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Dredging Research Technical Notes

Fluid Mud Survey Investigations at the Calcasieu Lake Entrance Channel, Louisiana

Purpose

This technical note describes fluid mud conditions encountered at the Calcasieu Lake (Louisiana) Entrance Channel during intrusive bathymetric surveys and related investigations. The occurrence of fluid mud in navigation channels is poorly documented, but is known to cause rapid shoaling and special problems for conventional acoustic survey methods. The Calcasieu Entrance Channel is significant in these respects because fluid mud layers are thick and require large-volume dredging to maintain channel conditions.

Background

Methods for intrusive survey and analysis of fluid mud channel bottoms have been developed around a firm-bottom or navigable depth concept as part of the U.S. Army Engineer Waterways Experiment Station's Dredging Research Program (DRP). The overall goal is to reduce channel maintenance costs by improving dredging efficiency through better definition of bottom conditions in areas of fluid mud. Rheologic analysis of mud samples has been used to establish conservative, physics-based criteria that can be used to gage the firm bottom, safe for vessel passage and appropriate for dredging.

A fluid mud survey system has been developed which integrates an instrumented towed sled, a conventional dual-frequency acoustic depth sounder, and hydrographic survey positioning-control and logging components. The system was described in the *Dredging Research Technical Notes* (DRP-2-05, Teeter 1992). The towed sled has nuclear-transmission density, pressure, cable tension, and multiple tilt sensors. The sled has been adjusted to ride at a certain shear resistance when towed, corresponding to a density slightly higher than that at which the material begins to exhibit continuous interparticle cohesion and thus a space-filled structure. The firm-bottom depth is obtained by direct contact with the physical horizon where resistance to motion increases sharply. Comparisons of 24- and

200-kHz acoustic depths, and sled depths obtained by the fluid mud survey system for various channels and channel conditions, reveal the complexity of fluid mud deposits and the difficulties arising in conventional acoustic surveys.

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Additional Information

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Introduction

Intrusive fluid mud survey systems and methods for the analysis of fluid mud have been developed under the DRP. Intrusive methods make physical contact with fluid mud at the firm-bottom or navigable-depth level where resistance to motion increases sharply. Two intrusive survey devices have been tested: a detailed towed sled and a simple towed body. Both devices have been adjusted to ride at a certain shear resistance when towed, corresponding to a density slightly higher than that at which the material exhibits a space-filled structure and appreciable shear resistance.

As part of field evaluation of these devices, vertical density profiles and samples for rheological analysis were also obtained. Field evaluations have been performed at several channels along the Gulf of Mexico including Calcasieu Entrance Channel (Teeter 1992). Previous fluid mud survey approaches have used density as the basic measurement criterion (Kirby, Parker, and Van Oostrum 1980; De Vlieger and De Cloedt 1987).

The occurrence of fluid mud in navigation channels is poorly documented, but is known to cause rapid shoaling and special problems for conventional acoustic survey methods. The Calcasieu Entrance Channel is significant in these respects because fluid mud layers there are thick, and large dredging quantities are required to maintain channel conditions. Shoaling is rapid, and dredging cycles are often less than 1 year. Compounding the problems associated with the need for large amounts of dredging are the difficulties associated with surveying and determining accurate depths.

Problems associated with conventional acoustic surveys in fluid mud channels become apparent when intrusive methods are used in conjunction with acoustic soundings. In particular, measurements have shown that thick layers of fluid mud can exist between the depths indicated by 200-kHz acoustic signal reflections and by the survey sled described later, while 24-kHz acoustic signal reflections can overestimate firm-bottom depth. Surveying difficulties can lead to uncertainties in dredge scheduling and in estimating required dredging volumes. Potential benefits of a more accurate determination of mud bottom depth include improved efficiency in maintenance operations through better definition of what areas actually require dredging, what has been dredged, dredging priorities, and dredge scheduling.

Fluid Mud in Navigation Channels

Much of the sediment materials dredged from waterways is estuarine fine-grained, cohesive mud, some with densities ranging from 1.05 to 1.35 g/cu cm, generally referred to as fluid mud. Concentrations of these muds range from 50 to 500 g/L, or 2 to 13 percent solids by volume.

Thick layers of fluid mud occur at some times and at some places, especially in estuarine areas, where fine sediments are frequently resuspended and trapped by hydrodynamic conditions. Fluid muds generally form a lutocline, or area of steep vertical density gradient, near the bed. Unlike sands, fine-grained fluid muds are slow to consolidate and can persist in a fluid-like state for long periods. Wave agitation can maintain muds in a fluid state. Channels where fluid mud is likely to collect have moderately high flows with maximum current speeds of 1 to 3 fps but with very small net tidal-average current speeds. Moderate flow speeds maintain conditions suitable for fluid mud but are unable to completely entrain and disperse the material. Fluid mud can move with the flow, or it can remain stationary and gradually consolidate by settling and self-weight into a heavy soil.

A particular mud is mobile and navigable if its density and viscosity are sufficiently low. The material property that produces greatest frictional effect is viscosity. However, of the parameters most directly related to navigability, only density can be measured in situ. Flow properties of muds depend on material characteristics such as clay type and content, and therefore fluid muds from different locations can act differently, even at the same concentration or density. Fluid muds have density transition points at which viscosity, shear modulus, and yield stress increase sharply.

Transition densities establish reference values for comparing sediments and developing appropriate density criteria. Definitions of navigable or firm-bottom depth can be based on density (a readily field-measurable physical property) corresponding to a viscosity and strength (not field measurable) near the transition point for a local site. This is a conservative starting point for the development of a criterion, subject to local adjustment.

Calcasieu Site Description

The Calcasieu Entrance Channel is the approach to Calcasieu Pass and Lake at the western edge of Louisiana in the Gulf of Mexico. Calcasieu Lake is the estuary of the Calcasieu River that drains 3,300 square miles. The long-term daily average freshwater inflow is 6,300 cfs, and the monthly average inflows range from 2,000 cfs in October to 11,200 cfs in February. Tide range at the jetties is about 1.9 ft over a diurnal cycle. The tidal prism is roughly 1.4 billion cu ft. Between the jetties, average maximum flood tide currents are about 3 fps, and the corresponding ebb tide currents are 4 fps. Wind and wave conditions seaward of the jetties are often adverse for surveying in 47- to 65-ft-long vessels.

The Calcasieu Entrance Channel project dimensions are 42 ft deep, relative to mean low gulf (mlg) datum, by 800 ft wide seaward from a pair of jetties. The channel is 22.5 miles long and consists of three tangents. The area of fluid mud and heaviest shoaling is located just seaward of the jetties in the first channel tangent. A plan view of the study area is given in Figure 1. Maximum currents in this area are typically 2 fps. A 28-kHz acoustic profile along the channel is shown in Figure 2. The separation between the first and strongest acoustic signal returns shown in Figure 2

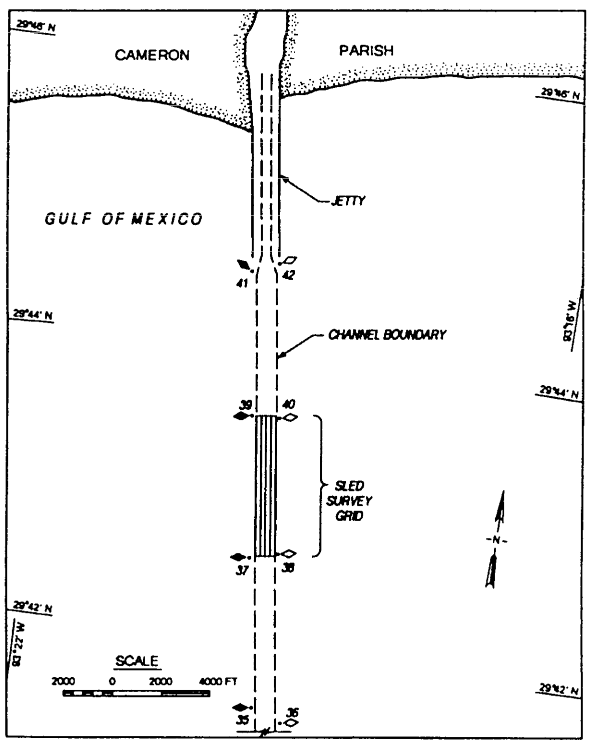

Figure 1. Calcasieu Entrance Channel near the jetties

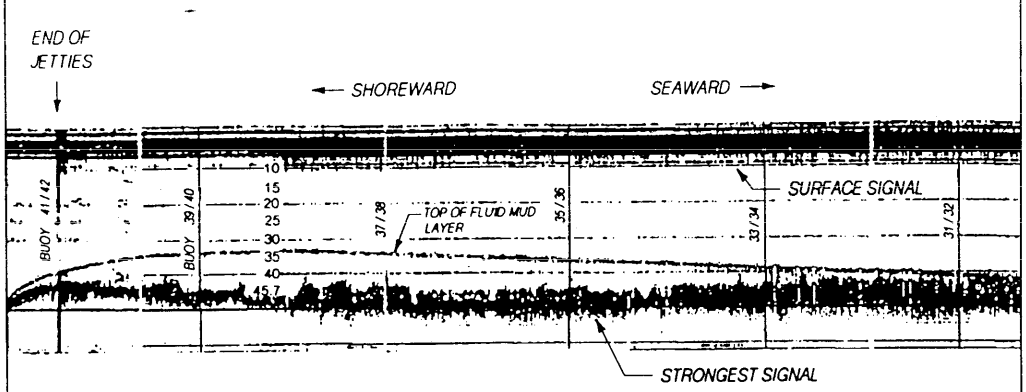

Figure 2. Acoustic sounder record from inside the jetties seaward along channel center line showing the top of fluid mud layer (the first 28-kHz acoustic signal reflection) and the deeper, stiffer sediment layer (the strongest 28-kHz acoustic signal reflection)

is indicative of the presence of fluid mud in the channel. The shape of the fluid mud layer appears to be formed by distinctive hydrodynamic conditions such as diminished tidal currents and net landward tidal-average bottom currents that exist seaward of the channel jetties.

Equipment and Procedures

The U.S. Army Engineer District, New Orleans, uses a procedure (actually a reconnaissance-level survey) in which they traverse the channel center line using 200- and 28-kHz acoustic gear in a 65-ft-long survey boat. Sea conditions permitting, lead-line soundings are taken at certain buoy crossings. However, wind and wave conditions are typically too rough to obtain reliable lead-line soundings.

The DRP 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 lead line. The concept was to furrow into fluid mud to the depth being defined as navigable. The intrusive survey device makes physical contact with the mud, which serves 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 stresses in the mud "support" the towed device. The assumption has since been validated by laboratory tests and relationships between rheologic properties and density established for numerous sites.

The detailed fluid mud survey system integrates an instrumented towed sled, a conventional dual-frequency (200 and 24 kHz) acoustic depth sounder, and hydrographic survey positioning-control and logging components. (It should be noted that the New Orleans district uses 28 kHz, while the DRP fluid mud survey system uses 24 kHz for low-frequency acoustic soundings.) The sled has nuclear-transmission density, pressure, cable tension, and multiple tilt sensors. The static weight of the sled is about 260 lb in air and 60 lb in water. The top-view projected area is about 12 sq ft. The sled is towed by a 47-ft-long survey boat, as shown in Figure 3. A more complete description of the fluid mud survey system is given by Teeter (1992). The sled was used to make longitudinal channel profiles and channel cross sections over a 6,000-ft-long survey grid before maintenance dredging in June 1991 and after dredging in November 1991.

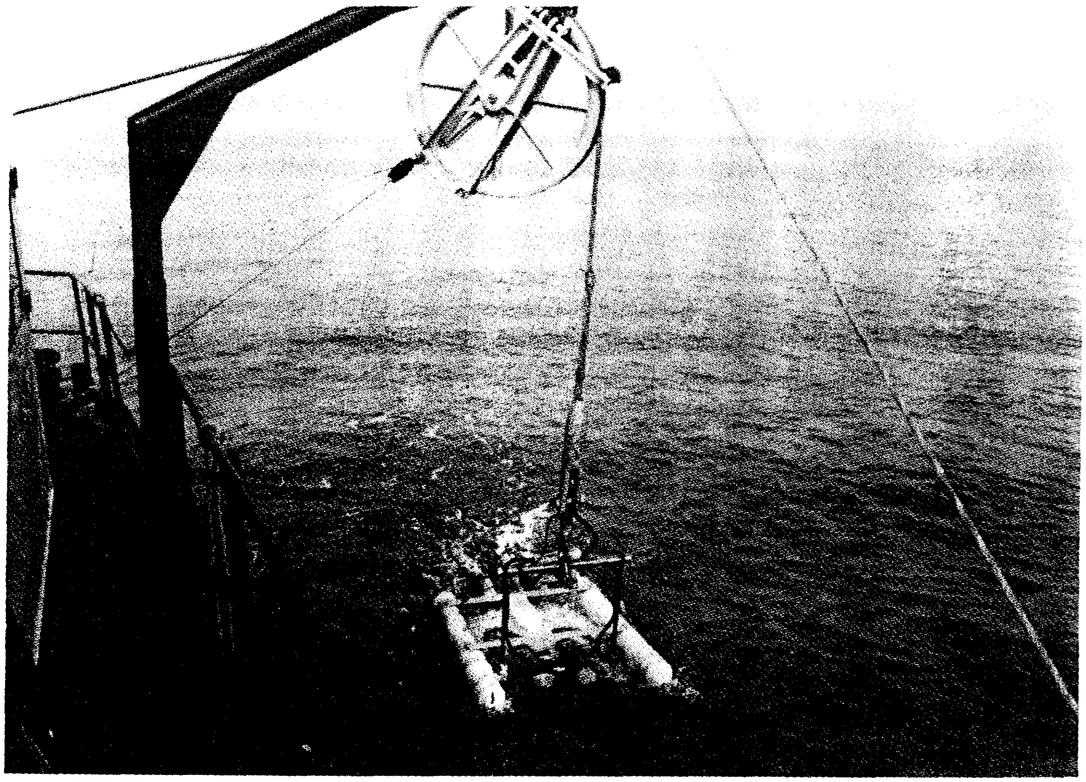

Figure 3. Detailed survey sled in tow at water surface

Measurements of the vertical density structure of fluid mud layers were made for predredging and postdredging conditions during July and September 1989 using a SIRAD (Sediment Instrumentation Research and Development, Inc., Portland, OR) backscatter nuclear density gage. This density gage is a drop probe. The separation distance between the gamma source and detector is 1 ft, which can cause sharp density gradients to appear more gradual than they are.

Variability of Fluid Mud

Under predredging conditions, vertical density profile data indicate that the transition from a density of 1.15 to 1.20 g/cu cm occurred over a small depth increment at the quarter points of the channel. At the center of the channel, where deep-draft vessels have been observed to resuspend and fluidize bed sediments, the same 1.15- to 1.20-g/cu cm density increase occurred over a greater depth increment under predredging conditions. Examples of this effect are shown in Figure 4. Five predredging quarter-point profiles had average depth increments of 0.5 ft while two center-line profiles had average depth increments of 2.9 ft. Depth increments for the 1.15- to 1.20-g/cu cm density change were observed to vary somewhat along the channel as well, but not as greatly as between the center line and the quarter points.

Under predredging conditions, a sharp interface occurred at the channel quarter points at a density of about 1.2 g/cu cm (where rheological tests indicated the formation of a space-filling structure and where the fluid

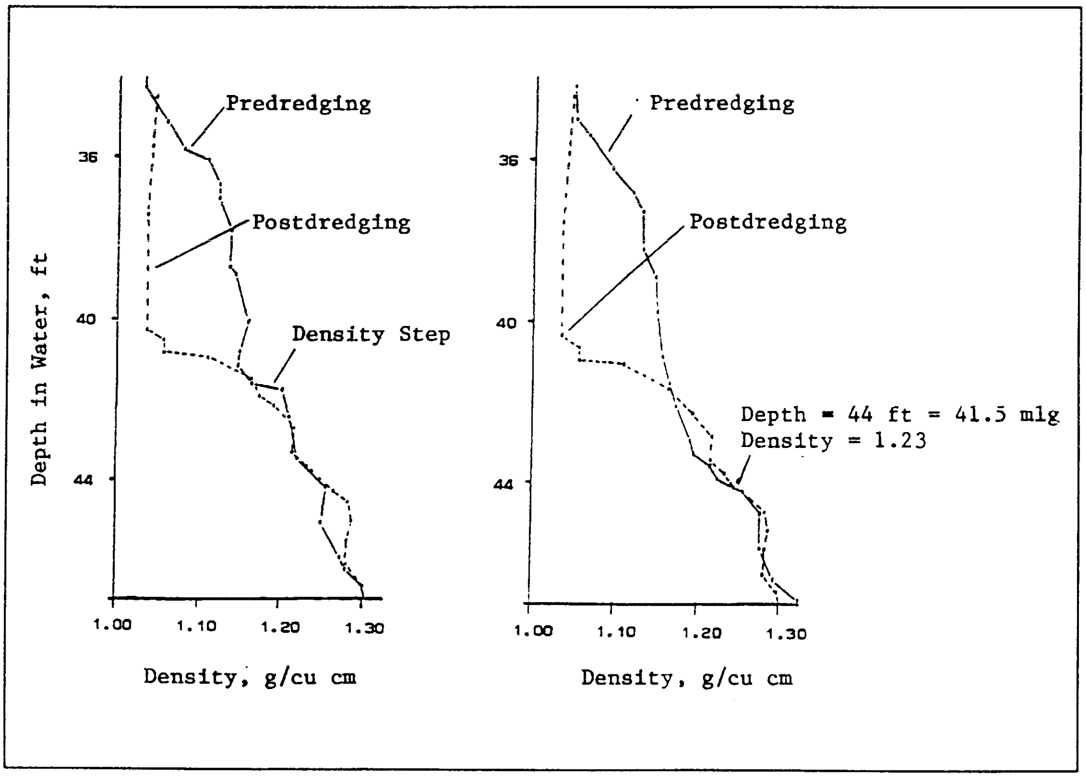

Figure 4. Vertical density profiles at quarter points (left panel) and center line (right panel)

mud survey sled rode). Vertical profiles indicated that undisturbed fluid muds at the channel quarter points develop sharp density interfaces. The nuclear density gage on the sled monitors the upper density at this interface since it does not penetrate into the lower layer.

Vessel disturbances produce appreciable effects on fluid mud layers in the central portion of the channel and make the navigable density values slightly higher here. Near the channel center line, fluid mud is frequently disturbed. For example, a vessel passage was observed to "fluff" the upper layers of fluid mud by about 1 ft in Calcasieu Entrance Channel according to the 200-kHz acoustic signal and to cause a second 200-kHz acoustic signal 2 ft below the first and about 3.5 ft below the vessel's keel, indicating the deepest level of mud disturbance.

Where gradients near the transition density are weak, such as the center line under predredging conditions, the sled tracks at a deeper level and slightly higher density. The sled stabilizes at a level where the additional buoyancy contributed by the increased density, in combination with the shear strength of the material, supports the submerged weight of the sled. Postdredging vertical density profiles indicate sharpest gradients at 1.05- to 1.10-g/cu cm density. The previously described density interface at 1.15 to 1.20 g/cu cm was absent from the postdredging survey, probably because sufficient fluid mud layer thickness at densities below this had not yet redeveloped. Profile features were similar to predredging conditions below the 1.20-g/cu cm horizon and also give an indication of the density of the material that was removed by dredging.

Postdredging vertical density profiles shown in Figure 4 indicate that material less than about 1.2 g/cu cm was removed by this particular dredging operation, while the remainder of the sediment column was not affected. The center-line profile shown in Figure 4 shows a distinct break at -44 ft mlg, which corresponds closely to the project depth (-42 ft mlg). The density at this point is 1.23 g/cu cm. The depth and density tracked by the sled were similar, 1.22 g/cu cm at -41.7 ft mlg.

Sled Surveys

Predredging and postdredging surveys were performed with the towed sled to define firm-bottom depth and thus the true channel condition. A series of longitudinal survey lines were established over a 6,000-ft-long reach of the Calcasieu Channel containing fluid mud. This profile grid was surveyed in June 1991 and again in late November 1991, immediately following completion of maintenance dredging by hopper dredge. Depths were measured with 200- and 24-kHz acoustic signals and with the fluid mud survey sled. The median fluid mud density measured by the sled was 1.192 g/cu cm in June 1991 and 1.208 g/cu cm in November 1991. Thus, the sled rode near the bottom of the 1.15- to 1.20-g/cu cm density interval discussed earlier. Sample cross-sectional data are shown in

Figure 5. Sample longitudinal profiles were presented in the *Dredging Research Technical Notes* (Figures 6 and 7 of DRP-2-05, Teeter 1992).

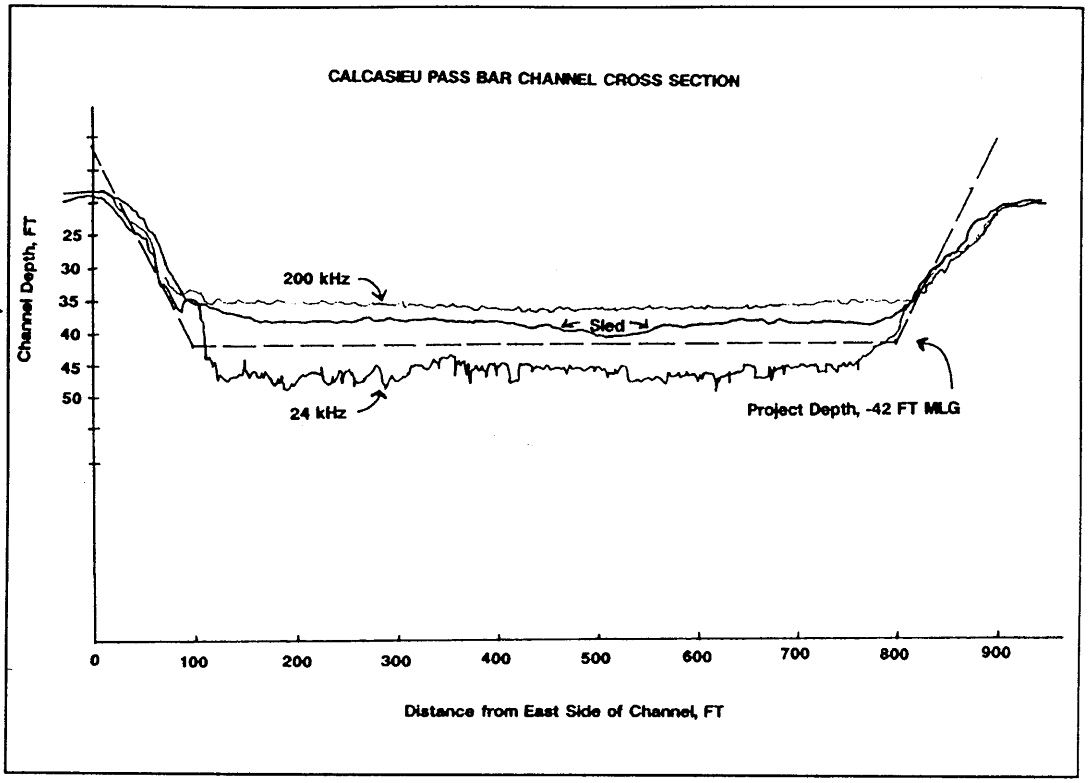

Figure 5. Example cross section from Calcasieu Entrance Channel

Both predredging and postdredging 24-kHz acoustic depth sounder signals penetrated the fluid mud layers to -45 ft mlg, well below the dredging prism. The predredging 200-kHz frequency survey was about -36 ft mlg and was 2 to 4 ft shallower than the towed sled survey. The postdredging 200-kHz survey was also shallower than the towed sled surveys and did not indicate that the channel was navigable to the authorized depth of -42 ft mlg. Based on the sled survey data, dredging increased channel depth from -38 to -43 ft mlg. This depth information was collected along density levels of 1.19 to 1.21 g/cu cm, as previously described.

Comparison of Channel Fill Volumes

The purpose of the DRP sled research is to better define quantities of material which must be and have been dredged using the firm-bottom or navigable depth approach. Volume of sediment in the channel prism is a good measure for comparison of different survey techniques. Channel fill volumes were calculated over the 6,000-ft grid covered by the sled surveys described in the previous section. Volumes for the three survey techniques from before and after dredging are compared in Table 1.

Table 1
Channel Fill Volumes Computed Using Three Survey Methods

Survey Method	Channel Fill Volume, cu yd		
	Before Dredging (B)	Difference (B-A)	After Dredging (A)
200 kHz (H)	1,028,860	728,817	300,043
Difference (H-S)	299,381		234,734
Sled (S)	729,479	664,170	65,309
Difference (S-L)	645,345		25,784
24 kHz (L)	84,134	44,609	39,525

Note that the 24-kHz fill volumes resulted from material at the toes of the channel. The 6,000-ft survey grid is near the locus of heaviest fluid mud accumulation and is not representative of the entire Calcasieu Entrance Channel. Depths from the three survey methods would be much closer farther offshore, as indicated in Figure 2. The total volume difference for the entire entrance channel between the different survey methods is not known. Sled results indicate that the density of most of the material dredged during the 1991 operation was greater than 1.20 g/cu cm, in contrast to the 1989 dredging cycle when most material dredged appeared to have a density less than about 1.175 g/cu cm.

Summary

Conditions frequently occur in the Calcasieu Entrance Channel which form gradual or stepwise fluid mud gradients at the channel bottom and obscure the firm-bottom bed from detection by conventional acoustic instrumentation. Calcasieu Entrance Channel has fluid mud layers immediately seaward of the entrance jetties, while farther than about 5 miles offshore, fluid mud does not accumulate in the channel. The accumulation of fluid mud in the channel results from an abundant fine-grained sediment supply, the deep channel cut, hydrodynamic forces which trap sediments in the channel, and sediment properties and environmental conditions that foster fluid mud.

Fluid mud layers were as thick as 13 ft gaged by the separation of the 200- and 24-kHz acoustic signals, or 4 ft gaged by the difference between

the fluid mud survey sled and the 200-kHz acoustic return. Layer thicknesses between 200-kHz signals and the survey sled averaged 1.3 to 1.7 ft over the entire survey grid. Intrusive surveys produced channel fill volumes that were 29 to 78 percent smaller than 200-kHz acoustic surveys and 65 to 767 percent larger than 24-kHz acoustic surveys.

Vertical density structure of the fluid mud layer in the channel was affected by deep-draft vessels. The bed at the channel quarter points showed a steep gradient at about the density of firm-bottom depth. The same density step occurs over a larger depth increment at the channel center line. Navigable depth density varies somewhat over the width of the channel and probably along the channel as well.

The sled was the only survey device employed which accurately gaged the amount of material to be dredged or showed that the required material was actually dredged. Acoustic signals depend strongly on steep vertical density gradients, and such gradients were found to be time- and location-dependent and not uniformly associated with specific densities. The 24-kHz acoustic signals may not have indicated necessary maintenance material and thus overestimated navigable depth. The 200-kHz acoustic signals did not always determine whether sufficient material was removed by dredging, nor did they accurately estimate maintenance volumes required to keep fluid mud channels navigable. Data obtained under various channel conditions reveal the complexity of fluid mud deposits and the difficulties arising in conventional acoustic surveys.

References

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