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Dredging Research Technical Notes

Evaluation of New Fluid Mud Survey System at Field Sites

Purpose

This technical note presents an intermediate evaluation of a fluid mud survey system with respect to operability, practicability, and repeatability based on field tests conducted at Calcasieu River, Louisiana; Sabine River, Texas; and Gulfport Harbor, Mississippi, entrance channels from 1989 to 1991. Also included are the conceptual and mechanical design of the towed sled and a description of the fluid mud survey system components.

Background

A major objective of work unit Measurement and Definition of Navigable Depth in Fluff and Fluid Mud in the Dredging Research Program's (DRP) Technical Area 2 is developing a survey tool to determine navigable depth in areas where fluid mud obscures the bottom to conventional acoustic methods such as the Fathometer. The potential benefits of a more precise determination of mud bottom depth include improved efficiency in maintenance operations through better definition of what areas actually require or have been dredged, dredging priorities, and scheduling.

A towed sled device has been designed, constructed, and tested to conduct navigable depth surveying. The towed sled exploits the shear resistance of the in situ material to determine navigable depth, a new approach for a towed device. Devices that measure density have been used in European harbors to reduce maintenance costs where fluid mud causes sporadic heavy shoaling. The design objective for the DRP fluid mud survey system that includes a towed sled is a simple, rapid, and practical survey tool that will likewise reduce maintenance costs in Corps-maintained navigation channels.

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Principles of Operation

Fluid mud forms gradients at the bottom of navigation channels with gradual or stepwise changes in density occurring vertically over many feet. Fluid mud is a viscoelastic material having a density transition point at which low-shear viscosity, shear modulus, and apparent yield stress increase sharply. The density at this transition point and the rate of increase in viscosity with density depend on the composition of the fluid mud and other conditions, and must be evaluated for specific locations as discussed later. Transition densities establish reference points for comparing sediments and developing appropriate density criteria.

Definitions of navigable depth will be based on density (a readily field-measurable physical property) corresponding to a viscosity and shear modulus (not field measurable) near the transition point for a local site. This is a conservative starting point for the development of a navigability criterion, subject to local adjustment. The navigable depth concept and implementation were described in *Dredging Research*, Volume DRP-91-4 ("Navigable Depth Concepts for Channels with Fine-Grained Sediment").

The approach taken for the rapid determination of navigable depth was to design a towed device to ride automatically at the level appropriate to a moving leadline. The concept was to furrow into fluid mud to the depth being defined as navigable. The towed sled would make physical contact with the fluid mud and serve as prima facie evidence to the navigability of the material. This concept assumes the existence of a physical horizon or level where resistance to motion (and navigation) increases sharply, and thus where the combination of viscous and normal stresses in the mud "support" the towed device. The assumption has since been confirmed by laboratory tests and relationships developed between rheologic properties and density for several sites, as will be described later.

The behavior of an object towed in fluid mud depends on the characteristics of the object and cable, the manner in which it is towed, and the fluid mud characteristics. The mechanical system (towed object and cable) has horizontal and vertical forces distributed along its length that are dependent upon the component submerged weight and drag. The catenary formed by the cable between the survey boat and towed object can be calculated for known forces since cable drag forces can be estimated with confidence. However, precise calculation of the drag force on a towed object in fluid mud is not possible by the present state-of-the-art. The survey sled was designed with body characteristics such that it exerts a moderate vertical force at normal tow angles and is supported by the fluid mud at a level tow attitude. As the sled is towed in fluid mud, the sled tow (bridle) angle is an indicator of relative drag.

Design Summary

Figure 1 is a schematic of the sled. The static weight of the sled is about 260 lb in air and 60 lb in water. The frontal (or bow) area of the sled is about 1 sq ft, and the top-view projected area is about 12 sq ft. The volume of the sled is about 3 cu ft.

The steel-armored tow cable has a diameter of 0.9 in. with a submerged weight of 0.7 lb per ft. The cable termination is 4 in. outside diameter (OD) by 2 ft long and has a submerged weight of about 40 lb. The tension link and tow angle indicator are located on the termination. The distance between the cable termination and sled bridle is 1.3 ft. The bridle

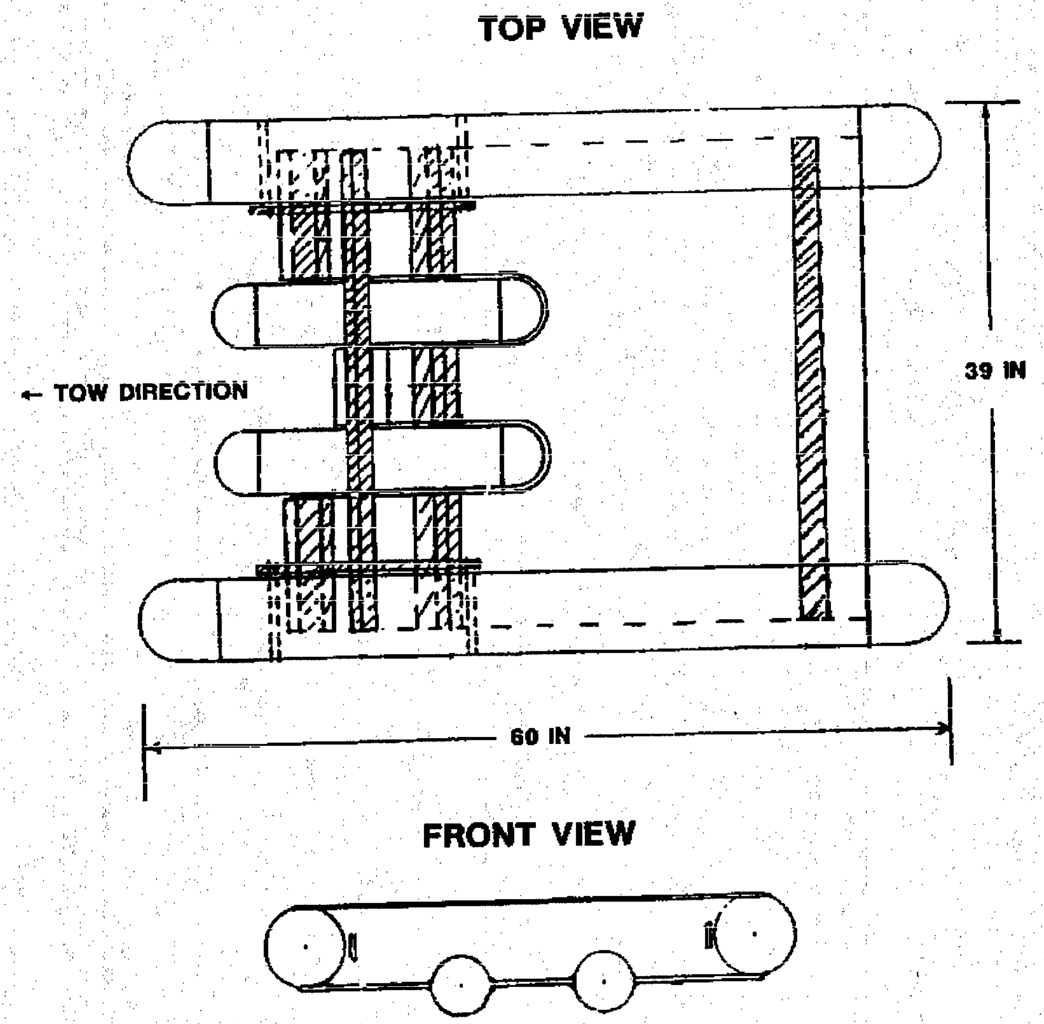

Figure 1. Schematic of the towed sled

cross piece is 1.5-in. OD stainless steel, and the cable conductor splice is 4 in. OD.

The tow cable is led over a 36-in.-diam block to an electro-hydraulic winch. The 5-hp winch is equipped with a slip ring cable conductor connection and has the capability for computer control. A safety feature on the winch allows the cable to pay out after a 2,500-lb cable load is exceeded.

Transducers are mounted in or on the sled. A nuclear transmission density gage uses a 3-millicurie, cesium-137 gamma source. A hydrostatic pressure gage measures depth. An acoustic doppler unit is used to indicate sled speed. One tilt sensor is mounted to measure sled attitude (angle of attack), and another tilt sensor is mounted on the bridle to measure tow angle (or cable tow angle). A strain gage between the cable termination and tow bridle monitors cable tension. As a precaution, an acoustic transponder beacon is mounted in case of accidental sled separation from the cable.

Onboard the survey boat, fluid mud survey system components include analog-to-digital converters, power supply, density gage ratemeter, data logger, and real-time data display for monitoring sled conditions during surveying. Time plots of all the data from the sled sensors (in engineering units), together with the acoustic depths, are available for evaluation within minutes. A small boat survey system developed at the Waterways Experiment Station was implemented for survey control and postprocessing. The survey system software runs in parallel with the sled data logger on a personal computer (IBM-PC compatible), and controls the survey process on a predefined grid. Positioning data are supplied to the system by a Motorola Mini-Ranger Falcon IV. Data for the sled depth, fluid mud density, and depths measured with high- and low-frequency acoustics are exported from the sled data logger to the survey system data logger after the survey. During postprocessing, corrections are made for the tide and for trailback of the sled from the survey boat position. Cross and longitudinal section and plan-view plots can be generated, and dredging or fill volume computations can be made based on survey depths and channel grade.

General Field Test Results

Before field testing, the sled was ballasted in a large high-velocity flume at Iowa Institute of Hydraulic Research. No further ballast adjustments have been necessary. The first field trials were at the Calcasieu River, Louisiana, entrance channel in 1989. The channel center line was surveyed from channel markers 37 to 41 in a thick layer of fluid mud (8- to 13-ft difference between 200 and 24-kHz depth traces). The same line was repeated with variations in survey boat speed and length of cable payed out. Although the recorded depth along this line varied somewhat from one run to another, the recorded density and the overall mean depth along the line repeated well. Thus, the sled (without adjustment) was found to track in a narrow range of mud density along a channel while the sled depth varied. Information from the survey and from analysis of samples indicated that the sled followed a physical horizon related to quasi-constant sediment density and viscous characteristics and that the fluid mud horizon tracked by the sled was not greatly affected by moderate changes in boat speed or cable length.

The initial results supported the design concept. Because the drag of a towed object depends upon the square of the tow speed (roughly), it might be anticipated that boat speed may greatly influence the level of the sled. The sled depth is relatively insensitive to boat speed because the sled is constrained at the level where stresses in the mud support the sled. Limited variations in cable length are taken up by changes in tow bridle angle, which allows for about 2 ft of vertical change in depth between the sled and the end of the tow cable.

Channel debris did not impede towing. During surveys, the sled was lifted to the water surface for inspection after each 2,000- to 6,000-ft longitudinal line. Frequently snagged pieces of seaweed, fishing line, and other debris were found, but nothing to change the towing characteristics of the sled appreciably. Heavy sediment material that might have affected towing behavior only attached when the sled encountered dense cohesive material. This only occurred outside the navigation channel during cross-section surveying of the channel.

The sled has been used to survey channel cross sections at Gulfport, Mississippi, and Calcasieu, Louisiana, entrance channels. Problems were experienced on the upslope side of the channel cross section when the sled (probably led by the cable) encountered dense, stiff material. During one cross-section run, the cable tension safety load limit was exceeded and cable was automatically payed out. Upon retrieval, the sled was found to have encountered consolidated sediments with densities of perhaps 1.7 g per cu cm. The side slopes of these channels were quite steep, especially in localized areas at Gulfport where the cross section was markedly asymmetric.

Some portions of the sled cross sections varied from the high-frequency trace near the toe of the channel side slopes. In those cases the sled appeared to initially ride too high in the mud at the toe of the downslope. Conversely, at the toe of the upslope, the sled tended to ride too low. These effects can be minimized with careful coordination between and handling by the boat and winch operators. Some sled cross sections produced excellent data. However, results discussed in the following paragraphs are based on longitudinal survey lines.

Evaluations of Repeatability

A good measurement technique should be both accurate and repeatable. Fluid mud survey system repeatability was gauged during surveys of Calcasieu, Sabine, and Gulfport channels by surveying sites multiple times over several days. Towed sled depth repeatability can be gauged in several ways using these data.

One way to assess depth repeatability of the fluid mud survey system is to compare multiple computed channel fill volumes obtained for a survey site. For example, the Gulfport channel site was surveyed three times from April to May 1991. Mean and standard deviations were calculated using the three sets of tide-corrected fill volumes. A coefficient of variation was calculated as the standard deviation divided by the mean. Table 1 summarizes these results.

Table 1. Volume Comparison of Three Gulfport Surveys

	Sled	High-Frequency (200 kHz)	Low-Frequency (24 kHz)
Standard deviation, cu yd	6,000	1,500	6,700
Coefficient of variation	0.093	0.016	0.300
Range of results, cu yd	13,000	2,700	13,300

The sled results were more repeatable (smaller standard deviation) than the low-frequency acoustic results, but less repeatable (larger standard deviation) than the high-frequency results. A problem with survey site comparisons was caused by the relatively steep slopes close to the toe in this channel. Variation in boat position along the toe survey lines created large sled depth differences between surveys that translated into volume differences. Variations were smaller for the high-frequency acoustic method because depths so measured were more uniform across the channel than those measured by the other methods. The 200-kHz acoustic reflections came from suspension layers with densities on the order of 1.05 g per cu cm, and these layers apparently have level upper surfaces.

Another way to assess sled depth repeatability is to examine how well channel depth features were repeated between surveys. This is most easily done using individual survey lines. Figures 2 and 3 show survey line comparisons for Gulfport and Sabine surveys. These figures show that the sled was able to reproduce distinct depth features, especially at Gulfport where cutterhead dredging left the channel more sculptured. Features with characteristic dimensions of from 50 ft to several hundred feet can be distinguished in Figure 2. Figure 3 shows very little sculpturing in the case of hopper-dredged Sabine Channel, and good depth repeatability was obtained under these conditions also.

Still another way to assess repeatability of the towed sled method is to compare depths obtained by two different towed devices. This comparison actually tests whether the measurements are instrument dependent, a more strict measure of repeatability. Figure 4 shows a comparison of a survey section line taken with the towed sled and with a simplified towed body. The simplified towed body is a device that was developed to test certain design characteristics. The simplified towed body is much smaller than the sled and is towed with a lightweight cable fitted with a hydrodynamic depressor about midway along its length. Figure 4 shows a comparison of time plots covering the same channel survey line. The depths

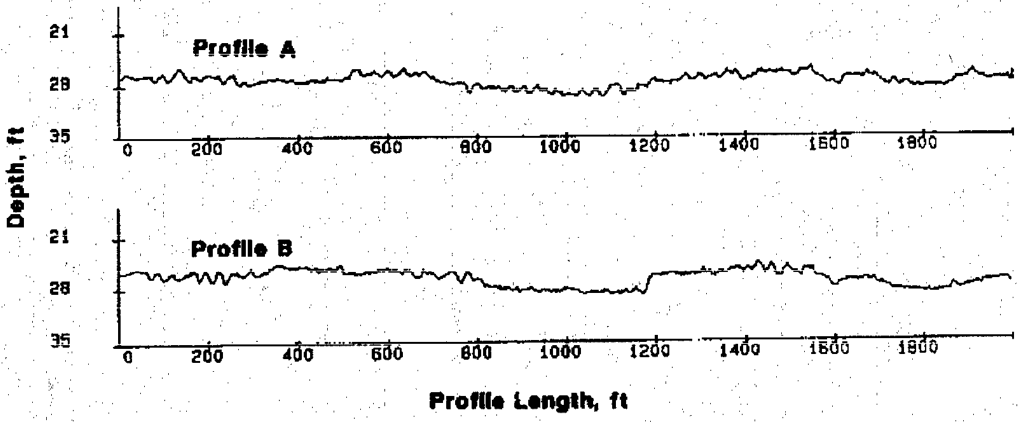

Figure 2. Gulfport Channel center line for April 1991 (Profile A) and May 1991

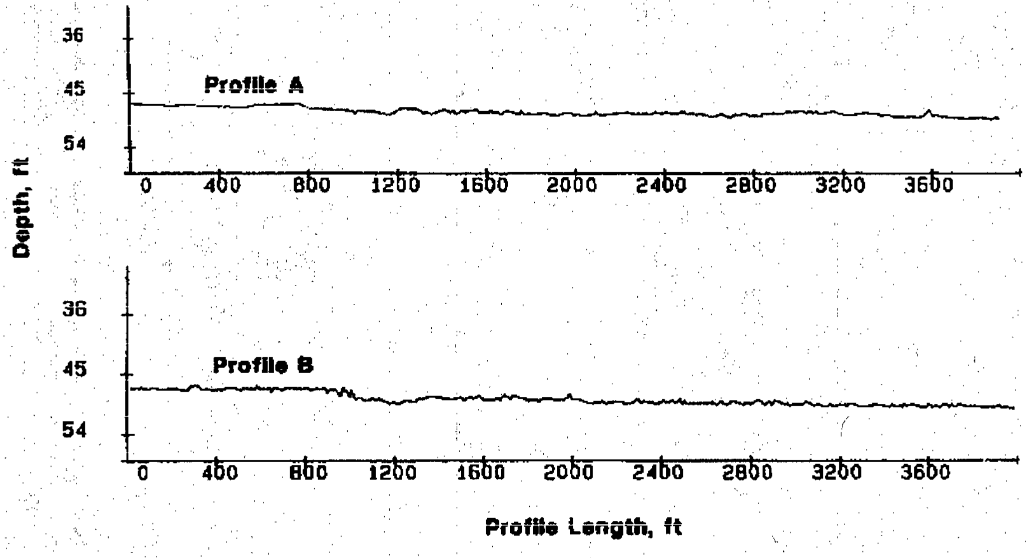

Figure 3. Sabine Channel center line for November 1991 (Profile A) and November 1991 (Profile B)

obtained by low- and high-frequency acoustics did not repeat very well during portions of the first one-third of the data. The repeatability of the sled and the simplified towed body were very good over the remainder of the survey line. Although the two devices are physically not that similar, the consistency of the two very different devices lends strong support for the conceptual approach. The measurements were not strongly

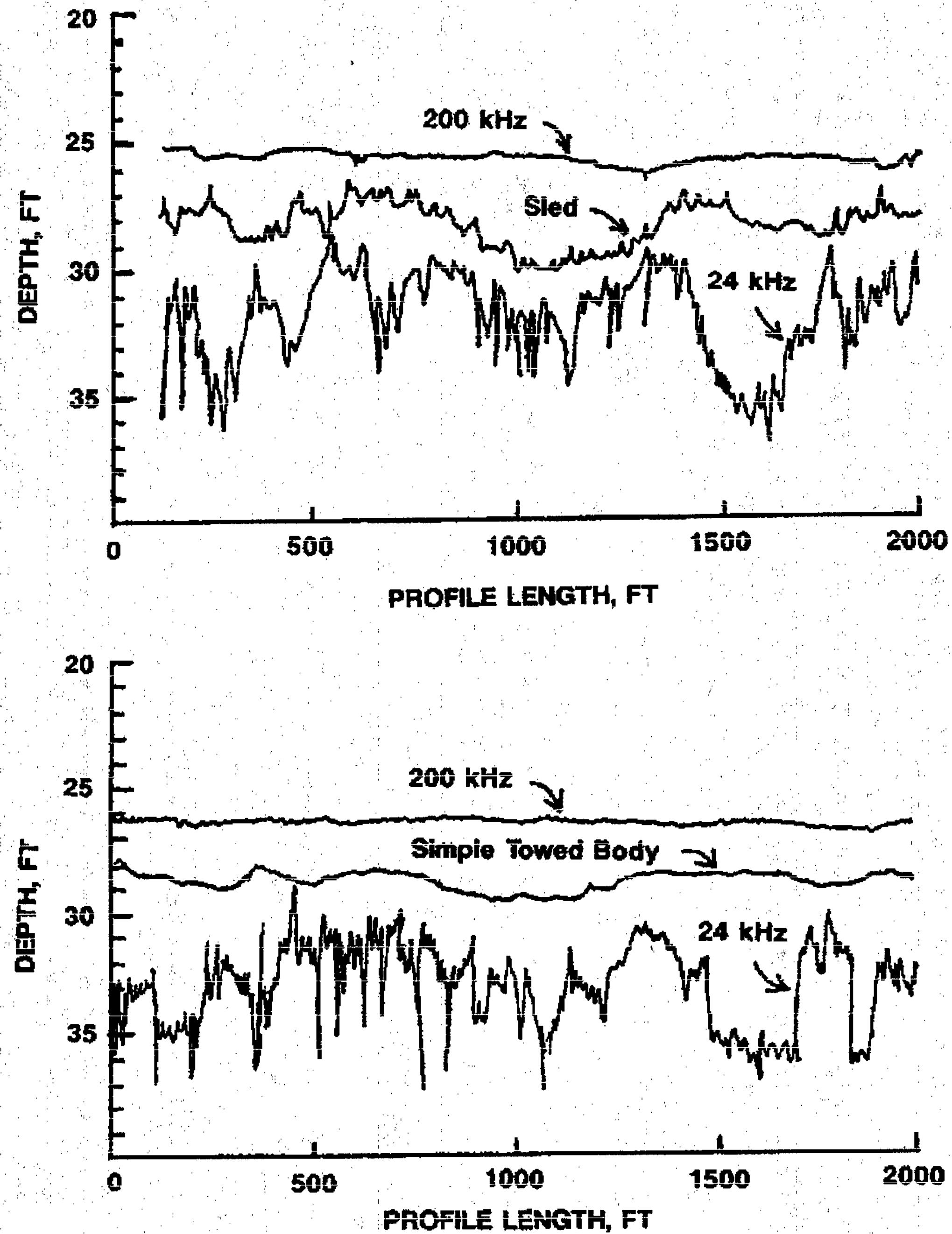

Figure 4. Gulfport Channel section line surveyed with the sled (top) and simplified towed body (bottom) showing high- and low-frequency acoustic returns

instrument dependent because of the existence of a distinct fluid mud horizon and related sediment properties.

Repeatability of density at the level of the towed sled also was determined. Table 2 presents density (grams per cubic centimeter) statistics for two surveys each at Calcasieu and Gulfport.

Table 2. Densities for Two Surveys Each at Calcasieu and Gulfport

	Density, g per cu cm	
	Calcasieu Channel Site	
	June 1991	**November 1991**
Mean	1.187	1.205
Median	1.192	1.208
Quartiles*	1.169, 1.210	1.188, 1.223
	Gulfport Channel Site	
	April 1991	**May 1991**
Mean	1.154	1.141
Median	1.155	1.141
Quartiles*	1.147, 1.163	1.133, 1.148

*Quartiles are the 25 and 75 percentile values.

The data from Table 2 indicate that the sled rides at a fairly consistent density level for a given survey and site and that there was a distinct difference in sled-depth densities between Calcasieu and Gulfport channels. Some variations might be expected for a given site at different times as, for example, fluid mud viscosity is temperature dependent.

Determining navigable depth criteria is another aspect of the research undertaken by this work unit. Rheological testing has been performed on discrete samples using various techniques and equipment and will be the subject of a subsequent technical note. Figure 5 shows an example comparison of viscosities measured at a shear rate of 0.6 reciprocal second (or second^{-1}) for two channels. Trend lines were computed using a locally weighted smoothing function. The data indicate that the sled surveyed a level of equal fluid mud shear resistance in both cases, though there is appreciable scatter in the data and the intercept of the trend lines with survey densities at exactly the same low-shear viscosity is probably coincidental. Less dramatic variation in density between sites over the same channel reflects variations in fluid mud shear resistance at the level of the towed sled.

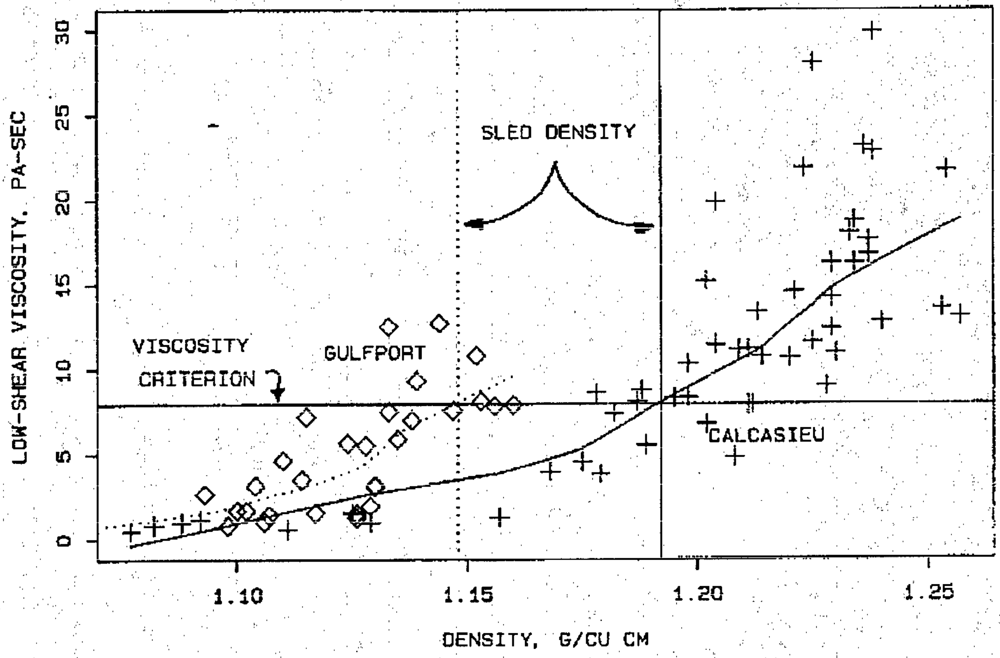

Figure 5. Low shear viscosities of fluid mud samples taken from Gulfport (◊) and Calcasieu (+) channels with corresponding sled-depth densities

Determination of Channel Grade

In 1991, predredging and postdredging surveys were performed that demonstrated the utility of the fluid mud survey system in defining navigable depth and channel grade. Problems associated with conventional acoustic surveys in fluid mud channels also were made apparent. A series of longitudinal survey lines were established over a 6,000-ft-long reach of the Calcasieu channel containing fluid mud. This site was surveyed in June 1991 and again in late November 1991, immediately following completion of maintenance dredging by hopper dredge.

A sample of centerline profile data is shown in Figure 6. Both predredging and postdredging 24-kHz frequency Fathometer depth signals penetrated the fluid mud layers to -45 ft mean low gulf (mlg) datum, well below the authorized project depth. The predredging 200-kHz frequency survey was about -36 ft mlg, and 2 to 4 ft shallower than the towed sled survey. The postdredging 200-kHz surveys also were shallower than the towed sled surveys. Figure 6 shows that even the postdredging 200-kHz profiles did not indicate that the channel was navigable to the authorized depth of -42 ft mlg.

The acoustic data sets revealed that the 24-kHz frequency may not have indicated necessary material for maintenance dredging and, thus, overestimated navigable depth. The 200-kHz acoustics did not always determine whether sufficient material was removed by dredging, nor did it

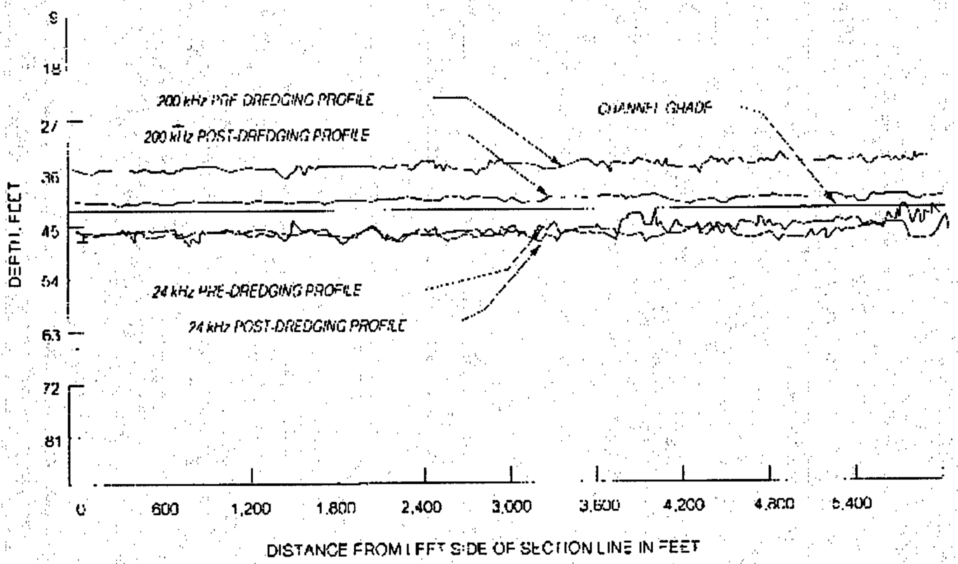

Figure 6. Predredging and postdredging acoustic depths for Calcasieu channel, 1991

accurately estimate maintenance volumes required to keep fluid mud channels navigable.

Maintenance operations along the profiled section of the Calcasieu channel includes the provision for 1 to 2 ft of advance maintenance. Figure 7 shows the towed sled survey along the same profile line shown in Figure 6. According to the sled data, the channel was deepened from -38 to -43 ft mlg. This depth information was collected along density levels of 1.19 to 1.21 g per cu cm as previously described. The towed sled was the only survey method used which accurately gaged the amount of material to be dredged or which indicated that the required material was actually removed by dredging. The sled will provide vastly improved capabilities to determine channel grade in areas of fluid mud.

Ship Effects on Fluid Mud

Occasionally during field surveys, a deep-draft vessel would pass through the channel and resuspend mud, and anecdotal information on the level of navigable depth was obtained from these events. One such passage occurred in the Calcasieu channel in June 1991 before maintenance dredging. The ship sailed through the site near the center line of the channel, and the captain reported the *MV Star Baltic* was drawing 37 feet of draft. Corrected for tide, the still-water draft was to -34.5 ft mlg. Less than 1/2 hr later, the center line profile line was surveyed. The high-frequency acoustic signal returned a "split" or dual trace. The passage of the ship had disturbed the more fluid portion of the channel mud and formed a 2-ft-thick layer of material so light that the 200-kHz signal reflected from both its upper and lower interfaces. The ship passage had "fluffed" the upper layers of fluid mud to -35 ft mlg according to the

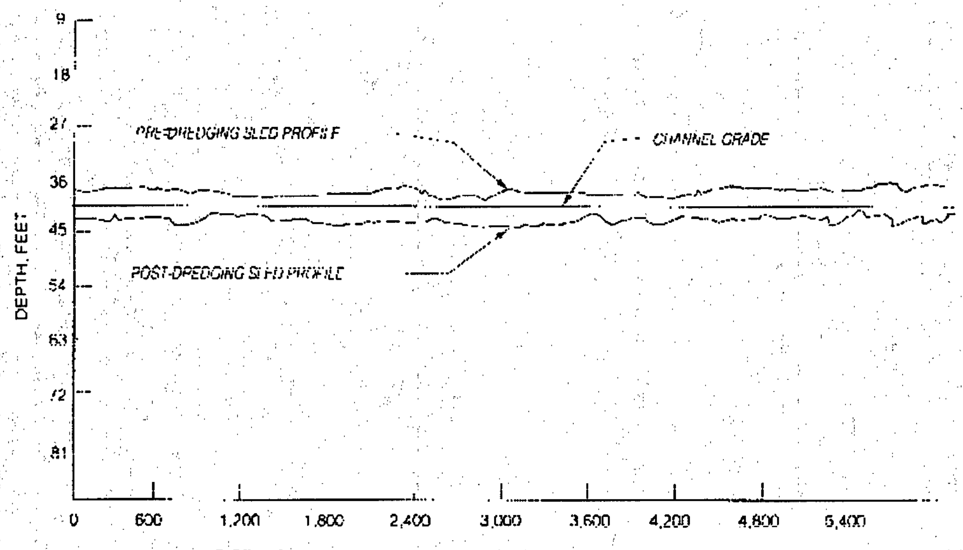

Figure 7. Predredging and postdredging sled depths for Calcasieu channel, 1991

200-kHz acoustic return, with another return from -37 ft mlg indicating the deepest level of vessel disturbance. The 200-kHz depth profiles outside the vessel's path were -36 ft mlg. The sled indicated navigable depth at -38 ft mlg, 1 ft below the level of vessel disturbance and 3.5 ft below the level of the vessel's keel. The density 1 ft above sled level was not determined precisely, but was estimated at about 1.15 g per cu cm (or about the transition point shown in Figure 5 for Calcasieu sediments). This indicated that the deepest level of ship disturbance (de facto navigable) was about 0.04 g per cu cm less dense than the navigable depth value of 1.19 g per cu cm determined by the towed sled.

Evaluation Summary and Conclusions

A towed sled has been developed that will track on a navigable depth at a constant fluid mud shear resistance, that is, at about a constant density for a given channel. It can be used as part of a fluid mud survey system to survey navigation channels at speeds of about 4 knots. Surveys are repeatable and relatively insensitive to operating conditions. Longitudinal section lines worked well in conjunction with towed sled surveying. Debris in channels has not been a serious operational problem. Both the towed sled concept and the hardware developed have proven to be sound.

Experience in the field has led to numerous refinements in hardware, software, and operating procedures. At present, the towed sled is a relatively sophisticated research device, but indications are that it can be greatly simplified for production use by Corps field offices. The nuclear density gage being used to monitor performance during testing probably can be excluded from the final sled configuration for most applications.

The navigable depth survey approach will better define channel conditions and allow local Corps offices to more effectively manage and monitor maintenance dredging operations. Acoustic depth surveys will continue and can be augmented by towed sled data to provide improved information for judging navigation conditions, dredging needs, and dredging effectiveness in areas of fluid mud.