe is the high frequency "sing-around" transducer and its associated reflector. This precisely spaced pair is used to measure the velocity of sound in water by transmitting and receiving a signal across their known separation distance. After the first transmission, the received echo is gated and introduced into the feedback loop of an oscillator that re-triggers the transmitter and begins the cycle again. The frequency resulting from this regenerative feed-back loop is determined by the distance the signal travels (transducer to reflector and back) and is directly proportional to the velocity of propagation of the sound pulse through the measured medium (in this case water). This method of direct sampling means that all factors that influence the speed of sound, including salinity, pressure, and temperature, are taken into account. An embedded RISC processor in the probe digitizes the sing-around frequency and depth information, sending that data along with temperature and calibration constants in ASCII format via a 2 wire current loop up the cable to the hand-held control unit at a 10 Hz rate. In the control unit, another microprocessor accepts data from the probe, converting the frequency information to sound velocity, and the pressure data into depths, storing them in internal memory. In addition to converting both values to usable units, the control unit provides an operator interface. The multi-line display and system of menus guide the operator through the steps required to complete a velocity cast. Other features of the control unit include, data storage space, interfacing circuitry for transmission of collected data to a PC, and a power source (three Alkaline C-cells) for driving both the probe and its own internal circuitry. The velocity and depth information collected from up to 10 casts can be stored in DIGIBAR-PRO's internal memory. The average velocity value of each cast can be calculated, or the entire velocity profile of the cast can be up-loaded to a PC, in spreadsheet format, for subsequent use in ray-bending calculations. The unit not only samples, displays, and stores values for the speed of sound in water, but it also ties each collected value to a precise depth. The instrument is made up of a hand-held controller (splash rated to IP-65), a Kevlar reinforced cable (with a 400 lb. breaking strength rating), and a marine grade stainless steel probe. The velocity of sound and depth values displayed on the DIGIBAR-PRO front panel are measured, stored in memory, and displayed by the system's internal

microprocessor and its associated circuitry. The processor applies Del Grosso's formula to the sing-around frequency calibration constants, yielding accurate and traceable velocity results. The meter has a pressure sensor to determine depth of the probe. The precise profiling capabilities allow multibeam sounders to utilize the output of the DIGIBAR-PRO directly in their critical ray-bending calculations.

Figure 9-17. Odom DIGIBAR PRO velocity meter

b. Velocity probe quality control test. A quality control test must be performed one time each week that the velocity meter is used to determine sound velocity corrections. These tests may vary depending on the manufacturer's recommendation. The following equipment is typically needed for data quality assurance tests of velocity probes:

- Calibrated thermometer
- Clean fresh water
- Clean vessel (plastic bucket) large enough for the probe.

Fresh water is needed because its salinity (parts per thousand) is less than that of sea water. In some cases the fresh water salts, pollutants, or other particles in suspension may affect the water density or the elasticity. Distilled water should be used if this is the case. Reduction of salinity and pressure effects leaves the elastic water property a function of temperature only for practical purposes. This determines the average sound velocity through the layers in the water column. Using the manufacturer's chart, the propagation velocity can be computed with known temperature. A worksheet similar to that shown in Figure 9-14 may be used as a record of the test. This worksheet was constructed for the Odom velocity meter. Computer programs are also available from the manufacturers for this calibration.

c. Velocity meter corrections/calibrations. The velocity probe measures the actual sound velocity over the entire depth measurement range. From these data, a correction algorithm can be devised for on-line or post-processing data reduction. If velocity probe data are used to obtain an average sound velocity over a given range, then this average velocity (or velocities) may be used to adjust the digital or analog recording device as is done with a bar check calibration. The average velocity from a probe will be the same as the indirect velocity determined by a bar check. A velocity probe calibration does *not* confirm/check the index/draft setting on the analog/digital recorder. This *must* be done with a standard bar check.

d. Index correction. The application of the probe's average velocity data depends on the type of probe system used and any software included with that system. The Innerspace 443 probe system used by some USACE districts automatically determines the average velocity (v_1) of the layer between the surface and the upper project depth (UD) and the average velocity (v_2) between the UD and lower project depth (LD). The average velocity is dialed into the depth recorder (digitizer), and the index setting is computed from the following equation and set into the recorder:

$$Index\ Correction = [\ UD\ (v_1\ -\ v_2\ )\ )\ +\ Draft \cdot v_2\ ]\ \div\ v_1 \qquad \text{(Eq 9-5)}$$

Where:

UD	=	upper project depth
v_1	=	average velocity -- surface to UD level
v_2	=	average velocity -- UD to LD levels
Draft	=	measured draft of vessel

A major advantage of a velocity probe check over a bar check is the ability to perform rapid calibrations in heavy seas or currents. Calibrations are thus more easily (and frequently) performed directly at the project site. If repeated comparisons between the velocity probe and bar check yield consistent velocity measurements, then the velocity probe can be used with confidence. It is important to remember that the velocity probe measures only the "v" term in Equation 9-1. Therefore, a conventional bar check must be periodically performed in conjunction with a velocity probe measurement to calibrate system indexes and draft corrections. Those velocity probes that additionally derive the draft and index constants in Equation 9-1 must also be verified with a bar check device. These corrections may also prove to be relatively stable over the long term, as has been indicated by field results.

9-11. Squat and Settlement Calibration Test

As a vessel's velocity increases, it generally settles or squats into a lower profile in the water, causing an error in depth measurement that must be corrected--Figure 9-18. A squat test should be performed at least annually to determine the relation between boat speed and transducer height above or below the static sounding reference plane. Report results of this calibration test using a standard field book. Squat correction tables/curves should be permanently posted aboard the vessel--see example in Table 9-5. Without squat correction, channels may be actually dredged deeper than the drawings indicate. RTK DGPS systems which provide direct (absolute) antenna-transducer elevation eliminate the need for the squat correction, as the antenna height will record the squat in real-time. However, if the RTK DGPS system is set up to provide only the antenna height and is not configured to resolve the transducer elevation, then the squat correction must still be applied.

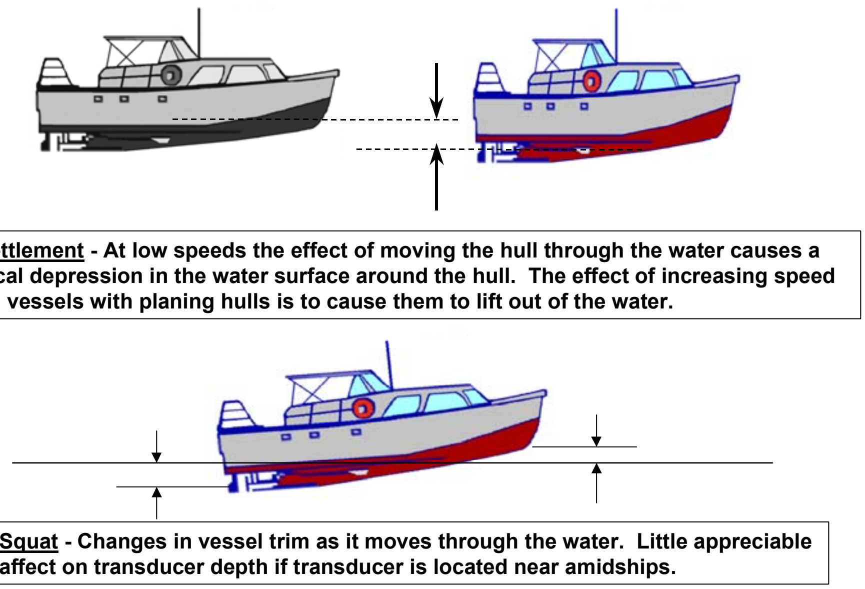


Figure 9-18. Squat and settlement effects on vessel draft (from NOAA)

Table 9-5. Squat and Settlement Calibration (65-ft Surveyboat Florida, Jacksonville District)

Conducted 29 May 1998, St. Johns River, Jacksonville, FL

Engine RPM	Upstream Rod	Downstream Rod	Tide	Squat	HYPACK Entry
Dead in water	0.70	--	1.12	0.00	
800	0.73	0.73	1.19	-0.10	+ 0.10
1000	0.65	0.63	1.33	-0.15	+ 0.15
1200	0.62	0.58	1.43	-0.21	+ 0.21
1500	0.58	0.58	1.50	-0.26	+ 0.26
1800	0.43	0.41	1.60	-0.20	+ 0.20

a. Conventional differential leveling techniques are utilized to measure the required calibration constants under normal loading (fuel/personnel) conditions. A level is set up on a pier or bulkhead with the boat in a static position in calm water, and elevations are taken at a point on the boat directly over the transducer, i.e., amidships (see Figure 9-19). With a stadia board or level rod held at this point, the boat is driven past the instrument at various speeds, and elevation differences are noted at each speed. In moving bodies of water (wind and/or current), this procedure must be run both up and down current to obtain the mean speed/squat. Boat velocities and observed rod readings are recorded on the form. A subtraction of rod readings after due correction for tide differences gives the squat corrections at each velocity.

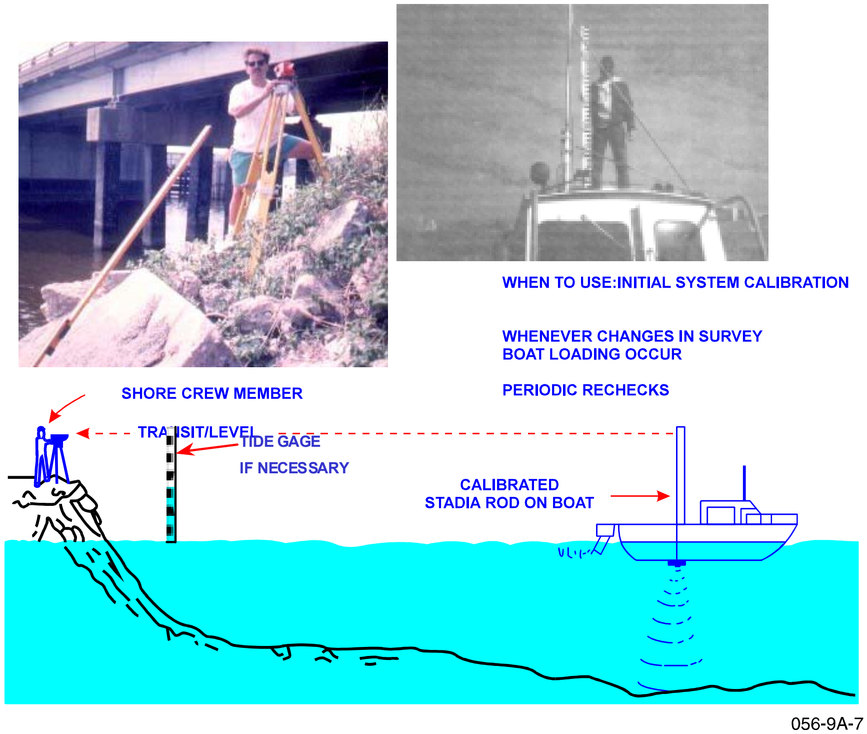


Figure 9-19. Squat and settlement test procedure with differential leveling

b. Corrections are added to the soundings to refer them to a static state. Squat corrections are therefore considered positive quantities as the transducer depresses (squats) deeper into the water at increased speeds. In this case, a *positive* squat is *added* to the raw observed/recorded depth. A *negative* squat may occur with high-speed planing, surface effect, or hovering type vessels. For these types of survey vessels, a squat test is especially critical and must be performed more frequently.

9-12. Miscellaneous Controls and Checks

a. Vessel draft variation correction. Boat loading variances during the course of a survey will affect transducer height. Short-term variations in the draft due to fuel usage may be observed directly from scribe marks on the hull abeam of the transducer. Any such variation should be evidenced directly in subsequent bar checks, and only then may these draft variation corrections be applied to observed depths. The actual draft/index setting on the recorder/digitizer should *not* be changed to reflect a draft variation. These variations should be applied during the on-line or post-processing sequences. Likewise, a physically measured draft is not directly entered into a echo sounding/recording device but must be confirmed by an independent calibration. The actual draft should be determined by performing a standard bar check calibration near the upper water surface with the upper bar level set just below the transducer depth, i.e., 3 to 6 ft. A sequential trial-and-error calibration is performed as described previously. When no further adjustments are required either at the selected lower depth or at the upper depth, the final draft setting is considered to be the transducer draft. Data from this draft calibration observation should be compared with the water line mark readings to establish a record of draft variations, from which corrections can be directly applied to recorded depths based solely on hull waterline-mark elevations.

b. Sensitivity/gain control. Most echo sounders use a sensitivity control to vary the detection threshold at which a recorded acoustic signal is displayed. The shape and intensity of the returning pulse is partly a function of the bottom material. In unconsolidated sediments, slight variations in the sensitivity control can cause significant variation in the detection threshold, i.e., depth. Increased sensitivity can cause returns from vegetation to be recorded. Reflective characteristics of the check bar may also differ significantly from the bottom material. These constant variations can exceed 1 ft in some instances and can easily represent the major error component in depth measurement. The sensitivity/gain control may be varied during the initial bar check calibration to determine if there is any effect on the depth reading/display. If so, the sensitivity control should not be changed during the course of the survey; nor should automated settings be selected. To minimize errors due to this source, it is best practice not to change the sensitivity and gain controls during a survey or between successive surveys of the same project area.

c. Frequency stability. The stability of the mechanical frequency of older mechanical analog recording sounders can be a problem and must be continuously monitored. Many recorders display a “calibrate" line that records the frequency stability. This line should be stable to ±0.1 ft or ±0.2 percent. The machine frequency, or “speed of sound” control should never be changed except during an initial (before-survey) bar check. Echo sounders with erratic frequency stability should be replaced.

d. Draft display stability. The “draft” or “index” line on an older mechanical analog recorder must be stable to within ±0.1 ft during the course of a survey. Corrections must be made for lateral movements in the recording paper based on the movement in the index reference setting. Draft settings should never be altered except during initial calibration bar checks. Draft variations are not a problem on digital recording devices.

e. Display phase shifts. Calibrations of older mechanical analog recorders are valid only on the display phase on which they are performed. If use of a deeper display phase is required, the second phase must be calibrated separately from the first phase. Because some portable sounding recorders can have 2-ft or more phase shift errors, this check is critical in deep-draft projects in which switching between phases is common. If these phase errors are large, it is often easier to place a large index constant on the second (deeper) phase and perform all bar checks and surveys on this phase exclusively, eliminating any need to switch between phases.

f. Lead line calibration check on echo sounders. A hand lead line may be used to roughly check an echo sounder. This check should be done over a hard, flat bottom of depth at or near project grade. The echo sounder recorder velocity is then adjusted so that the displayed depth equals that observed with the lead line. Calibrating an echo sounder in this manner is only accurate at the lead line depth. *This method of calibration is acceptable only for non-navigation surveys*. However, it may have application in correlating dual frequency recorders in fluff areas.

9-13. Plotted Depth Options for Single Beam Surveys

Depth sounders are capable of recording depths at rates of 10 or more per second. However, positional updates are typically input every second. Thus, the processing software must interpolate and time-tag positions for the intermediate depths--Figure 9-20. Likewise, roll, pitch, heave and heading data comes in at varying times and must be time-tagged to each depth. This time-tagging is usually performed off-line. It is not feasible to plot all recorded "shot" depth data in plan view. Reduced sounding data are normally plotted on the final plan drawings at a density of between 4 and 8 soundings per inch at the scale of development--e.g., between 12 ft and 25 ft at 1 " = 100 ft. Higher densities (or all recorded depth data) may be plotted in profile form in section views.

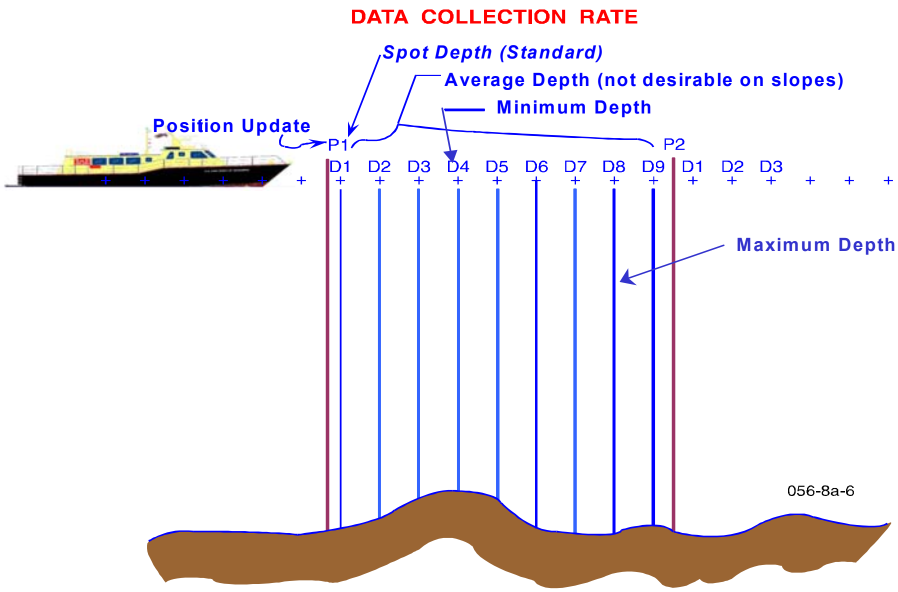


Figure 9-20. Tagging positions to intermediate depths

a. Depth filtering, thinning, and binning. Single beam profile data may be thinned using intelligent data thinning software routines. Placing data points at evenly spaced distances (single-beam binning) along the cross-section track may corrupt the topography. Intelligent software is available to filter and thin data while maintaining integrity of the profile--see Chapter 11, paragraph 11-12 (Multibeam Data Editing and Processing). When depth databases are thinned for plotting or other purposes, the random shot depth should be used. If databases are sorted to reduce the density of depths collected along a cross-section, then random depths along the section should be selected such that overplotting adjacent depths is avoided. Use of randomly thinned depths most correctly represents the original database and the accuracy of the individual observations. HYPACK sorting programs CROSS-SORT is designed to locate and plot the shot point depths in a selected region such that overplots are avoided.

b. Shoal biased minimum depths. Various depth data selection and thinning processes are employed to reduce depth data for plotting purposes. HYPACK sorting program "SORT" is designed to locate and plot only the minimum depths in a selected region such that overplots are avoided. Selection of minimum depths is termed "shoal biasing" in the Corps. Use of shoal biasing techniques is primarily intended for nautical charting purposes where the least recorded depth in a given area is desired. These minimum depth biasing techniques should not be used for dredging measurement and payment surveys--especially on after-dredging surveys where suspended sediment biasing can occur. Minimum depth biasing can also distort side slope depiction or bias shoaling along toes. Minimum depth selection should never be used when roll, pitch, and heave corrections are not observed and applied. Use of minimum depth biasing has led to numerous contract disputes and claims. Shoal biasing selected minimum depths may have application for project condition surveys when no quantity estimates are made from the data. Drawings should clearly note that original depth data was sorted and reduced by minimum depth selection methods.

c. Depth resolution. It is USACE policy to record and plot corrected depths to a resolution of 0.1 ft. Depths should be rounded using standard engineering practice.

9-14. Latency Tests

Latency is the time difference or lag between the time positioning data are received and the time the computed/processed position reaches the data logging module and is time-tagged. Latency typically results in a negative along-track displacement of the depth measurements--i.e., the time-tagged observed depth is acquired during the positioning system reading cycle whereas the output position is time-tagged when the computation cycle has been completed (see Figure 9-21). While surveying at slow speeds, this displacement will be small. At higher speeds, the displacement increases--i.e., it is proportionate to the speed. Position-depth latency distances of up to 40 ft have been observed--an intolerable systematic error that must be corrected and periodically calibrated. The impact of a latency error is illustrated in Figure 9-22 where a sawtooth contour results and dredge payment quantities become biased. Latency displacements are also a function of the type of positioning system used. For DGPS systems, the processing time for the position will vary with the number of observations used in the final GPS solution--thus causing small variations in the latency itself. Use of the T_0 pulse from the GPS receiver minimizes this error. If the time imbedded in the GPS message is used, then the correct synchronization between this time and the transducer or signal processing clock must be assured. The latency delay is computed by measuring the along-track displacement of soundings from the pair of coincident lines run at different speeds over a steep slope or other prominent topographic feature. Details on performing latency time bias tests are found in the Multibeam Systems chapter of this manual. Procedures for applying latency corrections (in real-time and/or post-processing corrections) are contained in hydrographic survey software manuals--typically under hardware setup sections where various positioning equipment offsets are entered. Latency bias calibration tests and application of correctors are absolutely mandatory for all USACE surveys.

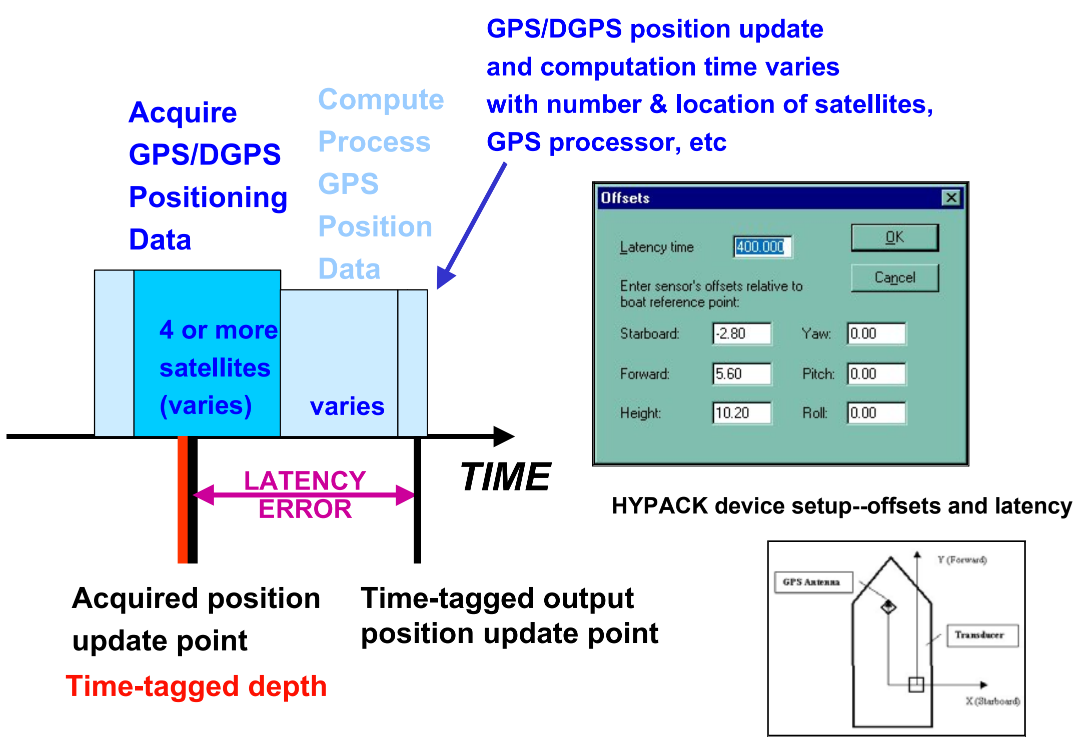
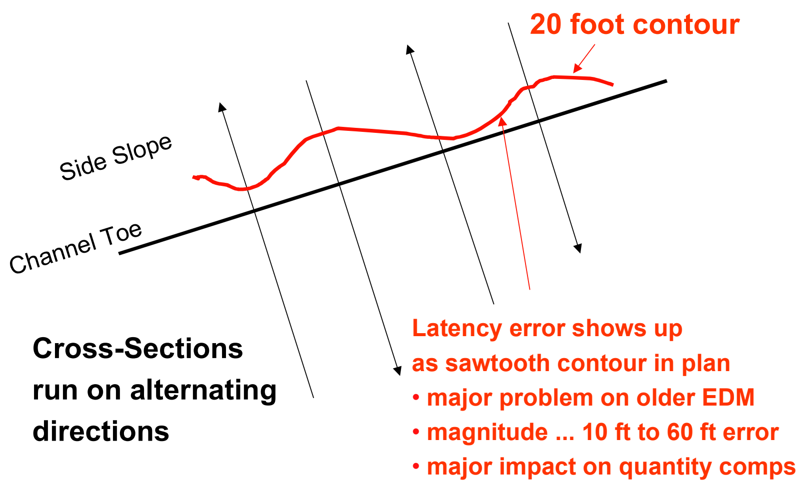
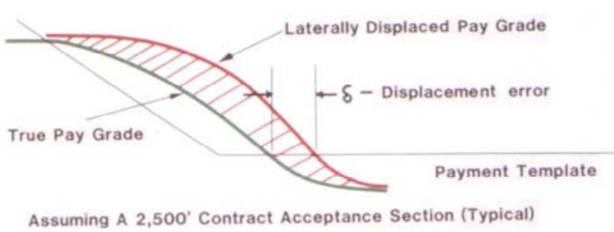


Figure 9-21. Positional latency correction





δ	△ $ (10 $/cy)
1 ft	$18,500
5 ft	$93,000
10 ft	$185,000
20 ft	$370,000

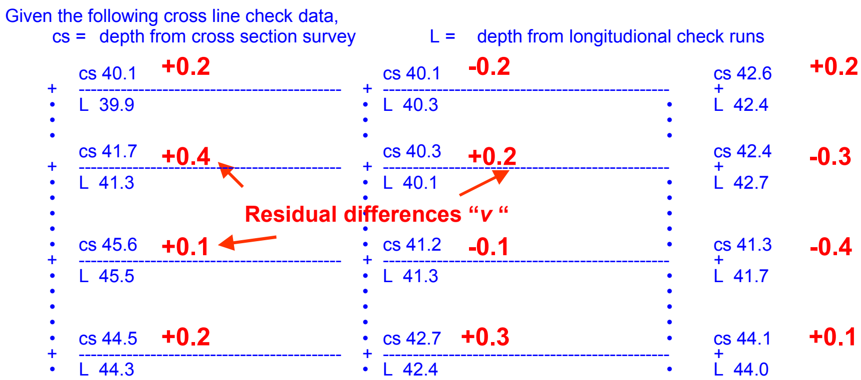
Figure 9-22. Effect of latency error in data contours as shown in plan view of channel (top). Potential impact of latency error on dredge payment shown in bottom view

9-15. Depth Quality Assurance Techniques for Single Beam Surveys

This section describes various procedures used to monitor quality assurance (QA) on a single beam hydrographic survey. These techniques are applicable to critical navigation and dredging payment surveys. The primary and most critical reason for these QA tests is to detect a systematic bias in the data--e.g., tide, velocity, squat, etc. QA tests generally rely on comparisons of depth measurements observed from independent surveys of the same area by the same survey vessel. The adequacy of these comparisons depends on the number of depth comparisons made and the independence of the comparative surveys; in many instances, the number of comparison points is not statistically valid and the surveys are not truly independent--see Chapter 4. From a rigid statistical sense the results of such comparisons are only an "estimate" of the true data accuracy. Therefore, comparative data derived from these surveys cannot be considered an absolute QA check.

a. Cross-line check method. To perform quality control checks on the internal consistency of dredging measurement and payment surveys, cross-line checks should be taken normal to the channel cross-sections. Preferably, these data are obtained at different tide/stage levels and after recalibration of depth sounding equipment. Elevations should be determined on survey lines and cross lines at each crossing by linear interpolation, using either manual or automated techniques. Differences should be tabulated and statistically analyzed. At least 100 check comparisons should be obtained--see minimum requirements in Chapter 4. The mean difference and standard deviations of crossing elevations should generally fall within the tolerances shown in Table 9-6. Exact linear interpolation for line intersections may not be necessary if the footprint size of the echo sounder is considered. The mean difference or bias between the two separate surveys is far more critical test than the standard deviation test result. A simplified example is shown in Figure 9-23. In this example, only 12 intersections are computed--a totally insufficient number of comparisons for any meaningful analysis--refer to paragraph 4-7 (Approximate Field Assessments of Depth Measurement Accuracy) in Chapter 4 for a discussion on the minimum number of cross-line checks that should be obtained. The mean difference and the standard error in this example are well within tolerances. The results of such an analysis will be noted on all plots, drawings, metadata files, maps, or charts as an indication of the data consistency obtained.

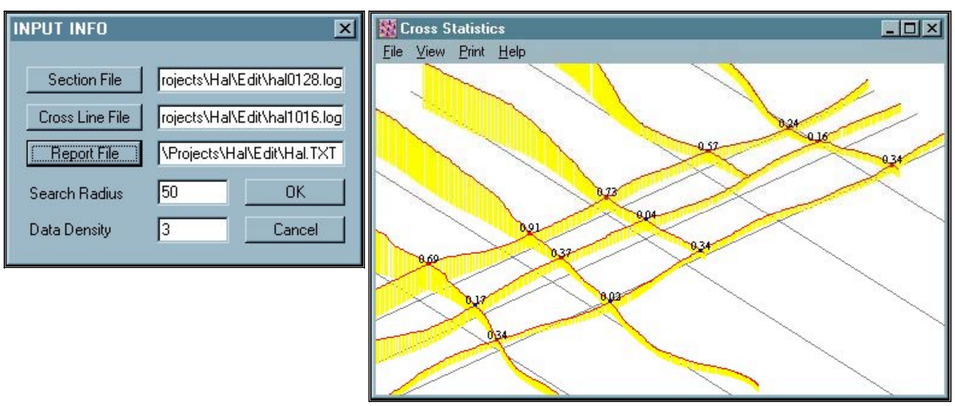
b. Automated computation of cross-line checks. Computer software to perform the cross-line check comparisons may be obtained from vendors. This software reads the cross-section profile data file and the longitudinal profile data file. It then computes the intersection and interpolates a depth from each input file. Each record of the output file lists the horizontal intersection, the interpolated depths, and the absolute difference in depths, along with the mean difference and standard deviation. If the output standard deviation is computed at the one-sigma level, then it must be multiplied by 1.96 to convert it to the 95% confidence level specified in Table 9-6 and Table 3-1. The example shown in Figure 9-24 is from HYPACK MAX Cross Check Statistics routines.



Mean of differences = sum (*v*) /n = +0.7 / 12 = + 0.058 ft << 0.2 ft allowed

Standard error (95%) = 1.96 * sqrt [sum |v^2| / (n-1)] = 1.96 * sqrt [(0.69) / 11] = +/- 0.50 ft
(+/- 2.0 ft allowed in > 40 ft project)

Figure 9-23. Sample cross line check computation



Cross Check Table	002_1022.PAT z1	z2	dif	003_1029.PAT z1	z2	dif	004_1032.PAT z1	z2	dif
007_1004.PAT	6.46	6.12	0.34	11.32	11.49	-0.17	24.37	23.68	0.69
008_1007.PAT	9.50	9.52	-0.02	9.33	8.96	0.37	13.78	12.87	0.91
009_1009.PAT	6.36	6.69	-0.34	11.72	11.76	-0.04	12.03	11.30	0.73
010_1011.PAT	n/a	n/a	n/a	n/a	n/a	n/a	11.53	10.96	0.57
011_1012.PAT	7.78	7.44	0.34	6.83	6.67	0.16	8.20	7.96	0.24

Figure 9-24. Cross line statistics routines (Coastal Oceanographics, Inc.)

c. External check line comparisons (Norfolk District). Another QA technique involves the establishment of external check sections. In order to verify accuracy of the vertical portion of the survey, check sections are set up on a large portion of projects. A track line is computed parallel with the channel and outside of it far enough that any activity in the channel will not affect the natural lay of the bottom covered by the track line. The line is computed so that it starts and stops on given station numbers, and an area is picked that is relatively devoid of any abrupt changes in elevation. Depending on the length of the survey there may be several lines, i.e. one in each tidal zone. These same lines are used each time the project is surveyed.

(1) How many times the check lines are run is largely a field decision made by field personnel that are on site. This decision is based on the weather, the length of time they have been surveying, the number of sections covered, and the performance of the depth recorder. At any suspicion that erroneous depths are being received, the calibration is checked and the check line re-run.

(2) Check lines are processed in the office just like any other line. These lines are not plotted on the map; instead they are run through a computer program that computes the average difference between each check line covering the same stations--see Figure 9-25. In this way it can be determined if a vertical shift has occurred. Such a shift would likely indicate problems in the local tidal model.

Cape Henry Channel -- External Checkline "A"
USAED Norfolk   Surveyboat Adams

Date of Section	Time		Average Depth	Residual	Residual Squared
06/26/92	947		37.83	-.01	.0001
06/26/92	951		37.85	.01	.0001
06/26/92	955		37.82	-.02	.0004
06/26/92	959		37.86	.02	.0004
		Totals	37.84	0.00	.0010

50% Error = (+/-) .0123146288346 = (+/-)0.6745 * Standard Deviation
Standard Deviation = (+/-) .0182574185835
90% Error = (+/-)1.6449 * Standard Deviation = (+/-) .030031627828

P&S Survey by Adams (RJW)

Date of Section	Time		Average Depth	Residual	Residual Squared
10/28/92	1622		37.95	0.00	0.0000
10/28/92	1627		37.95	0.00	0.0000
10/28/92	1631		37.92	-.03	.0009
10/28/92	1635		37.97	.02	.0004
		Totals	37.95	-.01	.0013

50% Error = (+/-) .0140408371664 = (+/-)0.6745 * Standard Deviation
Standard Deviation = (+/-) .0208166599947
90% Error = (+/-)1.6449 * Standard Deviation = (+/-) .0342413240252

Figure 9-25. External check line comparison (Norfolk District)

d. Averages of Extended Cross Sections (Norfolk District). Extended cross sections represent yet another quality control technique. They provide a means for comparing successive surveys of a given area. These comparisons help establish survey repeatability.

(1) The use of extended cross sections for comparing successive surveys requires that four conditions be satisfied. First, the number of extended cross sections needs to adequately represent the

survey. Second, each cross section must be extended beyond the area affected by dredging, since the comparisons could be made between surveys conducted before and after dredging. Third, the bottom outside of the dredging area must be relatively flat; otherwise it will be difficult to distinguish between the natural bottom and a survey discrepancy. Finally, the bottom must be relatively stable outside of the dredging area.

(2) The primary purpose of extended cross sections is to compare two given surveys by computing the average depth along the extended portion of each cross section. This is repeated for each successive survey of a given cross section. The algebraic difference between the average depth of each of the two surveys is computed. Then the average algebraic difference of all the cross sections is computed. The result of this analysis (Figure 9-26) will be a measure of how well two given surveys at a given cross section repeat each other and how well the two surveys of the entire group of cross sections compare overall.

Richmond Deepwater Terminal -- Average of Extended Cross-Sections
USAED Norfolk Surveyboat Adams

Average Depths are computed from 0 feet outside Toe to 100 feet outside Toe

Station No.	Avg. Depth (ft)	Avg. Depth (ft)	Col 1 - Col 2
5400.00	17.5	17.2	.3
5469.75	18.3	18.6	-.3
5500.00	18.4	18.3	.1
5600.00	18.0	18.1	-.1
5700.00	18.2	18.1	.1
5800.00	19.1	18.8	.3
5900.00	19.8	19.6	.2
6000.00	20.6	20.4	.2
6100.00	21.9	21.6	.3
6200.00	21.3	20.9	.4
6300.00	21.2	21.0	.2
Average	19.5	19.3	
Average Difference All Surveys =			.2

Figure 9-26. Extended cross-section comparison

9-16. Summary of Quality Control Criteria for Single Beam Echo Sounders

The following table contains critical QC and QA requirements for USACE single-beam surveys supporting dredging and navigation. This guidance has been developed from years of experience in numerous districts. It is intended to ensure Corps-wide consistency and quality in data used for water resource planning, design, construction, and operation. Requests for internal or external waivers from this guidance should be thoroughly justified and documented, especially if dredge measurement and payment surveys are involved. The table contains criteria for single-beam surveys in rock-cut projects. Since Table 3-1 requires 100% sweep coverage in such projects, use of a single beam system would not be practical. However, should a HQUSACE waiver from 100% coverage be obtained, then the criteria in Table 9-6 would be applicable.

Table 9-6. Quality Control and Quality Assurance Criteria for Single Beam Surveys

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys		Other General Surveys & Studies
	Bottom Material Classification		(Recommended Standards)
	Hard *	Soft	
TRANSDUCER MOUNTING LOCATION:			
In-hull amidships below antenna	Required	Recommended	Preferred
Port-starboard (over side) mounts	if full HPR corr'n	if full HPR corr'n	Optional
Stern or bow mount	if full HPR corr'n	if full HPR corr'n	Optional
ACOUSTIC FREQUENCY (± 10%)	200 kHz	200 kHz	200 kHz
Beam angle @ - 3dB power points	3 deg	8 deg	8 deg
Low frequency fluff applications	24-28 kHz	24-28 kHz	24-28 kHz
VELOCITY CALIBRATION PROCEDURES:			
Perform at least	2/day	2/day	1/day
Bar check	Preferred	Preferred	Optional
Ross Ball check (w/ periodic bar cks)	Optional	Optional	Optional
Check with bar every	Month	Month	Month
Velocity casts (w/ periodic bar checks)	Optional	Optional	Optional
Check with bar every	Month	Month	Month
Lead line calibrations allowed	No	No	Optional
BAR/BALL CHECK CALIBRATION:			
Bar/ball cables marked at least every	5 ft	5 ft	5 ft
Independently measure cables	Quarterly	Annually	Annually
Correct line errors exceeding	0.05 ft	0.05 ft	0.05 ft
Location of calibration	At project site	Near project site	Vicinity
Number of comparisons within range	3 + (every 5 ft)	2	2
Record calibrations to nearest	0.1 ft	0.1 ft	0.1 ft
Data rejection tolerance between checks	0.2 ft	0.3 ft	0.5 ft
VELOCITY PROBE CALIBRATIONS			
Perform internal calibration	Weekly	Weekly	Monthly
Record velocity to nearest	1 fps	1 fps	1 fps
Record velocities at least every	5 ft	5 ft	5 ft
Reject tolerance between checks	5 fps	5 fps	5 fps
Location of calibration	At project site	Near project site	Vicinity
MOTION COMPENSATION REQUIREMENTS:			
Compensation reqd if roll-pitch exceeds	> 5 deg	> 10 deg	No limit
Compensation reqd if heave exceeds	> 0.2 ft	> 0.5 ft	No limit
Roll-Pitch beam steering position displacement reqd if corr'n > 1 m	Required	Recommended	Optional
Roll-Pitch beam slope-vertical corr'n reqd if error > 0.2 ft	Required	Recommended	Optional
Yaw position correction	Recommended	Optional	Not reqd
Pitch bias test	at installation	at installation	Not reqd
Transducer stabilization	Optional	Optional	Not reqd

Table 9-6. Quality Control and Quality Assurance Criteria for Single Beam Surveys (continued)

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
	Hard *	Soft	
MISCELLANEOUS CHECKS			
Squat test calibration performed	Annually	Annually	Annually
Check vessel draft variations	2/day	2/day	2/day
LATENCY TEST			
Perform every	3 mos	6 mos	Annually
Recommended vessel speed NTE	5 kts	10 kts	Unlimited
QA CROSS-LINE PERFORMANCE TEST			
Requirement	Required	Optional	Not reqd
Maximum allowable mean bias	< 0.1 ft	< 0.2 ft	N/A
Standard deviation (95%)	[per Table 3-1]		N/A
Minimum number of comparison points	[100 points--see Chapter 4, section 4-7]		
RECORDED DEPTH			
Depth recording density	50-100 millisec	250-1,000 millisec	as reqd
Dredge payment quantities	Full density shot	Full density shot	N/A
B/D or A/D plot	Selected shot	Selected shot	N/A
Project condition plot (thinned)	Shot	Shot or average	Optional
Record depth to nearest	0.1 ft	0.1 ft	0.1 ft
ARCHIVED ANALOG DEPTH RECORDS			
Contracted construction	[Hard-copy or write-once disc]		
Project condition surveys	Digital	Digital	Optional

* HQUSACE waiver required

9-17. Referenced Equipment Manufacturers

a. Odom Hydrographic Systems, Inc., 8178 GSRI Road, Building B, Baton Rouge, LA. http://www.odomhydrographic.com

b. Innerspace Technology, Inc., 36 Industrial Park, Waldwick, NJ. http://www.innerspacetechnology.com

c. Knudsen Engineering Limited, 10 Industrial Road, Perth, Ontario, Canada. http://knudsenengineering.com

d. Ross Laboratories, 3138 Fairview Ave. E., Seattle, WA 98102. http://www.rosslaboratories.com

e. Raytheon Marine Company, High Seas Products, 22 Cotton Road, Nashua, NH. http://www.raymarine.com

f. Coastal Oceanographics, Inc. (HYPACK MAX). 11-G Old Indian Trail, Middlefield, CT. http://www.coastalo.com

9-18. Mandatory Requirements

The criteria for navigation and dredging surveys in Table 9-6, along with supplemental explanatory material throughout the chapter, are considered mandatory. Allowable exceptions or deviations from the criteria in Table 9-6 may be contained in these sections.