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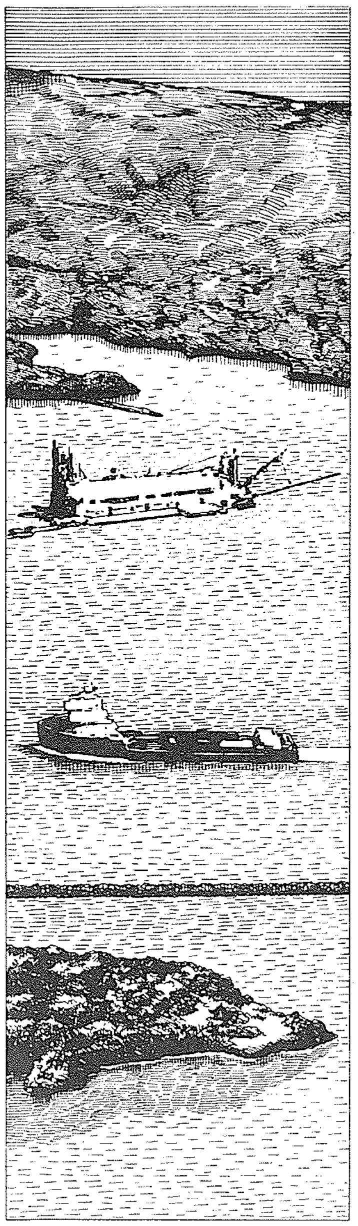

DREDGING RESEARCH PROGRAM

TECHNICAL REPORT DRP-94-2

WATER JETS AS A DRAGHEAD ENHANCEMENT DEVICE

Hydraulic Model Investigation

by

Noble J. Brogdon, Jr., Glynn E. Banks, John A. Ashley

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

June 1994

Final Report

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Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit No. 32473

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Area 1 - Analysis of Dredged Material Placed in Open Waters

Area 2 - Material Properties Related to Navigation and Dredging

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Dredging Research Program Report Summary

Water Jets as a Draghead Enhancement Device; Hydraulic Model Investigation (TR DRP-94-2)

ISSUE: Dragheads used on hopper dredges are very efficient suction devices when used in free-flowing silts, sands, or gravels. However, hopper dredges have experienced various problems picking up bottom sediments consisting of compacted silts or fine sands in both construction and maintenance dredging operations. The Corps dredge fleet as well as contract dredges leased by the Corps strive to maximize densities in suction lines at all dredging sites to maintain schedules and cost efficiencies of dredge operations.

RESEARCH: The objective of this laboratory study was to design and test various combinations of water jets and knives attached to the draghead for dredging compacted fine sands. This report describes the methods and procedures used in this development exercise as well as practical guidance in the application of findings from this study.

SUMMARY: Laboratory tests confirmed that dredge production increased with the addition of water jets in a compacted fine sand sediment. The addition of knives or blades to the water jet-equipped model draghead increased production rates even further. Calculations based on energy consumption of the water jet pump for various size jets versus volume of material removed provided mixed results. Based on high overall dredge cycle cost, the most erosion-producing draghead enhancement device within reason is usually warranted.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. National Technical Information Service (NTIS) report numbers may be requested from WES Librarians.

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Point of Contact: Mr. Banks, Principal Investigator for the work unit.

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Dredging Research Program

Technical Report DRP-94-2
June 1994

Water Jets as a Draghead Enhancement Device

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by Noble J. Brogdon, Jr., Glynn E. Banks,
John A. Ashley

U.S. Army Corps of Engineers
Waterways Experiment Station
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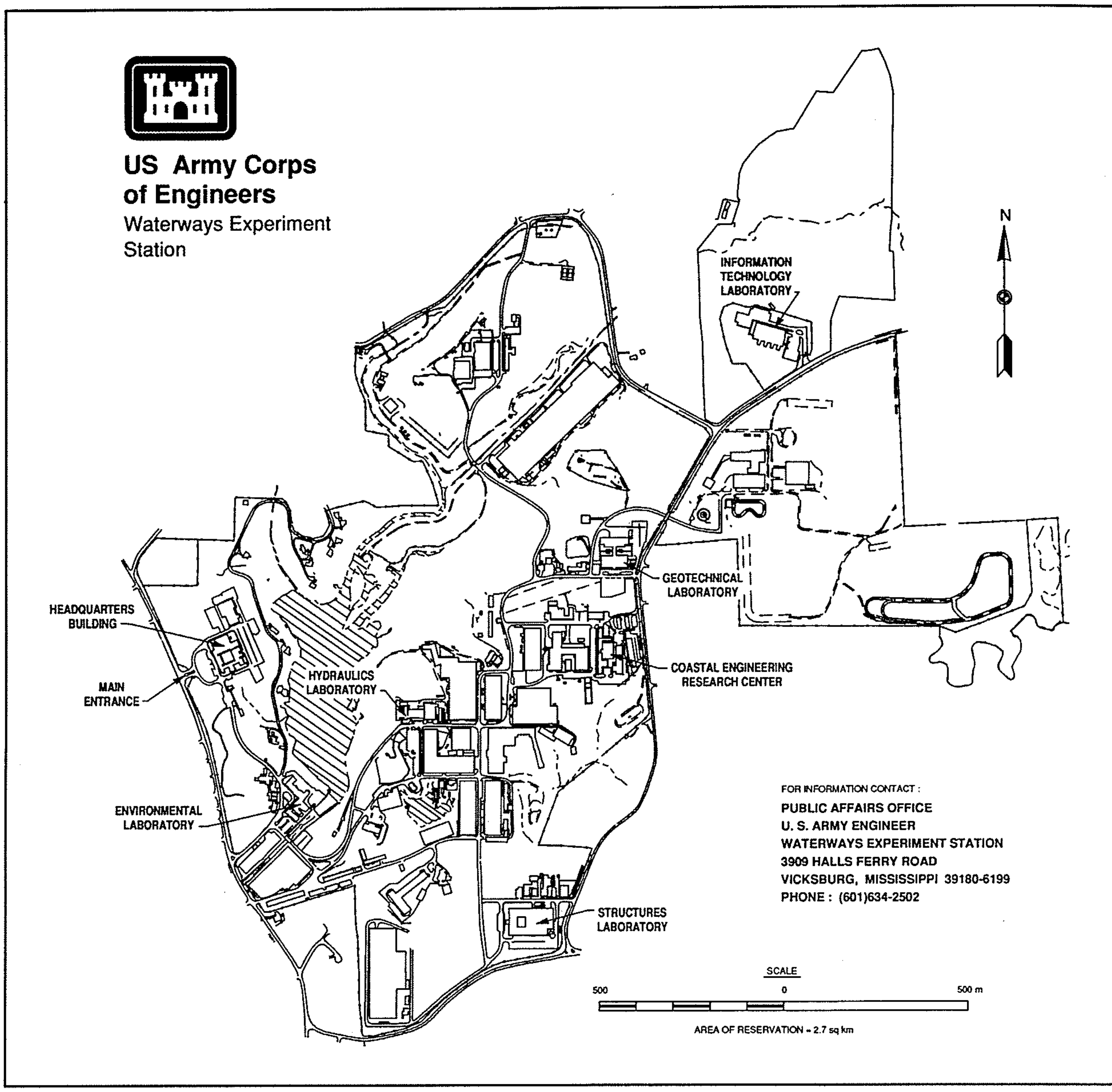

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Preface

The modeling study reported herein was Phase II of Work Unit 32473 entitled "Improved Draghead Design" (IDD) and was performed under the Dredging Research Program sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE). The work was conducted during the period October 1988 to September 1989. Phase I of this work unit, sponsored by the U.S. Army Engineer District, New Orleans, was performed during the period October 1987 to September 1988 and consisted of tests designed to investigate the positioning of knives on two different types of draghead sectional models. Results of Phase I work will be presented in a separate report. Technical Monitors for the DRP were Messrs. Robert H. Campbell and Gerald Greener.

This study was conducted in the Hydraulics Laboratory (HL) of the U.S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. F. A. Herrmann, Jr., Director, HL; R. A. Sager, Assistant Director, HL; Clark McNair, Program Manager, Dredging Research Program; W. H. McAnally, Chief, Estuaries Division (ED), HL; W. D. Martin, Chief, Estuarine Engineering Branch (EEB), ED; M. A. Granat, Acting Chief of EEB during report preparation; J. V. Letter, former Chief of the Estuarine Simulation Branch (ESB), ED; Glynn Banks, EEB, Principal Investigator; and N. J. Brogdon, Jr., ESB, Project Engineer. Physical model technicians who assisted throughout the investigation included John A. Ashley, Charles R. Holmes, and John T. Cartwright, all of ESB. Mr. Attlee Graves of Instrumentation Service Division, WES, provided instrumentation support throughout the study.

This report was prepared by Messrs. Brogdon, Banks, and Ashley. Mr. Martin was the Technical Manager for Problem Area 3, "Dredge Plant Equipment and System Processes."

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

For further information on this report or on the Dredging Research Program, please contact Mr. E. Clark McNair, Program Manager, at (601) 634-2070.

Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
feet of water (39.2 °F)	2.98898	kilopascals
gallons (U.S. liquid)	3.785412	cubic decimeters
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	25.4	millimeters
miles (U.S. statute)	1.609344	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
square inches	6.4516	square centimeters

Summary

Water jets and knives are being used successfully by commercial dredges. However, benefits realized by their installation have never been documented in controlled laboratory tests. The purpose of this report is to present data obtained from controlled laboratory tests for conditions consisting of (a) four types and sizes of nozzles and water jets, (b) two angles of attack, (c) two heights above bed, and (d) four different pressures at the nozzle head.

The tests reported herein were conducted in a U.S. Army Engineer Waterways Experiment Station Hydraulics Laboratory flume 60 ft long by 10 ft wide by 4 ft deep. All the apparatus used in tests were mounted on a carriage that traversed the flume at a speed of 1.0 mph. In an effort to reduce or eliminate similitude problems, all nozzles/water jets and knives were of prototype dimensions. The model draghead was simulated using a full-scale section from the tail section of a California type used by the dredge *Wheeler*. The draghead section used in the tests reproduced only a single side port opening.

Data presented herein show that production rates in fine compacted sand would be increased with the addition of nozzles or water jets, and that further increases would generally be realized when knives are added in front of the nozzle or water jets.

The analysis of water jet efficiency versus horsepower requirements revealed that lower pressure water jets were more energy efficient, but that the overall high cost of dredge operation may overshadow this cost savings especially when dredges have to travel a long distance to the disposal site.

1 Introduction

Background

The dragheads used on some of the U.S. Army Corps of Engineers hopper dredges were designed in the 1930's without the benefit of modern technology. These dragheads have been improved throughout the years with a whatever-works approach. As the navigation channels are deepened and maintained throughout the United States, more demands are being placed on the entire dredge plant to maintain and often increase its production in all types of bed material. Compacted fine sands and/or fluid mud in a channel require both special techniques and equipment. The basic problem is that dragheads presently used on Corps hopper dredges do not maintain an optimum production in varying bed material types at various depths.

Phase I of this study concerned positioning of knives in two types of sectional draghead models to increase production in compacted fine sands. Significant increases in model dredge performance were achieved by using 2.0- and 4.0-in.[1] depth-of-penetration bimetal knives or blades placed at approach angles of 30 and 45 deg from horizontal. Production increases from the application of a single blade placed in the line of flow through a single side slot of the model draghead ranged from 23 to 34 percent. Prototype modifications to a standard California draghead on the dredge *Wheeler* were made using the 30-deg approach angles with blade applications of 2.0- or 4.0-in. depth of penetration. Field testing of this design will be conducted later as field conditions warrant the need of a bladed draghead. The modeling results of this work are presented in Banks.[2]

Earlier physical model studies were conducted at the U.S. Army Engineer Waterways Experiment Station during the period May 1959 to April 1963 to investigate various shapes of dragheads. This work is described in Franco.[3]

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[1] A table of factors for converting non-SI units of measure to SI units is found on page viii.
[2] Glynn E. Banks. (1988). "Improved draghead design." *Proceedings, 21st Annual Dredging Seminar,* 20-21 October 1988, Metairie, LA. Texas A&M University System, College Station, TX.
[3] John J. Franco. (1967). "Model study of hopper dredge dragheads; Hydraulic model investigation," Technical Report No. 2-755, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Objective

The overall objective of the Improved Draghead Design work unit was to develop more effective draghead designs for use in areas where compacted fine sands and/or fluid muds are found. The objective of this particular phase of the work unit was to design and test various combinations of water nozzles, water jets, and knives that could be used in draghead design for dredging compacted fine sands.

A secondary objective of this study was to assess the relative efficiency of various arrangements of water jets versus power requirements to provide a designer a basic guide specification procedure for future prototype applications.

Scope of Work

The work described in this report consisted of two major tasks: (a) Task A, the evaluation of standard shelf-available water nozzles and simple shop-fabricated water jets with knives, and (b) Task B, the evaluation of water jets and knives using a sectional model draghead. Initial Task A nozzle tests were conducted with a standard fire hose type nozzle. This nozzle was not practical for field use, but was used to perform preliminary tests. Water jets and knives suitable for actual field use were shop-fabricated for final Task A assessments. Task A tests were conducted to determine the eroding capability of a single nozzle or water jet and knife without the influence of a suction draghead.

Task B tests were conducted using a sectional model California draghead and only the shop-fabricated water jets with and without knives. These tests were conducted to evaluate actual performance of the water jets and knives under the influence of a suction draghead.

2 The Facility

Flume

The flume (Figure 1) was of masonry construction plastered on the inside for waterproofing. Angle iron was attached on top of the flume walls as a track for the carriage. The flume was 60 ft long, 10 ft wide, and 4 ft deep. A 3-in. waterline was used for filling the flume to the desired level, and a 4-in. storm drain with appropriate valves was used to dewater the flume. An overflow pipe attached to the storm drain was installed to maintain a constant water level during testing.

Carriage

The carriage (Figure 2) consisted of a platform that spanned the width of the flume. It was mounted on grooved casters that traversed along the angle iron rails mounted on the flume walls. The carriage moved along a cable anchored at each end of the flume. The cable was wrapped several turns around a grooved sheave under the platform. Turnbuckles, located at each end of the flume, were used to tension the cable to ensure no slippage. A constant-speed reversible electric motor operating through a reduction gear box moved the sheave, which in turn moved the carriage along the cable. The drive sheave was connected to the gear box by a roller chain and sprockets. Carriage speed along the flume could be varied by ratio of the sprockets. Power to the carriage and motors was supplied by overhead travel cables. The model dredging equipment, including pumps, drag arm (suction line), draghead, and discharge line were mounted on the carriage. A 3,000-lb pressure cell (Figure 3) was installed in the cable (tension side) to measure force exerted by the various plans being investigated.

Slurry Pump

The dredge pump (Figure 2) consisted of a 900-gpm centrifugal pump powered by a 20-hp eddy current variable-speed drive motor (500-1,000 rpm at pump shaft). This pump was used only during Task B testing. The drag arm

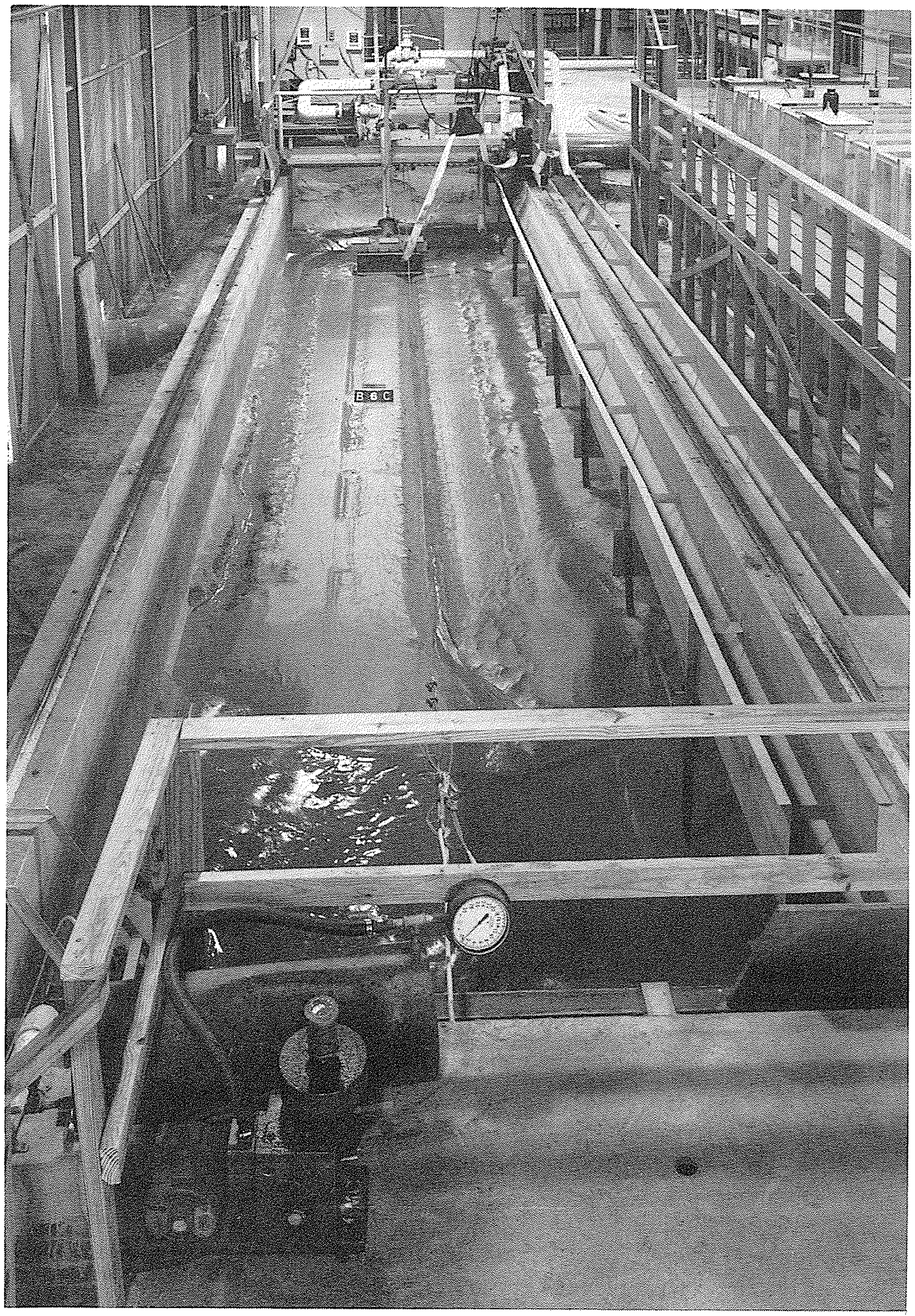


Figure 1. Flume facility

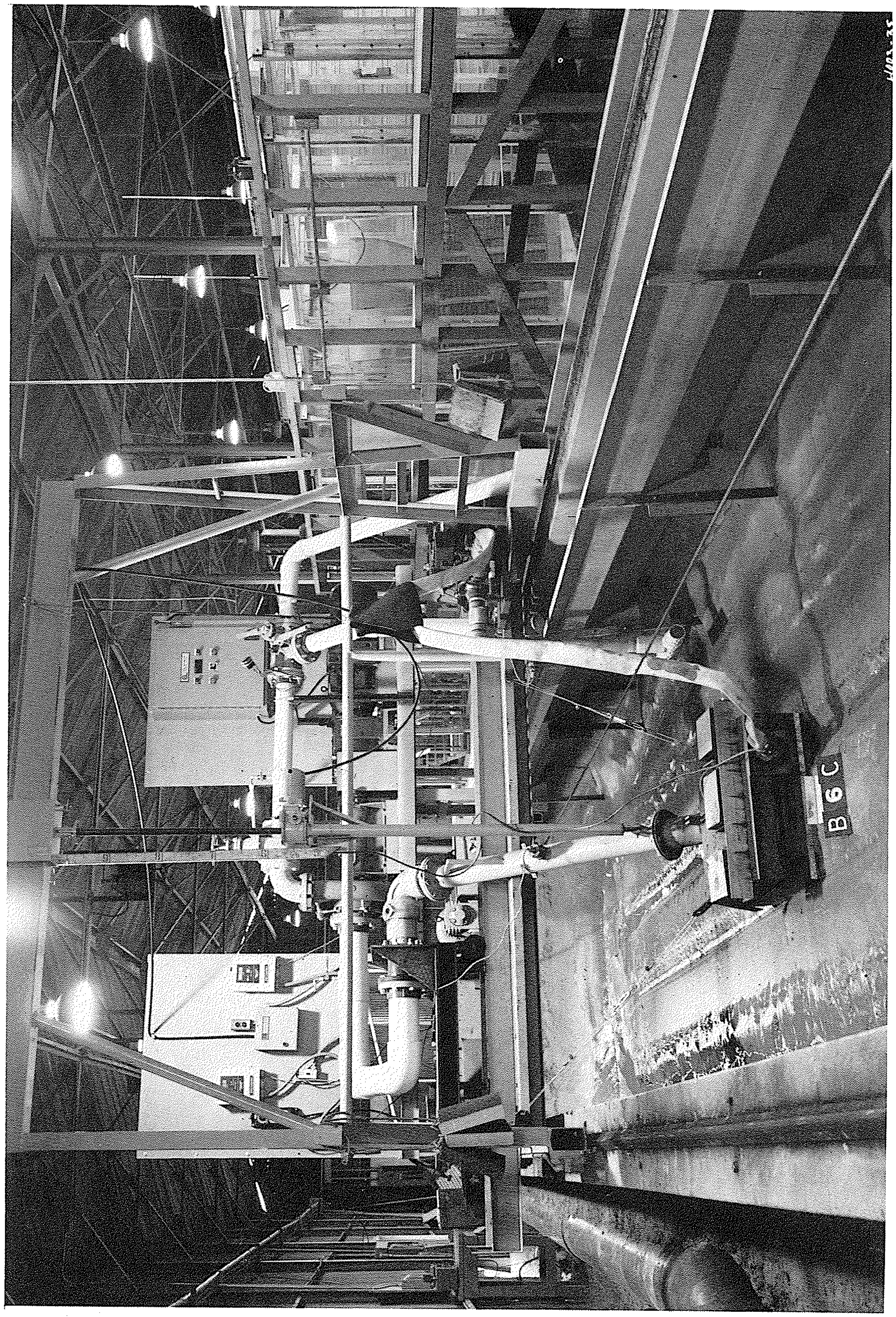


Figure 2. The carriage and pump assembly

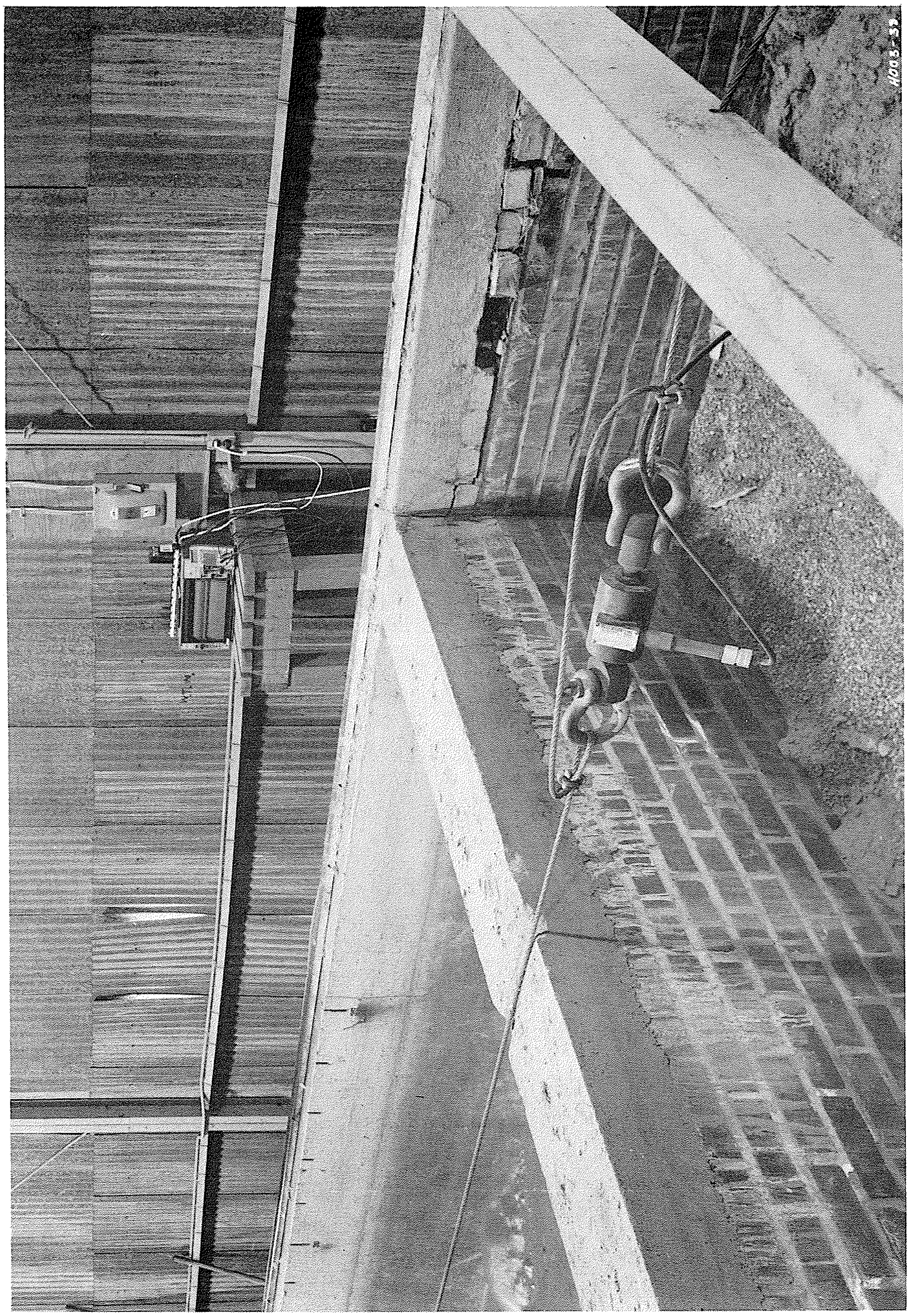


Figure 3. Pressure cell

was connected to the pump through a 90-deg swivel elbow to permit raising and lowering of the draghead. The drag arm for this phase of the study was in a fixed position (near the center of the flume). The pumped slurry was diverted from the master control line to the collection point by activating quick-acting valves. Metal chutes were mounted on the flume wall to divert the pumped flow either to the waste line or to the collection point.

High-Head Fire Pump

A high-head fire pump (Figure 4) was used to supply flow to the nozzle or water jet, depending on the test in progress. This 2.5-in. pump was driven by an 11-hp gasoline engine. The intake manifold extended into the flume water column, and the discharge line was a flexible hose connected to the nozzle or water jet being tested. A standard flowmeter was used to monitor flow rate.

Bed Material

The bed material used for the flume tests was obtained from a dredged material disposal site on the Red River near Marksville, LA. The gradation curve (Figure 5) of the material matches very closely the general characteristics from a typical problem area such as Aransas Pass, Texas. The D_{50} size of the Red River material and a typical problem area is 0.0750 mm (fine sand).

Sectional Model Draghead

The draghead sectional model used in Task B tests reproduced the midsection of a leg from a California draghead used on the hopper dredge *Wheeler*. The full-scale sectional model approach was used to alleviate many of the similitude problems associated with scaling, especially those concerning the knife-bed material interaction. Flow velocity through the model draghead side slot opening reproduced prototype flows as closely as possible. The sectional model (Figure 6) was 30 in. wide by 29 in. long. There was one slot opening (3.5 in. wide). Figure 7 shows the draghead, slot opening, and fire pump hose connection. A knife support plate was attached to the draghead during all Task B tests.

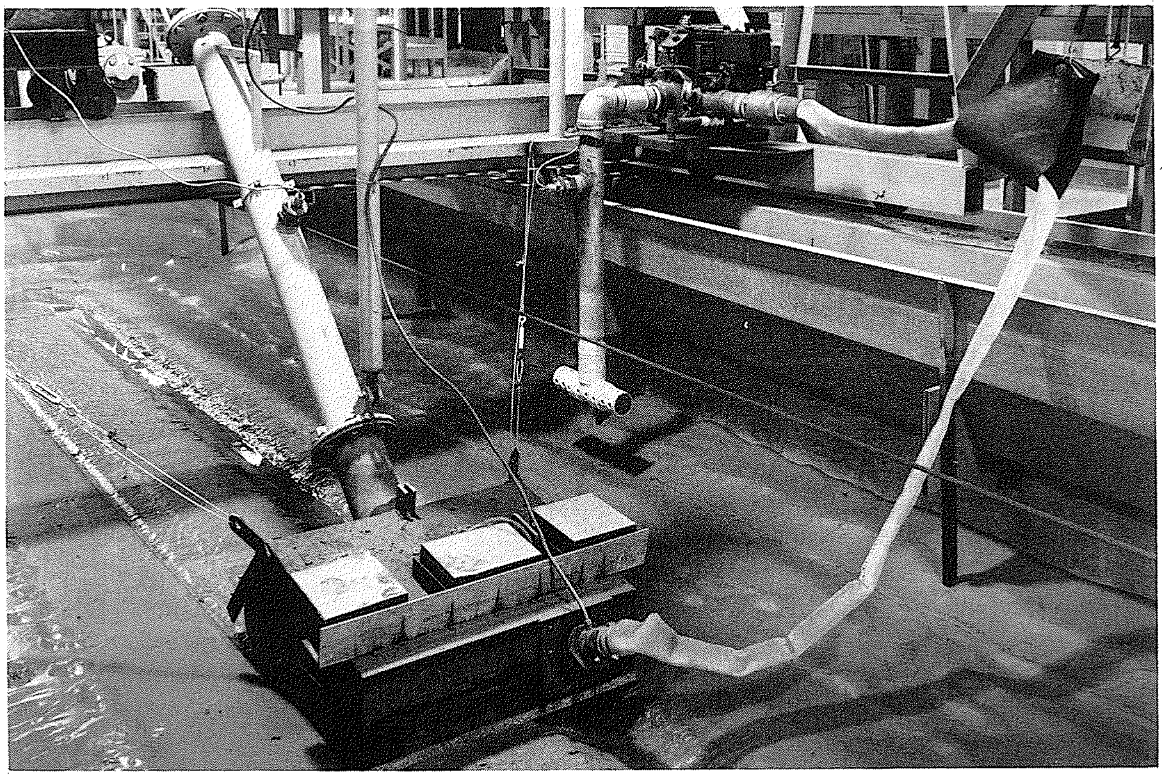


Figure 4. High-head fire pump

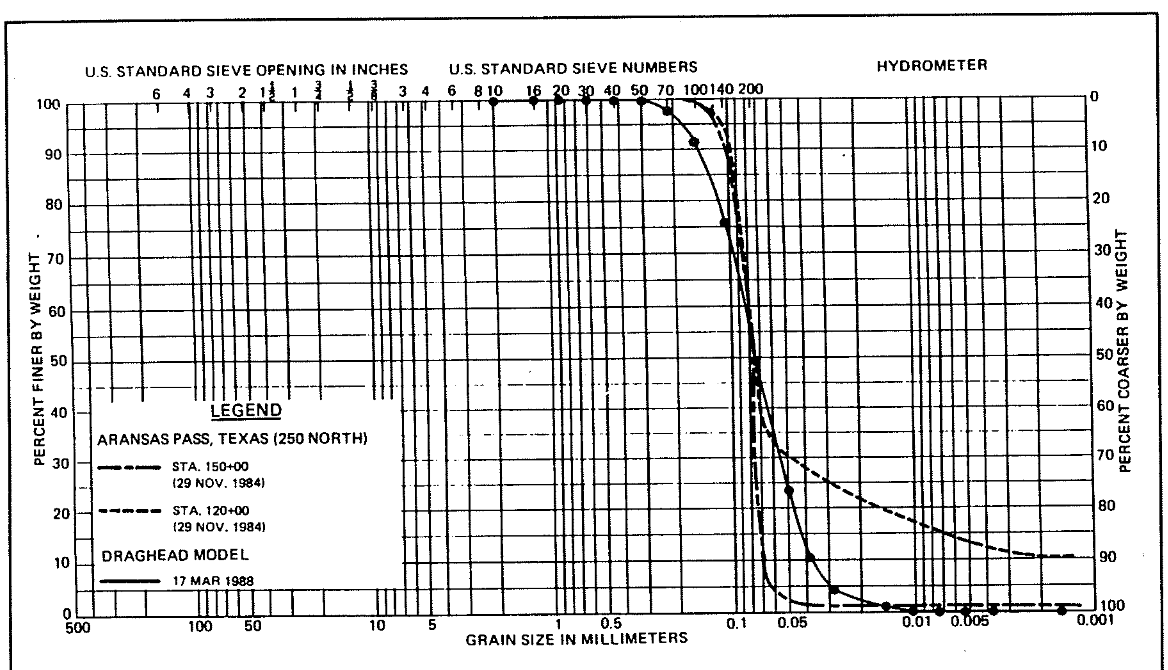


Figure 5. Sediment gradation curve

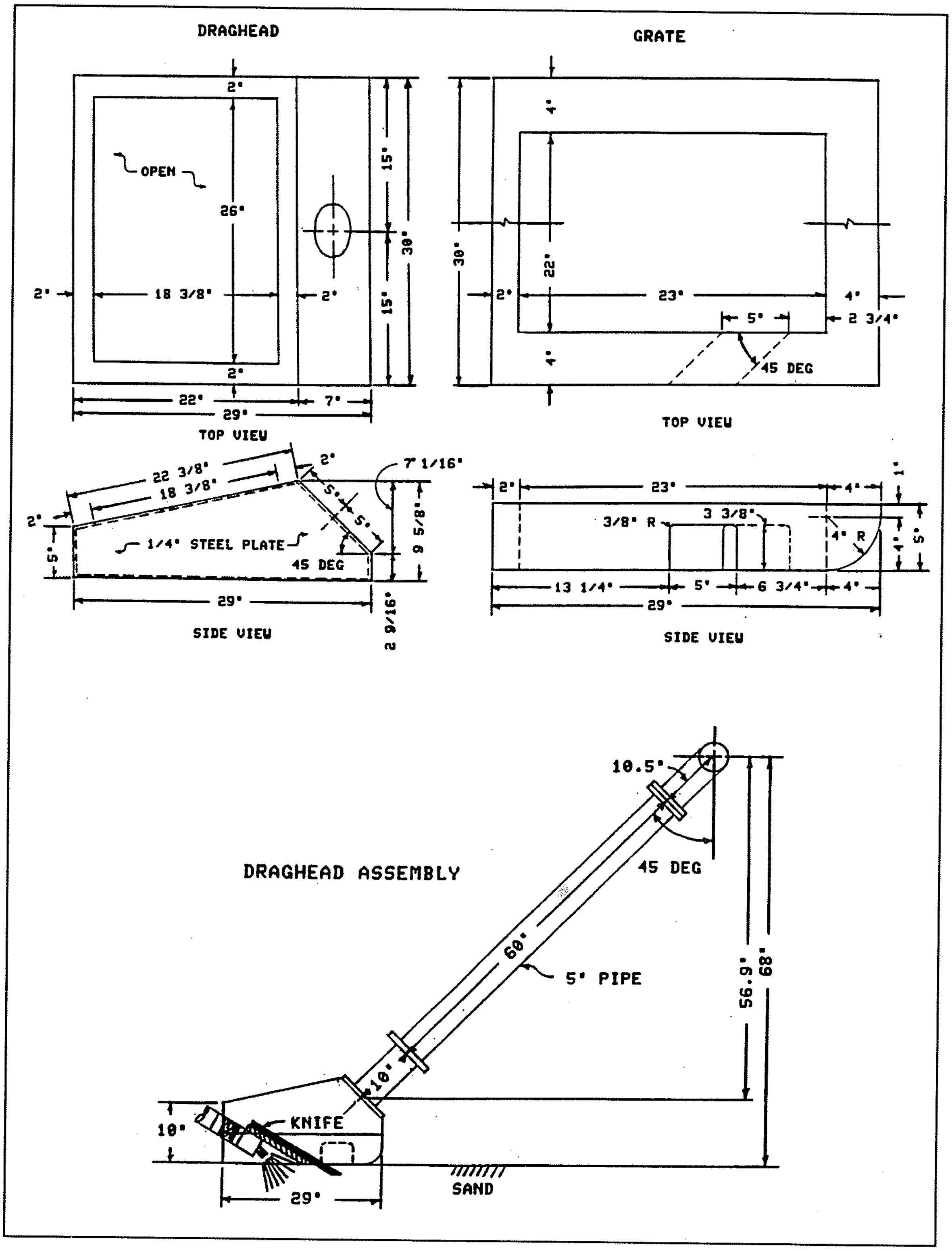


Figure 6. Details of sectional model draghead assembly

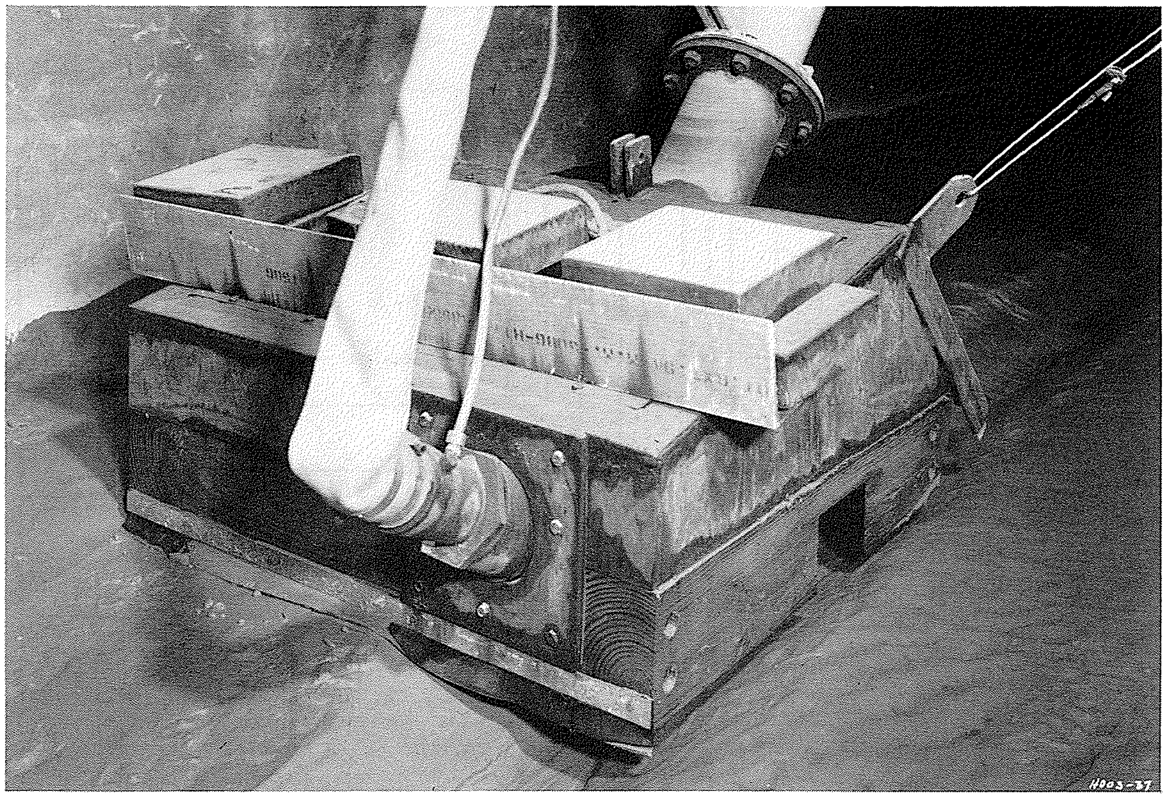


Figure 7. Sectional model draghead

3 Test Procedure

Bed Preparation

The bed material was placed in the flume to a depth of 1.0 ft. Preparation of the bed prior to testing involved several steps:

a. The material was covered with a thin layer of water, and a concrete vibrator (Figure 8) was pulled through the sand bed to remove trapped air and to pack the material.

b. A concrete smoothing device, commonly known as a bull float (Figure 9), was used to smooth and increase compaction of the bed.

c. Final grade was achieved with a specially designed leveling plow (Figure 10).

The desired or final grade of the bed was achieved by removing excess material in very thin layers; therefore, the process required multiple passes of the leveling plow before final grade was achieved. An extensive effort was made in the early stage of the study to achieve the maximum compaction using the tools available. The same bed preparation procedures were followed throughout the study. Following final grading of the bed, cone penetrometer readings were taken at several locations in the bed test section (Figure 11) to ensure compaction was in agreement with base conditions. Detailed undisturbed physical sampling of the top 2.0 in. of compacted materials during Phase I exercises of this work unit revealed cone penetrometer values of approximately 160 for a 1.0-sq-in. cone. This value verified that model bed materials were near the densities of prototype compacted materials commonly found in Aransas Pass. These standards were continued for Phase II exercises. Following the compaction check, a pretest survey of the bed elevation was made at several ranges to be used as a base (original bed elevation) for determining test results.

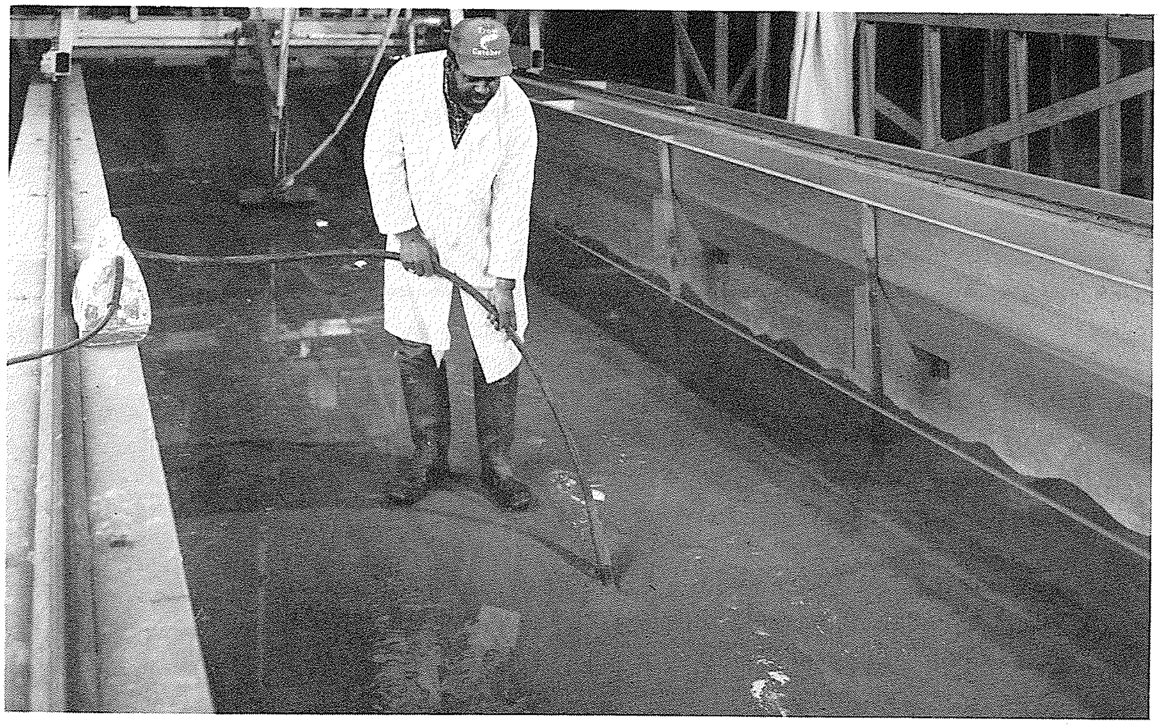


Figure 8. Concrete vibrator

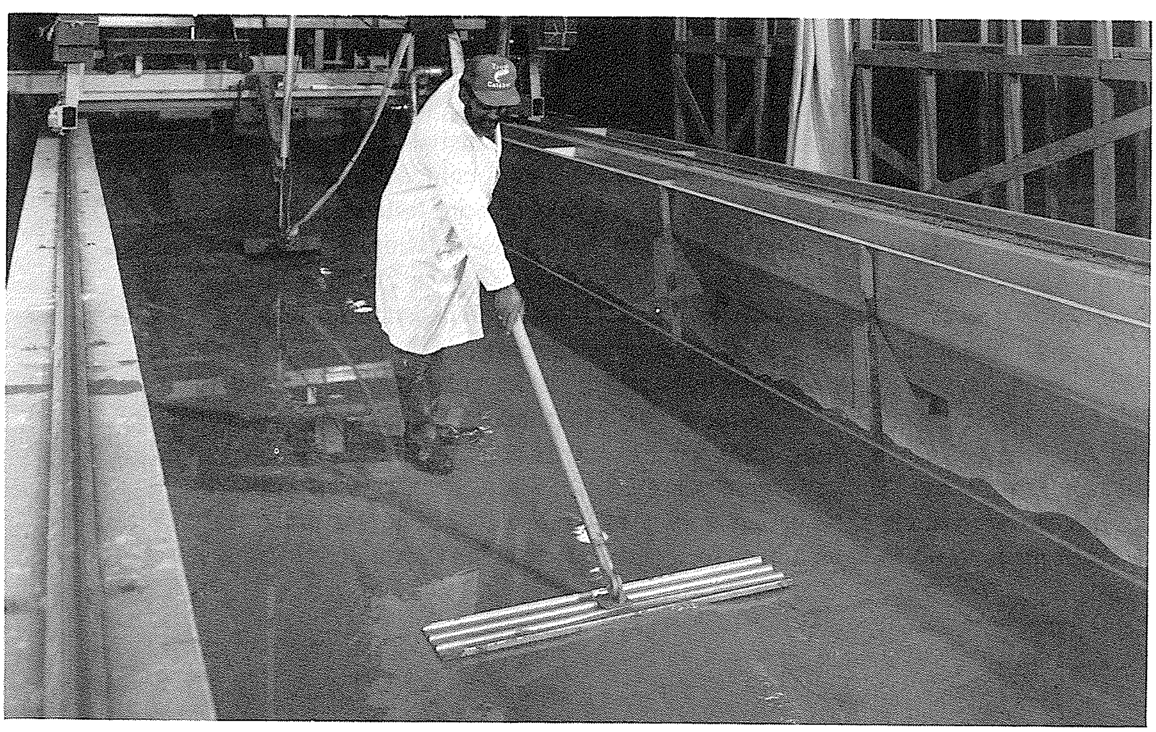


Figure 9. Concrete bull float

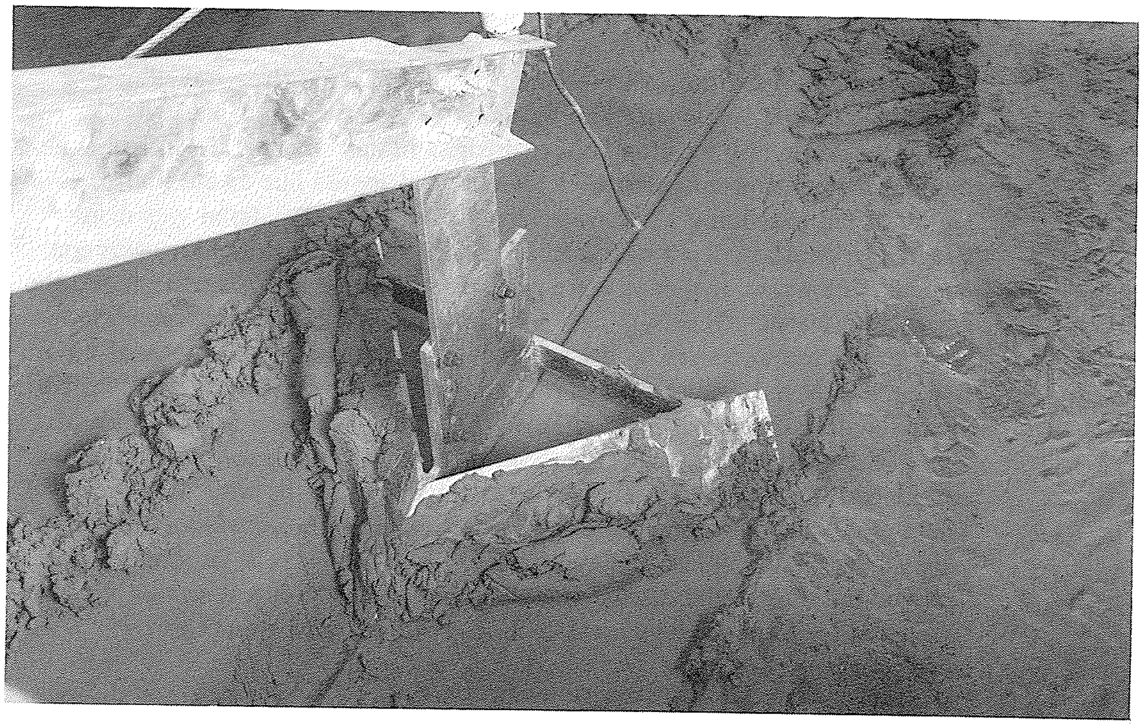


Figure 10. Leveling plow

Figure 11. Cone penetrometer

Testing

All tests reported herein were conducted with the carriage traveling at a speed of 1.0 mph. This speed corresponds to the low side of the typical 1.0-4.0 mph used by existing hopper dredges in this country. Model runs near the high range of prototype speeds were not attempted due to the limited length of the test flume. The water depth over the bed material was maintained at a constant depth of 2.0 ft. Only one test per bed molding was conducted. The pump or pumps were primed (depending on type of test) and the carriage activated. Generally, two identical runs of the same test condition were conducted to ensure model accuracy and repeatability. Results of these two runs were then averaged and plotted. The 10-ft test section was located in approximately the center of the flume. The draghead traveled a distance of about 15 ft (same grade as test section) prior to traversing the test section, and continued for another 15 ft before the carriage and pumps were shut down. Three cross sections along the test section (range +0, range +5, and range +10) were surveyed and the results averaged for later comparison to base profiles. The volume of material displaced or removed in the 10-ft test section was calculated from the average cross-section profile data by using the average-end-area method.

4 Test Description

Task A Nozzle Tests

Twenty-one tests were conducted with either 0.75-in.-inside-diameter (ID) or 1.0-in.-ID nozzles (Figure 12) at angles to the bed of either 30 or 45 deg and at heights above the bed of 1.0 or 4.0 in. Nozzle water pressure was maintained constant during each Task A nozzle test but varied between tests from a low pressure of 20 psi to a maximum pressure of 70 psi. Maximum water pressure for the 1.0-in.-ID tests was limited to 40 psi due to pump capacity. A pressure gage connected to the base of the nozzle by a copper tube was used to monitor pressure. The nozzle tests were conducted to determine optimum angle, height above bed, and nozzle pressure. Table 1 summarizes the Task A nozzle test conditions.

Task A Shop-Fabricated Water Jet Tests

Fourteen tests were conducted with 0.75-in.-ID and 1.0-in.-ID shop-fabricated water jets. All of the Task A water jet tests were conducted with a 2.0-in.-wide knife extending 2.0 in. below the bed. The knife angle was set at 30 deg and was not varied throughout the tests. The optimum angle and position of the knife were established in Phase I testing. Figure 13 shows the model setup for the water jet tests. These shop-fabricated water jets were designed to fit onto a plate that could be attached to the prototype-scale sectional model draghead. These tests were conducted with the water jet set at an angle of 45 deg straight or 45 deg tilted. The tilted series of tests had the jet oriented 45 deg from the bed (horizontal angle) then rotated 45 deg from the vertical to direct flow to the bottom corner of the knife cut, near the slot opening. Figures 14 and 15, respectively, show underside views of the water jet in the straight and tilted positions. Either the straight or tilted position was plugged during a test. Only one position was tested at a time. The height of the water jet above the bed was held constant at 1.0 in. for both the straight and tilted position tests. As with the nozzle tests, the pressure gage was used to monitor water jet pressure, which was maintained constant during each water jet test. Tests at 20, 30, 40, and 70 psi were conducted for the 0.75-in.-ID water jet. Maximum water jet pressure for the 1.0-in.-ID water jet

Figure 12. 0.75- and 1.0-in. nozzles

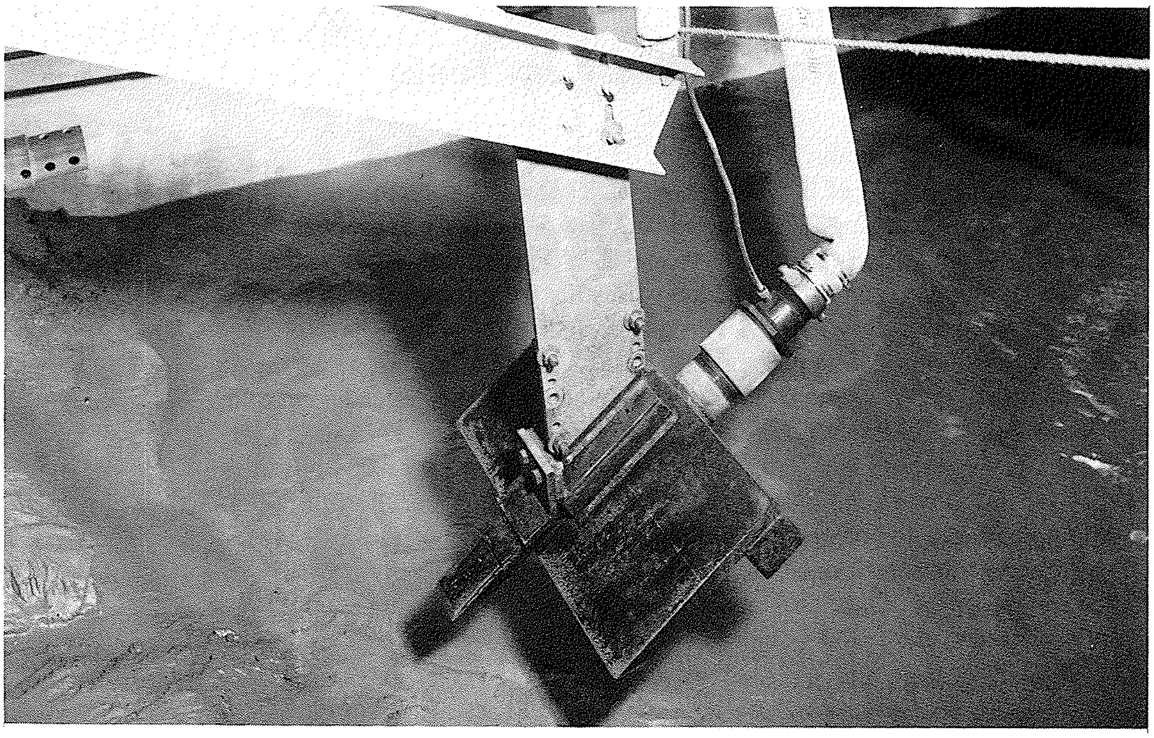


Figure 13. Model setup for water jet tests

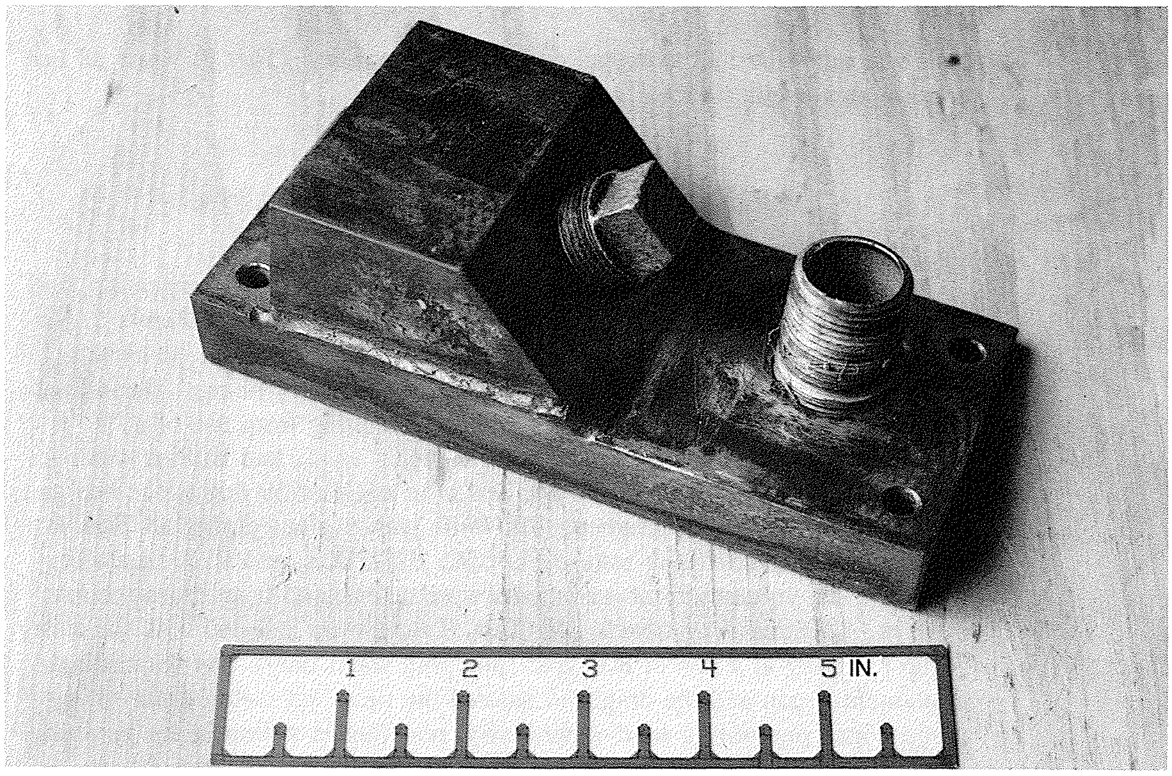


Figure 14. Water jet, straight position

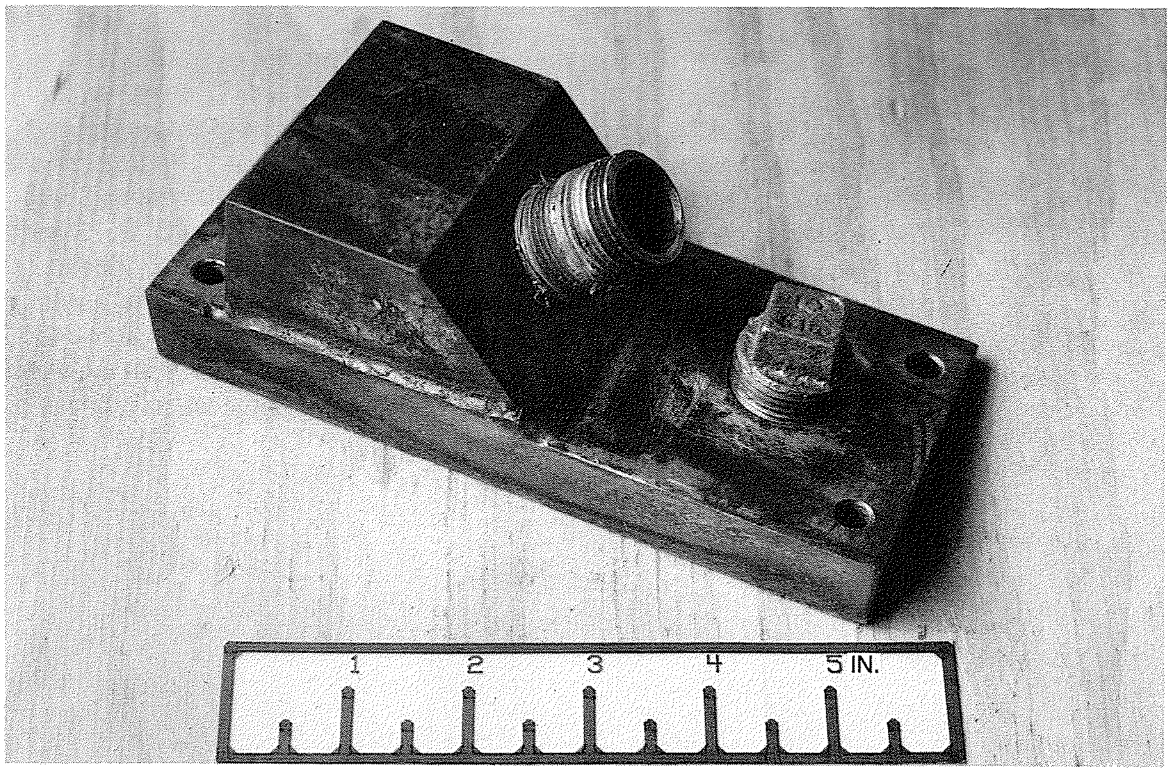


Figure 15. Water jet, tilted position

tests was again limited to 40 psi due to pump capacity. Task A water jet test conditions are summarized in Table 1.

Task B Sectional Draghead Model Tests

This series of tests involved a sectional draghead model, slurry pump, and fire pump. The model setup for this series of tests is shown in Figure 2. In this test series, the material displaced or dredged by the various plans was removed by the suction action of the draghead and slurry pump. These tests were designed to determine dredged volumes resulting from use of a 0.75-in.-ID or 1.0-in.-ID water jet, a knife (when used), and various water jet pressures. When used, the knife was set at an angle of 30 deg to the bed and at a depth of 2.0 in. into the bed. The knife was in place during all Task B tests except base condition tests B2A, B2C, B2D, B2E, and B2F. As with Task A tests, volumetric measurements were determined from cross-section profiles of the resulting trench. All Task B tests were initiated with the slurry pump pumping at a rate of 800 gpm (pumping water only). As the carriage movement began and the draghead entered the sand bed material, the slurry pump began pumping a sand-water slurry, resulting in a drop in the pumping rate. This loaded pumping rate was observed and recorded for each test. Task B test conditions are summarized in Table 2.

Cable Force Tests

Following Task B tests, a series of tests were conducted to determine the force exerted on the carriage cable by several test conditions. The force was measured with the pressure cell. Comparison of force required with and without the water jets on was determined for test conditions B3C, B3D, B5A, and B5C. Force measurements were recorded with the test in progress. About midway through the run, the flow to the water jet was cut off and the resulting force was recorded. The water jet in these tests was always 1.0 in. above the bed in the straight position. No force measurements were made with the water jet in the tilted position. Table 3 summarizes the cable force test conditions.

5 Test Results

General Trends

Due to size and shape of the mechanical sounding disk used to profile each cross section and the relatively steep slopes on the eroded trench, there were minor differences in the results. Slight deviations in expected trends or patterns of erosion can be found throughout the data. The actual results of each test are reported, but the general trend in the results is more important than any specific condition result.

Table 1 contains all pertinent information on Task A nozzle test conditions and test results. Plates 1-6 show average cross-section profiles for each of the designated series of tests.

Plate 1 shows average cross-section profiles (average of range +0, +5, and +10 cross sections) resulting from Tests A2A, A2B, A2C, and A2D. The only variable between these tests was the nozzle pressure and resulting fire pump discharge rate. Test A2A (20 psi, 65.9 gpm) displaced 0.601 cu ft of bed material in the 10.0-ft test section. The maximum trench depth and width were 0.126 ft and 1.4 ft, respectively. Test A2B (30 psi, 82.4 gpm) displaced 0.800 cu ft of bed material. The maximum trench depth and width were 0.157 ft and 1.6 ft, respectively. Test A2C (40 psi, 94.0 gpm) displaced 0.769 cu ft of bed material. The maximum trench depth and width were 0.177 ft and 0.8 ft, respectively. Test A2D (70 psi, 115.0 gpm) displaced 1.360 cu ft of bed material. The maximum trench depth and width were 0.236 ft and 0.8 ft, respectively. The other Task A tests can be analyzed similarly.

Task A

0.75-in.-ID-nozzle tests

A summary of Task A 0.75-in.-ID nozzle tests is shown in Figure 16. These data show that the amount of bed material volume displaced generally increased as nozzle pressure increased. The exception was noted for the test conducted 1.0 in. above the bed, with a 30-deg angle and a nozzle pressure of

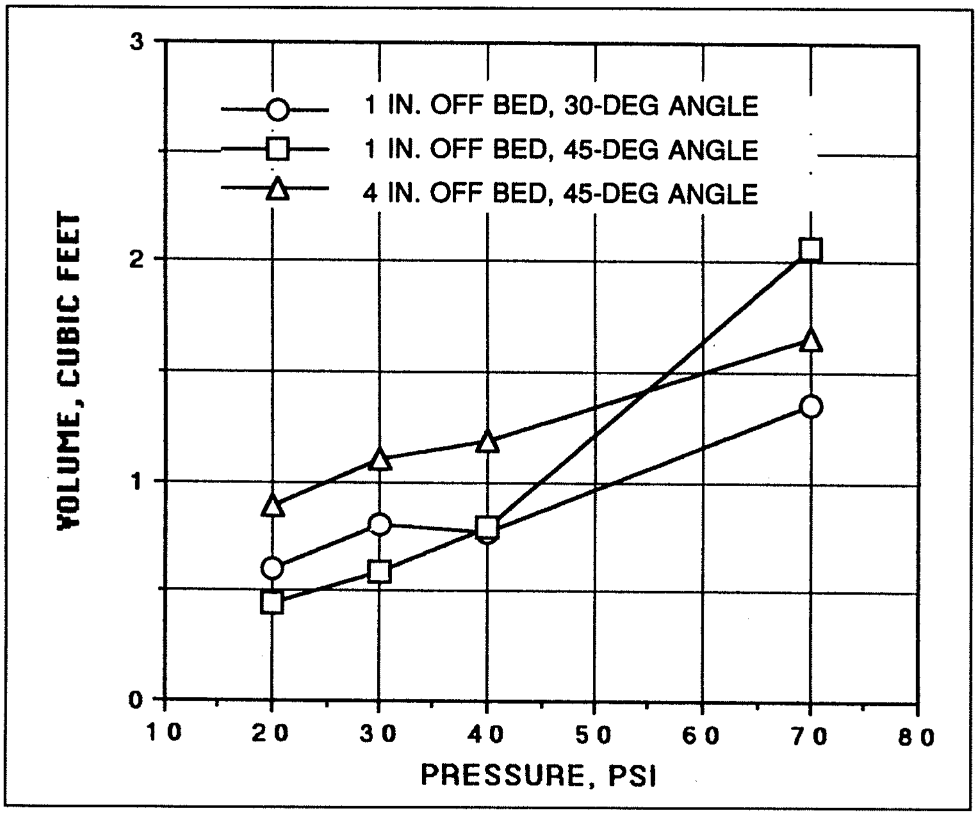


Figure 16. Task A 0.75-in.-ID nozzle tests

40 psi. The volume displaced with the 40-psi test (0.769 cu ft) was slightly less than with the 30-psi test (0.800 cu ft). This series of tests showed that the 30-deg nozzle angle was slightly more efficient at lower nozzle pressures than the 45-deg angle. However, at the high nozzle pressure (70 psi), the 45-deg nozzle angle was best. These data also show that a height of 4.0 in. above the bed was more efficient than 1.0 in. above the bed at lower nozzle pressures, but was not as efficient at the high nozzle pressures.

1.0-in.-ID-nozzle tests

The results of Task A 1.0-in.-ID nozzle tests are summarized in Figure 17. The relation between volume displaced and nozzle pressure (increased displacement with increased nozzle pressure) was generally similar to that observed for the Task A 0.75-in.-ID nozzle tests. In tests conducted 1.0 in. off the bed with a 45-deg nozzle angle, slightly more bed material was displaced at the high nozzle pressures (40 psi) than with the 30-deg nozzle angle. At lower nozzle pressures (20 and 30 psi) the 30-deg nozzle angle displaced more bed material than the 45-deg angle. The tests conducted 4.0 in. above the bed with a 45-deg nozzle angle generally displaced more bed material than those 1.0 in. above the bed.

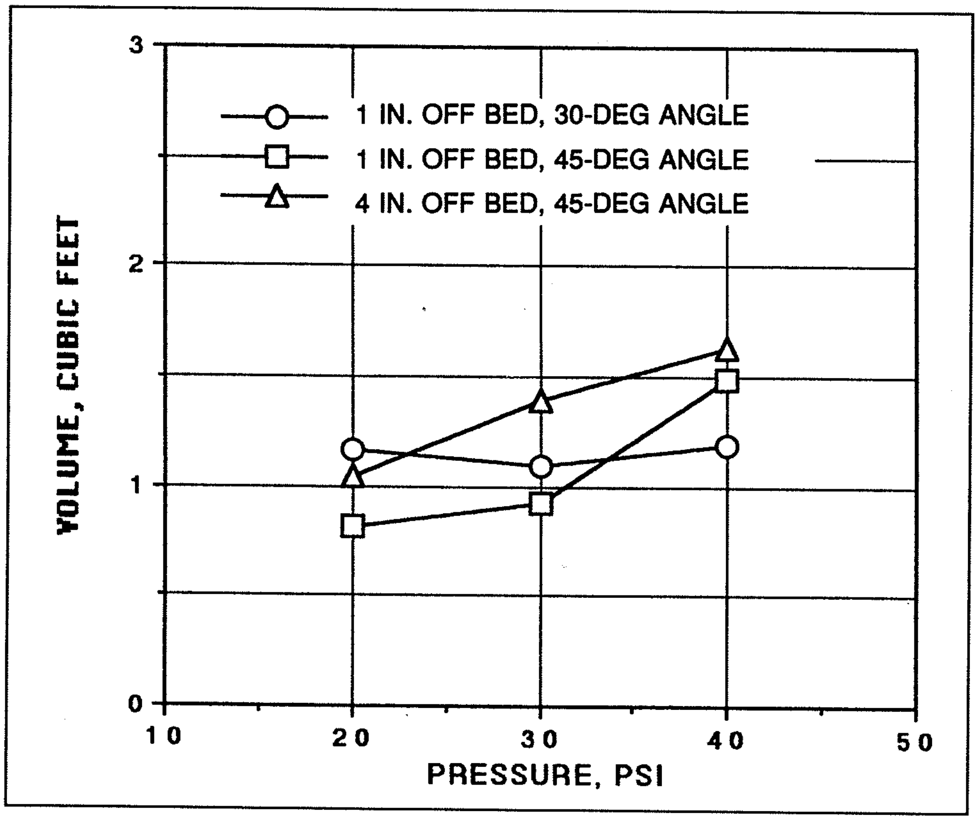


Figure 17. Task A 1.0-in.-ID nozzle tests

Shop-fabricated water jet tests

Table 1 and Plates 7-10 provide Task A Test A4A-A4D, A5A-A5D, A6A-A6C, and A7A-A7C results for water jet size, angle, and water jet pressure with a 2-in. knife mounted at an angle of 30 deg to the bed. The same data logging format as described in the section "General Trends" was used.

0.75-in.-ID shop-fabricated water jet tests. The summary of Task A 0.75-in.-ID shop-fabricated water jet tests is presented in Figure 18. All the 0.75-in.-ID water jet tests were conducted with the water jet 1.0 in. above the bed. The data presented in this figure show the relation between the water jet set in the 45-deg straight and 45-deg tilted positions. Each of these data sets shows, as did previous nozzle tests, that volume of bed material displaced increased with increased nozzle pressure. The water jet positioned in the straight direction was slightly more efficient than the water jet positioned in the tilted direction.

1.0-in.-ID shop-fabricated water jet tests. Figure 19 summarizes Task A 1.0-in.-ID shop-fabricated water jet tests. These tests were all conducted 1.0 in. above the bed with the water jet positioned 45 deg straight or 45 deg tilted. Again, as in the 0.75-in.-ID water jet tests, the 45-deg straight position

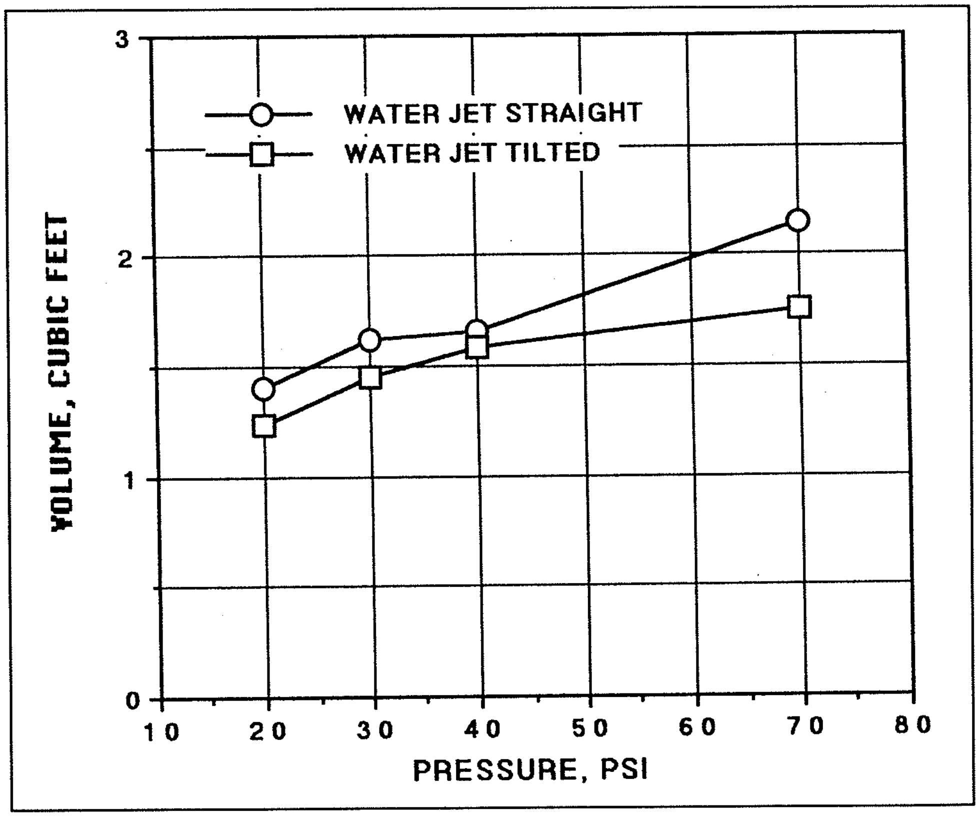


Figure 18. Task A 0.75-in.-ID water jet tests

was better than the tilted position. The volume of material displaced by the water jet with the 30-psi tests was greater than with the 20-psi tests; however, the volume displaced by the 40-psi tests was less than the 30-psi tests. This discrepancy is probably a result of experimental noise since observations during the experiment and analysis of test results did not provide any conclusive evidence of this trend.

Task B

Sectional model draghead tests

The results of Task B tests are presented in Table 2 and in Plates 11-16. Table 2 contains all pertinent information of test conditions and test results. Plates 11-16 show average cross-section profiles resulting from Task B tests.

Plate 11 shows average cross-section profiles resulting from Tests B2A, B2B, B2C, and B2D. Test B2A removed 0.964 cu ft of bed material from the 10-ft test section. The resulting trench had a maximum depth and width of 0.054 ft and 2.8 ft, respectively. The slurry pump dropped from a pumping rate of 800 gpm to 780 gpm when loaded. Test B2B removed 1.582 cu ft of bed material from the 10-ft test section. The resulting trench had a maximum

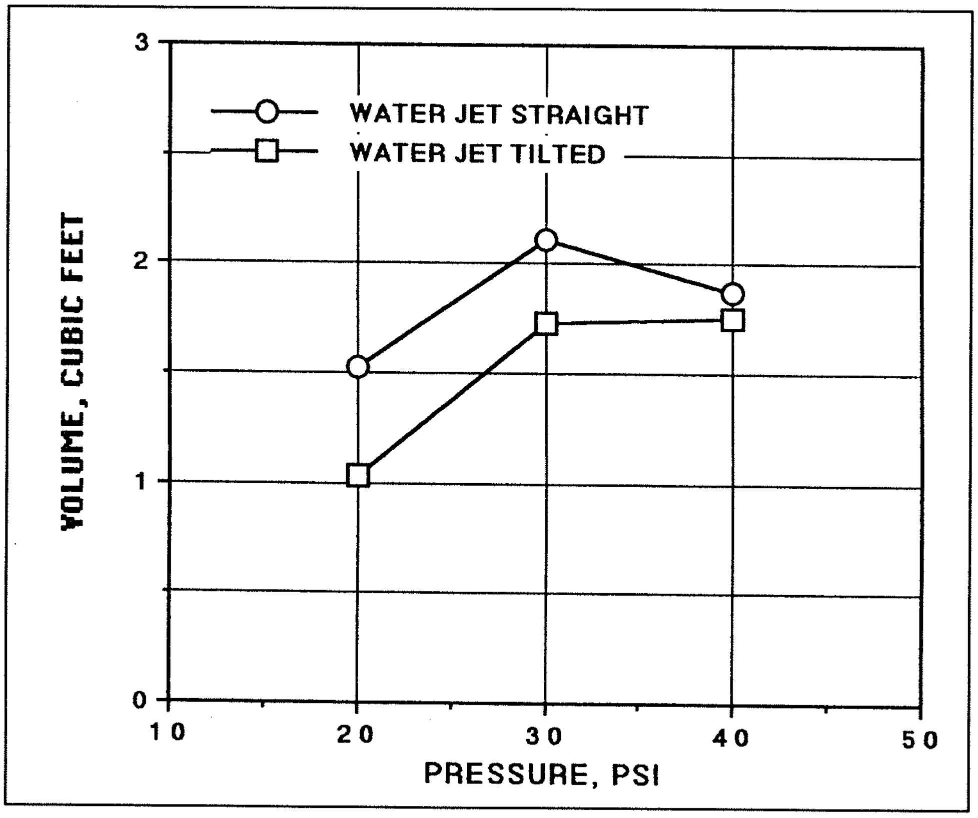


Figure 19. Task A 1.0-in.-ID water jet tests

depth and width of 0.173 ft and 2.8 ft, respectively. The slurry pump dropped from a pumping rate of 800 gpm to 770 gpm when loaded. Test B2C (40 psi, 97.6 gpm) removed 1.847 cu ft of bed material from the 10-ft test section. The resulting trench had a maximum depth and width of 0.232 ft and 2.2 ft, respectively. The slurry pump dropped from a pumping rate of 800 gpm to 742 gpm when loaded. Test B2D (70 psi, 123.0 gpm) removed 3.415 cu ft of bed material from the 10-ft test section. The resulting trench had a maximum depth and width of 0.402 ft and 2.2 ft, respectively. The slurry pump dropped from a pumping rate of 800 gpm to 750 gpm when loaded.

0.75-in.-ID shop-fabricated water jet tests

Results of Task B 0.75-in.-ID shop-fabricated water jet tests are summarized in Figure 20. All Task B tests were conducted with the sectional model draghead and slurry pump. Task B 0.75-in.-ID water jet tests were conducted with the water jet 1.0 in. above the bed in the 45-deg straight or 45-deg tilted positions. Data presented in Figure 20 show that the volume of bed material removed increased as water jet pressure increased. These data show that the 45-deg straight water jet position was more efficient than the 45-deg tilted position.

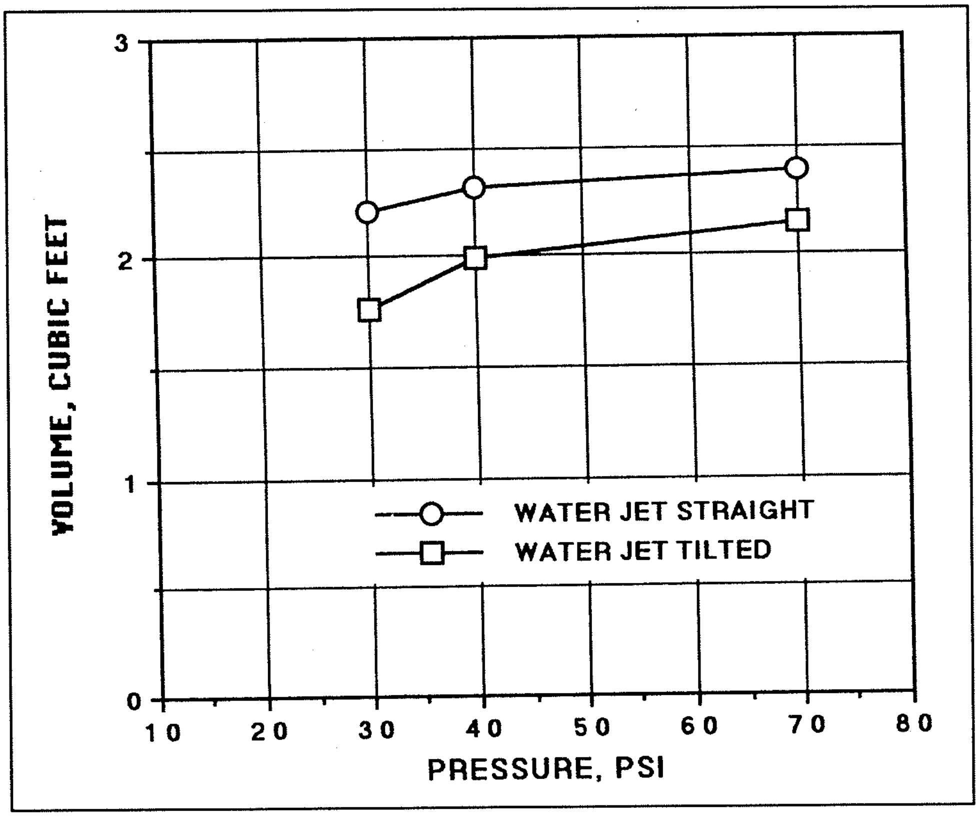


Figure 20. Task B 0.75-in.-ID water jet tests

1.0-in.-ID shop-fabricated water jet tests

Results of this series of tests are summarized in Figure 21. All Task B 1.0-in.-ID water jet tests were conducted with the water jet 1.0 in. above the bed. Data presented in this figure show that the volume of material removed increased as the water jet pressure increased. There was very little difference in volume removed between the 45-deg straight and 45-deg tilted position of the water jet.

Cable Force Tests

The cable force tests were conducted with the water jet in the straight position. No cable forces were analyzed for the tilted water jet tests. Table 3 summarizes cable force test conditions and results. Test FB3C (0.75-in.-ID water jet, straight position, 40 psi) exerted a force on the cable of about 500 lb with the fire pump on. When the fire pump was cut off, a cable force of 530 lb was measured, or an increase of about 30 lb. Test FB3D (0.75-in.-ID water jet, straight position, 70 psi) exerted a cable force of about 550 lb with the fire pump on, and about 500 lb when the fire pump was cut off, or a decrease of about 50 lb. Test FB5A (1.0-in.-ID water jet, straight position,

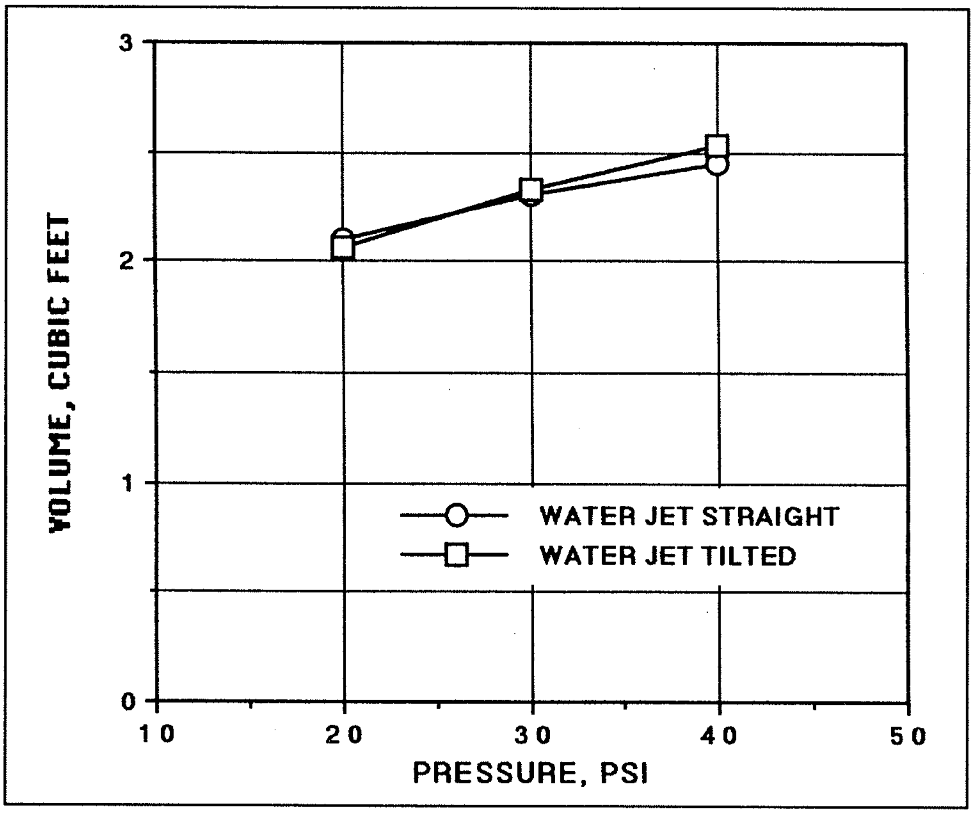


Figure 21. Task B 1.0 in.-ID water jet tests

20 psi) exerted a cable force of about 570 lb with the fire pump on, and about 750 lb when the fire pump was cut off, or an increase of about 180 lb. Test FB5C (1.0-in.-ID water jet, straight position, 40 psi) resulted in a cable force of about 470 lb with the fire pump on, and about 670 lb with the fire pump cut off for an increase of about 200 lb.

The results of the cable force tests were not quantitative since the duration of the tests was not sufficiently long for the force exerted on the cable to stabilize. However, the force measurements give a qualitative comparison of force requirements. In the four tests conducted, only a single test condition (FB3D) resulted in a decrease in the measured cable force when the fire pump or water jet pressure was cut off. These data show that water jets can reduce power requirements to pull a draghead equipped with knives. The exact degree of benefit cannot be concluded from these tests.

6 Prototype Applications Guidance

Test results show that water jets can significantly increase dredging production when a dredge is operating at slow speeds (less than 2 mph). The addition of knives placed in front of water jets further increases the efficiency, as indicated by most test results in this study. These general trends are verified by the range of results as depicted in the following tablulation:

Test No.	Water Jet Size in. ID	Operating Pressure psi	Volume Removed, cu ft	
			Without Knife	With Knife
B2A	No jet or knife installed		1.0	--
B2B	No jet/knife installed		--	1.6
B2C/B3C	0.75	40	1.8	2.3
B2D/B3D	0.75	70	3.4	2.4
B2E/B5A	1.00	20	1.4	2.1
B2F/B5C	1.00	40	1.6	2.5

It is anticipated that knives would tend to increase production at high travel speeds, since knives are sediment displacement devices. Water jet erosion benefits would tend to increase as travel speed decreases, since the jetting forces have a longer time to attack individual particles. These hypotheses are verified by personal communications with operating personnel on the dredge *Sugar Island*, owned and operated by North Atlantic Trailing Company, Oak Brook, IL. This commercial dredge has used cutterhead dredge teeth and water jets on California dragheads for several years.

Horsepower requirements of pumping clear water through the various sizes of water jets used in these tests were calculated by the following equation:

$$Brake\ Horsepower = \frac{flow\ rate\ (gpm) \times head\ (ft)}{3956 \times pump\ efficiency \left[\frac{\%}{100}\right]}$$

These power requirements were used to evaluate the efficiencies of each test condition based on energy consumption. This simple analysis does not consider differences in slurry flow efficiencies that occur as pipeline densities change due to increased erosion capabilities of the model draghead due to jets.

These calculations are based on water jet pump efficiencies of 75 percent (a realistic value for an underwater electrically driven jetting pump mounted on a drag arm). The following tabulation shows that larger diameter water jets operating at flow rates similar to that of smaller diameter water jets but at reduced pressures require considerably lower horsepower.

Jet Size in. ID	Head ft	Head psi	Flow Rate gpm	Power at 75% Efficiency hp	Knife
0.75	92.4	40	97.6	3.040	No
			98.0	3.052	Yes
0.75	161.7	70	123.0	6.703	No
			120.0	6.540	Yes
1.00	46.2	20	124.0	1.931	No
			121.0	1.884	Yes
1.00	92.4	40	154.0	4.796	No
			148.0	4.609	Yes

As an example, the 1.0-in.-ID water jet at a pressure of 20 psi requires less than one-third of the power required for the 0.75-in.-ID water jet operating at a pressure of 70 psi.

The right-hand column in the following tabulation, which lists erosion efficiency, depicts the calculated volumes removed per horsepower for each test condition.

Even though larger volumes are removed by the 70-psi pressure with the 0.75-in.-ID water jet than with the 1.0-in.-ID water jet operating at 20 psi, the larger nozzle operated at the lower pressure is a more energy efficient design. These two test conditions used approximately the same flow rate, 120 gpm.

From a prototype viewpoint, replaceable jet nozzle blocks that can be machined to either 0.75-in. or 1.0-in. sizes would be the ideal configuration. Prototype pump configurations should be sized based on the number and sizes of jets used and be capable of providing a minimum of 20 psi at the jet oulet.

Jet Size in. ID	Knife	Head psi	Volume Removed cu ft	Volume Removed per Horsepower Required cu ft
0.75	No	40	1.847	0.608
0.75	Yes	40	2.321	0.760
0.75	No	70	3.415	0.509
0.75	Yes	70	2.390	0.365
1.00	No	20	1.400	0.725
1.00	Yes	20	2.101	1.115
1.00	No	40	1.575	0.328
1.00	Yes	40	2.452	0.532

This should provide adequate power for most compacted sediments. This design pressure should be increased proportionally by the static pressure head due to the maximum water depth of draghead operation.

Considering the fact that in some cases, a prototype dredge cannot always reduce dredging speed in compacted sediments, knives placed at approximately 30-deg approach angles should provide a readily installed compromise design for fast or slow dredging speeds. The increased drag forces due to the jet momentum and knife operation should also be considered when determining the total number of erosion devices if ship propulsion systems are not adequate to maintain the desired dredging speed.

Since hopper dredging operations involving long haul distances (greater than 10 miles) to the disposal site must truly maximize suction pipe densities to be economically feasible, the analysis concerning power efficiency should be conducted with the true overall dredging cycle efficiency. Thus, the higher powers required to erode as much material as can physically be conveyed by the dredge pump may be justified. The larger power plants have associated larger initial costs and larger operating costs. However, the larger plants may improve the overall dredge cycle efficiency. Benefit to cost analysis should be performed for the estimated usage of these devices over an economic life of the dredge plant.

7 Conclusion

Controlled laboratory testing of prototype-scale water jets used as erosive devices to aid the production of a sectional model draghead revealed that volume of material removed from the compacted sand bed increased as the water jet pressure increased. This conclusion verified the general pattern of the individual tests of various size jets used alone.

These results were further analyzed in detail to evaluate the efficiency of various jet sizes and pressures. As expected, the higher pressure tests required larger horsepowers, but were not always the most efficient from an energy standpoint.

Examination of all operating costs that make up the daily operation costs reveals that water jet installation, maintenance, and operation may be a rather small cost related to the total cost of a dredge. Therefore the final recommendation for prototype installation is to design prototype systems for maximum volumetric efficiency if the dredge is hauling materials a significant distance.

Table 1
Nozzle-Water Jet Tests, Task A

Test	Nozzle				Fire Pump Rate gpm	Trench		Volume cu ft
	Size in.	Angle[1] deg	Pressure psi	Depth Off Bed in.		Depth ft	Width ft	
Nozzle								
A2A	0.75	30	20	1.0	65.9	0.126	1.4	0.601
A2B	0.75	30	30	1.0	82.4	0.157	1.6	0.800
A2C	0.75	30	40	1.0	94.0	0.177	0.8	0.769
A2D	0.75	30	70	1.0	115.0	0.236	0.8	1.360
A2E	0.75	45	20	1.0	69.0	0.123	1.5	0.440
A2F	0.75	45	30	1.0	80.0	0.153	1.0	0.592
A2G	0.75	45	40	1.0	91.0	0.175	0.8	0.787
A2H	0.75	45	70	1.0	115.0	0.389	1.2	2.070
A2M	0.75	45	20	4.0	67.2	0.148	1.5	0.886
A2N	0.75	45	30	4.0	80.5	0.171	2.1	1.106
A2O	0.75	45	40	4.0	91.3	0.175	1.9	1.187
A2P	0.75	45	70	4.0	112.0	0.206	2.2	1.659
A3A	1.00	30	20	1.0	111.0	0.191	1.6	1.159
A2B	1.00	30	30	1.0	140.0	0.217	1.5	1.092
A3C	1.00	30	40	1.0	160.0	0.189	1.4	1.185
A3D	1.00	45	20	1.0	114.0	0.16	0.8	0.810
A3E	1.00	45	30	1.0	140.0	0.173	1.2	0.929
A3F	1.00	45	40	1.0	164.0	0.25	0.7	1.489
A3J	1.00	45	20	4.0	113.0	0.153	1.4	1.041
A3K	1.00	45	30	4.0	138.0	0.2	1.7	1.392
A3L	1.00	45	40	4.0	160.0	0.235	1.0	1.629
Water Jet with 30-deg Knife 2.0 in. Deep								
A4A	0.75	45(S)	20	1.0	69.6	0.259	1.6	1.402
A4B	0.75	45(S)	30	1.0	86.0	0.276	1.7	1.625
A4C	0.75	45(S)	40	1.0	98.0	0.302	1.2	1.654
A4D	0.75	45(S)	70	1.0	123.0	0.342	1.1	2.152

(Continued)

[1] (S) = straight; 45 deg to bed.
(T) = tilted; 45 deg to bed and 45 deg vertical.

Table 1 (Concluded)								
	Nozzle					Trench		
Test	Size in.	Angle deg	Pressure psi	Depth Off Bed in.	Fire Pump Rate gpm	Depth ft	Width ft	Volume cu ft
A5A	0.75	45(T)	20	1.0	64.2	0.197	1.9	1.233
A5B	0.75	45(T)	30	1.0	76.3	0.221	2.2	1.452
A5C	0.75	45(T)	40	1.0	86.7	0.224	1.8	1.583
A5D	0.75	45(T)	70	1.0	107.0	0.253	1.7	1.749
A6A	1.00	45(S)	20	1.0	123.0	0.28	1.3	1.526
A6B	1.00	45(S)	30	1.0	148.0	0.348	1.3	2.115
A6C	1.00	45(S)	40	1.0	163.0	0.325	1.2	1.877
A7A	1.00	45(T)	20	1.0	103.0	0.202	1.5	1.028
A7B	1.00	45(T)	30	1.0	120.0	0.226	2.5	1.723
A7C	1.00	45(T)	40	1.0	135.0	0.246	1.6	1.748

Table 2
Water Jet Tests, Task B

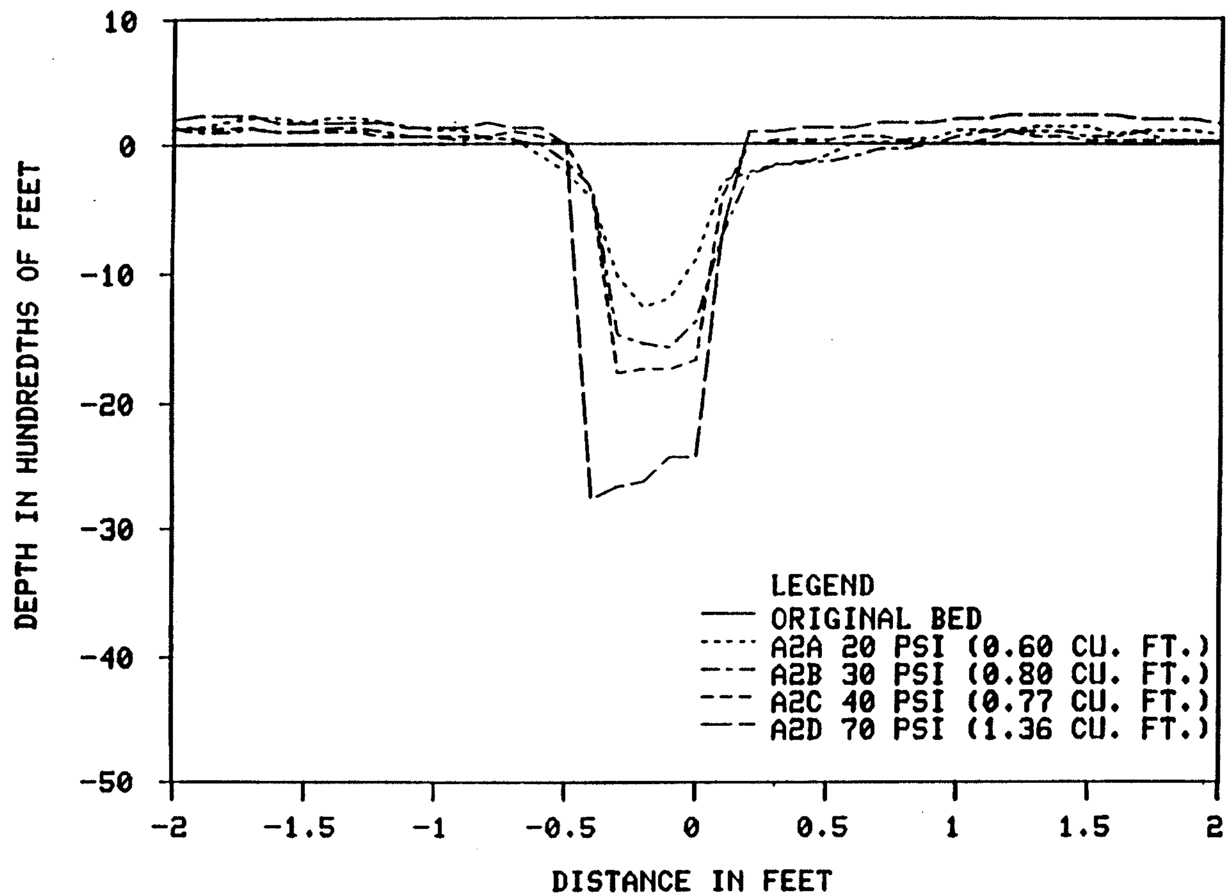
Test	Nozzle Size in.	Nozzle Angle[1] deg	Nozzle Pressure psi	Nozzle Depth Off Bed in.	Fire Pump Rate gpm	Trench Depth ft	Trench Width ft	Volume cu ft	Loaded Slurry Pump Rate[2] gpm
B2A	Base Test (no nozzle or knife)					0.054	2.8	0.964	780
B2B	Base Test (knife alone, no nozzle)					0.173	2.8	1.582	770
B2C	0.75	45(S)	40	1.0	97.6	0.232	2.2	1.847	742
B2D	0.75	45(S)	70	1.0	123.0	0.402	2.2	3.415	750
B2E	1.00	45(S)	20	1.0	124.0	0.208	2.2	1.400	756
B2F	1.00	45(S)	40	1.0	154.0	0.228	2.2	1.575	738
B3A	(No Tests Conducted)								
B3B	0.75	45(S)	30	1.0	85.00	0.265	2.7	2.212	740
B3C	0.75	45(S)	40	1.0	98.0	0.273	2.7	2.321	740
B3D	0.75	45(S)	70	1.0	120.0	0.339	2.5	2.390	760
B4A	(No Tests Conducted)								
B4B	0.75	45(T)	30	1.0	75.6	0.219	2.9	1.767	748
B4C	0.75	45(T)	40	1.0	86.0	0.224	3.1	1.995	753
B4D	0.75	45(T)	70	1.0	107.0	0.230	3.3	2.145	699
B5A	1.00	45(S)	20	1.0	121.0	0.247	2.3	2.101	683
B5B	1.00	45(S)	30	1.0	135.0	0.283	2.0	2.309	683
B5C	1.00	45(S)	40	1.0	148.0	0.297	2.0	2.452	735
B6A	1.00	45(T)	20	1.0	104.0	0.225	3.3	2.068	784
B6B	1.00	45(T)	30	1.0	123.0	0.225	3.5	2.325	761
B6C	1.00	45(T)	40	1.0	138.0	0.233	3.3	2.537	758

Note: For all tests, the knife was set at a depth of 2.0 in. and an angle of 30 deg.
[1] (S) = water jet straight, 45 deg to bed.
(T) = water jet tilted, 45 deg to bed and 45 deg vertical.
[2] All tests started with a pumping rate of 800 gpm.

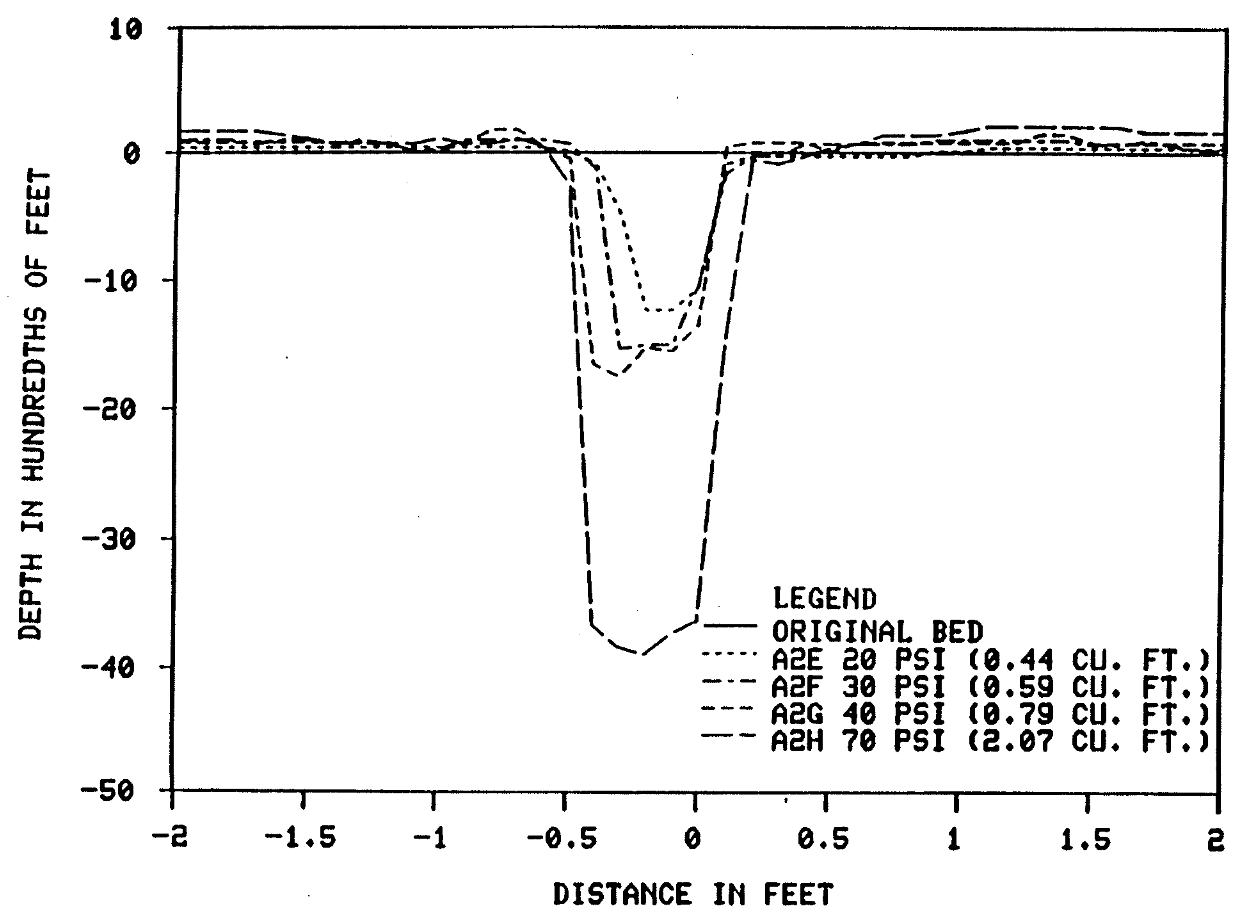
Table 3
Cable Force Tests

Test	Water Jet			Fire Pump gpm	Cable Force, lb		
	Size in.	Angle[1] in.	Pressure psi		Pump On	Pump Off	Difference (Off - On)
FB3C	0.75	45(S)	40	85.0	500	530	+30
FB3D	0.75	45(S)	70	120.0	550	500	-50
FB5A	1.0	45(S)	20	121.0	570	750	+180
FB5C	1.0	45(S)	40	148.0	470	670	+200

Note: For all tests, the knife was set at a depth of 2.0 in. and an angle of 30 deg.
[1] Water jet straight, 45 deg to bed.

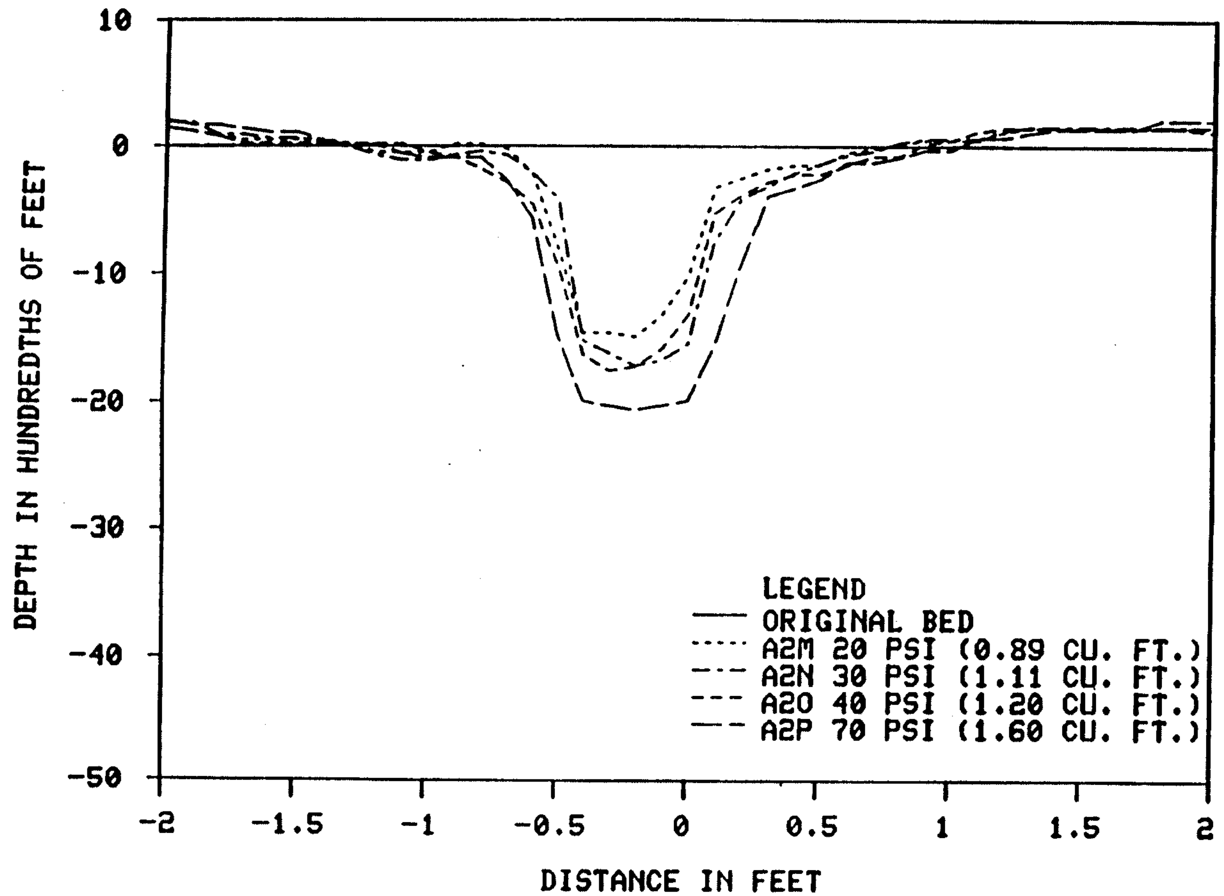


AVERAGE CROSS-SECTION PROFILES
TASK A
3/4-IN. NOZZLE
30-DEG ANGLE, 1 IN. OFF BED



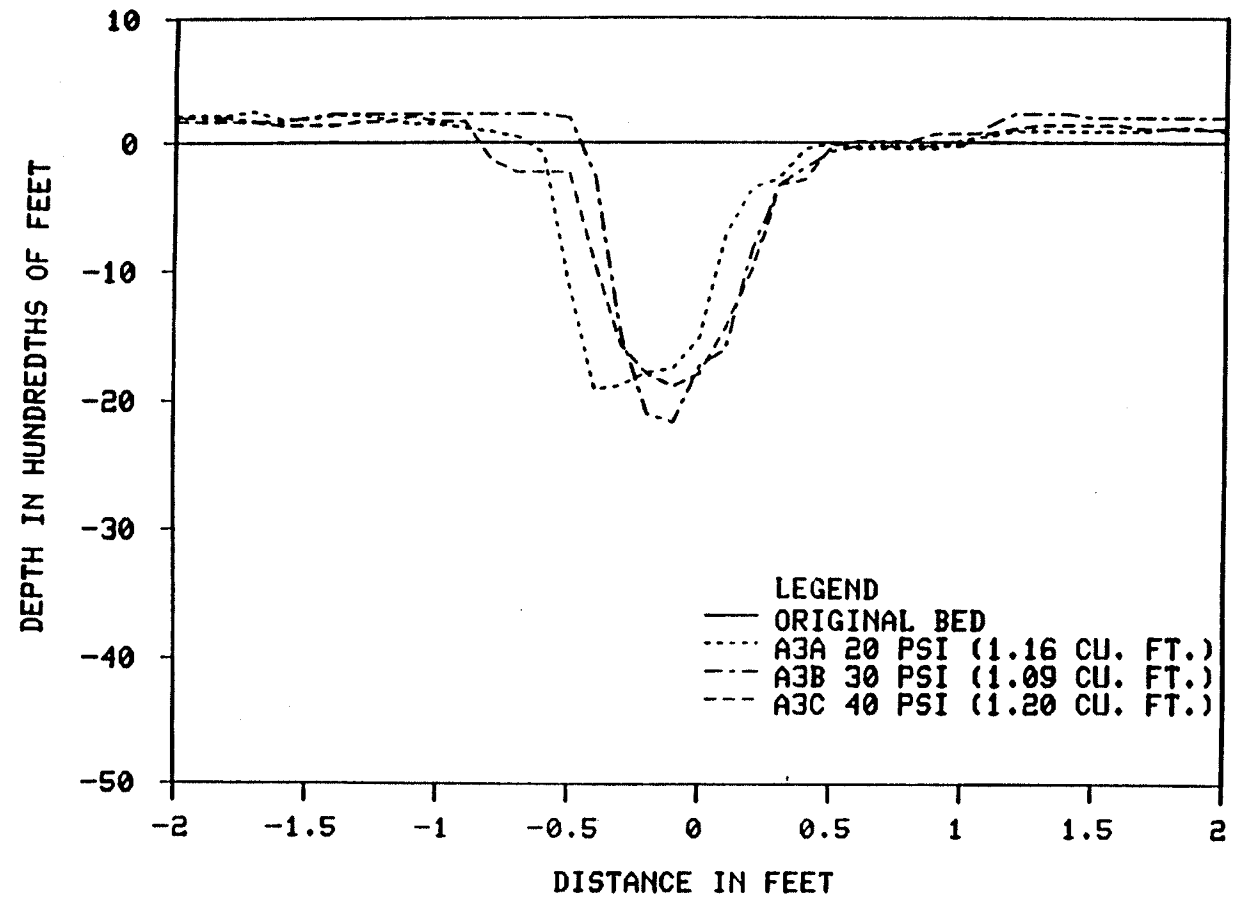
AVERAGE CROSS-SECTION PROFILES
TASK A
3/4-IN. NOZZLE
45-DEG ANGLE, 1 IN. OFF BED

PLATE 2



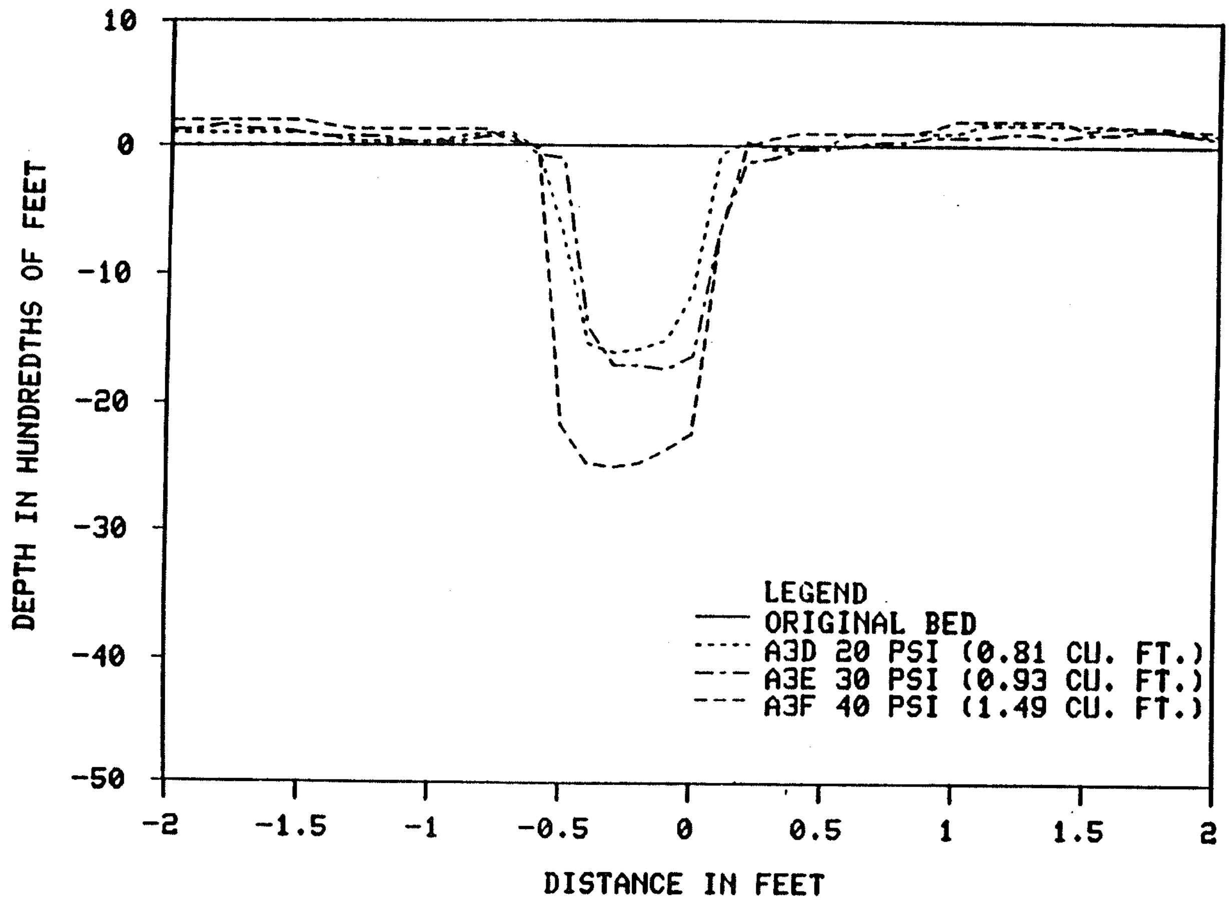
AVERAGE CROSS-SECTION PROFILES
TASK A
3/4-IN. NOZZLE
45-DEG ANGLE, 4 IN. OFF BED

PLATE 3

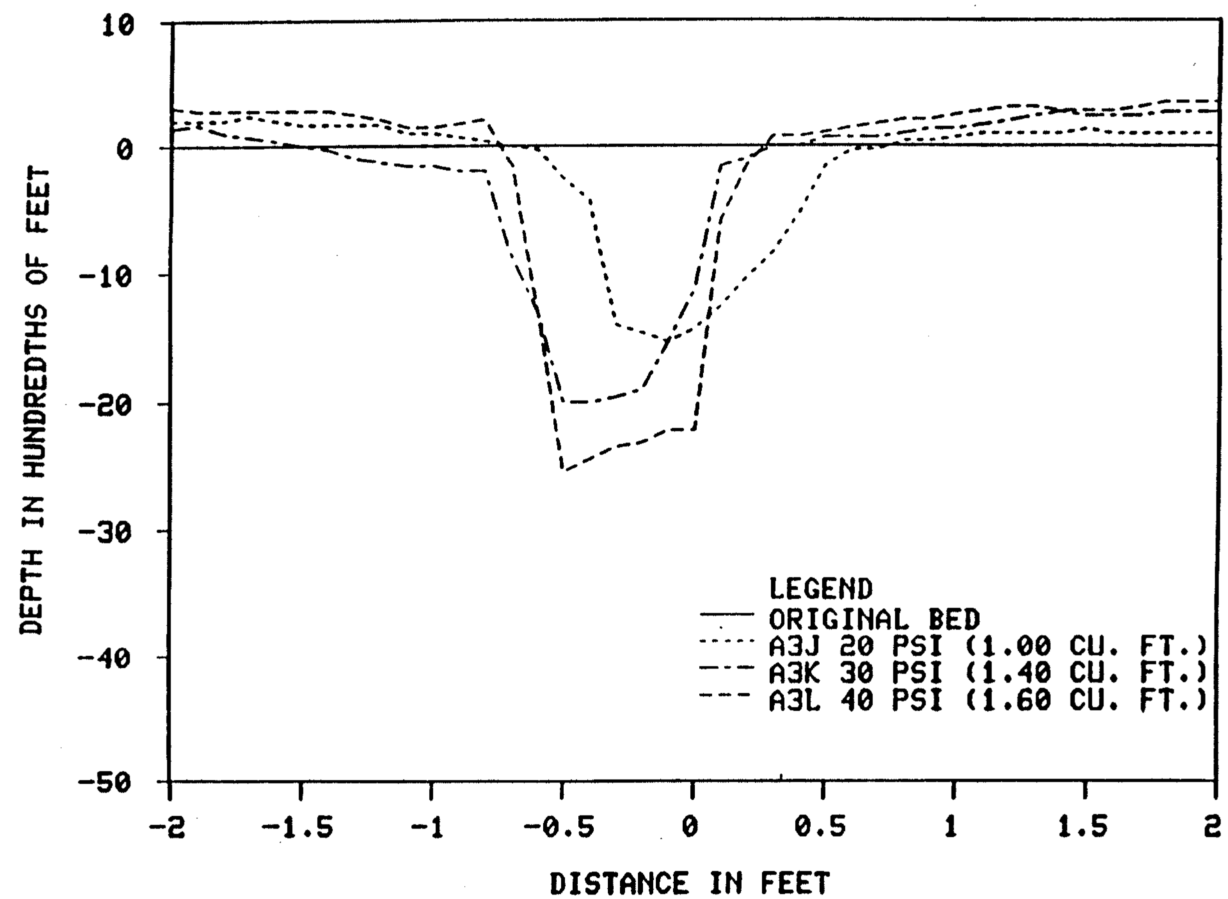


AVERAGE CROSS-SECTION PROFILES
TASK A
1-IN. NOZZLE
30-DEG ANGLE, 1 IN. OFF BED

PLATE 4

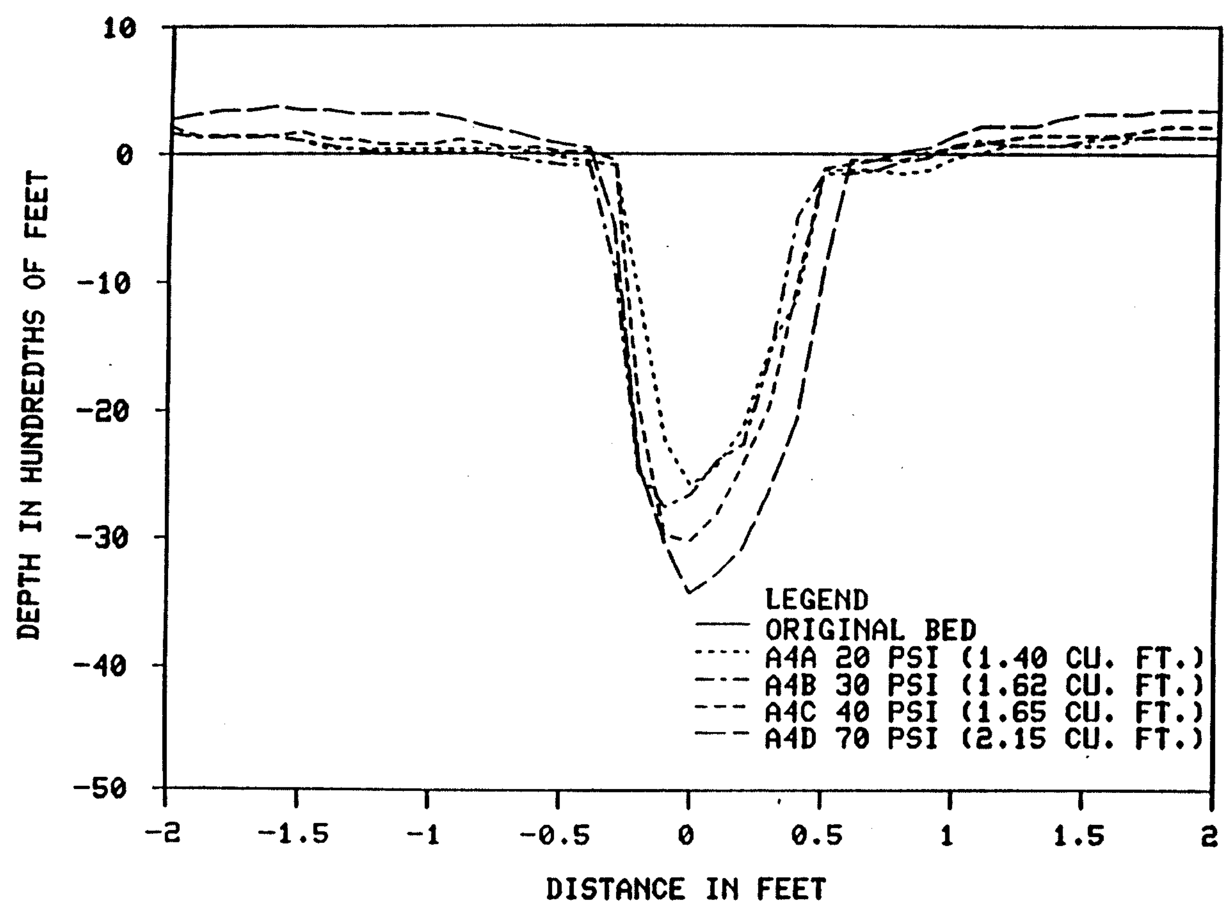


AVERAGE CROSS-SECTION PROFILES
TASK A
1-IN. NOZZLE
45-DEG ANGLE, 1 IN. OFF BED

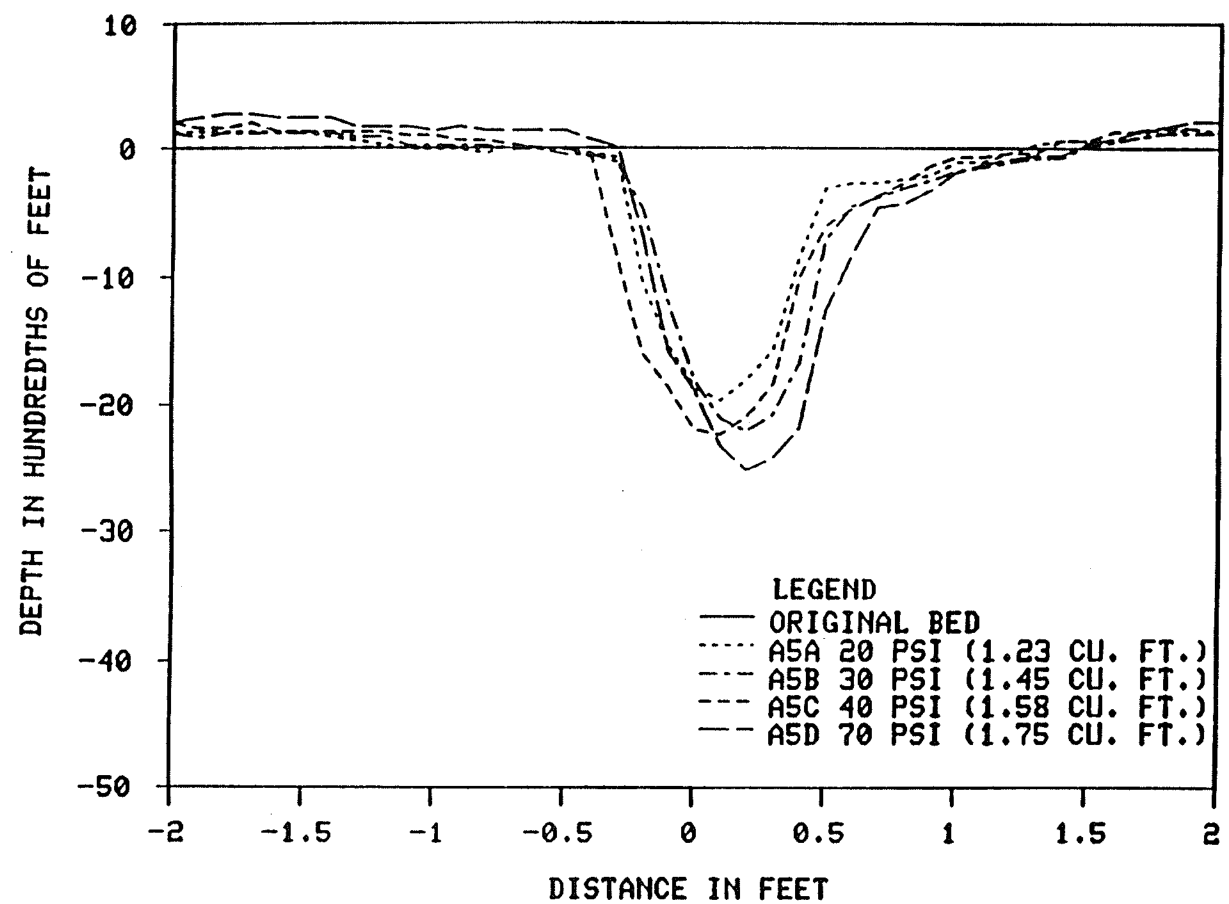


AVERAGE CROSS-SECTION PROFILES
TASK A
1-IN. NOZZLE
45-DEG ANGLE, 4 IN. OFF BED

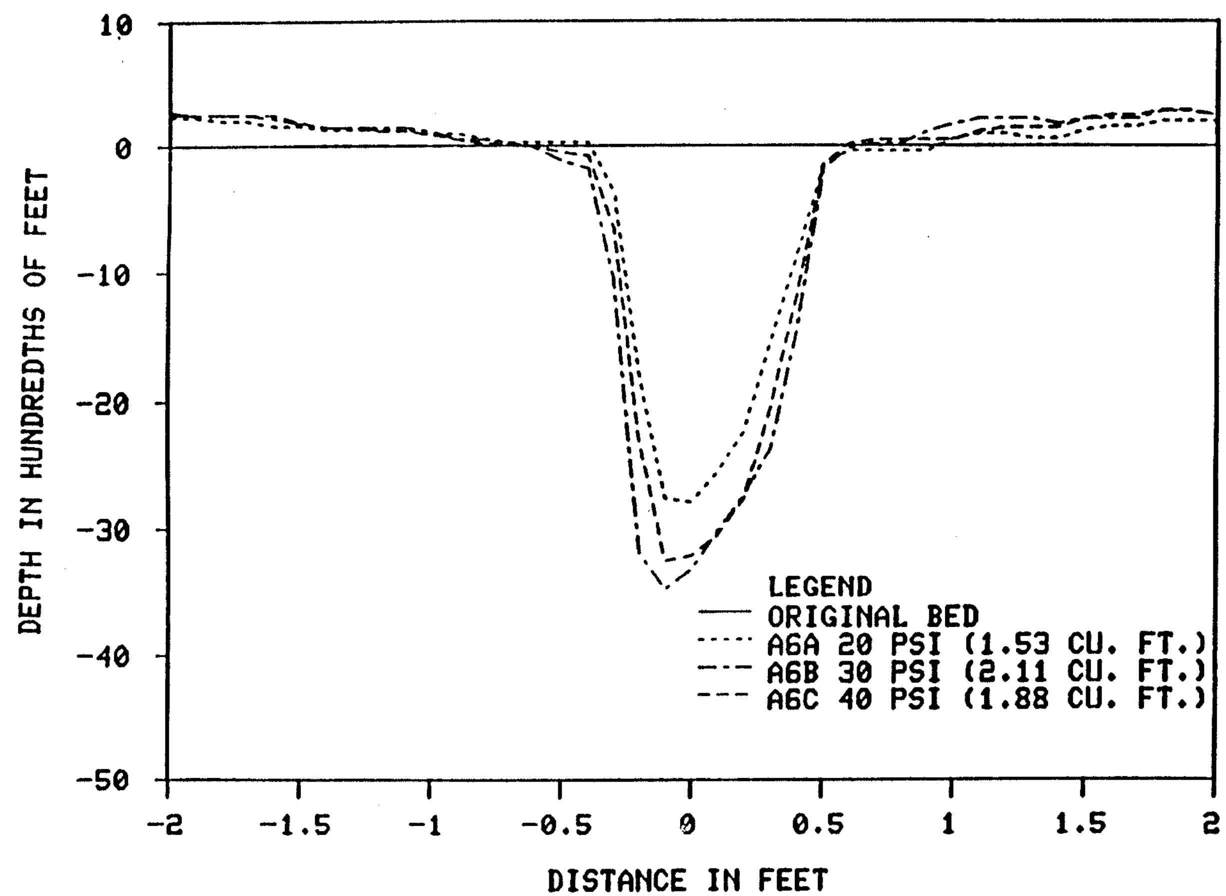
PLATE 6



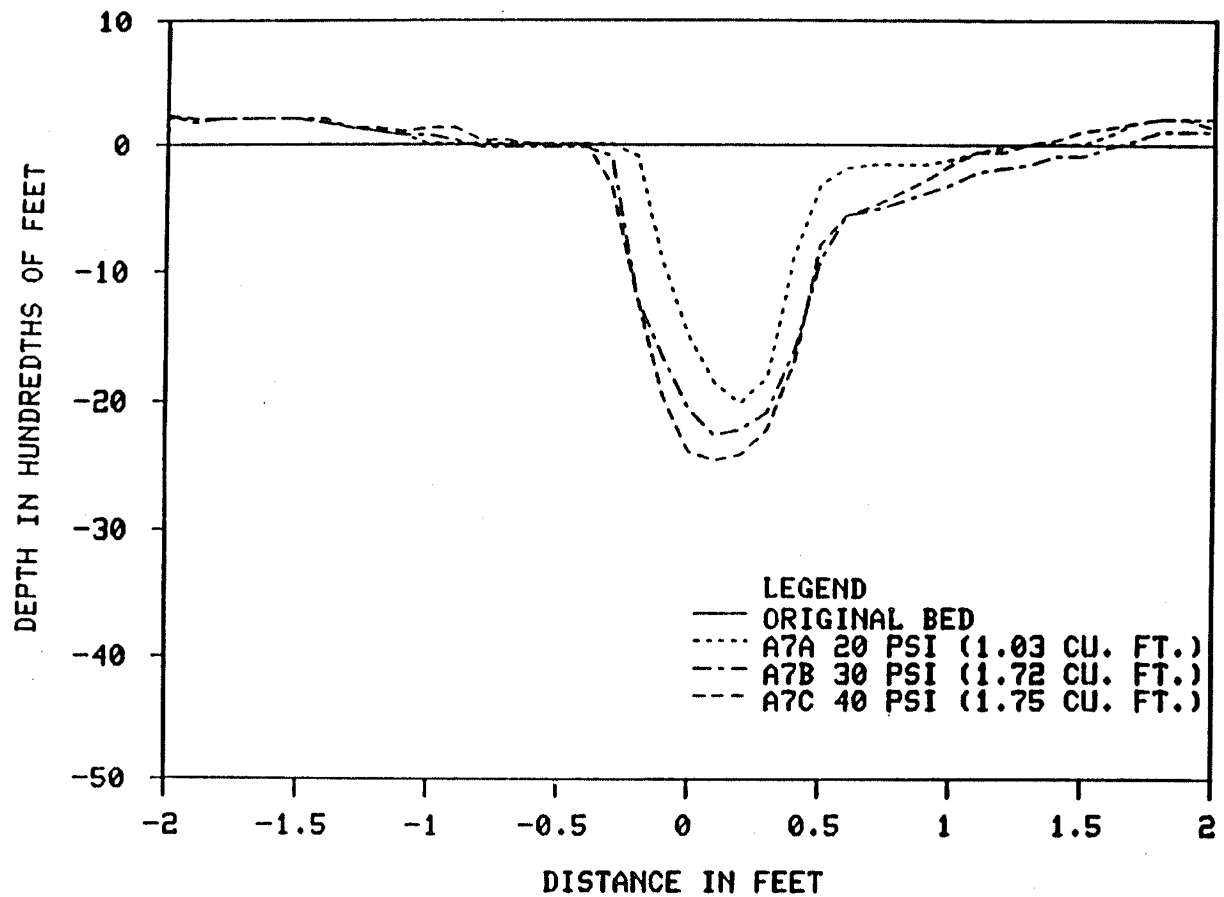
AVERAGE CROSS-SECTION PROFILES
TASK A
3/4-IN. WATER JET (45 DEG STRAIGHT)
KNIFE 2 IN. DEEP, 30-DEG ANGLE



AVERAGE CROSS-SECTION PROFILES
TASK A
3/4-IN. WATER JET (45 DEG TILTED)
KNIFE 2 IN. DEEP, 30-DEG ANGLE



AVERAGE CROSS-SECTION PROFILES
TASK A
1-IN. WATER JET (45 DEG STRAIGHT)
KNIFE 2 IN. DEEP, 30-DEG ANGLE



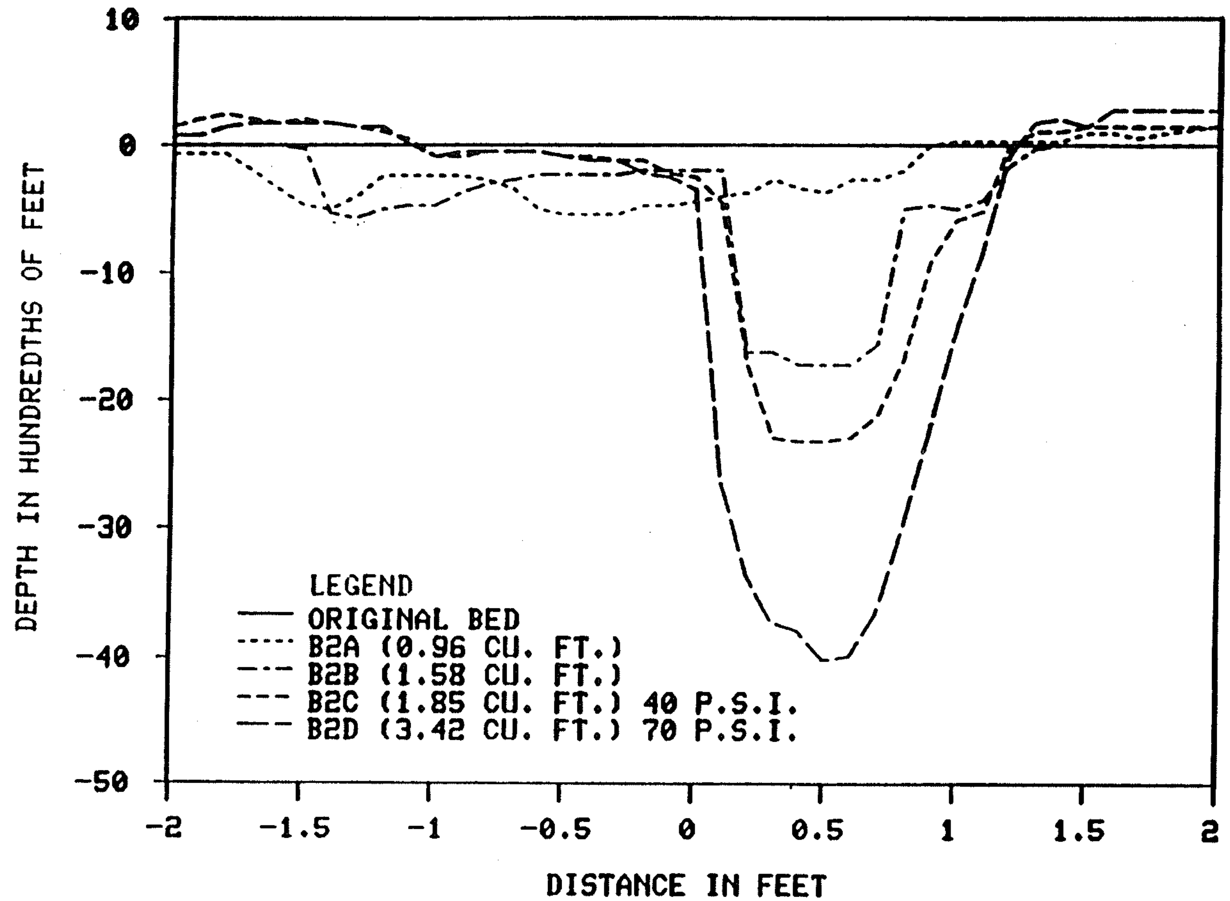
AVERAGE CROSS-SECTION PROFILES

TASK A

1-IN. WATER JET (45 DEG TILTED)

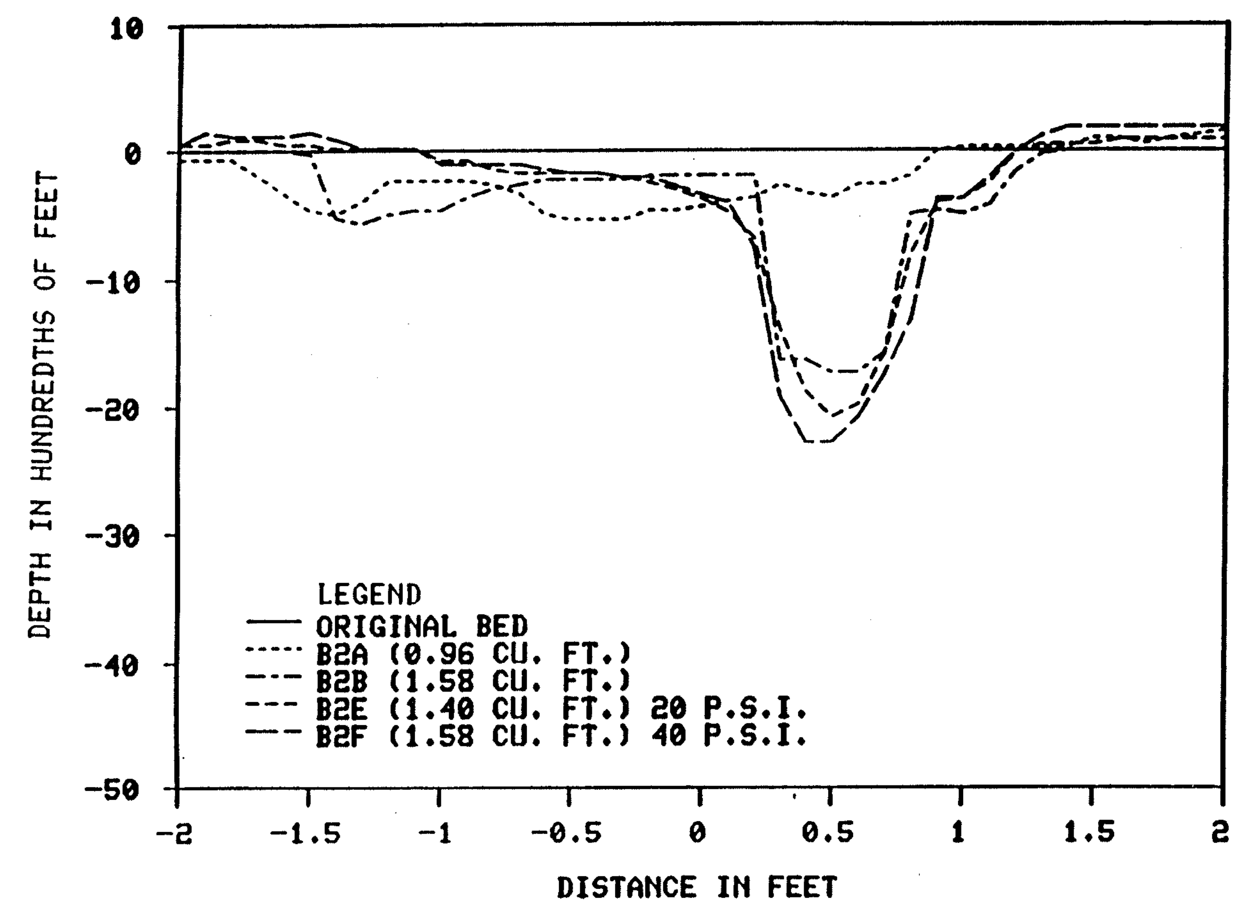
KNIFE 2 IN. DEEP, 30-DEG ANGLE

PLATE 10

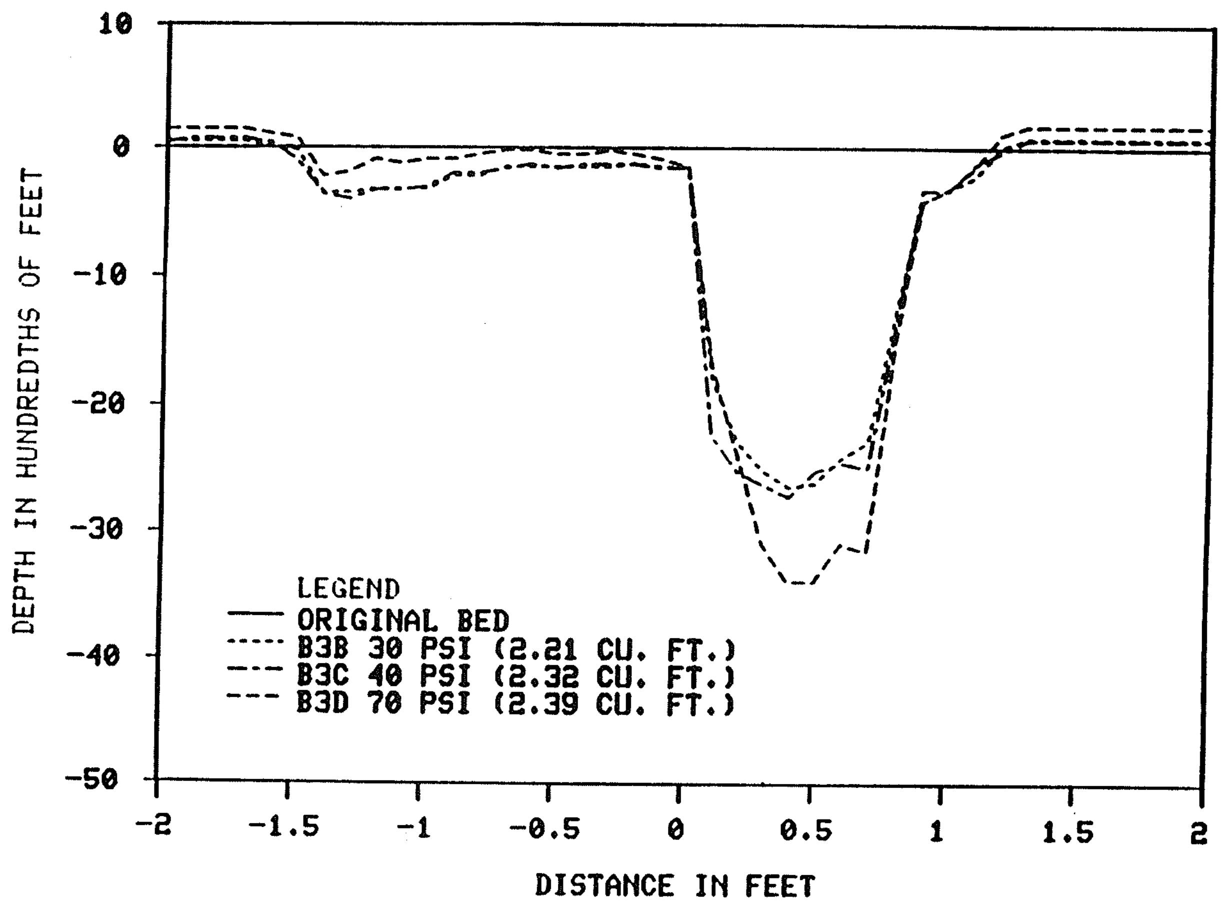


AVERAGE CROSS-SECTION PROFILES
TASK B
3/4-IN. WATER JET (45 DEG STRAIGHT)

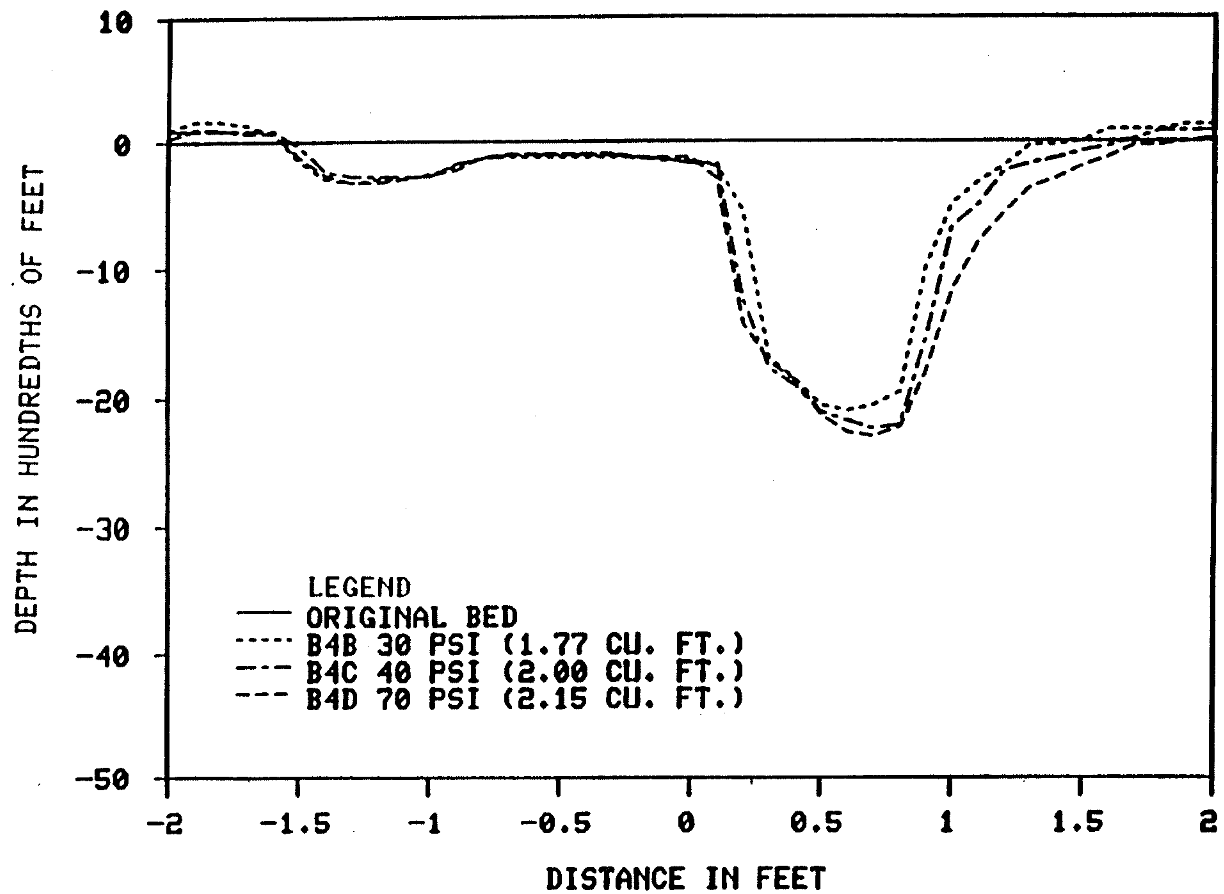
PLATE 11



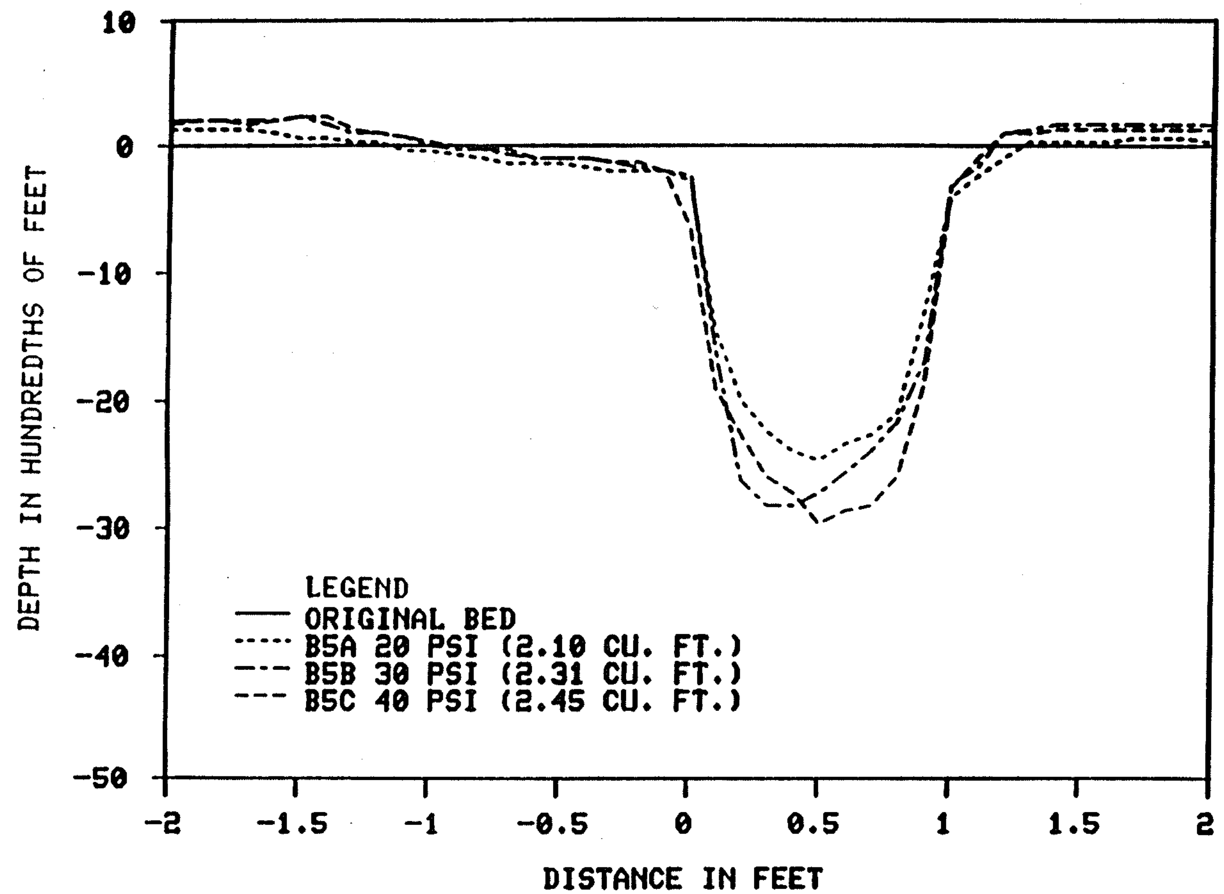
AVERAGE CROSS-SECTION PROFILES
TASK B
1-IN. WATER JET (45 DEG STRAIGHT)



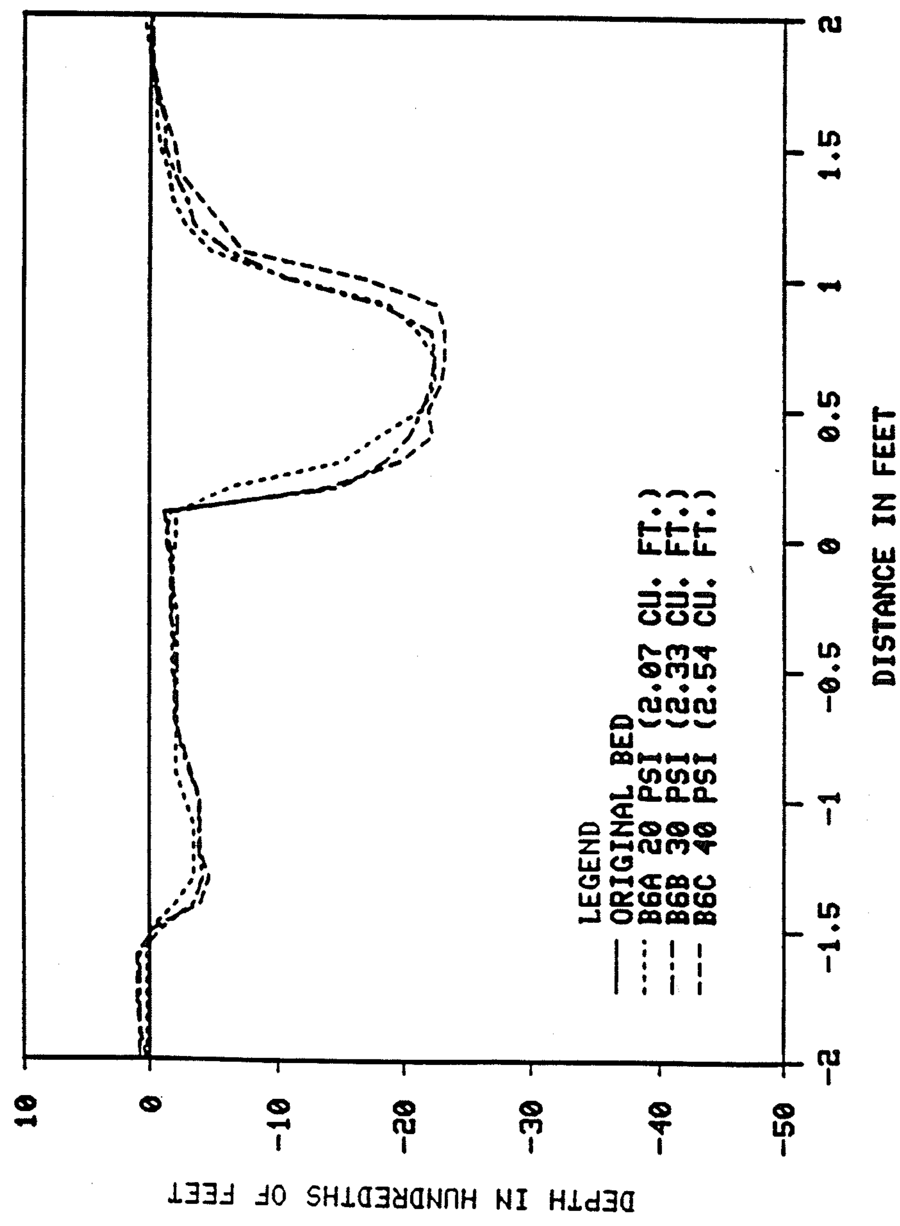
AVERAGE CROSS-SECTION PROFILES
TASK B
3/4-IN. WATER JET (45 DEG STRAIGHT)
KNIFE 2 IN. DEEP, 30-DEG ANGLE



AVERAGE CROSS-SECTION PROFILES
TASK B
3/4-IN. WATER JET (45 DEG TILTED)
KNIFE 2 IN. DEEP, 30-DEG ANGLE



AVERAGE CROSS-SECTION PROFILES
TASK B
1-IN. WATER JET (45 DEG STRAIGHT)
KNIFE 2 IN. DEEP, 30-DEG ANGLE



AVERAGE CROSS-SECTION PROFILES
TASK B
1-IN. WATER JET (45 DEG TILTED)
KNIFE 2 IN. DEEP, 30-DEG ANGLE

PLATE 16

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*
This report describes the test facility and conditions tested and presents results from a series of laboratory tests conducted to determine the effects of injecting water under pressure using off-the-shelf water nozzles and shop-fabricated water jets in combination with bimetal type agricultural knives to improve dredging quantities in fine compacted sand. The study was divided into two separate tasks. Task A defined the dislodging effects of off-the-shelf nozzles having inside diameters of 0.75 and 1.0 in. Task A tests were conducted with the nozzles located at an angle of 30 or 45 deg to the bed, and 1.0 or 4.0 in. above the bed, and water pressures at the nozzle head of 20, 30, 40, or 70 psi. Task B tests involved shop-fabricated water jets and bimetal type agricultural knives in combination with a sectional draghead model. Task B tests were conducted with water pressures of 20, 30, 40, or 70 psi at the water jet, with the water jet positioned either straight or tilted. These tests showed that dredging quantities would increase as a result of installing water jets and knives on dragheads when dredging in fine compacted sand. The results of the laboratory tests were analyzed from an energy efficiency standpoint to provide basic guidance for future prototype applications. Even though lower pressure water jets are more energy efficient, the high cost of dredge operation where long haul distances are required may warrant the use of the most erosion-producing device regardless of initial cost or operating cost.

14. SUBJECT TERMS

Blades	Dredging	Nozzles
Compacted sediments	Hopper dredges	Water jets
Draghead	Knives	

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