REMR Technical Note CO-SE-1.4

SIDE SCAN SONAR FOR INSPECTION OF COASTAL STRUCTURES

PURPOSE: To provide information on operating rules-of-thumb, and suggestions on Side Scan Sonar (SSS) uses in coastal engineering.

APPLICATION: Historically, SSS has been used primarily in reconnaissance and search applications such as pipeline and cable tracking, exploration, wreckage/debris location, navigational hazard mapping, and identification of bottom material (sand, rock, mud, etc.). Importantly, SSS use allows early detection of damage and deterioration of underwater portions of coastal structures; action to minimize further degradation and planning for repairs or rehabilitation with greater lead time is then possible. Sonar's unique ability to penetrate water too turbid or too dangerous for visual or optical inspection makes it the only effective means of inspection in many environments. Also, SSS is relatively fast and cost-effective for large-scale surveys. Real-time display capability permits onsite decisions and modifications to data collection strategy. SSS has been used to inspect breakwaters, jetties, groins, and port structures. It has proved especially effective in examining the toe of rubble structures for scour and displacement of armor units. Other current coastal applications are found in dredging (identification of borrow and placement areas, determination of optimum orientation and spacing for bathymetric sounding lines), lost instrument search, and bottom evolution monitoring.

EQUIPMENT AND PERSONNEL REQUIRED: Components of an SSS system include: a "tow fish" and cable, a control/processing/display/recording/power unit, and a speed log. The tow fish is a torpedo-shaped housing for the two transducers mounted on each side. Signals between the fish and the control unit are transferred through an electrical cable which may double as the towing cable. Forward speed of the transducer is measured by a separately-towed speed log, by a speed log built into the tow fish, or by direct input of the towing vessel's speed. Vertical elevation of the fish above the bottom is determined by a separate downward-pointing acoustic transducer or from a downward-directed portion of the side-looking transducer's "beam." Optional and auxiliary equipment include: data processing software/hardware modules for automatic distortion corrections, image enhancement, digital recording, etc.; alternative displays (e.g. dry paper plotter, color CRT); separate DC power supply; annotation keyboard for placing marks and messages on the image; and positioning equipment.

The type of problem to be studied, the site conditions, and the resources available dictate the choice of platform. An advantage of the modern SSS systems is that they are small enough to be deployed in a variety of ways. Most commonly the SSS system is deployed from a boat (Figure 1). In shallow water under calm conditions, a boat as small as an outboard-powered inflatable can

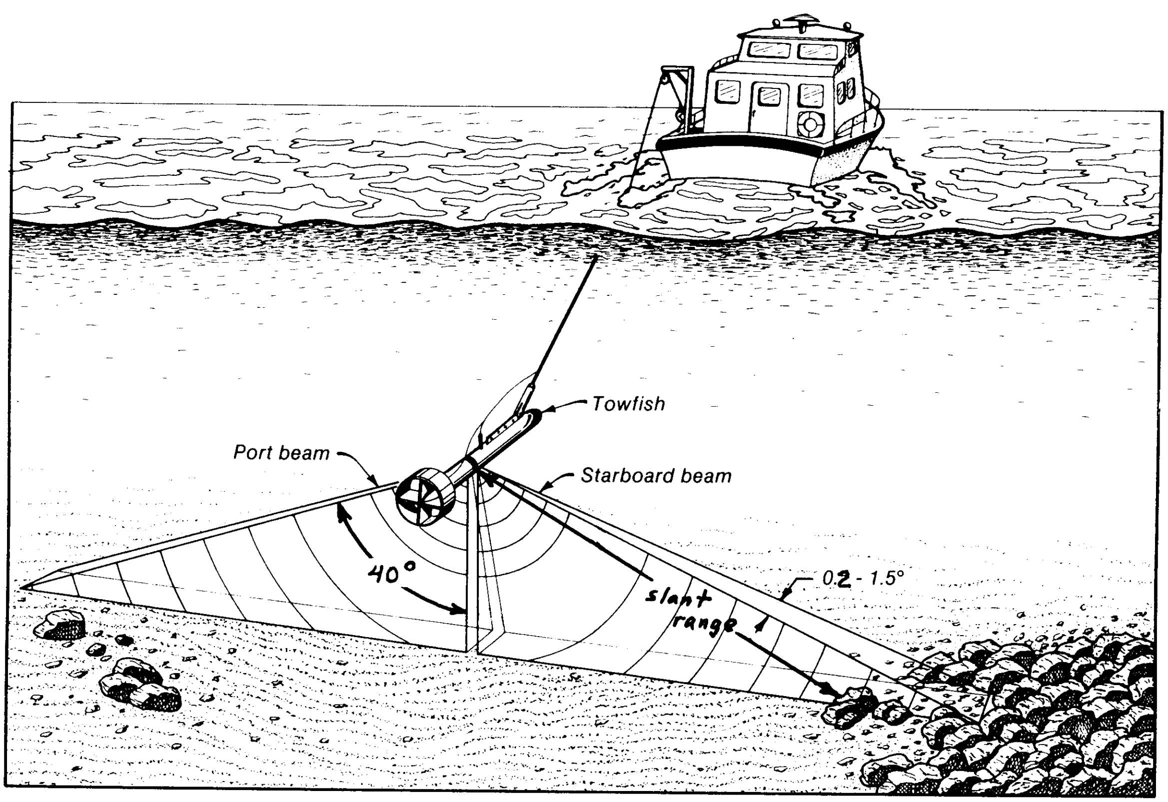

Figure 1. Side scan sonar in operation.

be used (a further discussion of vessel requirements is found in the section on operations). In addition to the deep water deployment method that has the fish towed from the stern, deployment from the bow or the side of the boat is preferable in shallow/rough waters. A boom can be used to extend the cable away from the hull. The tow fish must be kept away from the props and wake for reasons of both safety and desirable transducer performance. Bow deployment is advantageous for vessel maneuvering and precise positioning of the fish. Midship deployment minimizes undesirable vertical heaving of the tow fish in seas which cause the boat to pitch; a boom extension may aid in getting the fish closer to the structure while maintaining a safe clearance for the hull. Midship deployment, however, may make it difficult to avoid propeller noise "blanking out" the record from the near-side transducer which faces the hull. Another option, which may be particularly well-suited to surveys of coastal structures, is to deploy the tow fish from a truck-mounted crane; the boom of the crane extends over the water, and the truck is driven onto the structure itself. Other, less-likely, platform possibilities include helicopters and submersibles.

Generally it would be preferable to have one person working full-time at the control unit, observing the display and making adjustments as needed (note that with the modern digital image-correcting systems there is little need to regulate settings once a survey is underway), and a second person responsible for launching and positioning the tow fish. With the lightweight, flexible tow cable designed for shallow tow depths, the control unit operator probably can also handle fish positioning. However, a minimum boat crew of two is recommended.

OPERATIONS: An important part of planning for SSS inspection is selection of a time window likely to have favorable environmental conditions, that is, minimum currents and waves, and maximum water depth. Also, the possible presence of other vessels, such as fishing boats, must be considered. It is a good idea to allow for a practice run and several passes at different tow fish altitudes to get different "viewing" angles. Follow-up diver inspection of problem spots identified in the SSS survey may be necessary, especially when it is not clear what the displayed record (sonograph) is showing. The advantages of state-of-the-art digital auto-correcting SSS systems over older systems for coastal engineering applications are the following:

- The need for operator experience is greatly reduced.
- There is greater consistency in the quality of the imagery generated from one survey to the next due to removal of speed variation- and slant range-induced distortion.

a. Speed variation correction consists of matching the speed at which the chart paper passes under the printing mechanism to the actual over-the-bottom speed of the tow fish. The use of positioning equipment is recommended; with currently available equipment and careful attention to the tow fish position relative to the onboard antenna, pinpointing of features' positions can be done with relative accuracy, and over-the-bottom speed of the tow fish can be supplied to the speed-correcting unit as an alternative to the towed speed log data.

b. Slant-range correction consists of using the tow fish altitude to convert the actual straight-line distance between the tow fish and the target to the corresponding horizontal distance between a point on the seabed directly below the tow fish and the target. These corrections help make the sonograph more like a "map" presentation; however, there are several distortions which are either not compensated for by the currently available systems, or are introduced by the correction process. Therefore, even image-corrected sonographs should be considered only "semi-quantitative".

The key aspects of a desirable survey boat relate to providing a protected, convenient, and electro-mechanical noise-free environment for the control unit, and positioning the transducers so that image quality and usefulness are maximized. The vessel needs to have the power and stability to follow a prescribed course at relatively low speed while transmitting a minimum of non-forward motion to the tow fish. Erratic tow fish motion will decrease image resolution as well as accuracy of automatic corrections. Also, the captain should keep in mind that the tow fish will tend to fly deeper for a given cable length at low speeds--care must be taken in turning not to let the fish hit bottom or let the cable become fouled in the propellers. A winch is required if the longer and heavier deep water tow cable is used. Although slower tow speeds are desirable since they allow more "looks" at a point target, in choppy conditions the boat motions at low speed may be excessive; also, time required to complete the survey must be considered, since periods of low currents are generally short in the vicinity of coastal structures.

Currents are undesirable as the tow fish will tend to orient itself in line with the current; also, if a speed log is being used, there will be an error in the auto-correction which is based on over-the-bottom speed. However, it should be pointed out that in zones where currents are unavoidable, at least some qualitatively useful data can be obtained. In calm conditions, it may be possible to get close and use 500 kHz frequency for sharp, detailed images of features selected from a screening run at the less motion-sensitive 100 kHz frequency (in general, as frequency increases, usable range decreases, and as range increases, resolution decreases). The transmission of acoustic energy in water is also affected by turbidity, salinity, velocity, and thermal non-uniformities; speed of acoustic energy travel can differ from that assumed by the manufacturer in calibrating the unit, and discontinuities caused by the above factors can cause refraction and/or reflection of pulses. None of the errors introduced by non-uniformities can be removed from the data with current equipment; therefore, it is best to try to schedule around conditions in which there is strong stratification. Keeping the tow fish out of the wake is important for an additional reason: air entrained in the water column will interfere with the transmission of the acoustic pulses; the same applies to wave-breaking zones on the structure--another reason why surveying at high tide on calm days is recommended.

Rules of Thumb

- Environmental limitations:

  - avoid wave heights over 2 ft at shallow water (under 100 ft depth sites); in depths less than 20 ft, near calm required.
  - survey during high-water slack for max depth, min currents.

- Deployment method:

  - tow point on centerline at bow, with 10- to 20-ft boom extension.
  - midship tow point preferable in special circumstances.

- Tow speed:

  - min 1 knot, typically 2- to 4 knots.

- Tow fish depth:

  - 1/2 to 2/3 of average depth at shallow water sites (single pass).
  - 10% of range setting in deep water, noncorrecting SSS system.
  - 15 to 20% of range in deep water, autocorrecting SSS system.

- Frequency:

  - 100 kHz for reconnaissance, screening, or rough water survey.

  - 500 kHz for close range, detail inspection.

- Range:

  - 75 m or greater, depending on safe operating distance.

DATA INTERPRETATION: It is beyond the scope of this note to give a detailed guide to sonograph interpretation; however, it is useful to have some introduction to the subject when one is considering investing in SSS equipment. Experience plays a primary role in interpretation, which remains more art than science at present. An important aid is familiarity with the area or structure to be surveyed. Also, an understanding of underlying principles of operation is crucial.

High-frequency (ultrasonic) acoustic pulses are emitted in two fan-shaped "beams" (Figure 1) which travel perpendicularly outward and encounter the bottom and its features. The instantaneous area being "illuminated" is long in the across-track direction and narrow in the along-track direction. "Side scan" refers to the fact that the pulses are emitted laterally to the forward motion direction of the tow fish; as such, the area of seabed scanned has a limited width and a length corresponding to the path length traveled by the transducer. Using the strength of the reflected energy and the time required for the return trip to the transducer, the processor produces an image, typically a plan view of the bottom and objects resting on the bottom. If automatic correction for transducer position and forward speed is included in the processing software, and if input from positioning equipment is fed to the unit, the resulting overlapping "strip" records can be pieced together to form a mosaic image which is an approximately accurate (scale) map of the bottom and its features. Additionally, the vertical dimensions of some features can be estimated from the length of "shadows" they cast, and other qualitative information can be inferred from the image, such as shape and relative position of large, isolated objects. The image resembles a black and white photographic negative of a scene lit by a pair of spotlights moving forward along the track.

Good acoustic reflectors are smooth steel and concrete; whereas soft, textured objects, such as seaweed beds, generally tend to absorb rather than reflect. For bottom materials, gravel has highest, sand has intermediate, and mud has lowest reflectivity. Target shapes or orientations which tend to reflect toward the transducer result in strong traces; thus surfaces which slope towards the transducer (such as breakwater faces) can be expected to reflect well, relative to surrounding horizontal surfaces. Features are only identifiable on sonographs when they present a contrasting reflectivity to their surroundings. The resulting amount of detail is primarily controlled by frequency, range, and degree of nonforward tow fish motion. Discrimination of isolated features is aided by acoustic shadows; however, shadowing presents problems in distinguishing nonisolated, irregularly-shaped targets; for example, individual armor units cannot usually be distinguished from their neighbors because of shadowing and lack of contrast. The following noncomprehensive list gives an idea of what kinds of things can (sometimes) be "seen" with SSS:

- outline of structure toe (jetties, breakwaters)
- isolated displaced armor units
- depressions and mounds (scour holes, spoil piles)
- abrupt changes in slope
- sunken boats, vehicles, debris
- bottom material boundaries (e.g. sand patches on clay bottom)

- bottom relief such as sand ripples (useful in determining current and transport direction), dredge/anchor/ice marks
- cables, chains, piles

Vertical structures can be imaged with the tow fish in the conventional horizontal deployment position, or it may be beneficial to rotate the fish on one of its axes to view the structure from a different angle. Since vertical walls are ordinarily used only in coastal environments with very low wave energy, it may also be possible to fix the tow fish in a frame or other more stable, controllable configuration (such as the truck-mounted crane deployment mentioned earlier). However, because of the very low angle of incidence for vertical walls and their other reflectivity characteristics, returns can be so intense as to make discrimination of features difficult. When returns are present in a site being surveyed, if contrast is adjusted to permit discrimination of less reflective features, there can be a "ghost image" produced on the trace from the transducer on the opposite side of the fish from the wall (this phenomenon is also referred to as "cross talk"). Circular-shaped vertical features such as steel sheet pile cells can result in image artifacts called diffraction hyperbolae. Often, cavities and cracks can be recognized as dark traces perpendicular to the otherwise unbroken dark/light linear boundary resulting from the wall face. Rectangular-shaped cavities may result in points of high reflectance caused by the "corner reflector" phenomenon, a situation in which returns are reflected directly back toward the transducer over a range of incident angles.

An example sonograph from an inspection of the rubble mound breakwater at Crescent City, California is provided as Figure 2.

POTENTIAL COASTAL ENGINEERING APPLICATIONS: With current systems, the further expansion of qualitative coastal structure inspection uses can be expected, particularly in high-turbidity environments with large and irregularly-shaped structures. Port and harbor structure inspection using unconventional mountings and platforms for the transducer is an application likely to expand. As techniques and technology continue to improve, especially those which permit a more quantitatively accurate image to be obtained, the uses of SSS and related acoustic tools (such as scanning sonars) will increase in quantitative applications, for example, bottom evolution monitoring for modeling efforts, and construction-related surveying.

EVALUATION OF AVAILABLE EQUIPMENT: Two side-scan systems and two scanning-sonar systems were examined. A more complete discussion of the results is given in the Ref d. Of the SSS systems, the EG&G system (Model 260 Image Correcting Digital SSS) was found to be preferable for coastal engineering purposes, although given the rapidly changing nature of the technology and the market, one should check out the current situation before purchasing equipment. Cost for a basic system is roughly on the order of $100,000.

SUMMARY: In spite of computerized digital image processing available in off-the-shelf SSS systems, even under the best of environmental and site conditions, SSS has limited quantitative application in coastal engineering. Information on structure slopes, condition of individual armor units, and percent of units displaced (to name a few examples) is not currently measurable in a repeatable, quantitative way. However, the semi-quantitative sonograph

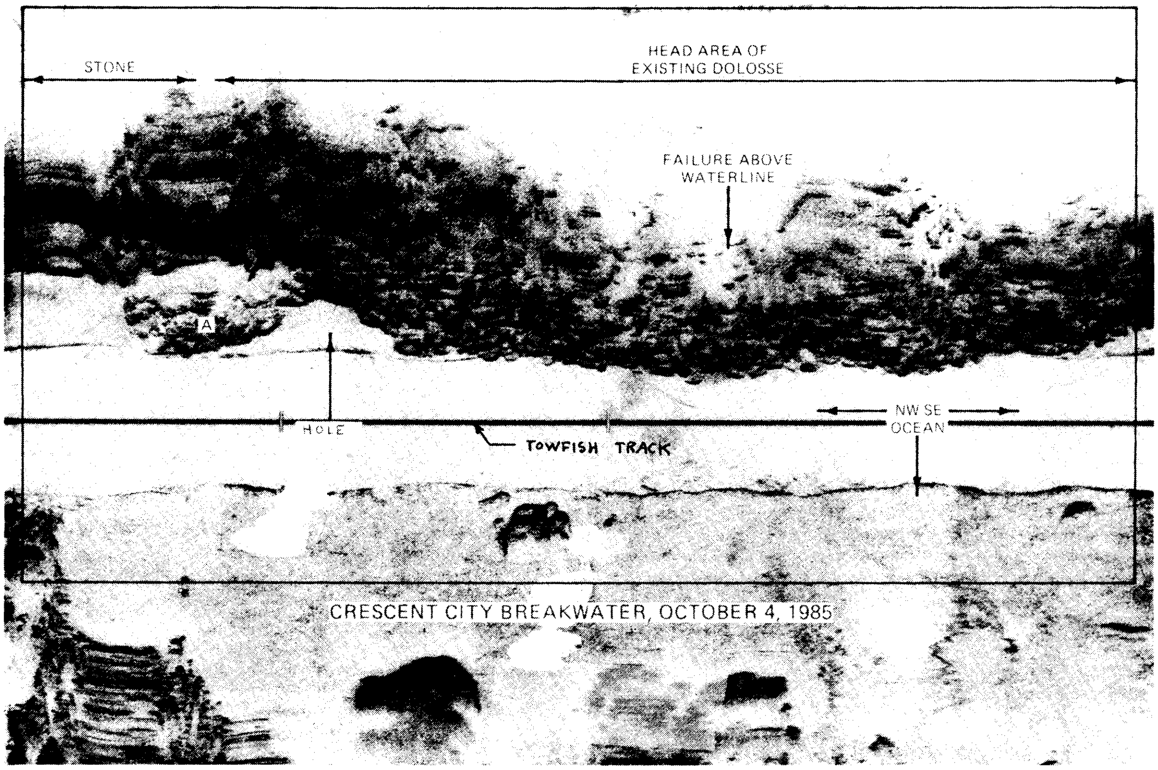

Figure 2. Portion of sonograph from image-correcting digital SSS (EG&G Model 260).

record can be very informative, particularly to someone who has developed a familiarity with the structure or feature being viewed from repeated SSS surveys. Also, strong points for the SSS are its ability to collect rapidly information in murky water while being deployed at a safe distance from the structure; thus it is a safer, and in most cases, superior alternative to visual inspection by divers.

REFERENCES:

a. Clausner, J. E., and Pope, J. In Press. "Side-Scan Sonar Applications for Evaluating Coastal Structures," CERC Technical Report, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

b. EG&G Environmental Equipment; 1986. "Model 260 Image Correcting Side Scan Sonar Instruction Manual," Waltham, MA.

c. Flemming, B. W. 1976. "Side Scan Sonar: A Practical Guide," International Hydrographic Review, Vol 53, No. 1, pp 65-92.

d. Kucharski, W. M., and Clausner, J. E. In Press. "Side Scan Sonar Uses in Coastal Engineering: Maintenance Inspection of Coastal Structures," REMR Technical Report, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

e. Mazel, C. H. 1983. "Considerations in the Display of Scale-Corrected Side Scan Sonar Data," in Methods of Display of Ocean Survey Data, Linton, ed., Natural Environment Research Council and the International Cartographic Association.