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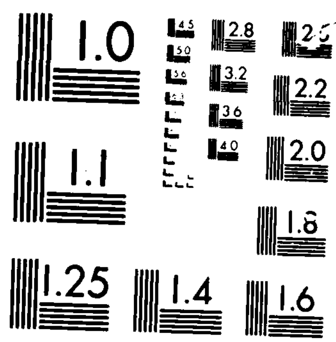

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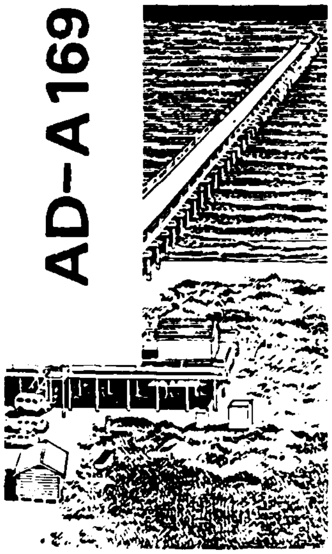

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FIELD COMPARISON OF FOUR NEARSHORE SURVEY SYSTEMS

by

James E. Clausner, William A. Birkemeier, Gene R. Clark

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Four types of nearshore survey systems used by the US Army Corps of Engineers were evaluated at the Coastal Engineering Research Center's (CERC's) Field Research Facility in Duck, N. C., during 1984 under ideal conditions. The systems include a survey boat with fathometer and microwave positioning, CERC's Coastal Research Amphibious Buggy (CRAB) and a boat-towed sea sled used with an electronic total station, and a hydrostatic profiler developed by the
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20. ABSTRACT (Continued).

Scripps Institution of Oceanography. The systems were evaluated on the basis of accuracy, repeatability, cost, speed, and manpower requirements.

PREFACE

This report was prepared and published using funds provided by the Office, Chief of Engineers, under the Evaluation of Navigation and Shore Protection Structures Research Work Unit 31232 of the Coastal Structure Evaluation and Design Program at the Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES). The field tests described in this report were funded jointly by CERC and the US Army Engineer District, Los Angeles (SPL).

The report was prepared by Messrs. James E. Clausner, Coastal Structures and Evaluation (CS&E) Branch, Engineering Development Division (EDD), CERC; William A. Birkemeier, Field Research Facility Group, EDD; and Gene R. Clark, formerly of CS&E, EDD. Ms. Joan Pope, CS&E, EDD, was Principal Investigator of the work unit, and Mr. Thomas J. Dolan, SPL, was Project Engineer for the field tests.

The authors wish to acknowledge the support of the Field Research Facility staff during the field portion of this work. In addition, the Wilmington District Survey Section, headed by Mr. Glenn Boone, provided valuable assistance in this project.

Work was performed under direct supervision of Mr. Thomas W. Richardson, Chief, EDD, and under general supervision of Mr. Charles C. Calhoun, Jr., and Dr. James R. Houston, Assistant Chief and Chief, CERC, respectively. This report was edited by Ms. Shirley A. J. Hanshaw, Publications and Graphic Arts Division, WES.

COL Allen F. Grum, USA, was Director of WES during the publication of this report, and Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
pounds (mass)	0.4535924	kilograms
miles (US statute)	1.609347	kilometres
cubic yards per foot	2.508382217	cubic metres per metre

FIELD COMPARISON OF FOUR NEARSHORE SURVEY SYSTEMS

PART I: INTRODUCTION

1. There has always been a need for accurate nearshore surveys, particularly through the surf zone where shallow water and wave action hamper the use of conventional methods. Accurate surveys of this zone are required for the design and monitoring of most coastal projects. Traditionally, the Corps has used a survey boat with a fathometer and microwave positioning system for nearshore surveying combined with a rod and level wading survey for the beach to obtain nearly complete coverage of a beach profile. This method's major disadvantages are the indirect nature of depth measurement (relative to water level), difficulty in filtering out wave effects, and problems in merging two different survey methods. Recent advances in survey equipment and innovations in technique have resulted in the development of several alternative methods for nearshore surveying.

2. In the spring of 1984 the Los Angeles District (SPL) requested that the Coastal Engineering Research Center (CERC) evaluate the Scripps Institution of Oceanography hydrostatic profiler which was being used in the Coast of California Storm and Tidal Waves Study. SPL wanted an objective field test of the hydrostatic profiler's performance before renewing the contract. Because the Coastal Research Amphibious Buggy (CRAB) was the most thoroughly tested reference system and was available on short notice, CERC decided to perform a field comparison at the Field Research Facility (FRF) at Duck, North Carolina. SPL requested a comparison of the hydrostatic profiler to a conventional fathometer/survey boat system. CERC had recently developed a boat-towed sea sled and decided to include it in the comparison.

3. The majority of the tests were done in July 1984. The systems were evaluated on their ability to survey the nearshore region, including the surf zone, vertical and horizontal accuracy, repeatability, speed, cost, and manpower requirements. This paper discusses the four tested systems and the results of the field tests. The advantages and disadvantages of each system are addressed along with recommendations for system selection. Although there are other systems that are capable of surveying the nearshore and surf zones, the scope of the study limited comparison to these four systems.

PART II: SYSTEM DESCRIPTIONS

Fathometer Survey System

4. The US Army Engineer District, Wilmington (SAW), provided the 47-ft-*long survey vessel, Beaufort, used in the tests. The Beaufort is equipped with a Raytheon 719B analog fathometer, used with an Innerspace 412 digitizer. Depths are recorded once every 2 sec along with position information from a Motorola Mini Ranger III positioning system which also provides course correction information. Data are processed by a Motorola Data Processor and recorded on tape by a Tektronix 4923 recorder. Operation of the Mini Ranger is similar to other line-of-sight microwave positioning systems; i.e., two remote transponders are set up on shore at known locations, and the master receiver transmitter system is on board the vessel. By measuring the round-trip time of the signals from each of the transponders, distance from each transponder is calculated; and the location of the vessel is calculated within 10 ft (manufacturer's stated accuracy). The cost of the electronics and spare parts associated with this type of system is over $100,000. Potential sources of error associated with using the positioning system, although not likely in this test, include poor operating geometry, low signal strength, interference from military radars, failure to convert from slant range to true range, multipath phase cancellation, and failure to account for the horizontal distance between the shipboard receiver and the fathometer transducer. Potential sources of error which may be possible for this test are (a) poor horizontal control on shore stations and (b) system calibration for distances significantly different from those used in the test.

5. In a typical operation, three persons are required on the boat with one person on shore to set up and move the transponders. To increase the amount of overlap between the conventional rod and level survey on the beach and the fathometer survey from the boat, SAW usually surveys within 2 hr of high tide. It takes 20 to 45 min to program the data processor, which is usually done on the way to the site. A bar check, used to calibrate the fathometer for the velocity of sound in water, is done on site and takes 5 to 15 min

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

to complete. About once a week, the Mini Ranger system is calibrated on a known coordinate. Because of tide and transponder movement constraints, approximately sixteen 2,000-ft-long profile lines spaced 1,000 ft apart can be surveyed per day. To prevent damage to the vessel propellers and rudder, all surveys are run toward the shore. SAW generally uses raw digitized data corrected for tide and for vessel squat (the change in depth of the fathometer transducer as the boat speed changes). No correction is made for waves. Other districts, such as SPL, hand-smooth the fathometer trace and digitize the resulting line to adjust for wave effects.

6. Advantages of the boat/fathometer system are its high speed and its relative insensitivity to bottom conditions and currents. Disadvantages include the indirect nature of the depth measurement, the effects of water level variations and boat motions and inability to survey the surf zone.

CRAB

7. The CRAB is a self-propelled 35-ft-high tripod (Figure 1) capable of operating in water depths up to 30 ft and in waves up to 6 ft high. Its position and elevation are determined by a shore-based electronic total station.

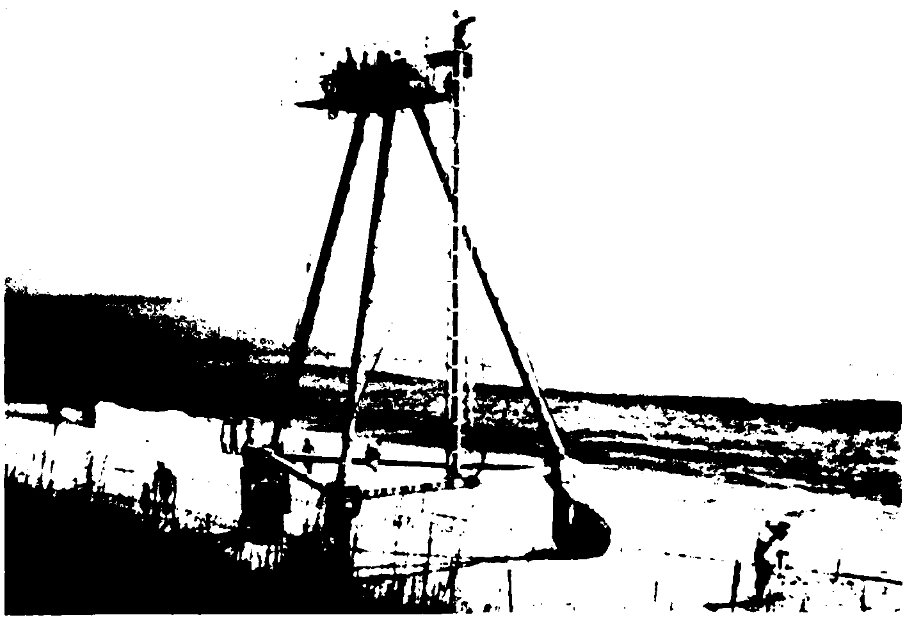

Figure 1. CRAB

This instrument incorporates in one compact unit an electronic distance meter and theodolite, microprocessor, rechargeable power supply, and interchangeable solid state memory. Surveying with the CRAB requires a crew of two, a CRAB driver and an instrument operator.

8. The CRAB was designed and built by SAW in 1980 at a cost of $75,000. It consists of a tripod of 8-in. schedule 80 aluminum pipes tied together at the base by horizontal members 7 ft above the ground. The distance between the rear wheels is 27 ft, and the distance between the front and rear wheels is 24 ft. Each wheel is 5 ft in diameter. Power is supplied by a 53 hp air-cooled engine on the deck which drives a variable stroke hydraulic pump. This main pump drives a hydraulic motor on each wheel. Total vehicle weight is about 18,000 lb with ballasted tires and 15,000 lb without ballast. The ballasted tires allow the CRAB to withstand a 20-deg tilt. Top speed is 2 mph on land and somewhat less in water, depending on wave conditions. Transporting the CRAB to other sites is difficult. It is most easily moved by Chinook helicopter, but it can be barged to a site and off-loaded by crane. More detailed information on the CRAB, including a discussion of its accuracy, can be found in Birkemeier and Mason*.

9. The position of the CRAB is determined using a Zeiss Elta-2 electronic total station. The instrument is capable of measuring angles to 0.6 sec and distances to ±0.02 ft. Cost for the instrument and associated computer interface equipment is $40,000 (1985). When optically aimed at a reflecting prism assembly located on the CRAB, the instrument calculates, records, and displays the X, Y, and Z coordinates of prism reflectors mounted directly above the axis of the rear wheels of the CRAB. Changes in rear wheel elevation are translated directly into an elevation change of the prisms. The accuracy and operating range of the instrument depends on conditions and the number of prisms. When used with a triple prism assembly, survey measurements can be made easily to ±0.1 ft or better, both horizontally and vertically, at a range of 1 mile. Though traditional instrument errors, such as reading errors, are reduced or eliminated by the Zeiss, other potential error sources do exist. Because of the long survey distances, the instrument must be carefully leveled and aimed. Temperature and atmospheric pressure differences which

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* W. A. Birkemeier and C. Mason. 1984 (Mar). "The CRAB: A Unique Nearshore Surveying Vehicle," Journal of Surveying Engineering, Vol 110, No. 1, pp 1-7.

affect the refraction of light can also have an impact on accuracy.

10. It usually takes about 15 min to initially set up the Zeiss. Approximately 10 sec are required to aim, shoot, and record each data point. A typical survey of 30 points over a 2,000-ft-long profile line takes about 35 min. Because the actual coordinates of each point are displayed, the CRAB can be kept on a predetermined course to within several feet. Once a survey is completed, the solid state memory is removed from the instrument, and the data are transmitted by a Zeiss interface directly to a computer. A useful feature of the Zeiss system is its ability to record additional pieces of information at every point. This has been important for manually entering the angular tilt of the CRAB which occurs on steep sections of the beach. This tilt is automatically compensated for when the data are processed.

11. Advantages of the CRAB/Zeiss system are the small crew, the direct nature of the measurements, the ability to traverse the entire profile, and the ease of data processing. The CRAB can serve also as a general purpose platform for other tasks such as sediment sampling and coring. Disadvantages include the discrete nature of the survey points (important points could be missed), lack of portability, and mobility limitations on some types of bottom.

Sea Sled

12. CERC's sea sled/Zeiss system combines many of the advantages of the CRAB with increased portability and reduced cost. Like the CRAB, the sled carries a prism cluster for use witn the electronic total station. The sled is towed by a boat or LARC (Lighter Amphibious Resupply Cargo) vehicle. The use of early sled systems for nearshore surveying required both a boat to pull the sled seaward and a truck-mounted winch to retrieve it*. CERC has improved the system by eliminating the winch and long tow line and by using the electronic total station.

13. The sled consists of a 20-ft-long by 14-ft-wide aluminum pipe frame with 1.5 ft of clearance below the lowest cross member (Figure 2). The frame separates down the middle for easy transport. A 35-ft-long sailboat mast is

* A. H. Sallenger et al. 1983 (Feb). "A System for Measuring Bottom Profile Waves and Currents in the High-Energy Nearshore Environment," Marine Geology, Vol 51, pp 63-76.

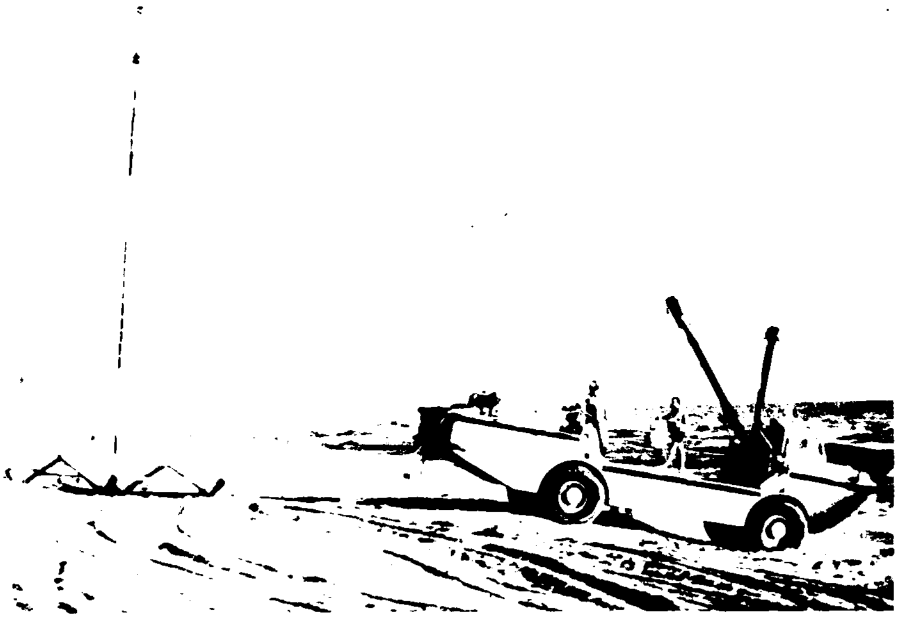

Figure 2. Sled with LARC

attached to the middle crossbar with 3 guy wires. Setup time for the entire sled is about 30 min. Weight of the sled when empty is approximately 500 lb, and lead ingots provide additional ballast during operations. Construction cost of a sled is between $3,000 and $5,000. Although the sled can be towed by a small inflatable boat with a 35 hp outboard, use of a LARC permits surveying in higher wave conditions and simplifies the work required to bring the sled up on the beach. Other boats could be used, but they must be designed for launching and loading from the beach. The operating crew consists of an instrument operator and boat crew (two persons for a small inflatable boat and three for a LARC).

14. In operation, the boat first leaves the sled on the beach. Once safely through the surf zone, the boat begins to tow the sled, stopping at surveying points. Points are selected by the instrument operator who watches the movement of 1-ft gradations on the mast. The procedure for surveying toward shore is similar. The sled is pulled to the outer edge of the surf zone and left while the boat is beached. The tow line is then passed through a pulley block anchored on the beach and attached to a 4-wheel-drive truck. Survey points are then taken through the surf zone as the truck drives down

the beach, pulling the sled toward shore. The upper part of the beach profile is usually taken using a hand-held rod with a prism assembly. When a LARC is used, it replaces both the boat and the truck. Should the sled be snagged, it can be released and towed in the opposite direction using a safety release and tow line which are attached to the mast. On steep slopes, the tilt of the mast is determined by measuring the position and elevation of a second prism on the mast.

15. Operating conditions for the sled are dependent both on the boat and on the weight and height of the sled. The system works well in breaking waves under about 2 ft with an inflatable boat and up to 3.5 ft with the LARC. The sled/Zeiss has accuracy similar to that of the CRAB and is slightly faster, taking about 25 min for a 2,000-ft line. Because it is towed, the sled is more difficult to keep on line than the CRAB. The sled is limited by bottom conditions, although its lighter weight should allow it to be used on softer bottoms than the CRAB.

16. Advantages of the sled system include low cost, portability, accuracy, and its ability to survey through the surf zone. Disadvantages are wave height and depth limitations and the maneuvering needed to keep it on line. Also, elevations at a given point are averaged over the length of the runners, making it difficult to discriminate changes in elevation over short distances.

Hydrostatic Profiler

17. The hydrostatic profiler system was developed by Scripps Institution of Oceanography. Since detailed discussions of the system have been given by Seymour and Boothman* and by Gable and Wanetick,** only a short explanation will be given here. Basically, the profiler determines the difference in hydrostatic pressure between two ends of a fluid-filled tube using an onshore reference pressure transducer and a transducer towed along the bottom. Because of this unique design, the measurements are unaffected by variations in actual water depth. The sensors are connected by a 2,000-ft-long

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* R. J. Seymour and D. P. Boothman. 1984. "A Hydrostatic Profiler for Nearshore Surveying," Coastal Engineering, Vol 8, pp 1-14.

** C. G. Gable and J. R. Wanetick. 1984 (Sep). "Surveying Techniques Used to Measure Nearshore Profiles," Proceedings, 19th Coastal Engineering Conference, Houston, Tex., pp 1,879-1,895.

fluid-filled tube/electrical cable assembly fabricated for the system. The distance to each survey point is determined by measuring the length of tube/cable assembly retrieved as it is winched shoreward. The components of the system are shown in Figure 3. The estimated cost of the system, excluding the truck and inflatable boat, is between $50,000 and $60,000.

18. In operation the offshore sensor, which is mounted on a small sled (Figure 4), is towed out through the surf zone by a small inflatable boat. After the boat is positioned on-line using range poles, the sled is lowered to the bottom and pulled to shore by the winch (Figure 5). Distance is measured by passing the tube/cable assembly through a pinch wheel distance counter graduated in decimeters. The winch is rated at 130 lb of pull at 3.3 ft/sec.

19. Because of pressure fluctuations in the tube due to fluid acceleration, the profiler must be stopped for readings at specific intervals based on distance. At each point the profiling sled is stopped and kept stationary for 1 to 2 min while the pressure fluctuations stabilize. Some guidance on system performance is provided by a real-time frequency counter which indicates the stability of the signal, whether the pressures are within the measurable range of the sensors, and whether the tube/cable assembly may be "strumming." Strumming refers to vibration of the tube/cable assembly by longshore currents or other exciters and is most noticeable when the assembly crosses a trough or is suspended by a sharp-crested bar. The strumming motion drives a pressure oscillation in the fluid-filled tube that makes reading difficult or impossible.

20. When the profiler's sled is pulled up on shore, it is placed on a previously surveyed reference point in order to tie the data to a known position and elevation. Distance and pressure readings are fed into a Sea Data 12A data logger which records the data on tape for later computer processing. It takes about 120 min to survey a 2,000-ft-long profile line including setup, deployment and retrieval. The hydrostatic profiler can be operated with a crew of two, one person in the boat and one person at the winch. For safety reasons, it is felt that two people should be in a boat towing a cable through the surf zone, so the usual crew size is three.

21. Advantages of the system include its portability, simplicity, and compact size. Though limited by cable length, it is not depth restricted. The small size of the sled also permits its use on many types of bottoms. In the event of a snag it is easily freed by divers. Its main disadvantages are

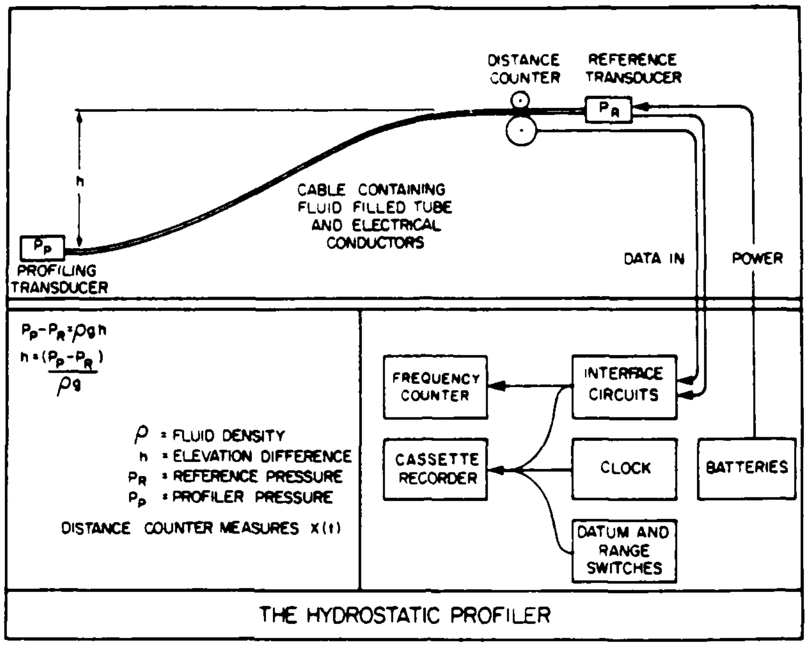

Figure 3. Schematic diagram (after Seymour and Boothman 1984)

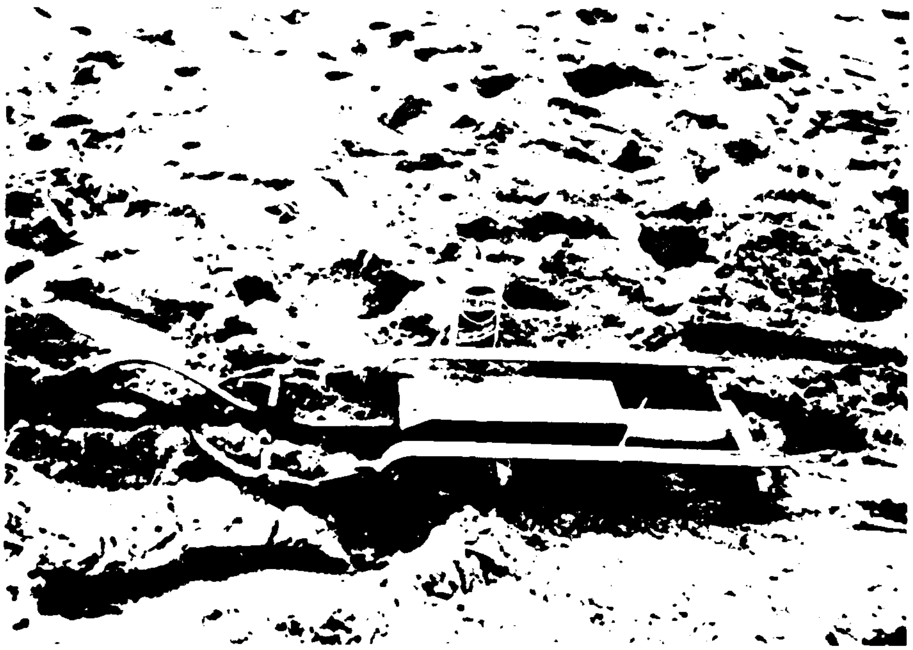

Figure 4. Hydrostatic profiler's sled

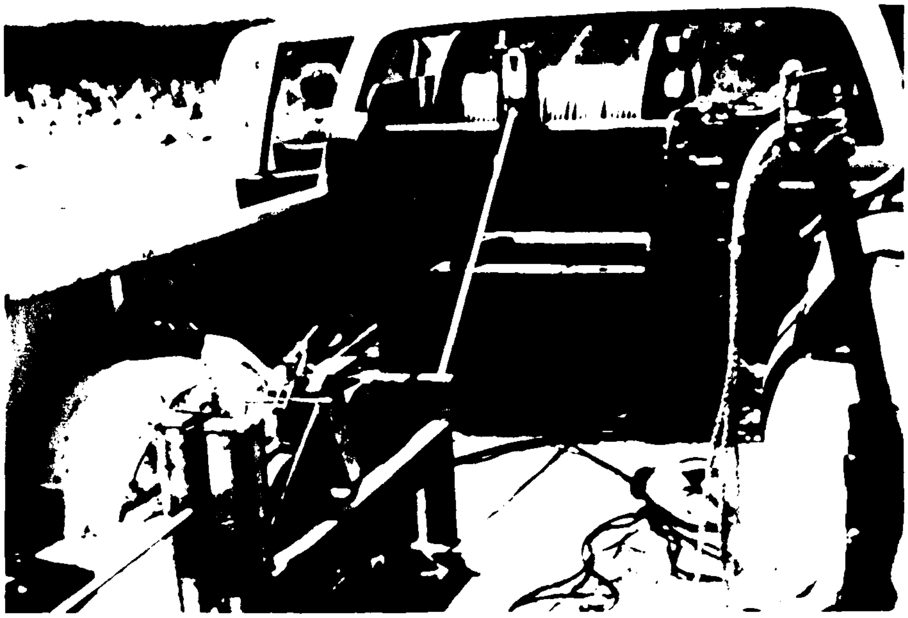

Figure 5. Hydrostatic profiler winch and meter wheel

lack of exact position information, relatively short surveying distance, and susceptibility to strumming and slowness. On gently sloping beaches the hydrostatic profiler may not be able to survey out to closure depth. It must be assumed that the profiler is deployed on line and that it remains on line during retrieval. These assumptions limit use to periods when the cable will not be moved significantly by waves or currents. While use of a small inflatable boat to tow out the profiling sled keeps the operating crew down to three, the size of the boat limits it to operation in waves under 3 ft. The lack of onsite depth or position information makes field checking on the data impossible except in a very gross manner.

PART III: FIELD TESTS

22. The field tests were designed to evaluate each system's ability to survey a known profile cross section, stay on line, and produce repeatable results. The tests were conducted at the FRF from 16-26 July 1984 and on 13 December 1984. Ocean conditions were excellent, especially for testing the towed devices (profiler and sled) and the fathometer. Each test day was characterized by small, long-period waves and moderate to low longshore currents. Table 1 summarizes the test conditions.

Table 1

Summary of Test Conditions

Date	Test	Wave Height ft	Wave Period sec	Current Longshore ft/sec
18 Jul 1984	CRAB envelope Fathometer envelope	1.9	8.8	2.1
19 Jul 1984	Profiler surveys	1.5	16.0	2.0
20 Jul 1984	Profiler surveys	1.5	15.3	1.6
24 Jul 1984	Profiler envelope	1.1	13.0	1.2
25 Jul 1984	Profiler envelope	1.0	14.0	0.2
13 Dec 1984	Sled envelope	1.3	9.4	1.3

23. The repeatability tests were intended to include five repetitive surveys by all systems of the same profile on the same day. This turned out to be impractical due to time, equipment, and manpower limitations. Mechanical problems with the hydrostatic profiler, an over-stretched cable, and air in the fluid delayed the profiler tests and ultimately caused a delay in the sea sled tests. Moreover, the profile first selected and used by the CRAB and fathometer turned out to have a steep nearshore bar and trough that caused strumming of the hydrostatic profiler's tube/cable assembly. A different profile had to be selected and the tests rerun. The slow speed of the hydrostatic profiler caused its envelope tests to be performed on two consecutive days. For all the repeatability tests, except the sea sled, the reference profile shape was determined by careful surveys with the CRAB. Therefore, all stated accuracies are relative to the accuracy of the CRAB.

24. In order to determine the true horizontal position of the profiler,

a small fishing line carried by the CRAB was attached to the profiling sled. This permitted the CRAB to follow the profiler without perturbing its behavior. When the profiler was stopped to take a survey reading, the CRAB was positioned so that its prisms were in line with the sled in the shore-normal direction and approximately 9 ft seaward. The position of the CRAB was then determined with the Zeiss.

PART IV: RESULTS

Vertical Repeatability

25. The digital data from six repetitive surveys of the fathometer are shown in Figure 6. Note how "noisy" the data are, a result of the 2-sec sample rate and the 2-ft waves on the day of the test. The upper portion of the figure represents the difference between the highest and lowest points recorded at a given distance along the profile. The CRAB reference survey is plotted for comparison. It is worth noting that the fathometer profiles are all offset above the CRAB survey at distances greater than 1,000 ft offshore and that the offset increases with distance.

26. The CRAB reference survey was verified through comparison with earlier and later surveys using completely different instrument locations. Therefore, the most likely explanation for the offset is a variation in the speed of sound in water caused by a temperature gradient.* However, the results can be considered typical of what can be expected in normal operations under good conditions, since standard calibration and surveying procedures were followed.

27. Since not all Corps Districts use digital fathometer data, the Survey Branch of SPL hand-smoothed and digitized the original fathometer traces for the tests shown in Figure 6. The resulting envelope is shown in Figure 7. This procedure filtered out some of the wave effects and reduced the envelope width. Smoothing did not improve the correlation to the CRAB data.

28. The repetitive CRAB surveys are shown in Figure 8. Generally, the repeatability is very good; however, on two surveys the CRAB missed the inner bar crest, causing the large difference at a distance of 600 ft. The difference at a distance of 420 ft is due to the selection of discrete points on the steep portion of the profile near the wave step where a large change in elevation occurs over a relatively short distance. However, the horizontal distance is so short that the cross section area associated with the difference is negligible. Also there appears to be one offshore point in error (at 1,500 ft), probably the result of triggering the Zeiss before the prisms were properly sighted.

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* Personal Communication, Glen Boone, Chief, Survey Beach, SAW.

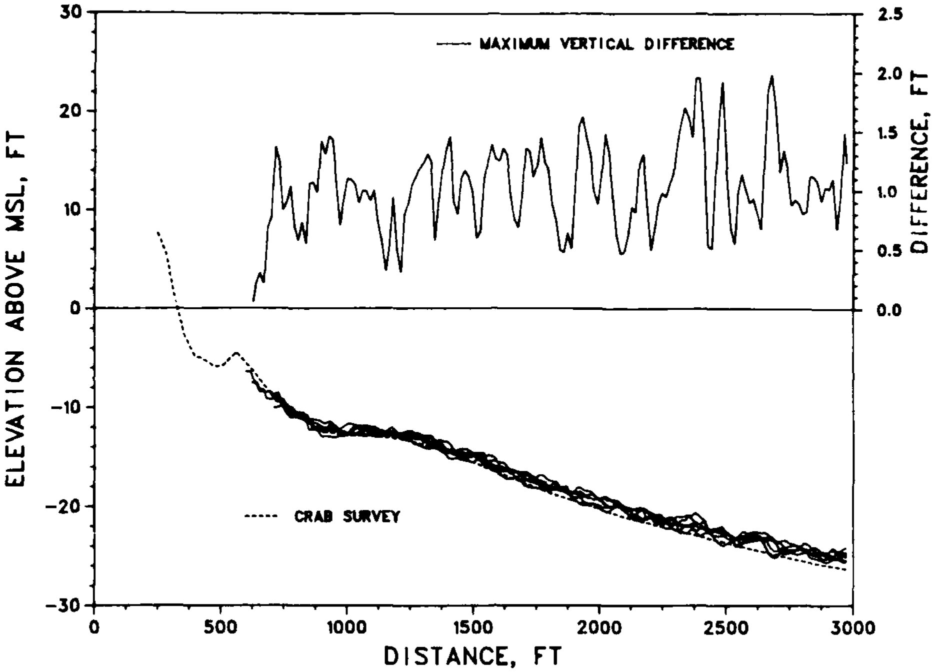

Figure 6. Envelope of six digital fathometer surveys

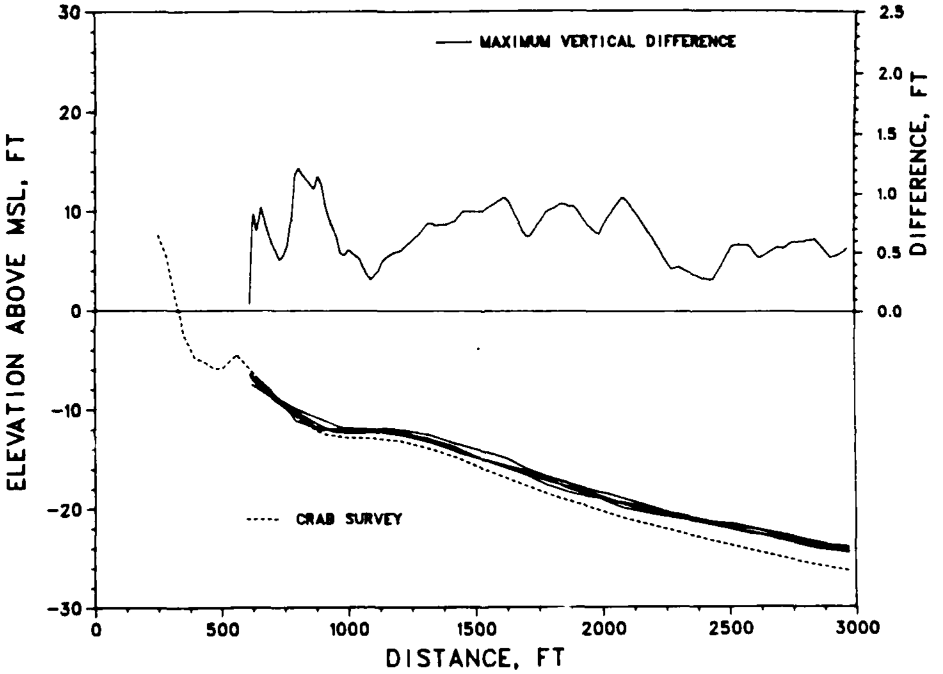

Figure 7. Envelope of five analog fathometer surveys

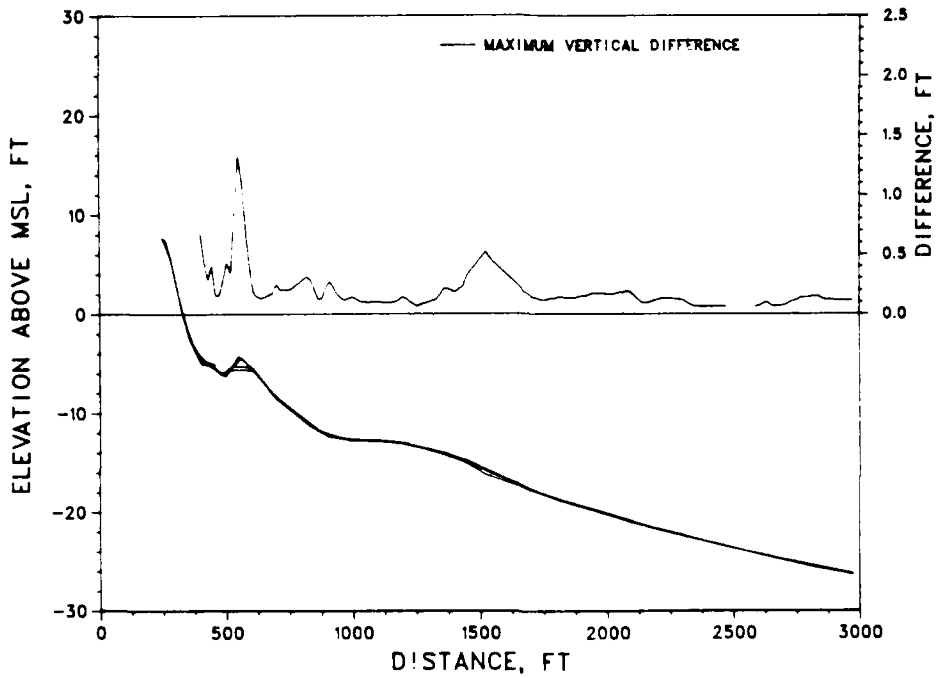

Figure 8. Envelope of five CRAB surveys

29. Figure 9 shows the envelope of sled surveys. Repeatability is very good throughout the entire profile, particularly offshore. Similar to the CRAB, repeatability for the sled is less on steep slopes such as the nearshore bar. At depths greater than 20 ft both the CRAB and the sled show virtually no difference in repeated profiles. This is not surprising since the CRAB and sled systems are essentially similar.

30. Results from the hydrostatic profiler repeatability tests are shown in Figure 10. Repeatability is very good, although there is some noise on the offshore slope of the bar. These differences can be attributed to the system since surveys with the CRAB taken before and after the profiler runs indicate an unchanged profile. A trend of decreasing repeatability similar to that shown by the CRAB and sled is evident on the steep nearshore portion of the profile.

31. Table 2 summarizes the vertical repeatability results. A mean profile was calculated for each method by averaging the measured elevations at specific distances. The differences between the actual survey points and the mean were then computed and averaged at each distance. Finally, an overall average of these individual averages was computed over the entire profile length to give the "average difference from mean." The "average width of

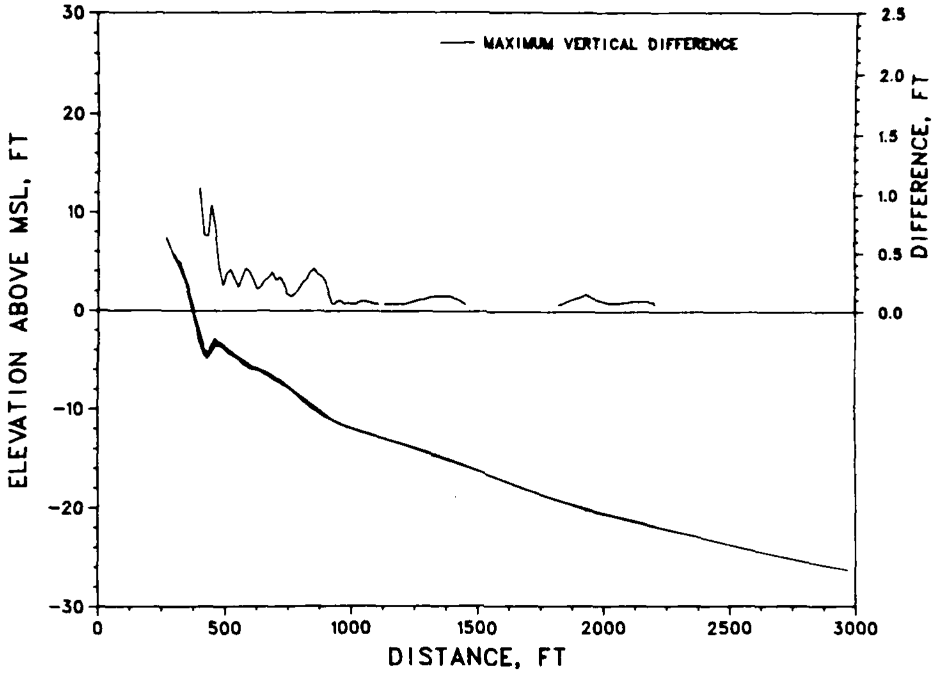

Figure 9. Envelope of five sled surveys

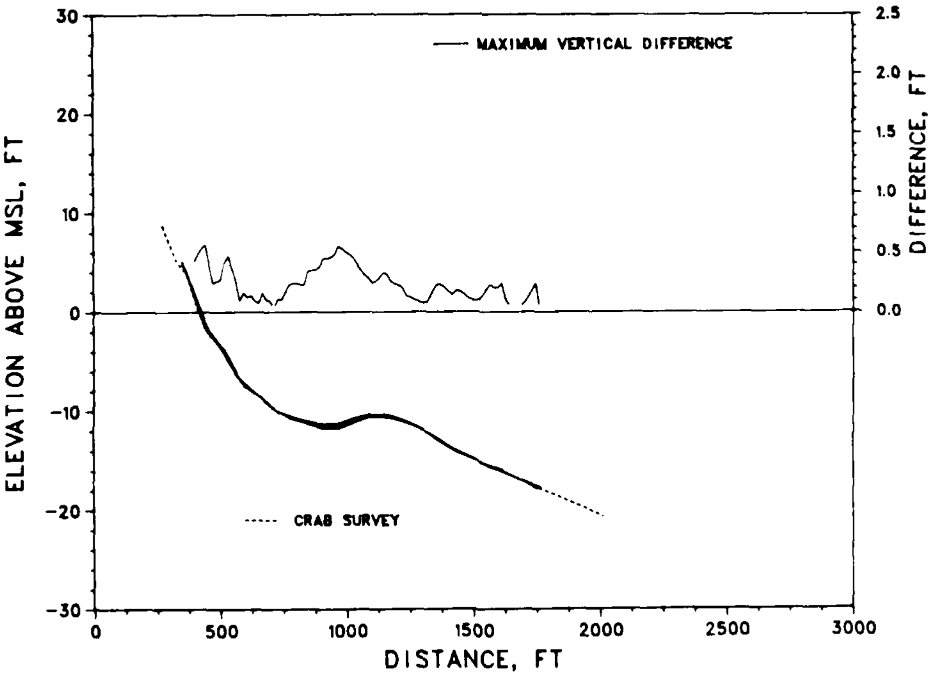

Figure 10. Envelope of four hydrostatic profiler surveys

vertical envelope" is the difference between the highest and lowest measurements at a given distance averaged over the length of the profile. This value measures the average maximum vertical variation. The sled exhibited the best repeatability, with the CRAB second. The hydrostatic profiler was in the same category, but it had absolute measures of repeatability 30 to 125 percent broader than either the sled or CRAB. The fathometer surveys have the worst repeatability. Hand-smoothing of the analog data improved repeatability over the digital data by 50 percent.

Table 2

Comparison of Vertical Repeatability

System	Number of Surveys	Points per Survey	Average Difference from Mean ft	Average Vertical Envelope ft
CRAB	5	210	0.06	0.18
Sled	5	175	0.04	0.10
Hydrostatic profiler	4	116	0.09	0.24
Fathometer				
(1) Digital	6	175	0.30	1.02
(2) Analog	5	160	0.20	0.64

Vertical Accuracy

32. The repeatability results only indicate a system's ability to repeat itself, not its ability to measure the true profile. Vertical accuracies for the hydrostatic profiler and the fathometer were computed by comparison with the CRAB surveys. A comparison between the CRAB and the sled was not made because the CRAB was not on site when the sled profiles were taken. Also, the CRAB and sled are assumed to have comparable vertical accuracies since the same survey system instrument is used on both systems. Mean profiles were calculated for each of the systems from the envelope surveys. The difference from the mean CRAB profile was calculated at 15-ft intervals, and the differences were summed and averaged over the total number of points. Table 3 shows these results:

Table 3

Comparison of Vertical Accuracy

System	Number of Points	Average Difference from CRAB Mean Profile, ft
Hydrostatic profiler	89	0.06
Fathometer survey		
(600-3,000 ft)	138	0.74
(600-1,000 ft)	25	0.31
(1,000-3,000 ft)	113	0.83

33. The difference between the CRAB and hydrostatic profiler is 0.06 ft indicating that a good measure of the true profile shape probably was obtained. In comparison the difference between the fathometer surveys and the CRAB profile was 0.74 ft on the average. This figure is more meaningfully broken into differences at specific distances. The 1,000-ft limit was chosen because that is the approximate distance at which the Beaufort changed engine speeds from 1,000 to 500 rpm. This reduction in rpm changes the squat correction from 0.2 to 0.0 ft. Inside of 1,000 ft, the difference between the profiles is only 0.31 ft, equal to the repeatability of the system. Outside of 1,000 ft, the difference between the CRAB and the fathometer survey steadily increased.

Ability To Stay On-Line

34. Data from measurements of horizontal position are shown in Table 4. The Mini Ranger was used to determine the horizontal position of the fathometer boat, while the Zeiss was used for all other horizontal positioning. No check was made of the Mini Ranger's accuracy. As might be expected, the CRAB was best at staying on-line. The fathometer and sled systems were about

Table 4

Comparison of Surveying Systems Horizontal Accuracy

System	Number of Surveys	Number of Points	Average Distance Off-Line, ft	Standard Deviation, ft
CRAB	5	165	1.6	1.3
Sled	5	118	6.0	5.1
Hydrostatic profiler	8	185	7.8	11.7
Fathometer survey	6	1,057	5.9	4.3

equal and the hydrostatic profiler significantly worse. The large standard deviation value for the hydrostatic profiler, 11.7 ft, is primarily the result of one survey where the profiler was up to 74.6 ft off-line.

35. Because the nature of horizontal position errors varies between systems, it is useful to examine the distribution of errors as shown in Figure 11. A system where the horizontal errors are small and random would show a distribution represented by a small box centered about zero such as shown by the CRAB data. Alternatively, a systematic error would be revealed by an offset box. The fathometer data are equally distributed but centered around a mean position of 5 ft off-line. Horizontal errors for the CRAB, sled, and to some extent, the fathometer can be minimized since they can be quickly corrected during the survey. Also, with these systems, the distance off-line does not affect the offshore distance (assuming shore parallel contours within the envelope of horizontal deviation). This is not true with the hydrostatic profiler which infers offshore distance by assuming that the profiler is on-line. Should a bow develop in the profiler tube/cable assembly due to longshore currents, all points will be off both horizontally and vertically,

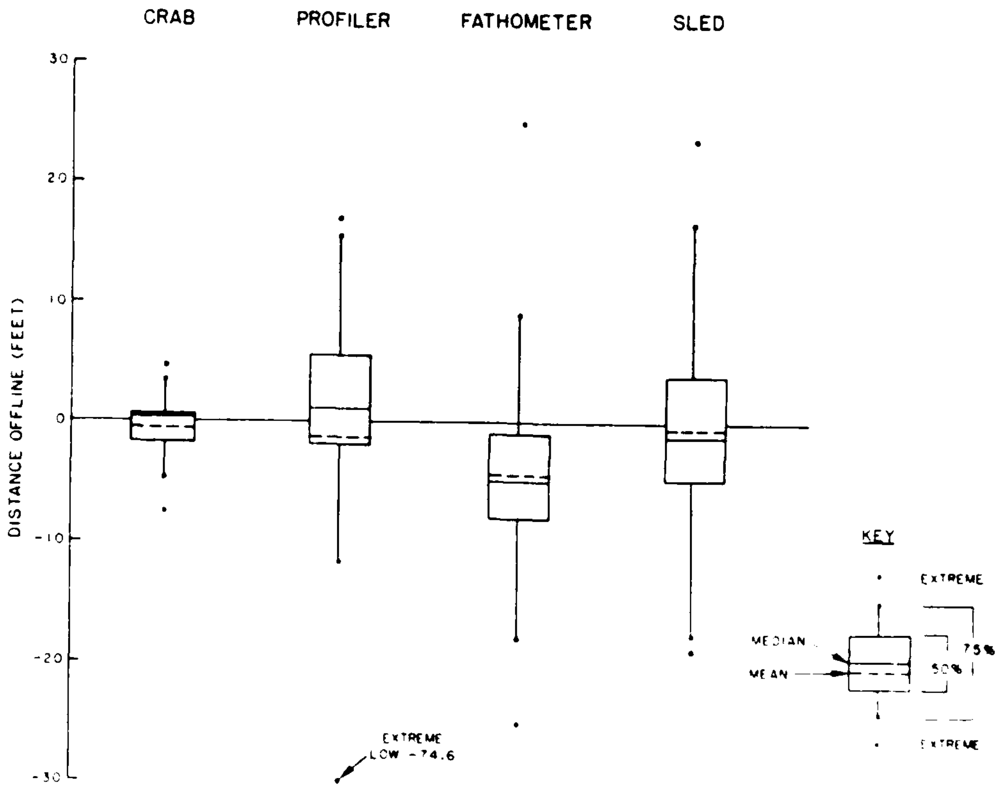

Figure 11. Off-line data (The boxes show the amount of data points falling within the stated percentage.)

and there is no way to measure or correct for it. A severe bow may reveal itself by the angle of the tow line relative to the beach; otherwise, the operator has no indication of this potential problem.

System Operations

36. Table 5 summarizes the operation requirements of the systems based on the performance of the systems during the field tests. The numbers in the table have been adjusted somewhat to provide meaningful comparisons. Setup time is the amount of time needed to get the systems ready for operation after they are on site. With all of the systems except the hydrostatic profiler, it is possible to make multiple surveys from one setup of the land based equipment. Profiling speed is based on 2,000-ft-long profiles spaced 1,000 ft apart during a work day consisting of 6 hr on site. Table 5 indicates that the fathometer survey is the fastest, the CRAB and sled are about half as fast as the fathometer, and the hydrostatic profiler is the slowest system. The fathometer system is actually capable of taking 24 profiles in 6 hr on site, but because of tide constraints surveying is restricted to the 4-hr period during high tide. Consequently, the number presented is based on 4 hr on site. All of the systems require additional surveying of benchmarks and of the beach profile on each line. This is easily and quickly done with existing equipment for the CRAB, sled, and hydrostatic profiler. No time or personnel estimate has been added for an additional land survey crew required to assist the fathometer crew. Most of the fathometer survey setup time, including programming the Mini Ranger, can be done on the way to the site.

Table 5

System Operations

System	Operating Personnel	Setup Time min	Number of Profiles per Setup	Time for One Profile min	Approximate Number of Profiles per Day
CRAB	2	20	7	35	7
Sled	4	20	7	30	9
Hydrostatic profiler	3	30	1	90	3
Fathometer survey	4	45	4	8	16

PART V: DISCUSSION

37. As stated in the introduction, the CRAB, sled, and hydrostatic profiler were all developed to improve the vertical accuracy of surf zone and nearshore surveying over conventional fathometer surveys. Table 6 shows how much of an improvement has been realized based on these field tests. These systems offer significant improvements over the fathometer both in terms of vertical and volumetric measures. Two measures of the fathometer survey system's repeatability are presented in Table 6. Number (1) is repeatability of the system and is the best the system could do if, in the mean, the data correctly represented the true profile. However, systematic errors in the fathometer system can result in more serious volume errors. Consequently, number (2) is the actual accuracy of the system relative to the CRAB as it performed in these tests. While it is possible that the accuracy of number (2) can be improved to approach the repeatability of number (1), the tests were probably typical of fathometer surveys.

Table 6

Effect of Vertical Repeatability on Volume Measurements

System	Average Difference from Mean ft	Volume Error cu yd/1,000 ft
CRAB/Sled	0.06	4,400
Hydrostatic profiler	0.09	6,600
Fathometer		
(1)	0.30	22,200
(2)	0.74	54,800

38. The volume errors were calculated by multiplying the average difference from the mean by the length of the profile (2,000 ft) and by a 1,000-ft-length of beach. This beach length is a common measure used by engineers and scientists when referring to beach changes. The volumetric errors produced by the fathometer may be as great as or greater than real beach changes that may typically occur. Though future improvements in data processing, on-site tide gages, and motion compensation have the potential to improve the accuracy of fathometer surveys, they still will not be able to traverse an active surf zone.

PART VI: SUMMARY AND CONCLUSIONS

39. An overall summary and evaluation of the tested systems is presented in Table 7. The CRAB has excellent vertical and horizontal accuracy, moderate survey speed, reasonable distance limits, and can work in high waves out to depths greater than required for most nearshore surveying applications. It is limited to relatively hard, obstruction-free bottoms and is not easily transported. The sled has most of the CRAB's advantages and disadvantages but is much less expensive and portable. The sled averages point elevations over the length of its runners, a potential problem on a small percentage of the profiles. The hydrostatic profiler has good vertical accuracy under ideal conditions, is easily portable, and not limited by depth. However it is slow, limited by distance (profiles may not extend to closure depth), limited to operating in low waves and moderate currents, has trouble on profiles with steep bars or troughs, needs obstruction-free bottoms, and has very limited capabilities for on-site data quality review. The fathometer surveying system has the poorest vertical accuracy and is expensive. However, it is fast, can survey out to greater distances and depths than the other systems, and it is not affected by bottom conditions.

Table 7

Summary of Survey System Characteristics

Characteristic	Crab	Sled	Hydrostatic Profiler	Fathometer Survey
Vertical accuracy*	3	3	4	8
Horizontal accuracy*	2	3	6	4
Survey speed*	5	5	9	3
Distance limits	5,500 ft	5,500 ft	2,000 ft	26,000 ft
Wave limits	6 ft	3 ft	2 ft	4 ft
Depth limits	<30 ft**	<30 ft**	NA	>5 ft
Other limitations	Bottom Type	Bottom Type	Bottom Type	NA
Initial cost*	8	2	6	9
Portable	No	Yes	Yes	Yes
Operating crew	2	4	3	4

* Based on a qualitative scale of 1-10; 1 best--10 worst.
** Values for configuration tested. Deeper limits are practical.

40. Selection of the survey method to use for a particular site must be based on the specific manpower, budget, time, and accuracy requirements. Based on this evaluation, the sea sled may be the best choice overall for accurate surf zone and nearshore surveying. The cost and lack of portability prevent the CRAB from being considered for most applications. The hydrostatic profiler under ideal conditions has the vertical accuracy needed, but its many limitations and susceptibility to the physical environment would appear to make it impractical for general production surveying work. The fathometer/survey boat combination's speed and ability to work far from shore over any type of bottom make it the system to use for surveying large areas or nearshore areas where high accuracy is not required.

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