CHAPTER 79

A SAND BYPASSING SYSTEM USING A JET PUMP

by

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INTRODUCTION

All harbors and tidal inlets that are located in coastal areas have one characteristic in common--the need to bypass littoral materials that collect nearby. If natural harbors and tidal inlets are left unattended, bypassing will often occur naturally, but in the process, the harbor or inlet is usually rendered unfit for commercial or navigation purposes. Quite often, the inattention results in the total closure of the inlet. Therefore, at almost all harbor entrances and controlled tidal inlets, the natural bypassing must be augmented by secondary, usually mechanical, means.

The customary technique for bypassing sand and maintaining harbors and inlets is the use of floating dredge equipment. This equipment is rugged, reliable, has been proved over and over, and appears to be irreplacable for many applications and locations. However, there are many locations and situations for which this floating equipment is not suitable and may, in fact, be detrimental or prohibitively costly. Waves of even moderate height, moderate-to-high tidal excursion and currents, draft limitations, limited maneuvering area, and interference with normal navigation operations are examples of conditions which decrease the desirability and application of floating dredge equipment. Small volumes of material to be bypassed are an economic liability for the floating plant since mobilization and demobilization costs contribute extraordinarily to the unit cost for bypassing work.

THE PROBLEM

In general, it is at the larger harbors and tidal inlets where the floating dredge equipment can be used effectively, efficiently, and economically.

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Also, it is usually at the smaller harbors and tidal inlets that the use of floating dredge equipment to accomplish the desired bypassing activities becomes questionable.

Until the present time, the coastal engineer with the responsibility for maintaining the smaller coastal harbors and inlets had little choice in the selection of the mechanical means for bypassing sand. Floating dredge equipment was usually scheduled regardless of economy except in isolated cases where land-based pumping plants could be effectively used.

Obviously a need for improved operations and maintenance techniques and equipment for bypassing sand at tidal inlets and other littoral barriers exists. The problem is one to which the methods and procedures of research and development may be profitably applied. Therefore, a research program, sponsored by the Office, Chief of Engineers (OCE), was formulated and implemented for the purpose of improving operations and maintenance techniques specifically to develop effective and economical methods for sand bypassing at tidal inlets and other obstructions to littoral drift.

A review of existing equipment and proposed concepts identified the jet pump as having great potential as a primary component in a sand bypassing system. The survey conclusion was that a jet pump bypassing system requiring limited watercraft and personnel and capable of great portability and reliability can be assembled at a reasonable cost using off-the-shelf equipment. The research program was therefore designed to provide performance criteria, systems design parameters, and deployment and operational techniques for sand bypassing systems using jet pumps.

JET PUMP THEORY

Currently, jet pumps are, in general, used as suction boosters on centrifugal dredge pumps. There are several instances where eductors have been used alone for sand and gravel mining, but all of the equipment in use to date has been designed to meet low head applications. However, there is adequate theory and empirical information to show that the jet pump is capable of producing the higher discharge heads required for a bypassing installation.

The basic principle behind the operation of the jet pumps is the exchange of momentum. High-pressure fluid, normally supplied by a centrifugal pump, is forced through a converging jet nozzle and is converted into a high-velocity, low-pressure jet stream. This jet stream contacts the suction fluid at the nozzle exit and drags it into the pump, thus initiating and sustaining secondary flow of suction fluid from the surrounding water mass. If the surrounding water mass contains solids, or if solid particles are entrained in the secondary flow approaching the jet pump intake, then solids are introduced into the pump mixing chamber. In the mixing chamber, the high-energy jet stream and the suction fluid mix further, exchange momentum, and experience a pressure recovery. The mixed fluids or slurry then pass through a diverging diffuser and into a discharge pipe for delivery to a booster or to a discharge point.

Operational characteristics of the slurry jet pump can be described by three dimensionless ratios[1,3]:

$$\text{Area ratio} \quad B = \frac{\text{nozzle area}}{\text{mixing chamber area}} = \frac{A_j}{A_{mc}} \tag{1}$$

$$\text{Flow ratio} \quad \emptyset = \frac{\text{pumping capacity}}{\text{driving capacity}} = \frac{Q_{suc}\gamma_{suc}}{Q_{sup}\gamma_{sup}} \tag{2}$$

$$\text{Head ratio} \quad H = \frac{\text{net jet pump head}}{\text{net driving head}} = \frac{h_{dis}S_{dis} - h_{suc}S_{suc}}{h_{sup}S_{sup} - h_{dis}S_{dis}} \tag{3}$$

where

A_j = nozzle area
A_{mc} = mixing chamber area
Q_{suc} = suction flow rate, gpm
γ_{suc} = unit weight of suction slurry
Q_{sup} = supply flow rate, gpm
γ_{sup} = unit weight of drive fluid
h_{dis} = total discharge head in feet of slurry
S_{dis} = specific gravity of discharge slurry

h_{suc} = total suction head in feet of slurry
S_{suc} = specific gravity of suction slurry
h_{sup} = total supply head in feet of drive fluid
S_{sup} = specific gravity of drive fluid

Using conservation of momentum, mass, and energy, Govatos[1] derived the following equation to give the relationship between H, $\emptyset$, and B.

$$H = \frac{U - V - W}{W - U + X} \tag{4}$$

where

$$U = 2B + \frac{2(\emptyset B)^2 \gamma_w}{(1 - B)\gamma_{suc}} - \frac{B^2(1 + \emptyset)^2 \gamma_w (2 + K_{mc})}{\gamma_{dis}} \tag{5}$$

$$V = \frac{\emptyset B}{1 - B}^2 \frac{1 + K_s}{S_{suc}} \tag{6}$$

$$W = B^2(1 + \emptyset)^2 \frac{K_{dis} - 1}{S_{dis}} \tag{7}$$

$$X = 1 + K_j \tag{8}$$

and

γ_w = unit weight of water, pcf
K_{mc} = loss coefficient due to the mixing chamber
γ_{dis} = unit weight of discharge slurry, pcf
K_s = loss coefficient due to the suction nozzle
K_{dis} = loss coefficient due to the diffuser
K_j = loss coefficient due to the drive jet nozzle

A set of curves similar to those in Figure 1 (from Reference 2) can be plotted by using the above equations and assuming a suction concentration and average loss factors for water.

The efficiency of the jet pump is dependent on several factors, but primarily on pump geometry. The four major geometrical parameters affecting

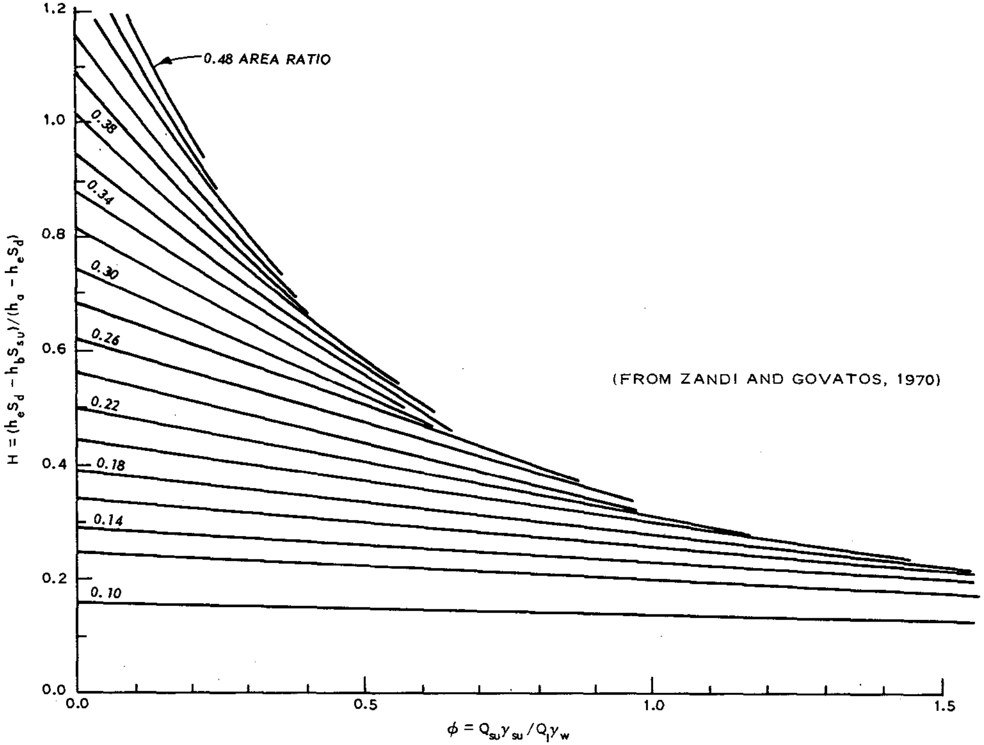

Figure 1. The relationship between dimensionless head ratio H , dimensionless flow ratio ϕ , and dimensionless area ratio for assumed arbitrary loss factors in the jet pump

efficiency are area ratio, the nozzle distance or distance from the tip of the nozzle to the entrance of the mixing chamber, the mixing chamber length, and the diffuser angle. With the exception of the area ratio, which can be varied by changing the nozzle characteristics, the geometry of the jet pumps tested was not altered in the research program.

LABORATORY TESTS

A laboratory test program was begun in 1973 and is continuing at this time. The purpose of these tests is to verify the theoretical and empirical relationships describing jet pump performance, to develop pumping techniques and methods for deployment and application, and to develop auxiliary devices such as hydraulic cutting assists and flow measuring techniques. The laboratory tests are designed to develop practical, reliable components and techniques for field evaluation as well as criteria for system design.

The laboratory facility, shown on Figure 2, consists of an excavation with sloping sides approximately 150 ft square. The facility is lined with plastic membrane to prevent local soil contamination of 2400 cu yd of medium sand (400 μ) used in the test. The size of the facility allows testing of prototype-size (6-in. discharge line) equipment to eliminate problems in scaling and also to provide valid information on deployment techniques.

The pipe network consists of 6-in. schedule 40 steel pipe, 6-in. floating rubber hose, and 6-in. PVC hose. The rubber hose is commonly used in dredging and gives the laboratory system sufficient flexibility to be moved about the basin. Instrumentation of the pumping system consists of magnetic flowmeters on the supply and discharge lines, a nuclear density meter to measure the sand concentration in the discharge line, and pressure transducers which monitor supply pressure, discharge pressure, suction pressure, and ambient pressure.

The flotation system for the jet pump assembly consists of a hollow spherical buoy attached to the jet pump, 6-in. rubber hose, air lines, and an air compressor. Through the use of a simple valving system on the pier, the air compressor can be used to regulate the buoyancy of the sphere. Air can also be pumped into the 6-in. rubber hoses to increase their buoyancy.

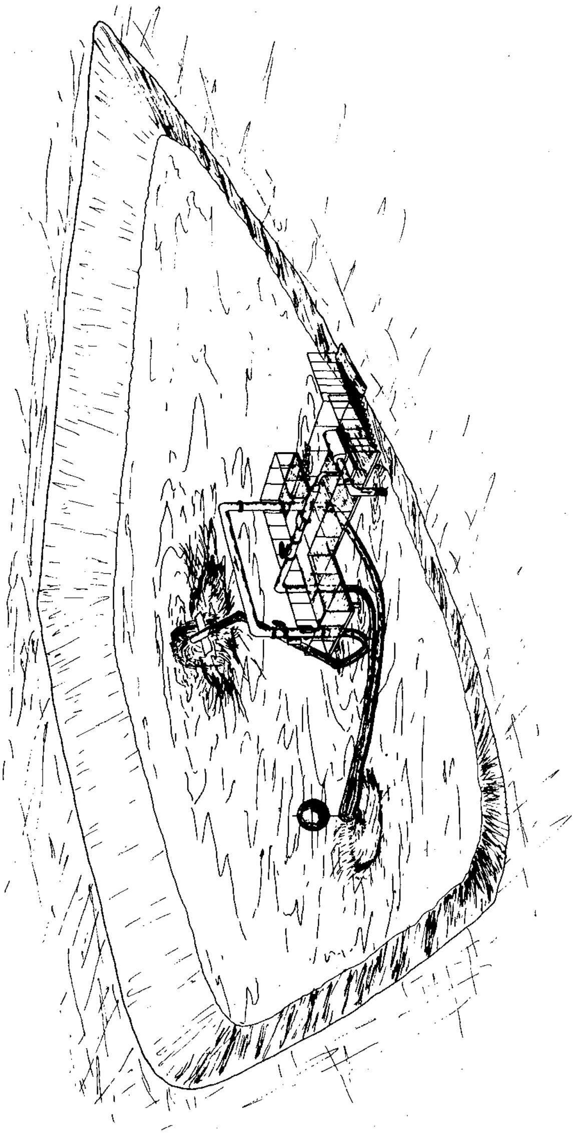

Figure 2. Artist's concept of laboratory facility showing 150-sq ft basin, work platform and piping arrangement

The initial series of laboratory tests were performed to verify the observations and accounts of other investigators as reported in the literature. Tests were first performed by pumping only clear water. In later tests, mixtures of sand and water were pumped and system parameters were observed for those conditions. Examples of the results of some of these tests are shown on Figures 3a and 3b.

A sufficient number of observations were obtained from the initial laboratory experiments to support the design of a prototype system for field testing. It was expected that the ideal conditions of the laboratory facility would be only an approximation of field conditions and that many of the conclusions reached and techniques developed in the laboratory tests would be modified or discarded after field testing of the system.

FIELD TESTS

Several potential field sites were evaluated for their suitability for initial field testing. Among the sites considered were: Santa Cruz and Oceanside, California; Port Mansfield and Colorado River Mouth, Texas; Perdido Pass, Alabama; Michigan City, Indiana; Moriches, New York; Masonboro, North Carolina; and Mexico Beach, Florida. The evaluation procedure determined that Mexico Beach, Florida, was the most suitable site for our initial field testing.

Mexico Beach is located in the Florida Panhandle approximately 30 mi east of Panama City. The test site is adjacent to a small navigation inlet maintained by the township. Local conditions at the inlet (see Figure 4) consist of a sizable sand accretion westward of the two jetties protecting the inlet and eroding beach conditions to the east of the inlet. The littoral drift is estimated to be almost entirely eastward and is in the order of 40,000-50,000 cu yd annually.

A field test unit comprised of a truck-mounted centrifugal pump, instrumentation, discharge and supply lines, and a single four-inch-diameter intake jet pump was put into operation at Mexico Beach in 1973 (see Figure 5). These tests immediately revealed the need for improved deployment techniques, a more manageable buoy system, more efficient operational techniques, and cutting

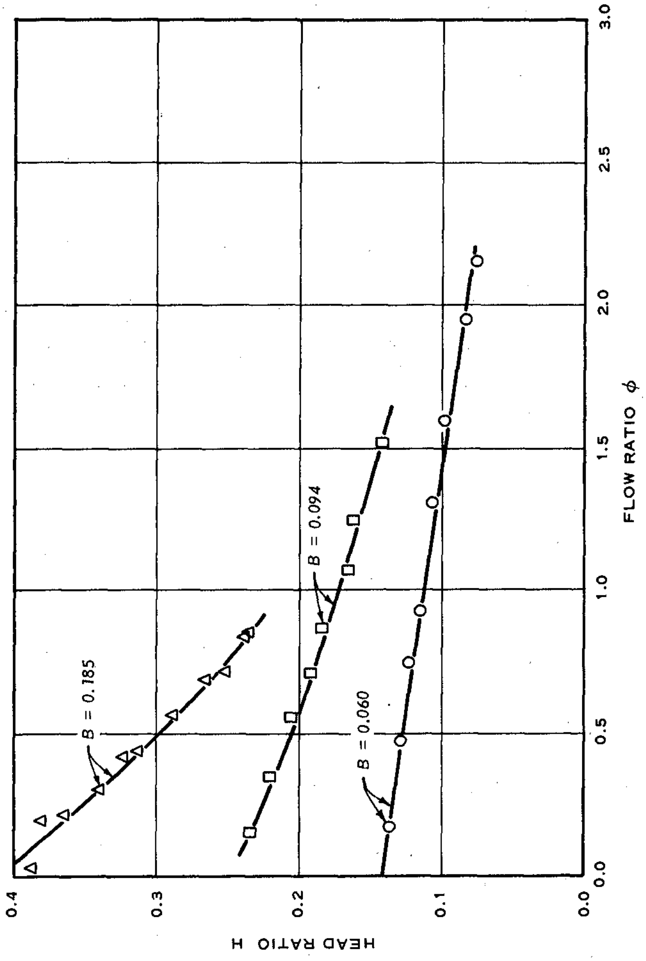

Figure 3a. Head ratio, H, flow ratio, ϕ, relationships for clear water data

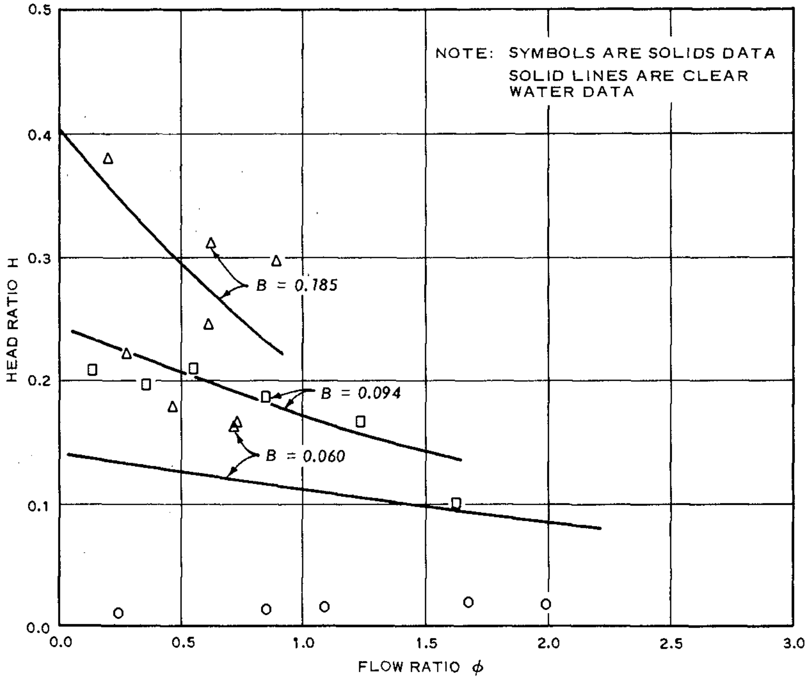

Figure 3b. Head ratio, H , flow ratio, ϕ , relationships for solids flow compared to clear water relationships

Figure 4. Mexico Beach, Florida, field site in 1972

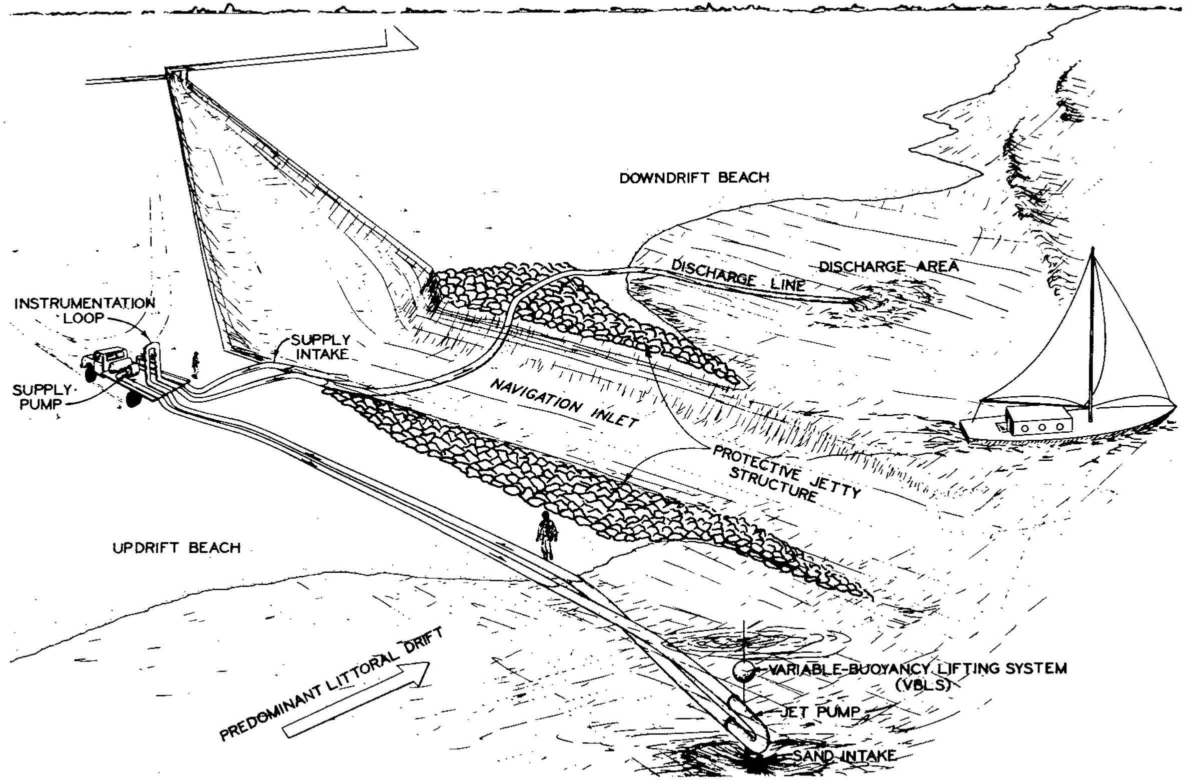

Figure 5. Artist's concept of sand bypassing installation at Mexico Beach, Florida

assists to overcome the cementing agents found in most natural beach sands. Other problems were also identified, including that of plugging of the jet pump intake port by shell fragments or other foreign materials and weaknesses in the various system components.

The jet pump, rigidly attached buoys, and flexible hoses were deployed from the beach using a vehicle winch and two anchors on the offshore bar with a block attached. A system of two or more permanent anchors with blocks can readily be used to reposition the jet pump. A 1/2-in.-diameter pipe was tapped into the supply side of the jet pump and teed into a two-jet cutting assist. The cutting assist was required to initiate a crater when the suction pipe was oriented other than perpendicular to the bottom. The jet pump will self-enplace in its own crater. The pump can also be shut down at any time by balancing the supply flow and discharge flow (zero suction flow) for a sufficient time to flush the sand from the discharge line. The jet pump was left in a crater bottom on several occasions until the crater was completely filled. When the sand was about 8 ft over the suction pipe, several hours of pumping were required before the flotation buoys could free the jet pump. When temporary clogging of the suction pipe was encountered, a valve in the discharge line was closed and the supply water forced out of the suction pipe. This technique is termed backflushing and was required frequently due to significant amounts of large shells blocking the suction pipe. Backflushing is also useful in jetting the suction pipe into the bottom in order to obtain an overburden on the suction pipe.

Most problems were satisfactorily worked out for the Mexico Beach site, and the system was put into a more-or-less operational mode. Over a period of several months, approximately 20,000 cu yd of material were bypassed from the fillet west of the entrance. The production rate of the operational system varied considerably with local conditions, but averaged about 75 cu yd per hour of operation.

The concept of overland portability where the relatively expensive drive-water and booster pumps are used to service several jet-pump locations in a local area was also evaluated during the Gulf of Mexico field tests. A site at Destin, Florida, which is within reasonable driving distance of Mexico

Beach and which has problems with maintenance of a small navigation channel into a harbor area was selected for this evaluation. A jet pump with associated supply and discharge lines was deployed at the Destin site (see Figure 6). The truck-mounted pump was uncoupled at Mexico Beach, driven to the Destin site, and recoupled to the jet-pump piping. The discharge point at the Destin site was such that a booster was added to the system. Otherwise, operational procedures at the Destin site and at the Mexico Beach site were similar.

The overland portability concept was successfully demonstrated at the Gulf of Mexico sites. This technique is to be recommended when several bypassing problems exist in a local area.

The experience, knowledge, and techniques derived from the initial laboratory work and the Gulf of Mexico field work were called upon for design of a system for an Atlantic coast site. Rudee Inlet, Virginia, which has a low-weir sand impoundment basin, was selected as the research site.

The system, as finally configured (see Figure 7), consisted of two electrically driven centrifugal-pump jet-pump units coupled with a single diesel-driven slurry booster pump. The jet pumps and associated piping are suspended from a row of piling near the center of the deposition basin. By maneuvering the jet pumps, the deposition basin can be cleared of most sand deposits. During the field test at Rudee Inlet, approximately 75,000 cu yd of sand were pumped from the impoundment basin to the beach area north of the inlet.

The entrance to Santa Cruz Harbor, California, shown in Figure 8, has been selected as a Pacific coast research site with tests beginning in the summer of 1976. The installation consists of dual-jet-pump, single-booster system with bypassing being accomplished from the shoals which form near the entrance channel. The pumping system will be based on the west jetty of the harbor, and the jet pumps will be maneuvered either by cables from shore or by a small work boat.

DISCUSSION

The jet pump sand bypassing system is simple in design and application and offers the coastal engineer an additional option in his search for solutions

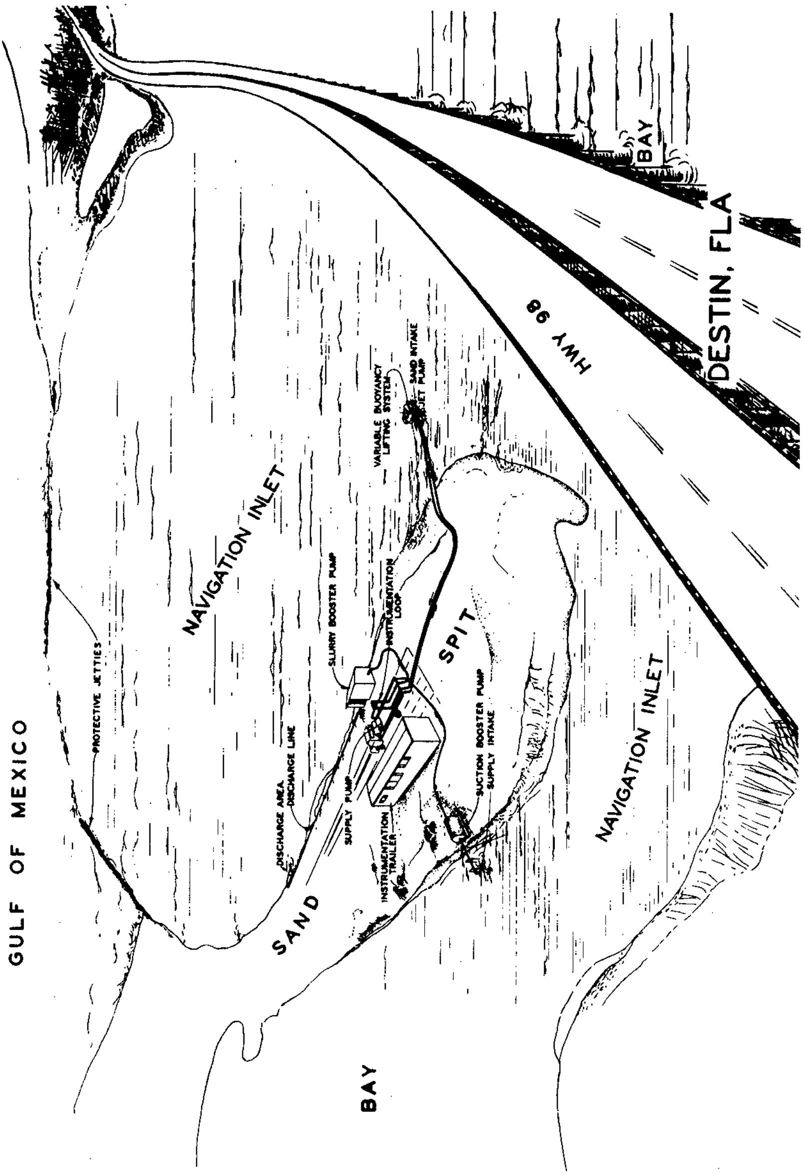

Figure 6. Artist's concept of sand bypassing installation at East Pass (Destin), Florida

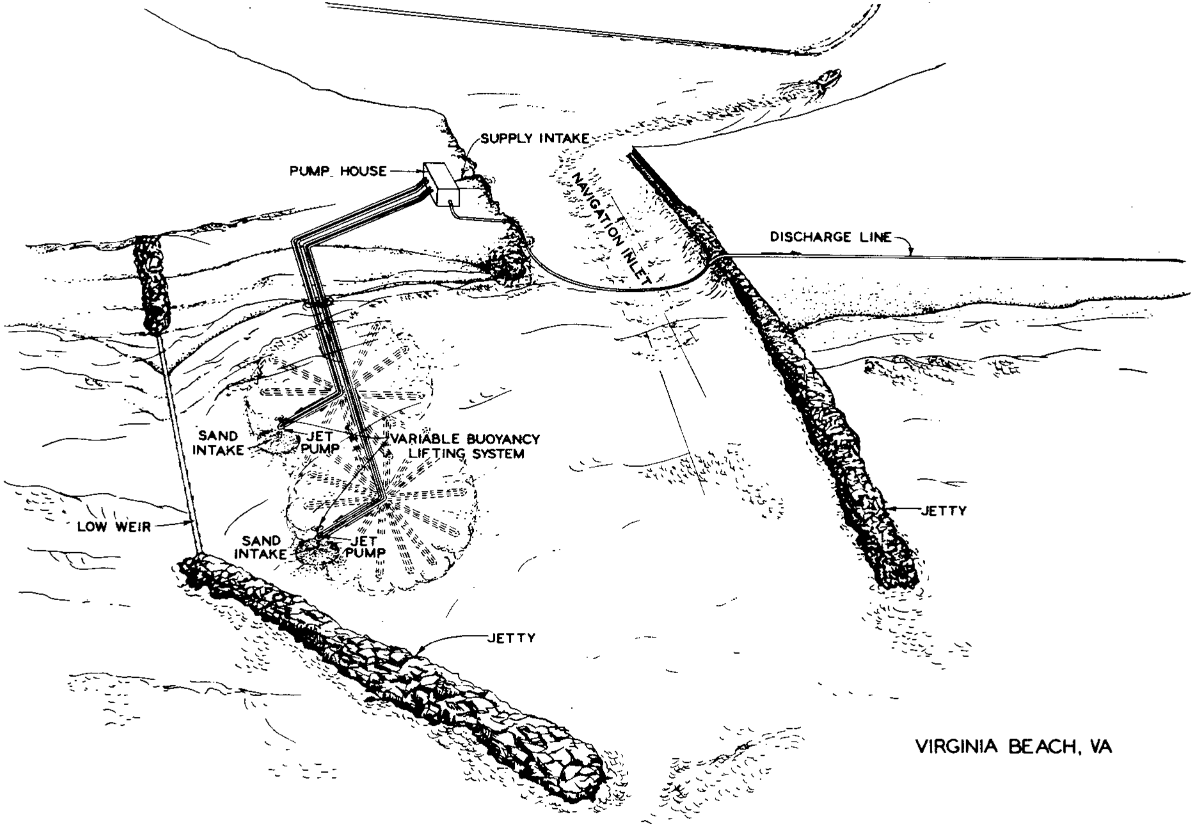

Figure 7. Artist's concept of sand bypassing installation at Rudee Inlet (Virginia Beach), Virginia

Figure 8. Sand bypassing test site at Santa Cruz Harbor, California

to coastal problems. The system has been demonstrated to be rugged, reliable, and effective. During the field tests on the Gulf of Mexico and at Rudee Inlet, Virginia, the system operated successfully in the surf zone, in areas where the currents exceeded 2 knots, and in one instance, through a squall where wind speeds exceeded 50 knots and breaker heights were estimated at 8 ft. Principle advantages of the system are: its relatively low first cost; its tremendous flexibility in location of the jet pump intakes; its relative immunity to wave and current action; its simplicity of operation; and its noninterruption of navigation activities at a bypassing site. Disadvantages are: its proneness to plugging by shell fragments or other debris; and its relatively low production capacity (requiring perhaps continuous operation).

The research program is scheduled for completion in 1978 and publications to be released by that time will include systems design criteria.

ACKNOWLEDGEMENT

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APPENDIX - REFERENCES

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APPENDIX - NOTATION

A_j = nozzle area, ft^2
A_{mc} = mixing chamber area, ft^2
B = area ratio = A_j/A_{mc}
h_{dis} = total discharge head in feet of slurry
h_{suc} = total suction head in feet of slurry
h_{sup} = total supply head in feet of drive fluid
H = head ratio = $(h_{dis}S_{dis}-h_{suc}S_{suc})/(h_{sup}S_{sup}-h_{dis}S_{dis})$
K_{dis} = loss coefficient due to the diffuser
K_j = loss coefficient due to the drive jet nozzle
K_{mc} = loss coefficient due to the mixing chamber
K_s = loss coefficient due to the suction nozzle
Q_{suc} = suction flow rate in gallons per minute
Q_{sup} = supply flow rate in gallons per minute
S_{dis} = specific gravity of discharge slurry
S_{suc} = specific gravity of suction slurry
S_{sup} = specific gravity of drive fluid
γ_{dis} = unit weight of discharge slurry in pounds per cubic foot
γ_{suc} = unit weight of suction slurry in pounds per cubic foot
γ_{sup} = unit weight of drive fluid in pounds per cubic foot
γ_w = unit weight of water in pounds per cubic foot
ϕ = flow ratio, $(Q_{suc}\gamma_{suc})/(Q_{sup}\gamma_{sup})$
U, V, W, X = dimensionless computational parameters