THE EFFECTS ON BATHYMETRY OF SUSPENDED SEDIMENT IN THE WATER COLUMN

Surveying in Fluid Mud

Virtually all ports and channels throughout the world are currently monitored using the now familiar acoustic echo sounder. However, the very parameters upon which these instruments are based are often distorted in suspended sediment, resulting in erroneous seafloor indicators. The author reports on workshop discussions during Hydro 2005.

In many of the worldâ€™s most important ports and harbours the presence of unconsolidated material suspended in the water column requires the hydrographic surveyor to pay particularly close attention to good survey practices and techniques. The high-frequency pulses emitted by most echo sounders reflect off even a very sparse accumulation of material in the water column. Low-frequency transmissions, though able to penetrate this low-density material, are subjected to alterations in the reflected pulse. Hydro 2005, sponsored by The Hydrographic Society of America, included an afternoon workshop chaired by the present author during which a group of surveyors discussed hydrographic surveying in unconsolidated sediment. The problems encountered and techniques employed in resolving them are reported here.

Basic Modus Operandi
All modern echo sounders utilise similar basic modes of operation. The area beneath the transducer is pulsed by a transmit beam. This beam reflects off the bottom and the returned signal is received and processed. The elapsed travel time is converted to a range, and then a depth, by applying the velocity of sound. The point on the bottom represented by the return signal alters the pulse in amplitude and frequency. Transducer characteristics, as well as angle of incidence and reflective properties of the bottom determine the overall quality of the return signal. The accuracy of an echo sounder is based in large part on the speed of propagation of sound. In water containing suspensions three basic properties must be considered: speed of propagation, transmission losses and reflection characteristics. Suspended sediment in the water column has a direct effect on each of these parameters.

Speed of Propagation
Of all the variables affecting bathymetric survey, velocity of sound is pre-eminent. The velocity of the signal in water depends on temperature, pressure and salinity of the water, the density. Suspended materials in the water also have a significant effect on signal speed. Generally speaking, as the density of the suspended materials increases so the speed of sound decreases. This is true to a concentration point of about 0.28%, at which point the speed begins to increase. As a rule no hydrographic surveys are conducted at this level of consolidation, but up to 1.2kg/l density, navigable depth, the speed of the transmitted pulse constantly decreases. Any signal that has passed through this suspended sediment zone has been subjected to these speed variations and effects.

Transmission Losses
Acoustic impedance, the resistance to signal conduction, is equal to the density of the layer times the speed of sound in that layer. As a consequence, as the density of the suspended materials increases toward the seafloor resistance to conductivity also increases, even though the speed of the signal is decreasing. The result is a continuing increase in impedance with increasing loss in signal strength. The increased resistance tends to slow the speed, which in turn alters echo-sounder depiction of the various layers. In multiple sediment layers decreasing signal speed and increasing density of material for each successive layer intensifies this effect. The errors are thus cumulative in nature and provide misleading imagery of the seafloor.

Reflectivity Anomalies
Reflectivity is a function of the texture of material (surface roughness), angle of incidence and the density gradient or change in density between two mediums. This change is often acute in the presence of suspended material referred to as a lutocline. In the presence of fluid mud high frequencies will reflect off the shallow layers and appear to the surveyor to be the seafloor. Only using lower frequencies will the unconsolidated layers be revealed. Compounding the surveyorâ€™s problems is the fact that low frequencies often reveal multiple layers caused by changing densities in the suspended material. Now the surveyor is faced with determining which of these layers does in fact represent the depth of the channel. Particle size of the suspended material also plays a part in reflectivity. Additionally, the extended wavelength of lower frequencies means that the overall resolution of the sounding is reduced.

The Dilemma
The USACE Engineering Manual 1110-2-1003 recognises this difficult choice: "In general, higher frequency transducers (100kHz to 1,000kHz) will provide more precise depth measurement, due to both frequency characteristics and more-concentrated (i.e., narrow) beam widths," (PTC II-30, Approach Channels, A Guide for Design, 1997, Joint Working Group of IAPH and PIANC.). The manual continues, "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. In such areas, frequencies ranging between 20kHz and 50kHz are typically employed for payment." The manual also correctly points out that in unconsolidated bottoms, that is, fluid mud, records cannot be reliably interpreted without some form of correlating or corroborating information.

Correlating Data

With the recognition that acoustic echo-sounder information alone is not sufficient to establish the safe navigation depth of a channel when fluid mud or suspended materials are in the water column, the search begins for a tool that will confirm the depths being recorded by the sounder. Nautical depth has been defined as "the level where physical characteristics of the bottom reach a critical limit beyond which contact with a shipâ€™s keel causes either damage or unacceptable effects on controllability and manoeuvrability". Alternative methods have been devised as a defining factor for safe nautical depth.

Rheology of Fluid Mud

There are negative external forces on control and manoeuvring of a ship when it passes through a mud layer. The rheology of fluid mud, like that of any true liquid, is defined by viscosity, its ability to deform and reshape. The direct influence of this property on the safe navigation of a vessel would seem to make it an excellent means for delineating nautical depth. The difficulty arises, however, when one considers that the viscosity of the material is not readily obtainable in real time. Often samples have to be taken and then sent to a laboratory for analysis. The need for monitoring in real time and on an ongoing basis requires almost immediate results.

Measuring Density

There are several density-measuring devices that have the ability to discern the density levels of fluid mud in real time. Once the rheological properties have been established for materials in a particular location, appropriate density levels can be determined as safe navigation levels: nautical depth. Generally, these density-measuring devices are either directly tied to an existing echo sounder or provide their own particular acoustic signal. In most cases calibration is performed to establish the properties of local materials and then density levels can be determined during hydrographic surveying operations. Once established, the calibration values for a location change slightly or not at all. Only a periodic confirmation of the calibration values is required. The range of acceptable density levels varies widely from port to port. A table taken from a study done by IAPH and
PIANC indicates a cross-section of nautical bottom densities ranging from 1,150kg/m3 at Zeebrugge in Belgium to 1,270kg/m3 at Cayenne in French Guyana. A typical echo-sounder record with imagery based on density shows not only the depth of the channel but also the density level in the fluid-mud layer. This makes the determination of nautical depth a simpler, and certainly a more accurate matter.

Finding Solutions

Fluid mud in a channel or port creates difficulties above and beyond those already levied on a surveyor determining safe navigation depths. In addition to instrument calibration and attention to detail, audit path and daily adherence to good survey practice, there is also the effect of the suspended sediment on results and multiple-layer imagery to contend with. The surveyor has to pay especially close attention to details of the survey, and often to utilise other tools specifically designed to deal with misleading acoustic parameters. A typical example is density-measuring instruments that utilise the acoustic echo-sounder source but look at amplitude and frequency distortion as delineating factors rather than the time-based system used by the echo sounder proper.