CASE STUDY

Acoustic Techniques for Mapping the Distribution of Contaminated Sediments

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I want to begin by stating that the committee did an excellent job on the National Research Council (NRC) report. Earlier, everyone was talking about site-specific issues, which I also will address. I want to emphasize that I started my professional life as an engineer. Fortunately, someone twisted my arm and put me in the U.S. Navy as a civilian for 10 or 15 years, an association that I have continued. The Navy is the key reason why I am here today. I also want to point out that, in discussions and presentations such as those at this symposium, you always hear about the need for action.

I will begin with the technical aspects of the case study. First, a comparison. Say that someone has built a building on a particular site. The building has a sewer plant and bathrooms in it. There is a whole pile of codes and standards that people use when they build buildings. Unfortunately, in our site surveying and in the way we currently handle sediments issues, there are no codes. But there is a very simple solution. There is the American Society for Testing and Materials (ASTM), the association for standards in the United States. There is a guideline for writing codes.

I will talk about one example of the need for site surveying standards. I am sure that similar types of standards could be converted for coring and chemical analysis. This might resolve many of the questions we are talking about today, such as who is to blame, where we should put the material, and so on, because then we would be talking about facts with which everyone agrees.

The history of this case study dates back to the late 1950s, when the Woods Hole Oceanographic Institution staff started doing research for the Navy on building the first subbottom profilers, which were designed for mapping bottom-bound sonar systems. At the Naval Research and Development Center in San Diego, Edwin L. Hamilton—who in 1960 had a budget of $250 million, which makes what we are doing today look quite small—had the task to map the bottom of the oceans for their acoustic response and then relate this to the physical properties of the bottom—namely the grain size, density, and bulk modulus. He found some general engineering trends and devised a way to categorize the oceans. It worked very well—so well that it has been used now for about 30 years.

I was fortunate to be a student working under Dr. Hamilton, and in the early 1980s, when we began working with the U.S. Army Corps of Engineers (USACE), we used his data to establish a library of historical data on acoustics, which includes a summary of the Navy tables and the 44 surveys by the USACE from 1987 to the present. It provides a general characterization of the material type. The bulk density is the specific grain-size density, which usually is adjusted by the local geology. The material also has a wet density. Clays, where all the pollution is, are usually low density. The sands, which are usually clean, are high density. Porosity is the amount of void space. Another characteristic is mean grain size.

We also use the term "bottom loss." If you put in a sound wave that has 1 unit in amplitude, and it reflects back at, say 0.5 units, then the bottom loss is $20 \times \log_{10} 0.5 = -6.02$ decibels (dB). You can characterize the bottom reflection coefficient, normally called bottom loss, although some people still use the older engineering term "water content." The point is that these data are based on probably $300 million to $400 million in acquisition costs and span a time period of 40 years. These data are very repeatable and are for uncontaminated sediments.

Another term used to characterize sediments is acoustic impedance, which is like the resistivity in a resistor. It is basically the density multiplied by the sound velocity. A plot of impedance versus density for the U.S. continental shelf in the Atlantic Ocean turns out to be a rather nice curve, computed by Dr. Hamilton in 1972. All the data we have collected for uncontaminated sediments since then for the USACE have fit on the same curve. The other important measurement in acoustics is absorption, namely, an attenuation that is a function of frequency and material type. This is very important for classification.

You probably all know what a survey boat looks like: pingers in the front; a boomer, which is a low-frequency source towed behind, with a hydrophone array; an acquisition system; and, of course, the global positioning system (GPS). We were successful in the Trenton Channel (near Detroit, Michigan) portion of the Environmental Protection Agency (EPA) work in producing a final map that was accurate to within 1 m in three dimensions. An important, added feature of the quality control work, which relates to developing the standards, is that the coring rig was dropped right in between the two transducers. Hence, we were able to get the acoustic data exactly when we got the core data. Then, when the core data were sent for analysis of the physical properties (e.g., grain size, density), they also were subjected to an exhaustive chemical analysis. We analyzed everything, from the organics to the heavy metals to the polychlorinated biphenyls (PCBs).

Acoustics has been around since the early Navy days. There was a chief who, when I asked why I had to learn about acoustics, took his right fist and described very carefully why I had to learn it. Basically, sounds propagate from a sound source, and every time there is a change in acoustic impedance or material type you get a reflection. The major feature added with the EPA and USACE work, which is not a standard in the industry, is the fact that you add a calibration hydrophone. The work became a success because people have seen the changes. Frank Bohlen described various major spatial changes. How do you know this is true from a legal point of view so that you can defend yourself in court or at a permit hearing? By calibrating your acoustic system, just like you calibrate the cranes that built this building, you can work back to the baseline. The change is no longer a "guesstimate" or, more importantly, an interpretation; it is now a statement of engineering fact.

When you use sound source data, you use something called the sonar equation. If you calibrate with a calibration phone, then you know all the terms in the equation except the bottom loss, which is what you are trying to measure—the bottom reflection coefficient. You do your survey and compute all the numbers. The first step in the EPA work was the development of quality control procedures, which are very important. The overall objective is that you cover the survey distance. The key step is when you give actual measurements, along with the percentage of accuracy in how you measure every one of the acoustic parameters. When you finish the survey, you have it down perfectly, and there is no argument. The customer knows it; the permit people know it; the EPA people know it. Everyone knows exactly what goes into the answers.

A calibration record contains several things. First, there is the transmit signal coming to the calibration; second, there is the signal reflecting off the bottom. This is a simple geometric problem. As you lower the calibration phone, the bottom moves up and the signal to the calibration moves down, and you can identify the signals. Computer software automates the whole process; it is not difficult to operate the system. A ping can be taken right where the core was, and by using cursors, you can select various reflections. The software automatically does all the math and computes the bottom loss. With the bottom loss, there is a standard deviation. If you have high levels of organics or PCBs that have been there a long time, then there is a gas content, and the standard deviation is one of the indications for the gas content.

You also can compute the acoustic impedance as a function of depth and relate that to the material types. As I mentioned, absorption is important. This can be done using a Fourier transform (to convert time amplitude data to the frequency domain), which basically allows you to take a seismic section. The frequencies start at 400 Hz and go up to 5,000 Hz. The dynamic range is very wide, from 6 dB to 80 dB. The important point is that, in normal sediments, there is a fall-off at the high frequencies, depending on the material type (e.g., sands, clays). With contaminated sediments, this fall-off is orders of magnitudes greater, by as much as a factor of 10.

With gaseous sediments, there is a phase reversal when the signal reflects off the layer that contains gas. This is illustrated by using correlation techniques. If it shows a solid line, then there is no phase reversal; if there is a dashed line at the layer, then there is a phase reversal. The software picks out the major layers and plots the bottom loss. Other speakers have talked about spatial variations. For example, within a distance of about 10 m, there may be bottom loss variations on the order of almost 10 dB, which is like going from silty sands all the way to fine mud—a significant variation.

Cores normally are taken after the acoustic survey. For example, using the Hamilton approach to predict density, you may see 95 percent of the points fall within the 95 percent confidence interval. In other words, if the sediment is uncontaminated and you follow procedures correctly, then you can be 95 percent certain about the density.

A new finding of the EPA work at the Trenton Channel over the last three years was that we took the core data when we took the pinger data; based on the core data, the software said the bottom loss should have been X—like -10 dB—but actually it was -5 dB. We plotted the difference between what the bottom loss should have been and what we measured, and at the same time we plotted the core data. There are no measurements yet of the worst core case, so we combined the whole thing and looked at the total chemical, metal, and organic levels. The core that had the most was assigned a grade of 10, and we graded them down to zero for those with no contaminants. It was interesting to find that the deviation in bottom loss was directly proportional to the gross amount of pollution. I caution you that this is a site-specific curve. In other words, this type of curve must be developed for each location, because it depends on the historical contaminant deposition.

When we finished in the Trenton Channel, we were able to map the deposits. All the clays in the area were contaminated, as illustrated by the close agreement between the actual core data and the predictions. Before we arrived on site, they had taken 8 or 9 cores. We then took another 10 or 15 cores. The polluted stuff included polyvinyl chloride, and white suits had to be worn when handling it. The assumption was that a very large amount of polluted material would have to be removed. When we did the entire survey in detail, one area turned out to be rock, or hard sand. Thus, instead of dredging the entire area, we could make a risk assessment at some points. There were very polluted areas and spots with hardly any pollution at all. Only 25 percent of what they expected to remove actually had to be removed.

The thickness of each layer also can be mapped. Some layers are 2.5 m, whereas others are only around 0.5 m thick. It is obvious, as you heard this morning about the transport of materials, that some areas probably do not have to be dredged. Using either a sealed bucket dredge or one of the new bottom-trawling dredges, they may have to dredge only a small area. The state of Michigan is going in this summer to complete the job.

That was a quick summary of the technology available today to set up standards for surveying. Now I would like to recommend several things. If you know anyone who controls the funding, the USACE program that led to this success has been canceled. There are no funds for the staff in Vicksburg, Mississippi, to continue to make databases of all the surveys. Furthermore, the USACE's direct involvement in local surveying has stopped. That sets us back to where we were in 1985, when people were taking survey data that were good but were without any standard and were not calibrated. That is like having an independent contractor make different software for each of our nuclear submarines and destroyers and then trying to fight a war—you could not do it. The contractors may be good, but standards are needed. With the work being done at the EPA, we are just months away from being able to write a standard. If someone says to go ahead, then we can write a standard. That way, when we talk about the risks and measurements, we will have data on which everyone has agreed.