Chapter 21
Depth Measurement Over Irregular or Unconsolidated Bottoms

21-1. General Scope

Determining the clearance or payment grade is difficult when irregular rock fragments, soft strata, or suspended sediments are present. This commonly occurs during dredging activities when the excavation process has agitated the bottom material, resulting in clouds of suspended sediment material, often termed "fluff." In some cases, low-density saturated soils are naturally present, and a finite reference grade is difficult to define (especially for contract purposes). Other difficult depth measurement conditions include fluid mud, gassy sediments, wavy bottoms, moving bottoms, and vegetated bottoms. Also, small rock fragments may not reflect sufficient acoustic energy to be detected on standard echo sounders. Industrial waste can create problem areas where there are large discharges of organic material, such as downstream of paper or pulp mills where the suspended organic material can be acoustically very reflective but have very low shear strength. When the upper sediment layer is not well consolidated, the three major depth measurement methods used in USACE (sounding pole, lead line, and acoustic echo sounding) will generally not correlate with one another, or perhaps not even give consistent readings from one time to the next when the same type of instrument or technique is used. These potential variations in depth are shown in Figure 21-1. This chapter presents information about the causes of difficult bottom conditions and describes means of obtaining acceptable depth data in spite of the difficulties.

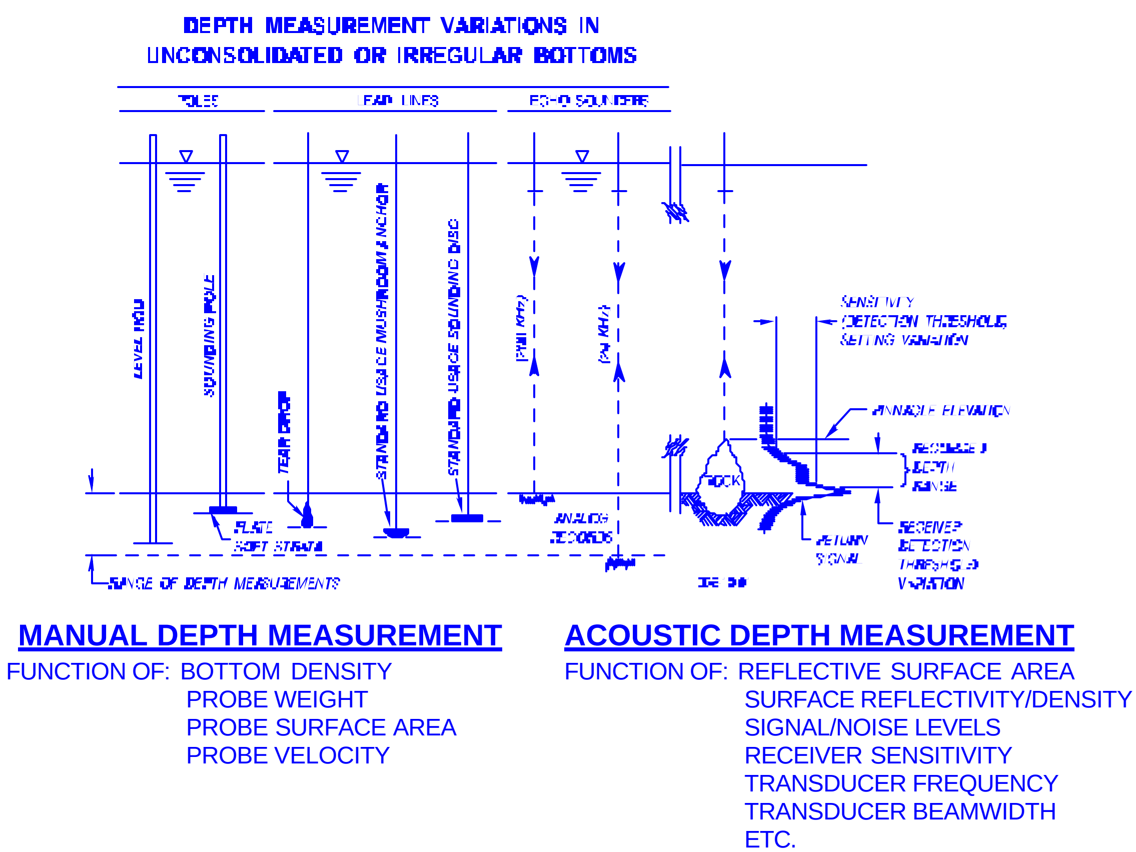

Figure 21-1. Depth measurement variations over hard and soft bottoms

21-2. Causes of Suspended Acoustically Reflective Material

Causes of fluff layers, fluid mud, and other soft bottom conditions are not understood very well. A significant amount of research has been conducted to improve an understanding of these effects and to develop improved methods of determining and defining the nautical bottom. Fluff conditions are reported most frequently from districts that maintain waterways in the warm-weather sections of the country. Fluff conditions are most prevalent in estuaries where mineral-laden fresh water mixes with salt water. In the mixing zone, the freshwater minerals react with the salt water and come out of solution as flocculates. These flocculate particles can be very close to the density of water and can hang in suspension for a long time. Several layers of progressively denser material can occur. The density within such a layer of suspended material tends to remain relatively constant.

a. *Dredging impacts.* Conditions downstream from a dredge will probably also be quite different from those described in the preceding paragraph. The suspended material will not become stratified for some time after being stirred up by the dredge, and a return signal can result from reflection and dispersion of the signal from a wide vertical portion of the water column. The acoustic reflection analysis given above, using the stratified layer concept, does not apply to turbulent non-stratified conditions such as this. While not applicable to depth measurements, acoustic reflection techniques have been used in research studies to trace the extent and time duration of the plume of suspended material resulting from dredge operations.

b. *Currents.* Swift natural currents also can cause turbulence that stirs up sediment material in clouds. This condition, like dredge turbulence, can cause acoustic reflection that will obscure normal reflection from the consolidated sediments of the waterway bottom. Acoustic reflection analysis of layer reflections does not apply to this condition.

c. *Fluid mud.* Fluid mud is sediment material that is heavy enough not to be suspended in the water but has no shear strength as does consolidated sediment material. Fluid mud can occur in layers 10 to 20 ft thick (as in the Europort channel), and the density can vary significantly from the top to the bottom of the fluid mud layer. A ship can pass through fluid mud without being grounded. The nautical bottom for this condition must be defined on the basis of effects that significantly impair the ship's steerage or speed. The nautical bottom, if defined on a density basis, may occur within the fluid mud layer. Acoustic reflection techniques, as currently developed, cannot define the nautical bottom within a layer. In such instances, direct contact methods must be used.

21-3. Acoustic Depth Measurement in Suspended Sediments

Figures 21-2 and 21-3 illustrate the kind of depth records that can occur when surveying over waterway bottoms with soft material surfaces or suspended material above the consolidated sediment surface. These records cannot be interpreted reliably unless other correlating information is developed. Automated depth digitizers will be even less reliable in providing a depth reading because such equipment cannot use any judgment in deciding whether to accept or reject the incoming information. Thus, the use of sophisticated computer-based survey systems does not help in this type of surveying environment, as far as getting good, reliable data is concerned. Records such as those depicted in the these figures result from the fundamental principle on which acoustic depth sounding is based. When there is a difference in density of the underwater material, some of the incident acoustic energy will be reflected. When using high-frequency transducers (i.e., 200 kHz), even very small density differentials will cause sufficient energy to be reflected, causing the depth sounder to print a return on the analog chart. For this reason, lower frequency transducers may be required to adequately depict the bottom.

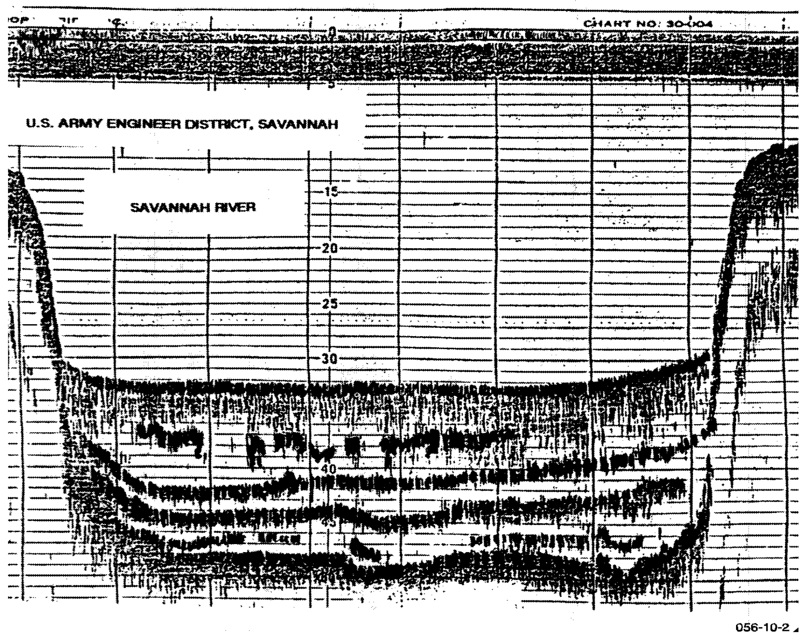

Figure 21-2. Suspended sediment record from Savannah River (Savannah District)

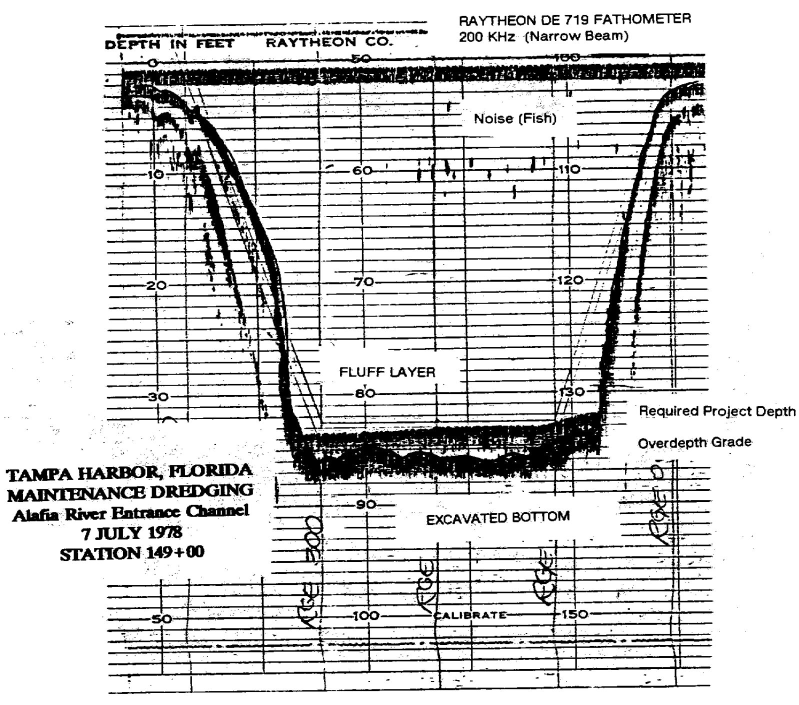

Figure 21-3. Suspended sediments on After-Dredge survey of Tampa Harbor (Jacksonville District)

a. *Acoustic impedance*. Figure 21-4 illustrates the reflection of acoustic energy from multiple stratified layers of underwater material. The percent- age of acoustic energy reflected at each density interface surface is a function of the relative densities of the two layers. An equation for the acoustic reflectivity of an underwater surface is given in Figure 21-4. In this equation, the acoustic impedance of water is equal to the density of water in grams/per cubic centimeter times the velocity of acoustic energy in water in centimeters per second. Acoustic impedance of the underwater layers is equal to the density of each layer times the velocity of sound in that layer. This equation is valid only for the simplified case in which the change in material composition from one layer to another occurs in a short vertical length compared to the wavelength of the incident energy. A more rigorous analysis would require that the density gradient from one layer to the other be known. Such an analysis is beyond the scope of this manual.

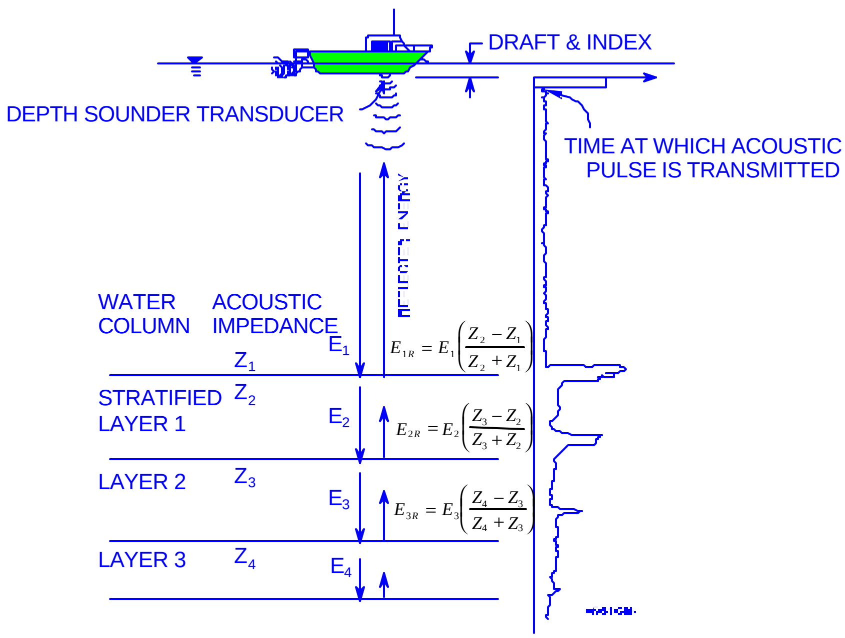

Figure 21-4. Acoustic impedance changes in differing sediment densities

b. Echo sounder sensitivity control. An important point to remember is that the amplitude of the first signal return is proportional to the density of the upper layer. Thus, a hard sand surface layer will give a much stronger signal return than a low-density fluff surface layer, no matter what frequency is used (see Figure 21-5). Keeping this fact in mind can be helpful in making a rational setting of the sensitivity control on a depth sounder. Consider the situation in which a survey is under way and the depth chart recording begins to print irregularly in a particular area. The natural tendency is to adjust the depth recorder sensitivity control until the depth chart prints a solid line again. Increasing the sensitivity of the recorder permits the chart to print a depth mark on the basis of a signal return from a softer bottom. The potential problem with this type of adjustment is that the higher sensitivity may cause the depth chart to register a "fluff" layer and not a true bottom. Thus, do not "crank up" the sensitivity control to keep a solid line on the recorder and do nothing else. If a sensitivity adjustment is necessary, it is also necessary to make a correlating depth check using one of the alternate depth measurement techniques described in this chapter. If the alternate method agrees with the depth chart, the sensitivity adjustment is probably warranted. If there is no correlation, use of the alternate depth measurement method is indicated (e.g. lead line, nuclear density probe).

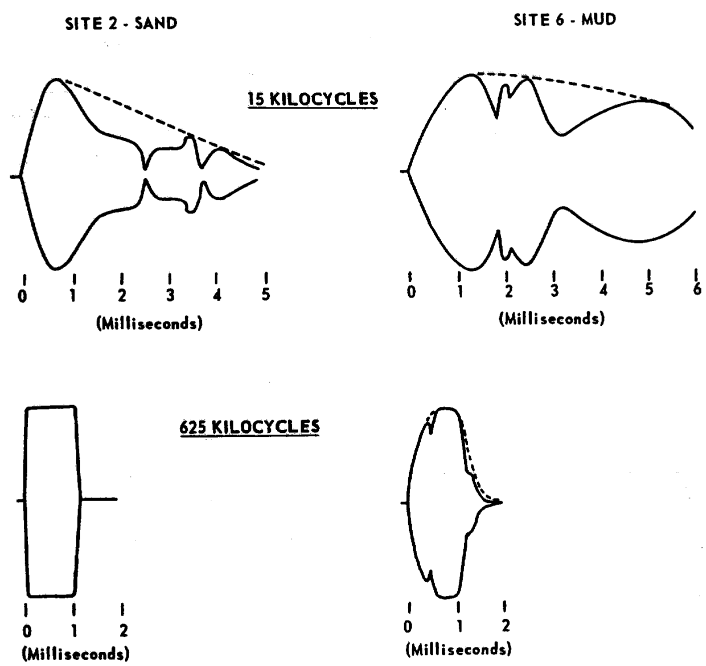

Figure 21-5. Signal return variations from sand and mud

c. Acoustic signal return in multiple sediment layers. When acoustic energy hits the upper surface of an underwater layer of material, some of the incident energy is reflected and some continues downward through that layer and hits the next layer. At the next interface, some of the energy is reflected and some continues downward. At each interface between layers, this process continues, with the incident energy becoming smaller with each transition due to reflection, attenuation, and scattering. Energy is reflected principally at the interface surfaces between layers and not in the interior of the layers, except where particles within a layer cause a local density gradient. Figure 21-6 depicts a 24-kHz signal return from multiple layers of material.

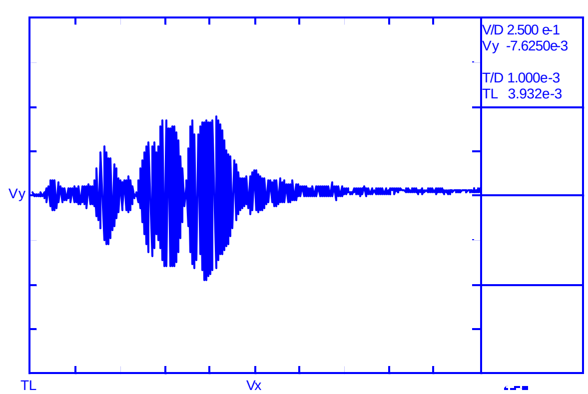

Figure 21-6. 24 kHz signal return in multiple sediment layers

21-4. Attenuation of Acoustic Energy in Suspended Sediments

As acoustic energy passes though a material such as water, underwater sediments, or suspended material, some of the energy is absorbed and the signal becomes weaker with the distance traversed. Energy absorption is referred to as "attenuation" and is usually given in decibels (dB). Different types of underwater materials will have different attenuation effects, and signal calculations must take this factor into account. At each interface surface, the downward-going acoustic energy will be reduced by both the preceding reflection reduction and the attenuation loss. The upward-going acoustic energy suffers the same reduction in amplitude ratio as does the downward-going energy (from attenuation and reflection redirection at each layer interface). These effects are doubled on the upward-going energy through the soil layers because it has twice the path length to traverse and must lose a proportion of reflected energy at each interface surface. Thus, because of the attenuation and reflection, a progressively smaller portion of the reflected energy comes from the lower layers of sediment, and the reduction in signal amplitude is drastic. The signal strength returning to the depth sounder transducer is an extremely small percentage of the transmitted energy. Only by electronic amplification is it possible to detect such minute signals.

a. Effect of frequency on attenuation. Attenuation of acoustic energy is directly proportional to the frequency, as illustrated in Figure 21-7. Thus, 200-kHz energy is attenuated ten times as rapidly as is 20-kHz energy when passing through the same material. Since high-frequency energy is attenuated more than low-frequency energy, a much smaller proportion of the high-frequency energy comes back to the depth sounder transducer from the lower layers of sediments than is the case with the low-frequency energy.

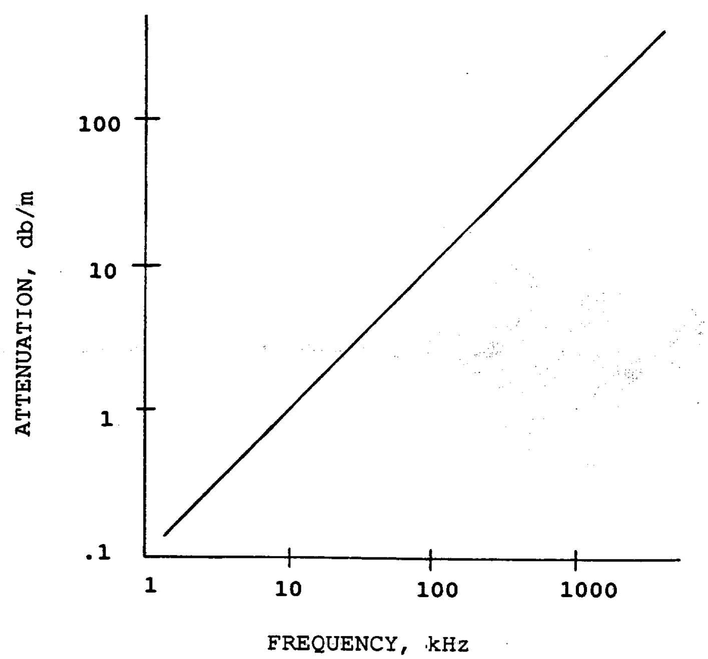

Figure 21-7. Acoustic signal attenuation versus frequency

b. Attenuation of different frequencies. An example showing the effect of attenuation as a function of frequency is given in Figure 21-8. This is a graph of the amplitude of the output from a 200-kHz transducer (upper curve) and the output from a 24-kHz transducer (lower curve). The two transducers were mounted side-by-side and aligned so that the response pattern of both transducers was vertical. Both transducers transmitted simultaneously, and the time scale is the same for both transducers. The 200-kHz channel was adjusted to have a higher gain than the 24-kHz channel so that the maximum amplitude of both channels, as viewed on the graph, was comparable. Due to the high attenuation of the 200-kHz signal, there is no detectable energy received from the lower sediment layers even though they had a higher density. The 24-kHz signal shows a maximum amplitude at one of the lower sediment layers because the attenuation of the 24-kHz signal in the upper layer is relatively low and the reflectivity of the upper layer is quite low. In this example, both transducers show the reception of first reflected energy at the same time. The 24-kHz energy reflected by the upper layer (the primary reflector of 200-kHz energy) appears to be very low in amplitude. The amplitude of the first layer reflection is, however, just as large at 24 kHz as it is at 200 kHz. However, the ratio of this reflectivity to the lower reflectivity gives the higher amplitude at the lower layer. The main point is that the reflectivity is about the same at both frequencies, but the attenuation is much higher for the higher frequency. The net result is that the high-frequency depth channel normally registers the upper layer of reflective material, even a very low-density one, and the lower frequency depth channel will register a lower layer if that lower layer has a higher acoustic reflectivity than the upper layer. Low-frequency depth sounders will always penetrate to a lower depth than will higher frequency energy at the same transmitting power level and receiver sensitivity. From a hard upper surface such as sand or rock, the surface reflection will be the maximum reflection amplitude for either a high- or a low-frequency signal.

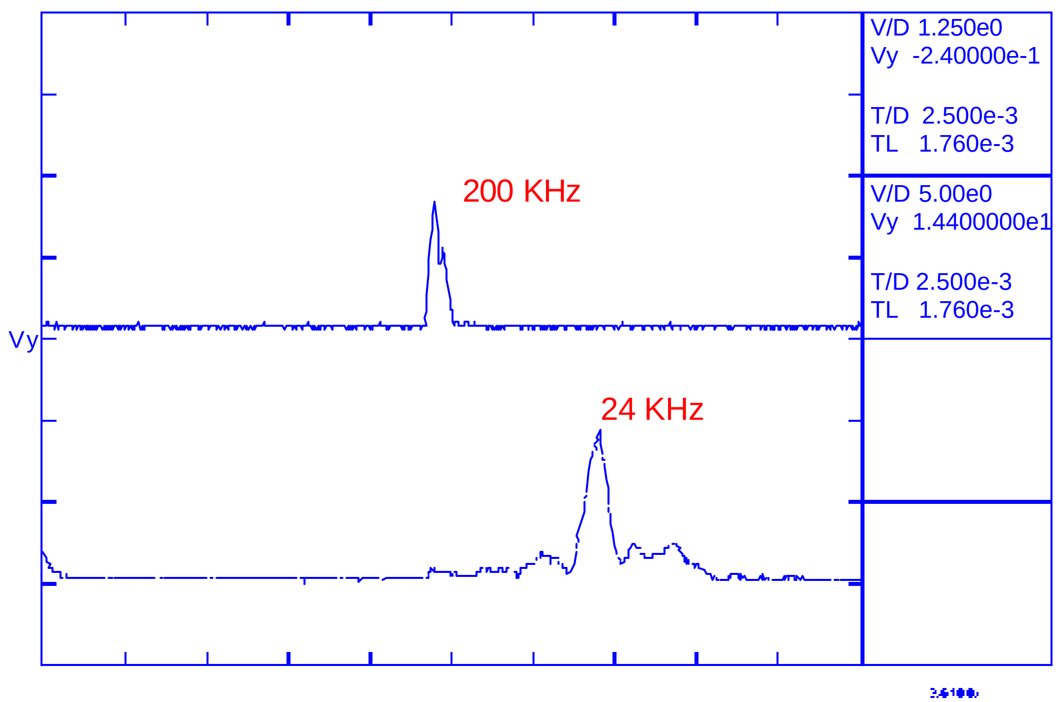

Figure 21-8. Comparison of 24- and 200-kHz signal attenuations

21-5. Effects of Surface Roughness and Incident Angle

Amplitude of the reflected signal will be affected by both the surface roughness and the incident angle. For depth sounding over level bottoms, the acoustic path will be close to vertical when using narrow-beam transducers or vertically aligned transducers. This simplified assumption is not valid for multibeam systems and when working with single-beam systems over sloping surfaces, when the survey boat is pitching and rolling, or when the transducer is not narrow-beam.

a. The four quadrants of Figure 21-9 illustrate some effects of surface roughness and bottom surface density. Quadrant 21-9a illustrates the reflection, refraction, and dispersion effects on a smooth hard bottom surface. Under these conditions, a high percentage of the incident energy is reflected and the dispersion of the reflected signal is low. Low dispersion results in a stronger signal along the reflection path. A vertical signal path and level bottom give the strongest possible signal return to the depth transducer. If the bottom surface is a sloping rock surface, a very low signal return may result because the energy would be directed away from the transducer in much the way a mirror reflects light. For this reason, small irregularly shaped rock fragments with smooth surfaces may go undetected by conventional echo sounders.

b. Quadrant 21-9b illustrates the reflection, refraction, and dispersion effects on a rough high-density bottom surface. In this instance, a much higher percentage of the incident energy is dispersed at angles different from the main reflection path. High dispersion results in a lower signal along the main reflection path. When the signal path is vertical and the bottom is level, there is a weaker signal return to the depth sounder transducer than under the conditions shown in quadrant 21-9a. When the bottom surface is not level, the rough surface illustrated in quadrant 21-9b may give a higher signal return than the smooth surface. As an example, a rough-surfaced boulder would be much easier to detect than a smooth-surfaced boulder.

c. Quadrant 21-9c illustrates the reflection, refraction, and dispersion effects from a smooth low-density bottom surface. A fluff layer in a channel without wind or currents to disturb the surface would approximate this condition. In this instance, low dispersion results in a stronger signal path along the reflection path. If the signal path is vertical and the bottom is level, most of the reflected energy is directed back at the transducer. The reflected energy would still be relatively low due to the low density. It is improbable that a low-density material will have other than a small surface angle because it will migrate down the slope.

d. Quadrant 21-9d illustrates the reflection, refraction, and dispersion effects from a rough low-density bottom surface. A fluff layer in a channel with wind or current to disturb the surface would approximate this condition. In this instance, the high dispersion in the surface reflection results in a weaker signal along the reflection path than the conditions illustrated in quadrant 21-9c.

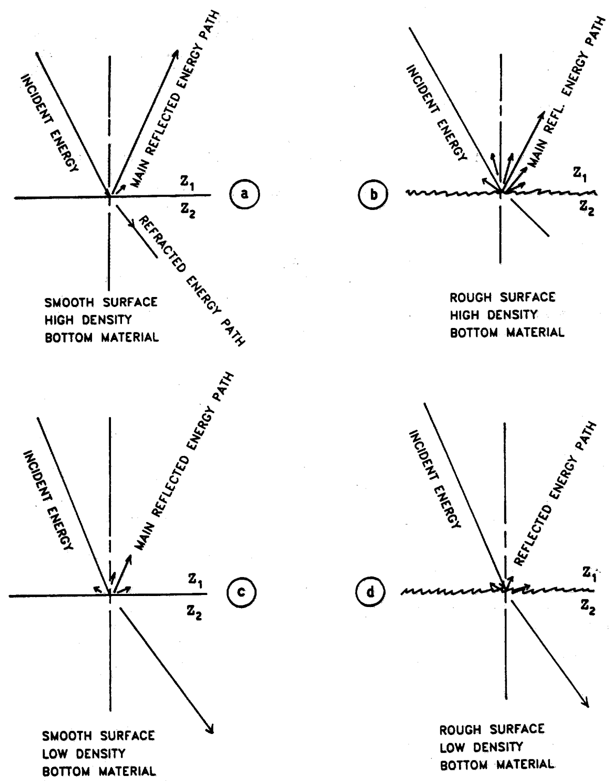

Figure 21-9. Effect of surface roughness

21-6. Alternative Depth Measurement Techniques in Suspended Sediments

The preceding paragraphs emphasize the principles underlying the operation of acoustic depth sounders and limitations of this technique under these difficult conditions. All depth measuring techniques have their limitations and constraints. The acoustic reflection technique was discussed first because it is by far the most widely used depth measurement technique. In the following paragraphs, the uses and limitations of other depth measuring techniques will be discussed.

a. Lead lines or sounding disks. Depth measurement using a lead line or sounding disk is usually considered a slow but very reliable method of determining depth. With hard bottom material, this assumption is valid. However, with soft bottom materials, it may not be. A lead weight will fall until the shear strength of the sediment is sufficient to stop the vertical movement of the weight. The high density of the lead weight is such that it will never come to an equilibrium depth on the basis of density. The shear strength of sediments can be affected by the velocity of the lead weight, stirring action, and the amount of time that the weight is allowed to rest on the soft sediment.

(1) As a result, two different people using the same lead line can get different results, depending on the length of time the weight is allowed to rest on the bottom and whether or not the weight is jiggled a bit to feel the bottom. With soft bottoms, it is difficult to feel when the weight actually touches bottom. Moving the weight while it is on the bottom tends to break down the internal structure of the soft sediment and convert it from a semi-solid to a viscous liquid, causing the lead line to sink deeper than if handled otherwise.

(2) In addition to not stopping at a consistent level, a lead line may not stop at a level that is an acceptable nautical bottom. For instance, a lead line pass through a sediment layer with a consistency of mayonnaise, but this kind of layer would probably so disrupt a ship's steerage that it would be unacceptable to shipping interests. A sediment with mayonnaise consistency would, however, probably give a good response on an acoustic depth sounder. This also would be the correct surface to call bottom for dredge need analysis. This example is given to show that when acoustic depth sounders and lead lines disagree, the assumption should not be made that the lead line is the correct depth. Other correlating information may need to be developed.

(3) Even with the above deficiencies in lead line measurements, it is still the most common method used to correlate echo sounder readings when suspended sediments are present. Lead line observations are compared with high- and low-frequency recordings to assess channel clearance and to arrive at an equitable payment for material removed.

b. Nuclear density probes. Nuclear density probes can be used to measure the density of bottom sediments. Most nuclear density probes work on the principle that a more dense material will absorb a higher percentage of the radiation passing from the source to the detector than will a less dense material.

(1) A typical probe is configured so that the sediment material passes between the source and detector as the probe is lowered. Nuclear density probes can give an accurate graph of sediment density as a function of depth if properly calibrated and used.

(2) Nuclear density probes are used as the standard depth measuring technique in the Netherlands, where fluid mud is a widespread condition and neither acoustic reflection nor lead line depth sounding techniques will give acceptable results. The Port of Rotterdam uses crane-supported nuclear probes to measure in-situ channel density from survey vessels. The probes describe the “nautical bottom.” The term “nautical bottom” has been used in Rotterdam at the maintained channel depth where the fluid mud is allowed to densify up to a 1.2 specific gravity maximum before dredging is required (USACE uses a specific gravity of 1.1 to define the nautical bottom). This definition for the maintained channel depth has amounted to a considerable savings in maintenance since the 1970s for Rotterdam's Europort.

(3) Nuclear density probes will not work in areas where there has been a discharge of radioactive material into the waterway. Calibration of nuclear density probes depends on having a uniform natural background radiation level in the area when the probe is to be used. Water discharged from industrial and government facilities has sometimes in the past contaminated the sediments with low-level radioactive wastes. These wastes distort the background radiation level and will cause the apparent density of the sediments to be seriously in error.

(4) Another limitation to the use of nuclear density probes is the severe regulations governing their use, including the extensive paperwork involved. Nuclear density probes can be used only by licensed personnel, and the license is difficult to obtain. Nuclear probes must be stored under special conditions that are expensive to implement and maintain. As a result, nuclear density measurements are generally not practical for most Corps applications.

c. Acoustic density probes. Acoustic density probes work in a manner similar to nuclear density probes. An acoustic signal passes between a source and a detector, with the material to be measured passing between the source and the detector. The probe is configured so that the sediment passes between the source and the detector as the probe is lowered. Calibration of an acoustic probe requires determining a correlation between acoustic signal attenuation and the density of the sediment material.

Acoustic signal attenuation is affected by more factors than just density, and the probe calibration is thus more site-specific than is the case for a nuclear density probe.

d. Calibrated acoustic reflection systems. Calibrated acoustic reflection systems are available from several manufacturers. A system manufactured by Caulfield Engineering Company can calculate the density of surface and subbottom stratified sediment layers. The Caulfield system works in conjunction with conventional depth sounders or subbottom profilers. The Caulfield system uses a computer and special software to calculate the acoustic impedance of sediment layers, and from this can calculate a good estimate of the density of the sediment layers at different depths. Further information on subbottom acoustic profiling systems is provided later in this chapter.

e. Electrical resistivity (ER) techniques. The ER is a drop probe used for fluff monitoring. The ER probe measures the change in electrical resistivity across two electrodes. This electrical resistivity is related to the acoustic impedance of the fluff which equals density times the speed of sound. This technique is similar to the nuclear and acoustic density probes.

f. Radar methods. A working radar system was developed by the USACE Cold Regions Research & Engineering Laboratory. This short-pulse radar system was designed for sediment layer identification in freshwater lakes. It cannot operate in salt water environments.

g. Mechanical methods. A 260-lb towed sled system has been developed at the USACE Waterways Experiment Station (WES) to measure fluid mud shear strength and density measurements. This system models the ability of a vessel to navigate, given a resistance developed by the fluff layers. The sled (a direct contact method) depicts the boundary between suspended and consolidated silt. Sled sensors measure hydrostatic pressure, sled velocity, sled attitude, nuclear density, and cable tension. Nuclear density measurements are used optionally by WES for redundant field checks against the shear strength. A crane winch assembly may be required to operate this system. The towed sled may have maintenance dredging benefits despite the vessel and personnel requirements for safe operation. The depth of the sled is determined by the hydrostatic pressure (head) gages on the sled. For hard-bottom channels the head gage is inferior, but for unconsolidated channel bottoms the sled may measure the material density which can impede a ship's navigation in the channel. In tests conducted at Gulfport Channel, the 200-kHz transducer was more consistent than the sled after repeated runs along the channel centerline. The sled was more consistent than the 24-kHz system. Weight was added to the sled in order to follow a density of 1.2 g/cm3 $\pm$ 0.1 g/cm3 (specific gravity (SG) of 1.2). The 200-kHz transducer was estimated to reflect off material at SG of 1.05. This tool is not made to replace acoustic depth measurement, but to augment soundings in areas of fluff or fluid mud.

21-7. Bottom Imaging Using Acoustic Impedance Measurements

Prior to dredging in areas comprised primarily of consolidated sediments, reflection seismic techniques should be considered for continuous documentation of bottom and subbottom materials. This method relies on acoustic impedance principles to predict density and material type. When employed in the planning phases of dredging operations, it can appreciably minimize the number of exploratory borings and ensure that those thought necessary are optimally located. Following is a brief discussion of the acoustic impedance technique:

a. General principles. The acoustic impedance method is a modification of the seismic reflection technique commonly used in offshore oil exploration but tailored to shallow water environments. As energy generated from an acoustic source (in the form of a plane wave) arrives at a boundary between two layers of differing material properties, part of the energy will be reflected back towards the surface and part transmitted downward. Portions of the transmitted energy will undergo absorption or attenuation in the layer while the remainder propagates through to the next stratigraphic boundary. Ratios between transmitted and reflected energy, called reflection coefficients (Equation 21-5), are dependent on the density and velocity of the materials through which the energy is propagating.

(1) Wave velocities are controlled by elastic properties of the two-phase sediment mass (sea water in pores and mineral structure). Properties such as porosity (volume of voids to the total volume) and grain size affect sound velocity only through their effects on the elasticity of the sediment. In previous studies it was concluded that elastic properties of water-saturated sediment could be expressed through Hookean elastic equations unless attenuation is considered, in which case linear visco-elastic equations are recommended.

(2) The basic equation for the velocity of a compressional wave *Vp* is:

$$V p = sqrt \ [\ (\kappa + 1.333 \mu) / \rho \ ] \qquad \text{(Eq 21-1)}$$

where

κ = incompressibility or bulk modulus and equals (1/β)
μ = shear (rigidity) modulus
ρ = saturated bulk density
β = compressibility

When a medium lacks rigidity, Equation 21-1 becomes:

$$V p = sqrt \ [(\kappa / \rho)] \qquad \text{(Eq 21-2)}$$

or

$$V p = sqrt \ [1 / (\beta\rho \ ] \qquad \text{(Eq 21-3)}$$

Compressibility *(*β*)* and density *(*ρ *)* in Equation 21-3 have been expanded into:

$$Vp = sqrt \ [1 / \{ (\eta\beta_w + (1-\eta) \beta_s) \ (\eta\rho_w + (1 - \eta\rho_s) \}] \qquad \text{(Eq 21-4)}$$

where η is the volume of pore space occupied by water (fractional porosity), and subscripts s and w indicate mineral solids and water.

(3) The influencing parameters of this basic seismic wave equation suffice to answer the question: "Why acoustics to characterize bottom/subbottom materials?" To continue, the acoustic reflection coefficient *(R)* is defined as:

$$R = sqrt \ [E_R / E_1] \qquad \text{(Eq 21-5)}$$

where

E_R = reflected energy
E_1 = total energy incident to the boundary

The reflection coefficient is also equal to:

$$R = (Z_s - Z_w) / (Z_s + Z_w)$$ (Eq 21-6)

where

$Z_w = \rho_w C_w$ = water impedance (resistance)
$Z_s = \rho_s C_s$ = soil impedance (resistance)
ρ_w = 1 g/cm3
C_w = 150,000 cm/sec

Hence, it is clear that the acoustic impedance *(Zs)* of the surficial layer can be calculated readily. The product of transmission velocity and density of material is the acoustic impedance and represents the influence of the material's characteristics on reflected and transmitted wave energy. The relationship between acoustic impedance and specific soil properties has been empirically based on an extensive database of world averages of impedance versus sediment characteristics. Table 21-1 displays benthic (water bottom) surface sediment type/acoustic impedance relationships.

Table 21-1
Soil Classification versus Acoustic Impedance Range

Material Medium	Acoustic Impedance (g/cm^2 per sec * 10^{-2})
Water	1450
Silty Clay	2016-2460
Clayey Silt	2460-2864
Silty Sand	2864-3052
Very Fine Sand	3052-3219
Fine Sand	3219-3281
Medium Sand	3281-3492
Coarse Sand	3492-3647
Gravelly Sand	3647-3880
Sandy Gravel	3880-3927

All values are corrected for temperature and salinity

b. Data acquisition and analysis. A seismic source of known energy content as a function of frequency, deployed just below the water surface, generates acoustic waves that propagate downward through the water column and sediments. High-resolution profiling systems specifically designed for shallow water are used with operating frequencies typically below 12 kHz. As a rule, lower operating frequencies allow greater energy penetration into the subbottom (due to longer wavelengths) but lack the vertical resolution of higher frequency systems.

(1) As transmitted energy propagates through sediment of varying densities and acoustic velocities, energy is reflected at geologic boundaries where there is a distinct contrast in the acoustic impedance between layers. Reflected signals are amplified, filtered, and recorded with a specially designed shallow seismic, digital data acquisition system.

(2) Due to the non-uniqueness of seismic reflection signatures, several combinations of geologic conditions could conceivably yield similar signal characteristics and computed impedance values. But in specific geologic regions such as the Mississippi Sound or San Francisco Bay, differing sediment units usually have a characteristic and relatively narrow range of impedance values. Therefore, using calibration procedures incorporating local core and laboratory data, seismic reflection data are processed

at known sample locations to yield acoustic impedance values of the known reflection horizons. Estimates of in-situ density are derived from computed impedance values and correlated with ground truth information. Acoustic predictions versus core data for consolidated materials were conducted in the Mobile Ship Channel. The results are within 1 percent. Acoustic impedance density predictions versus nuclear densitometer data were compared for fluff/fluid mud type materials in the Gulfport Ship Channel. Good correlation between the impedance-derived densities and the nuclear probe densities results from a database coupled with ground truth information (borings). Testing has shown that the data-based density estimates are within 5% of the in-situ values.

c. Presentation of results. In the normal course of data acquisition, field records related to amplitude of recorded signal, time, and distance provide the engineer/geophysicist with quick-look assessments of data quality and subbottom conditions. Data are oftentimes dually recorded by both analog and digital systems. Analog presentations are usually in shades of gray while digital data are displayed in color.

(1) Upon determination of the reflection coefficients and impedance function at known locations, the continuous seismic profiles are processed. The single-channel, digitally recorded data are read into the processing software, corrected for transmission losses due to spherical spreading, and compensated for absorption losses in each layer. Classical multilayer algorithms are used to compute equivalent reflection coefficients and impedances along the profile. This in turn provides density estimates of shallow subbottom layers and classifies the lithostratigraphy. The results are corrected for tidal fluctuations and correlated with survey positioning data. Processed results are presented in the form of annotated amplitude cross sections or 2- and 3-D views. The display is color-coded according to material density. This type of display delineates the extent of pertinent density zones of interest to the engineer, and the virtually continuous data coverage greatly decreases the possibility of significant material changes being undetected. Displays of this type provide much improved data interpretation and visualization for the end product user as compared to standard 2-D presentations generated exclusively from boring information.

(2) By incorporating the continuous coverage of subbottom materials with digital terrain modeling techniques, rapid and accurate computations can be made of volume and material type to be removed by dredging. Furthermore, a detailed database has now been established for project monitoring and long-term planning. Computed sediment densities within the project area can be displayed in a color-coded, 3-D view if desired by the user. The project planner may elect to view an area of interest from other angles or create different displays by stripping or slicing at any desired coordinate. Volume of any material to be removed can easily be calculated and displayed.

21-8. Procedures to Use in Unconsolidated Sediment Areas

When a survey is to be performed in an area where soft sediments or suspended material may exist, the following considerations should be observed if contract payment will be based on in-place measurements, or if payment is based on a daily rental basis. In fluff areas where resolution of in-place payment quantities is extremely difficult, then a rental basis should be considered. In either case, determination of final project clearance and release of the dredge will require use of some of the techniques described below.

a. Dredge and survey contracts should specify the equipment and techniques to be used during the survey work. The contract specifications should anticipate difficult bottom conditions and define mutually acceptable ways of achieving a satisfactory contract. For example, Savannah District uses the following contract measurement and payment clauses to address this problem:

Soundings for all dredging surveys under this contract will be obtained by the use of a marine depth recorder operating at a frequency of [24 kHz]. Sensitivity setting will be adjusted to reflect the type of bottom material in the area being surveyed. In areas where double bottom (fluff) conditions are encountered, soundings with an 8-lb lead with a 6-in. perforated disc will be taken in conjunction with sounding data secured by the depth recorder. Adjust the data thus secured to the depths equivalent to those obtained by lead line soundings.

If soundings obtained as stated in the above paragraph (adjusted by lead line soundings) indicate a fluff or double bottom condition which exceeds 5 feet above the adjusted firm bottom, the firm bottom line will be adjusted to 5 feet below the fluff line. This adjusted firm bottom line will be used for yardage (volume) calculations.

b. Use a dual-frequency depth measuring system (high-frequency 200-kHz nominal/low-frequency 24- to 50-kHz nominal). Record both the high- and low-frequency channels on the depth chart.

c. Monitor the depth chart frequently.

d. If the high-/low-frequency depth lines diverge in part of a survey section line, go back over this portion of the section line and check the depth with a lead line, nuclear density meter, or other independent direct contact method.

e. If the depth measured by the independent check method agrees with the high-frequency depth measurement, continue to use the high-frequency depth measurement.

f. If the depth measured by the independent check method does not agree with the high-frequency depth measurement but does agree with the low-frequency depth measurement, use the low-frequency depth measurement when the slope of the bottom is low and there are no structures nearby. Do not use the low-frequency depth reading on (or near) steeply sloped bottoms, pilings, or other structures.

g. If the depth measured by the independent check method does not agree with either the high- or low-frequency depth measurements, consider using the direct-contact method for the parts of the survey for which the two acoustic frequencies do not agree. A condition in which the lead line does not agree with either the high- or low-frequency depth chart readings may have a layer of fluid mud that causes this problem. If fluid mud is suspected, an alternate method (such as a nuclear density or acoustic density probe, radar, or STB) should be considered.

21-9. Dual-Frequency Depth Sounding in Areas with Suspended Sediment Conditions

Dual-frequency echo sounders are commonly employed in areas where fluff is present. In order to assess the data quality between the high and low frequency returns, it is helpful to be aware of some of the characteristics of each frequency, as listed below:

<u>High-frequency echo sounders – 200 kHz typical</u>

- Narrow Beam
- More Accurate Depth Measurement & Resolution
- Picks Up Small Density Changes
- Will Pick Up Multiple Fluff Layers ... Grass, Kelp
- Will Record Vegetation Above Hard Bottom
- Lower Power Requirements

- Side Echos Minimized
- Digital Depths Easier To Obtain
- Small Transducer Size
- Must Be Directly Over Object To Detect (Obtain Return)
- Limited In Depth Range... Few Hundred Feet
- More Difficult To Obtain Bar Check

Low frequency echo sounders – 24 kHz typical

- Wider Beam ... Side Echos Smooth Out Features
- Less Accurate Depth Measurement & Resolution
- Bar Checks Easy
- May Detect "True" Bottom
- May Read Through Bottom Grass
- Will Not Detect Small Density Changes
- Higher Power Requirements
- Large Transducer Size
- Increased Depth Range.

General features of high and low frequencies

- Acoustic Energy Is Absorbed At Each Density Layer
- Reflected Energy Also Absorbed On Return Path
- Returning Signal Strength Is Very Small (Amplifying Signal Becomes Problem)
- 200 kHz Energy Attenuated 10 Times More Than 20 kHz
- Low Frequency May Not Pick Up Initial Density Change If Small
- Low Frequency May Penetrate To Sub-surface Rock
- Signal Return Amplitude Proportional To Density Of Return Surface

The New Orleans District uses a low-frequency thermal depth sounder to identify shoaling areas in the Lower Mississippi River (Southwest Pass). This depth sounder, an Innerspace Model 449, provides dual frequency information with a low frequency operating at 20-50 kHz--see Figure 21-10. The gray threshold incorporated in the system allows the hard bottom to be printed in black and suspended sediments to be printed in gray using a single frequency. A second frequency module, at 208 kHz, can be mounted to the top of the 449 Unit. When this module is installed, the Model 449 can be used as a single-frequency or dual-frequency sounder with simultaneous sounding in both frequencies and dual digital depth outputs. The New Orleans District operates seven Model 449s, which are being used in high-speed (20 knots) condition surveys on the lower Mississippi River. These units operate at 27 kHz to penetrate the fluff materials and still digitize the hard bottom. Figure 21-11 is an example of a dual-frequency recording from a thermal shading echo sounder.

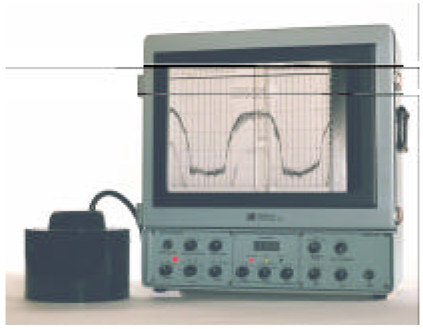

Figure 21-10. Innerspace Model 449 dual frequency depth recorder

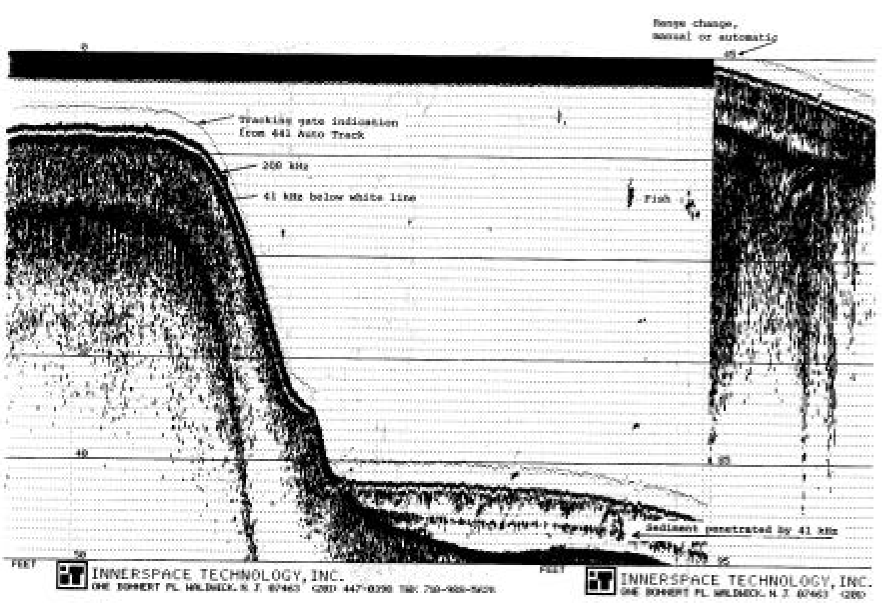

Figure 21-11. Recording from Innerspace Model 441 dual-frequency (41 kHz and 208 kHz)

The Knudsen Model 320M depth sounder has a dual frequency capability. Figure 21-12 depicts a dual frequency record from 38 kHz and 200 kHz transducers. The upper part of the figure shows the profiles recorded by the two separate frequencies. The bottom part shows the merged records in color-reverse grayscale. Figure 21-13 depicts low frequency (50 kHz) returns off bedrock--as plotted thermal hard copy paper. Figure 21-14 illustrates an Odom dual frequency return in soft sediment.

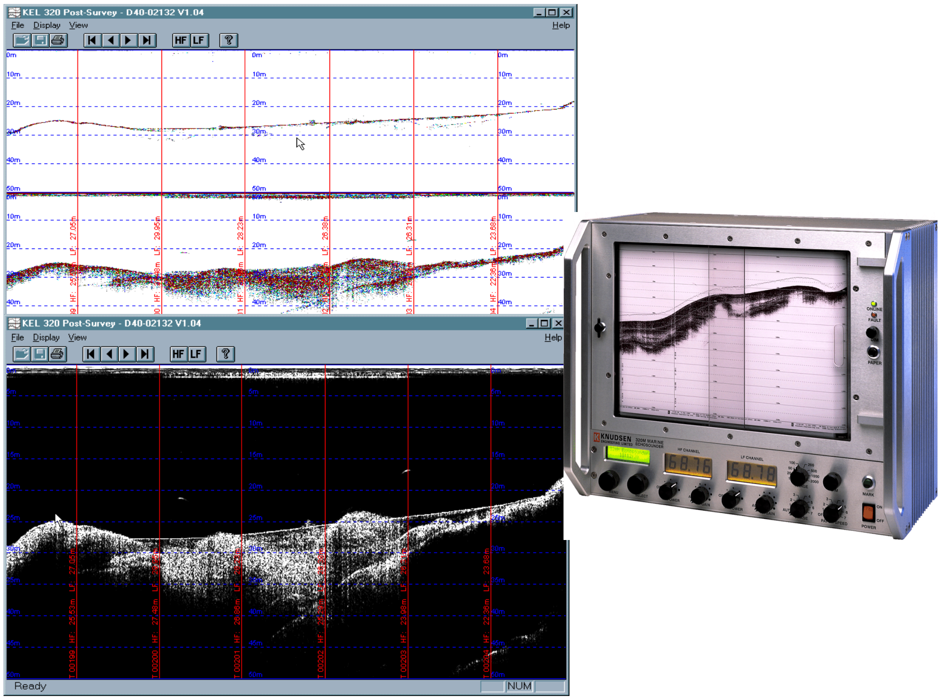

Figure 21-12. Knudsen 320M dual frequency recorder (38 kHz and 200 kHz)

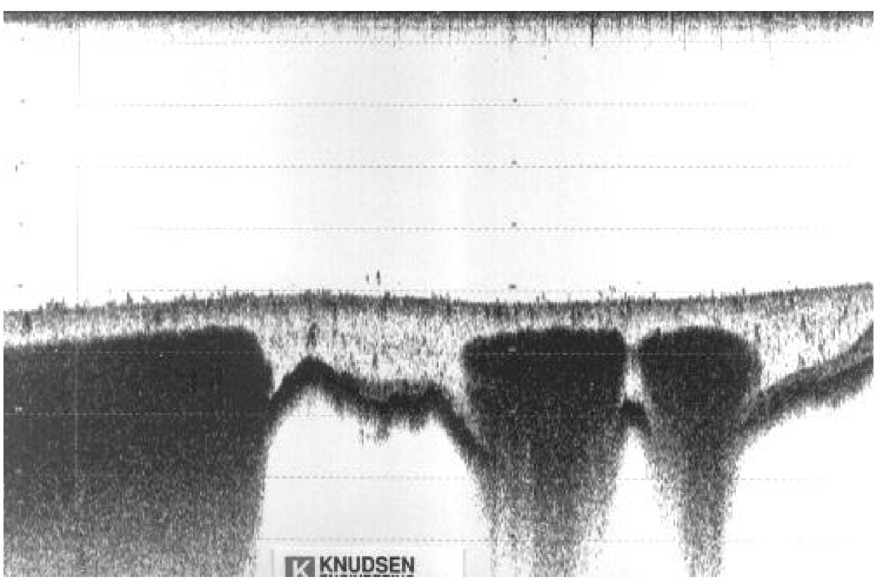

Figure 21-13. Knudsen 320M dual frequency thermal copy recorder (50 kHz and 200 kHz), depicting soft material over bedrock

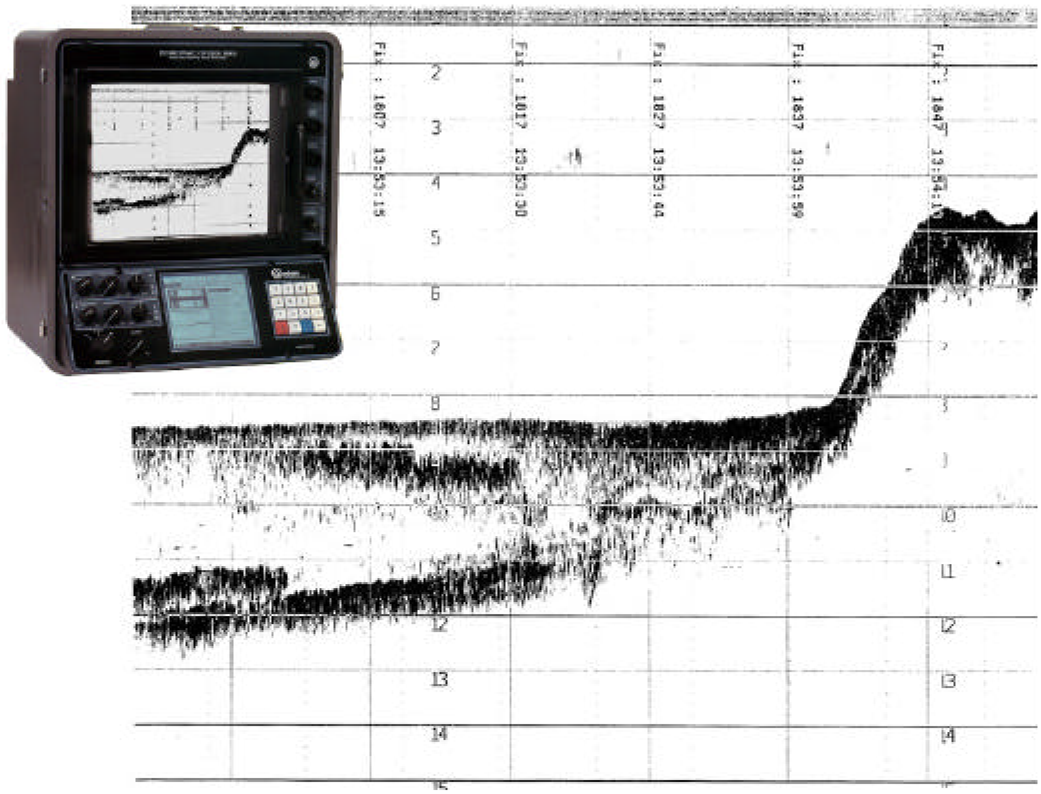

Figure 21-14. Odom Hydrographic DF3200 MKII dual frequency thermal echo sounder (24 kHz and 200 kHz), depicting soft sediment material over dredged channel

21-10. Dual Frequency Parametric Subbottom Profiling

The Odom Hydrographic Systems/Innomar SES-96 Parametric Profiling echo sounder uses the combination of two or more frequencies to measure subsurface layers and objects, such as pipelines. It can operate in water depths down to 400 meters with penetration up to 50 meters, and can resolve embedded objects or sediment layers as small as 5 cm. The term "parametric" refers to the mixing of frequencies to form sum and difference frequencies. Returns from the two high and low frequencies are added and subtracted, with the frequency difference being used to evaluate and measure penetrated sub-surface layers. Both frequencies have the same beam width. For small object detection, the survey vessel speed is kept to less than 2 kts during surveys. Applications of parametric frequency measurements include:

- Surveying the morphology of the bottom surface and evaluating muddiness for dredging tasks and environmental investigations
- Surveying sediment structures for geology
- Search for pipelines, sea cables, stones, navigation obstacles, and archaeological objects like wrecks and historical buildings
- Searchs for mineral resources

Figures 21-15 through 21-18 provided by Odom Hydrographic Systems illustrate some of the applications of the SES-96 profiling system.

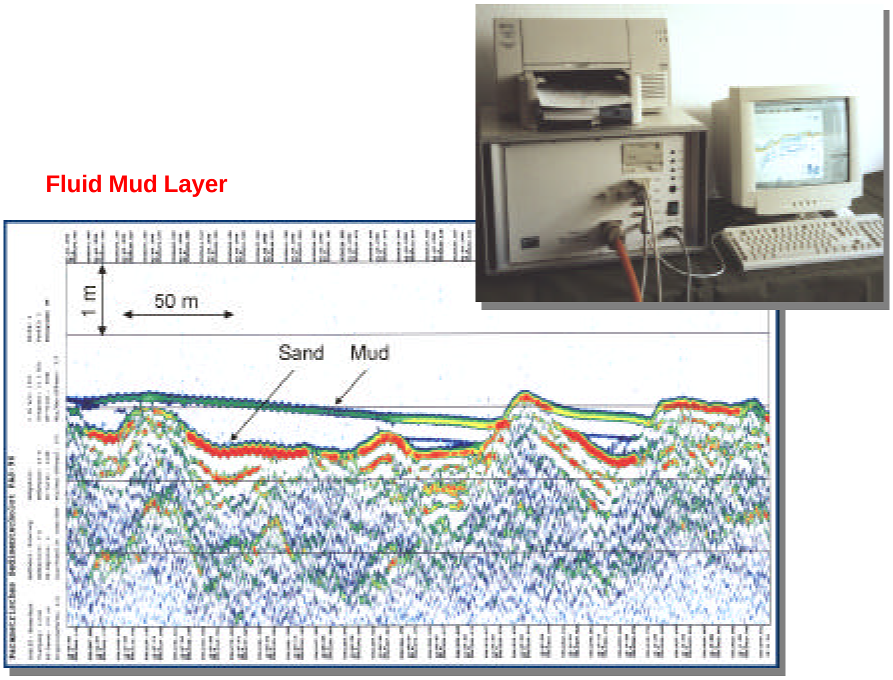

Figure 21-15. SES-96 Dual frequency profiling system. Enhanced processing of signals can identify different material layers in a channel, including fluid mud (Odom Hydrographic Systems)

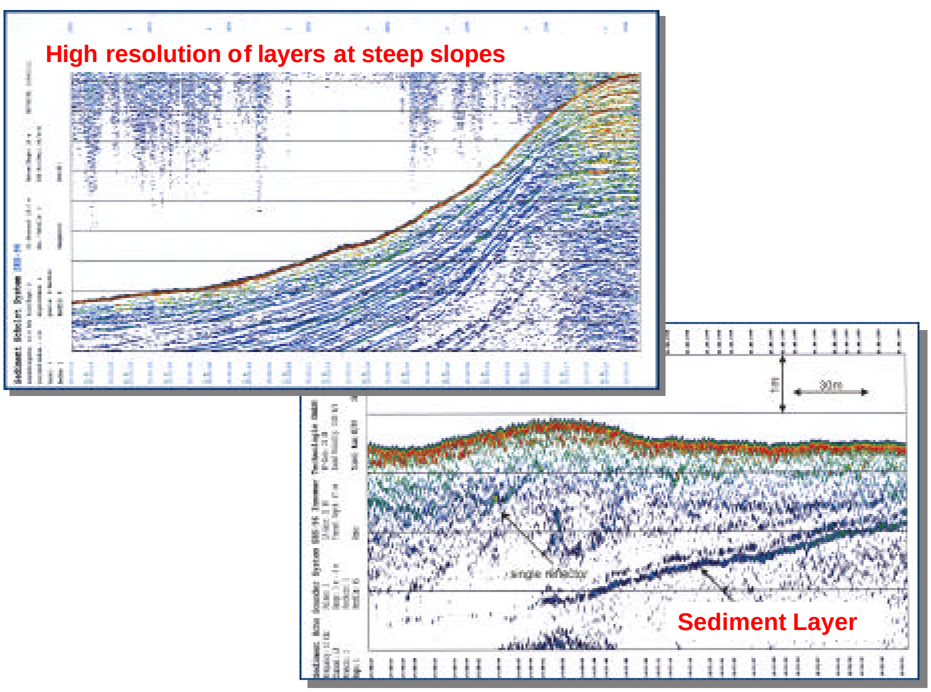

Figure 21-16. SES-96 imagery of subsurface sediment layers in channel (Odom Hydrographic Systems)

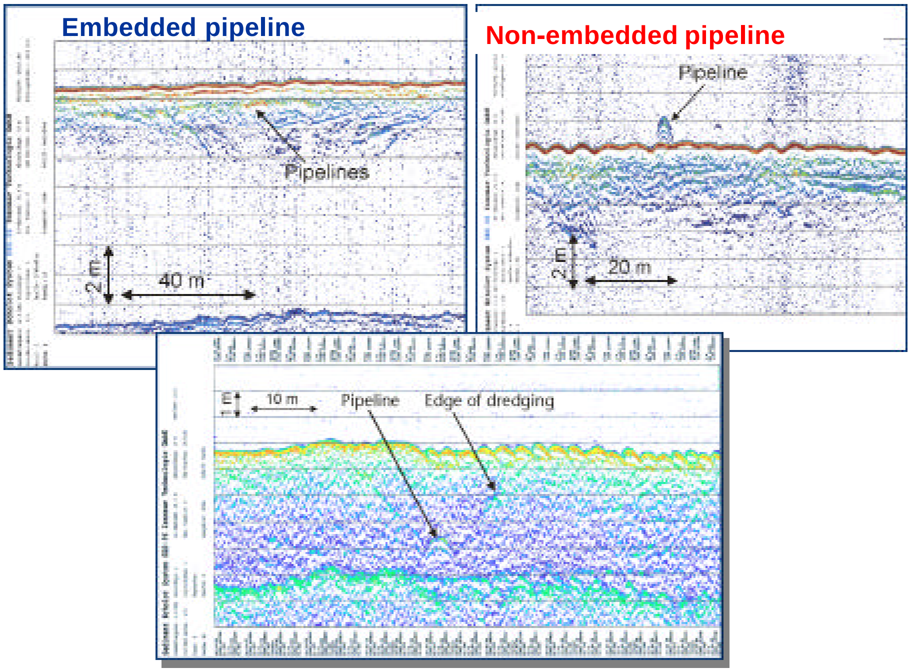

Figure 21-17. Search and monitoring of embedded and non-embedded pipelines and measurement of the pipeline´s depth in the bottom--SES-96 (Odom Hydrographic Systems)

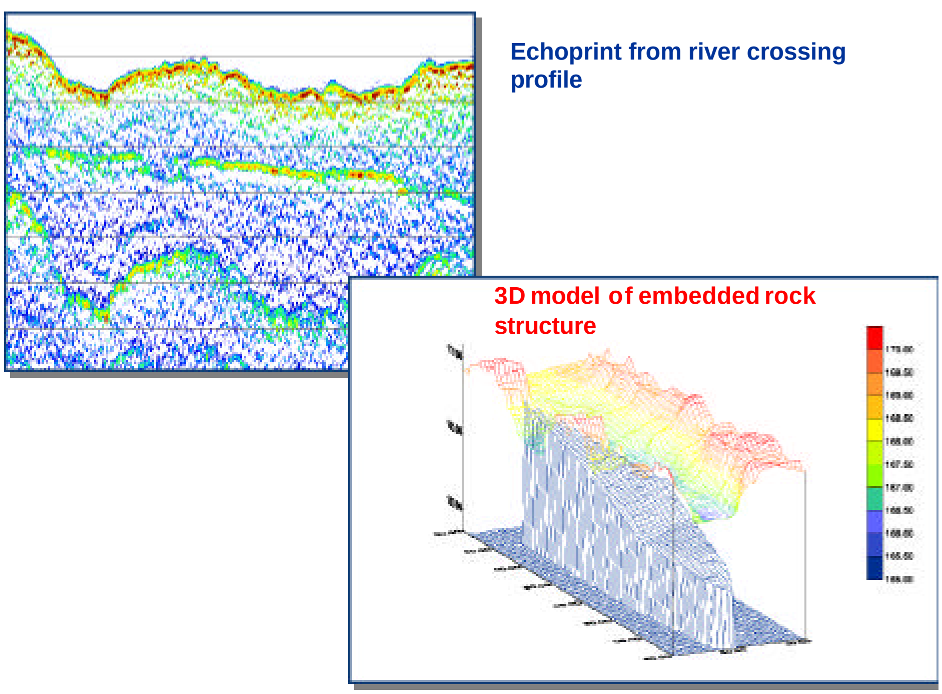

Figure 21-18. Combination of collected echo data allows calculation of 3D models for sediment structures (Odom Hydrographic Systems)

21-11. Standards for Depth Measurement in Irregular or Unconsolidated Bottoms

Table 21-2 below is a general checklist for surveys that will be performed in irregular or unconsolidated materials. It is intended for use in developing measurement and payment provisions in dredging contracts. It is not inclusive of all conditions encountered on Corps navigation projects.

Table 21-2. Checklist for Depth measurement--Dredging Contract Specifications

Identify potential existence of fluid mud or fluff in project--by station if available
    Contract by in-place measurement or rental?

Describe measurement and payment or clearance procedure
- dual frequency
- pre & post dredge frequency used for payment
- lead line or sounding pole, including measurement refusal times
- other methods

Specify high and low frequencies to be used
- specific measurement system (echo sounder)

Describe volume computation procedure (if in-place payment method used)
- data processing method
- data thinning method
- data set binning methods

Specify specific gravity of nautical bottom--e.g. 1.10
- systems for measuring density or identifying materials
- use of density in volume computation

Clearance procedures for rock fragments, underwater hazards, pipelines, etc.:
- acoustic sweep methods (bar, acoustic, side scan, etc)
- specific sweep system employed
- sweep overlap criteria (single or double coverage)
- required number of acoustic hits
- tolerances designed for hazards in required depth and overdepth prisms
- clearance methods

21-12. Mandatory Requirements

There are no mandatory requirements identified in this chapter.