CHAPTER 83

COASTAL SAND MANAGEMENT SYSTEM

by

Birchard M. Brush

Scripps Institution of Oceanography, University of California

La Jolla, California 92037

ABSTRACT

Interruption of sand transport is the most persistent worldwide coastal problem. Wave action produces sand transport which is not a problem in some areas but in others results in coastal erosion, obstruction of harbor entrances, and permanent loss of sand. Conflict between saving sand and bypassing it is caused by a lack of methods to manage this valuable resource. Separate elements of control have been used with varying degrees of success; now it is proposed to incorporate subsystems into an integrated system for management of the littoral transport. A coastal sand management system is to be evaluated using three principal subsystems: (1) a mobile jet pump for use with a crater sink and fluidization accessories; (2) interlocking inertial modules which simulate structural materials because of high intergrain stresses; and, (3) the tactical deployment of phase dependent roughness elements to direct (or reverse) the net transport of sand.

A coherent sand management system promises to make a start toward true control of littoral sand transport. In addition, there is the prospect of eventually establishing the first self maintaining harbors.

It is attractive to consider systems which would be operative within reasonable cost, which may be entirely submerged, and which are capable of operating without regard to surface seakeeping problems.

Some aspects of the system indicate possible use of the mobile jet pump as a means for estimating longshore transport in the field, use in archaeology, and as a dredging and maintenance tool for small nations whose investment capital could not support massive dredging operations.

INTRODUCTION

Everything in the coastal zone, as with life in general, turns into a system. It can be a system at the outset, or through insufficient planning, become one at a less convenient time. An example is the construction of a coastal feature which may have been erected without regard to all of the factors bearing upon the problem, and which then possibly caused new problems by its presence.

Historically, there did exist unique and systematic means of coping with littoral drift around 1500 B. C. Two types of harbors are known to have existed during those times; continuous self-flushing harbors, which accomodated large numbers of ships even by today's standards, and; flushable harbors, which were periodically flushed in the manner of a modern tank toilet, for the removal of sand and silt. Exemplary were the harbors of Tyre (rhymes

with fire) and Sidon (rhymes with widen) on the coast of Phoenicia, locations that on modern maps are on the southern coast of Lebanon.

In 332 B. C., a year before his death, Alexander The Great laid seige to Tyre. To gain access to the walled city which was on a small offshore island, he built a causeway which interrupted the current flow through the harbor, and the divided portions of the harbor began to accrete; the causeway became a tombolo through continued accretion of sand. The method of cleaning the harbor was lost at the time of the Romans and the harbor remains sand covered today.

The harbor at Sidon was flushed by a system of two large sea water storage tanks filled by wind driven swell in the absence of large tidal range which when discharged into the harbor could cause enough current to entrain sediment and thus make it available to bypass along the coast. While wise enough not to resist Alexander, this knowledge of the harbor's manner of operation was lost in about the second century A. D.

In spite of the fact that the resourceful methods of maintaining these harbors were rediscovered in the 1930's by a remarkably astute French priest-archeologist, Pere A. Poidebard, a harbor built by modern engineers in 1958 at Tyre, to provide a Mediterranean terminus for the Saudi-Arabian petroleum pipeline during the Suez crisis, silted up in four months (McKee, 1969).

Modern techniques were not available to the ancients, and because of that fact, they were quite resourceful and innovative. It would appear that today we are 'hoist by our own technological petard' in that sand handling and dredging skills are available only in single expensive remedies, if at all.

At the Scripps Institution of Oceanography, a coastal sand management system is now under study. Its aim is to establish methods for remedial sand bypassing. The coastal sand management system consists of (but is not limited to) three principal subsystems: (1) the crater sink sand transfer system with optional fluidization; (2) ballasted interlocking inertial modules; and, (3) the tactical deployment of phase dependent roughness elements to direct the net transport of sand (Inman and Tunstall, 1972) (Figure 1).

The Crater Sink

The 'jet pump', a form of eductor using the kinetic energy of pumped clear water to entrain sediment laden water, has undergone design and performance improvements in recent years. Originally used in the 1840's for water wells, and more recently as an aid in maintaining suction lift for dredge mounted centrifugal pumps, it now promises to become a dredging means when used alone (it was first proposed for coastal sand handling in 1911) (Knowles and Rice, 1911). The jet pump may be used to form and maintain its own crater (Inman and Harris, 1971), thus maintaining an intentional and purposeful sink. A header of flow controlled valves may be used as an adjunct to the crater. It would use a portion of the driving water to fluidize the sand bottom; the increase in pore pressure reduces the coefficient of internal friction of the sand and permits it to flow freely under the influence of currents and gravity. The current which feeds secondary flow to the inlet of the jet pump would then carry additional sand to the crater where the inlet to the jet pump would be enriched.

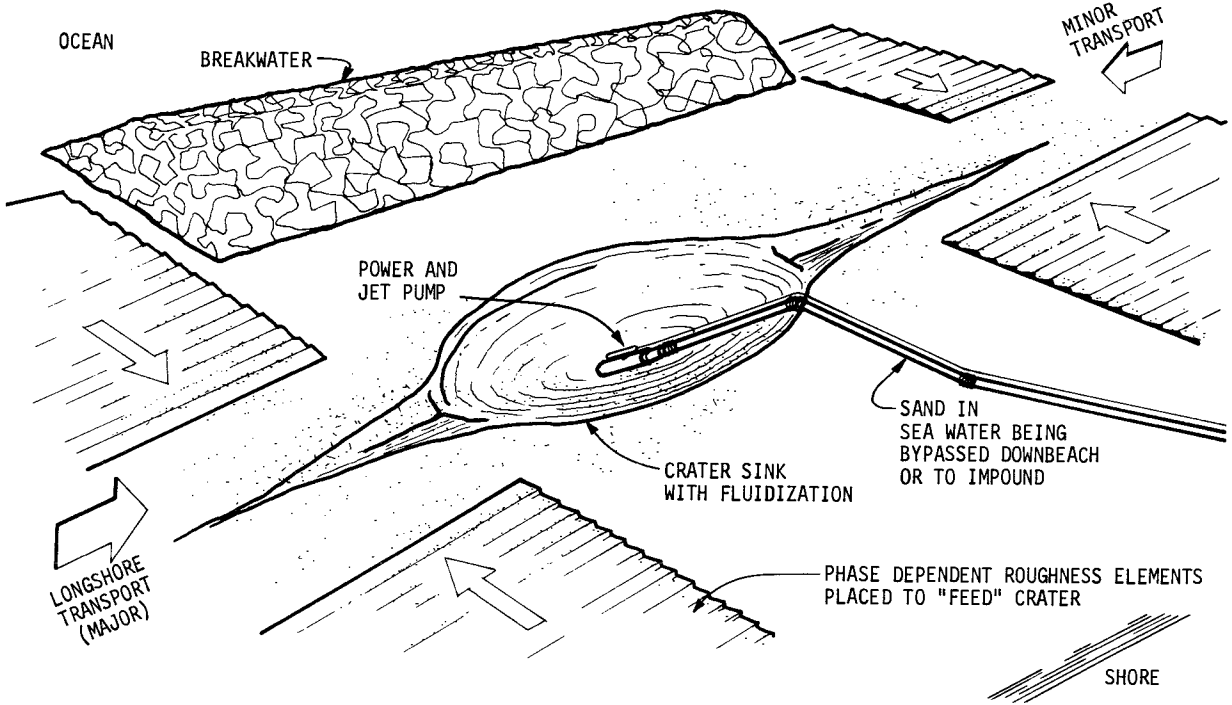

Figure 1. A coastal sand management system. Shown schematically are the crater-sink sand transfer systems, ballasted interlocking inertial modules assembled, for example, into a breakwater or other energy attrition means, and phase dependent roughness elements deployed to influence the direction of sand movement and enrich the crater. These elements are now under intensive study at the Scripps Institution of Oceanography.

A portable system is being assembled which consists of a trailer mounted power supply to drive a jet pump. This unit, fully instrumented, will be transportable. It will be tested in the Scripps Hydraulics Facility especially built slurry test loop. The closed loop test fixture will provide baseline data on carrying capacity, ability to maintain crater geometry by establishing quasi-equilibrium repose angle, ability to pump the crater free of induced cave-ins, ability to pump against slopes, and will continuously record the parameters of interest (Figure 2).

The desired information will include hydraulic head differentials, mass transport, flow velocities and establishment of Newtonian vs Bingham-plastic relationships. After completion of the laboratory phase, the design will have been refined in such a manner that it may be transported to a field location. The packaging will include a mobile power pack consisting of: engine, hydraulic pump, fuel, and instrumentation panel. Standard process electromagnetic flow meters, an important adjunct, will be used both in the test loop and hopefully, be modified for underwater use in the field. A submerged drive will power the pump from as near as possible to the water pump to avoid paying the hydraulic head penalty associated with surface pumping (Hammond, 1969). An air boost is an option which will be studied to determine its contribution as a velocity modulator, and as a means to augment hydraulic head differential.

It should be noted that this method holds promise for use in shallow water dredging, for which no satisfactory method now exists. In addition to a static application such as a crater sink, it has application to dynamic methods such as: 1) programmed 'sweeping' of a river channel or harbor entrance, or in response to wave climate information from sensors; 2) riding on the decks of ships using the harbor entrance (the hitch-hiking feature could be a portion of the harbor fees) for tide phased agitation dredging (Figure 3); 3) arrayed in fixed grids on the bottom. Units would be operable singly or in groups in response to storm impulses or wave climate changes either by operator choice, or as part of a feedback loop; and, 4) arrayed in series along a channel to resuspend sediment and eventually direct it to a crater sink.

In addition to the above direct applications for a mobile shallow water sediment bypassing system, the following uses should be studied: 1) the removal of sediment from dams and other river and stream obstructions; 2) use as a means of excavating a reference crater or channel along a sandy coast or harbor channel for the purpose of estimating littoral drift or channel accretion; 3) use for dredging sediment containing trapped gas (presently considered impossible to dredge because gas pockets break the suction on surface mounted centrifugal pump dredging equipment); 4) use for shallow water archaeology; and inland excavation by wetted crater if clear water may be pumped to the excavation (crater) site.
N. B: The only present options available to underwater archaeologists are the air lift, which requires large hydraulic head differences; and the water jet, which suspends as well as removes sediment thus limiting underwater visibility and not remotely relocating the sediment. 5) use in nations whose economic capability is limited, who cannot afford monster-dredge overkill. Many small harbors (for example; fishing harbors and marinas) could benefit by a small, efficient portable machine to control sediment. Further, the possibility of enhancing sediment movement by the use of two pipes, properly sized, with no machinery or external energy requirements should be studied

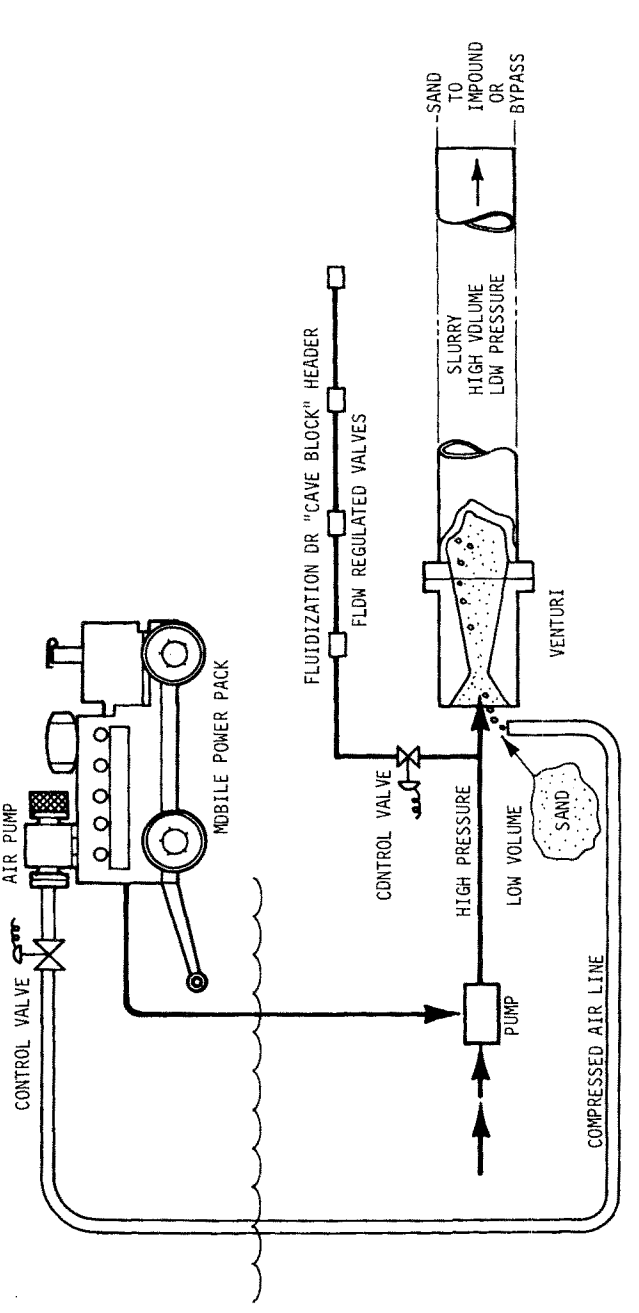

Figure 2. Schematic of the mobile power pack and pump which will be used to investigate sand transfer capabilities of a moderately sized unit. Single, two-phase, and three phase flows will be parametrically evaluated. The three-phase studies are a hybrid design, yet to be proven; but considered promising. "Cave block" refers to a possible technique for eroding the crater, thus enriching secondary flow to the jet pump.

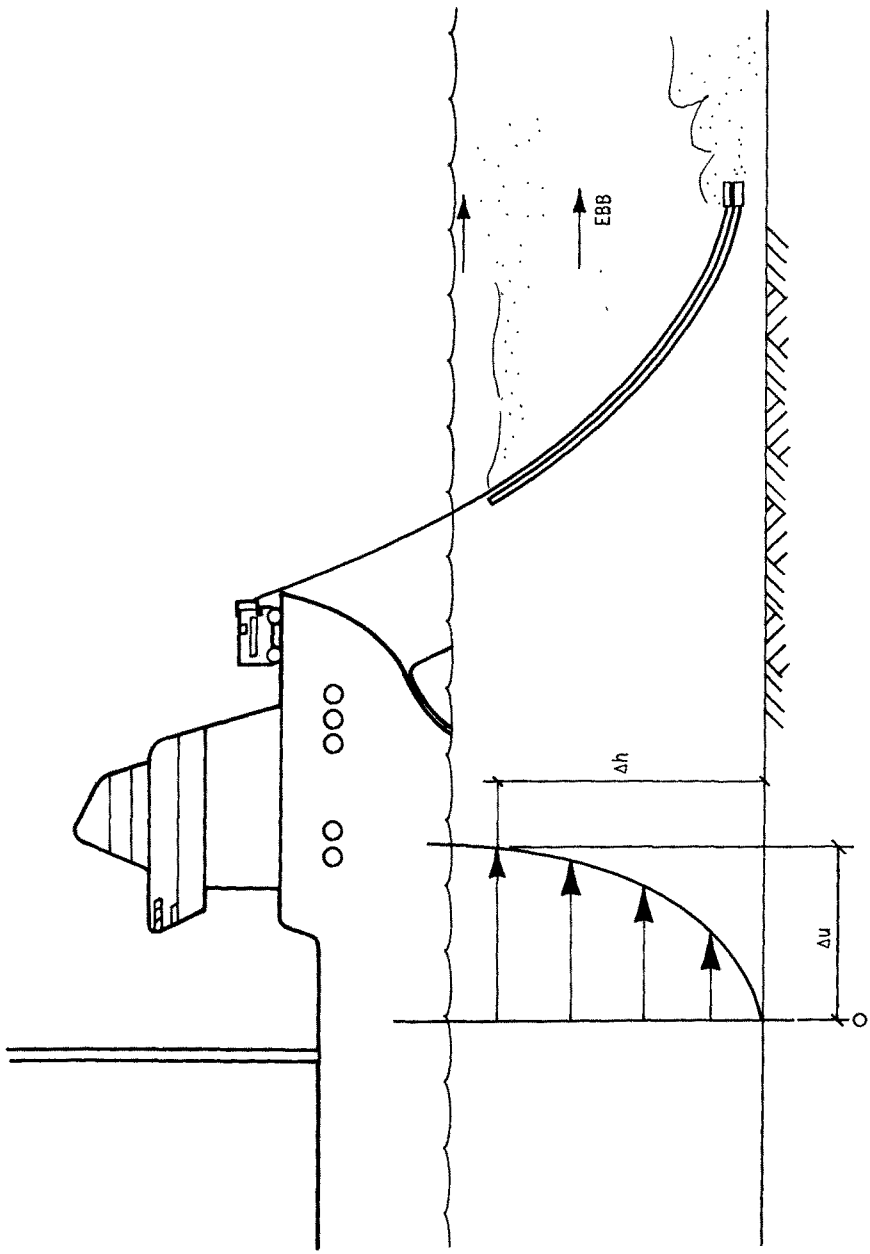

Figure 3. Current or tide-phased "agitation" dredging will be evaluated using the mobile power pack and jet pump. Δh and Δu interact to enhance the optimum relocation of sediment. For less affluent ports and harbors; the hitch-hiking mobile unit could offset, partially, the usual port fees.

(Figure 4). A series of pipes could be placed in a portion of a channel cross section offering the greatest velocity, and by means of a venturi tube, allow a smaller pipe to lift sediment from the bottom. Thus, periodically resuspended by these units at appropriate intervals, sediment could be relayed along, powered solely by the velocity due to the flowing water.

Ballasted Inertial Modules

Techniques to alter the angle of incidence, cause shoaling, or other encouragement of energy control for waves may be enhanced by manmade forms which ideally would utilize native materials, minimize labor, and be low in capital investment. Rocks, riprap, and other native forms have occasionally been augmented or replaced by manmade concrete forms whose inertia and dimensions tend to resist overturn, sliding or rolling by wave action. With the availability of manmade fibers which do not degrade rapidly in the marine environment or from ultraviolet degradation, a new generation of modules should be studied which would take advantage of the requirements listed above. For example, the tetrahedral shape (the botanical or medieval caltrop) may be placed in sites by pumping a dense sand and water mixture into a shape, manufactured of loosely woven polyvinyl alcohol fibers, or an equally durable material.

The water used to pack the sand into the shape would be forced out through the coarse weave, leaving a densely packed rigid form. The forms then could be arrayed in patterns which would endure for a reasonable economic period. Unlike the virtually permanent commitment of rock or concrete shapes, the fabric shapes could be slit and emptied, if necessary, by a diver with a knife. The prospect of searching for optimum shapes with rapid computer graphics is attractive, although regular polyhedra will pack to fill a space (Figure 5). This elegant and efficient technique forms the basis for much of R. Buckminster Fuller's structures (Fuller, 1969). By combining regular shapes to fill space, the critical shear stress for incipient movement becomes much larger, since it is nominally proportional to $(\text{volume})^{1/3}$. In addition, free body diagrams within the space indicate excellent resistance to internal shear because of the efficiently spaced ligaments which were the original shape boundaries. Tetrahedra may be formed when cut from continuous tubes, the method is well known in packaging technology; if a continuous tube with a circumference of four units is cut to a length equal to $\sqrt{3}$ units and the end seams are 90^{o} out of phase, the result will be a regular tetrahedron similar to the small diary product containers found in the U. S. Grain to grain stress may be increased, and specific gravity of sand filled shapes of over 2.0 may be achieved by two methods; 1) after filling, a girth ring (of standard industrial plastic banding) may be tightened around, say a sand bag, and for a slight reduction in volume, a high intergrain stress results. A limp sand bag when stiffened in this manner behaves like a structural unit even though the girth ring causes a reduction in the section modulus of the shape; and, 2) if the external shape is critical and must not be distorted, a small bladder may be introduced inside and expanded to gain higher intergrain pressure (Brush, in preparation).

Inert "shapes" were made with sea water only. Common porous canvas duck was filled with sea water and a polymeric gel (American Cyanamid AM-9 Grout) added which gelled the entire mass; the specific gravity is, of course, virtually that of sea water but a dramatic change in viscosity is achieved thirty seconds (or less) after the introduction of a small amount of the agent in power form.

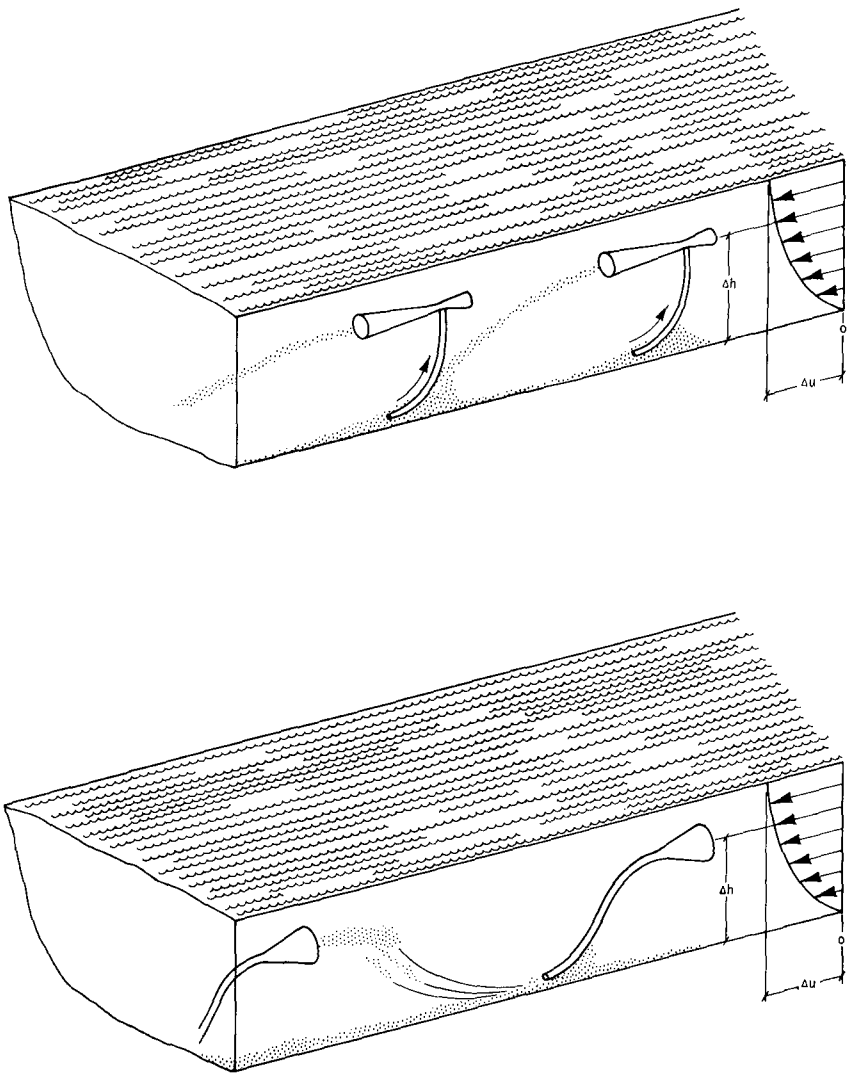

Figure 4. Cascade methods of enhancing sediment transportation need study to capitalize on difference in velocity potential in a fluvial system or in a harbor entrance. Tethered, buoyant units could capture the maximum velocity compatible with maximum ship depth and assist in channel maintenance without placing claims upon the earth's energy budget.

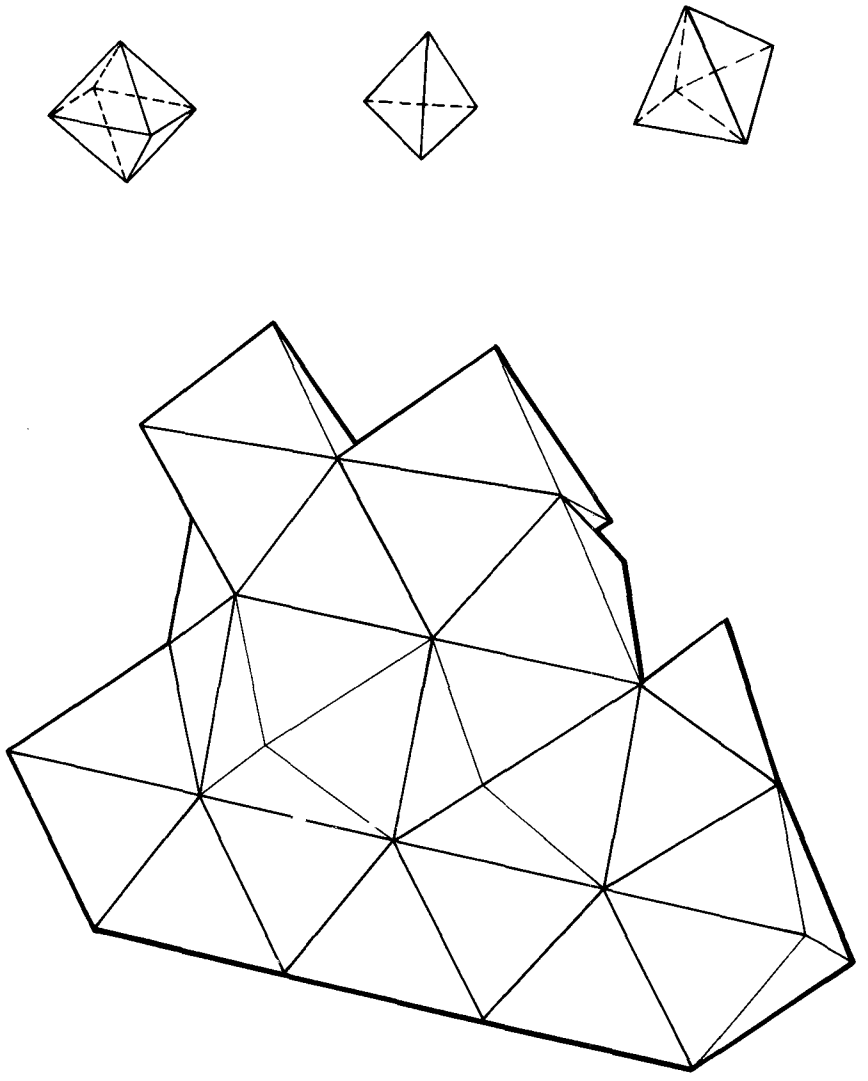

Figure 5. Regular polyhedra will pack to fill space in a complimentary manner. When space is filled in this manner, such as in the formation of a groin, the efficiently spaced ligaments (formed by the equilateral triangles that are the original boundaries of the shapes) have excellent resistance to internal shear.

Phase Dependent Roughness Elements

The importance of the shapes of ballasted modules becomes more evident when the phase dependent roughness elements which control, and even reverse sand transport are considered. Using shapes which, when filled, could be laid on the sea floor like a heavy carpet could enable sand to be directed by wave action to the jet pump from any desired direction.

The first models of elements were placed on the relatively smooth, sandy bottom of Scripps Beach in late 1971 and a larger array in the spring of 1972, all of these were rigid plaster or concrete forms and performed as laboratory studies had predicted. The first combined use of phase dependent elements with a flexible filled shape consisted of a frame of metal which dictated the height and wavelength of the elements. It was covered by a fabric "skin" whose panels had been partially rigidized with resin.

Recent laboratory tests and model experiments show that a remotely controllable array of elements may be made which will be movable, and respond to changes in wave climate, or to reversals in the direction of the principal sand transport. These modular shapes now are the precursors of elements whose slopes may be modified when control is achieved through a feedback loop in a given location. Changes in wave climate, fed into a computer, would cause modulation of the height-slope characteristics to cope with the changed conditions.

The System

When these subassemblies are integrated in order to act as a coherent system they promise to make a start toward true control of littoral sand transport (provided that the activities are preceeded by prudent and enlightened observation). In addition, there is the prospect of eventually establishing the first modern self-maintaining harbors. It is attractive to consider systems which would be operative within reasonable cost, which could be designed to be entirely submerged, and to operate without regard to surface seakeeping problems. The limitations of standard dredges have received comment (Wiegel, 1964), and additional incentives to the adoption of systems are the complicating factors of the 8 hour work day, and the forty hour week. These factors have forced costs higher because of the enormous cost attendant to the use of premium time, and multiple shift problems. One resort has been the use of larger and larger equipment to extract the maximum quantity from one 8 hour shift. The purpose of this contribution is to suggest that bigger is not necessarily better.

Conclusion

In a harbor which interrupts longshore drift, a system would provide an efficient and continuous means of bypassing or impounding sand for beach replenishment, commercial use, or simply to bypass downcoast. The prospect of maintaining deep channels for vessels drawing 70 feet or more is attractive because channels may be 'swept' using elements of this system. It would be possible to maintain a clear channel and manage the subaqueous profile of a sick harbor entrance. An economical method might make the competitive difference for a small harbor whose economic health was traffic dependent.

A form of jet pump has been in use for years in Colorado and in northern California for use in the extraction of heavy metals from crevices (Clark, 1972). It seems possible that the effort to continuously, or on a

sample basis, perform centrifugation of the effluent of the jet pump and sample the content of the crevices in the phase dependent elements, might result in enough income to partially defray routine maintenance expenses.

Some of the ideas advanced herein are admittedly conjectural but if successful and adequately promulgated, we may rest assured will be thoroughly dogmatized. The development of a coastal sand management system would provide a solution to an urgent and continuing problem.

Acknowledgements

I thank the U. S. Department of Commerce, NOAA, Sea Grant Program for providing an atmosphere which encourages innovation and dissemination without overpatronizing. The U. S. Army Corps of Engineers, Waterways Experiment Station, for supporting innovative research, and Professor Douglas Inman, Scripps Institution of Oceanography, for patient and helpful criticism.

REFERENCES

Brush, B. M., in preparation, "Ballasted interlocking inertial modules".

Clark, W. B., 1972, "Diving for Gold in California", California Geology, vol 25, no 6, p 122-143.

Fuller, R. B., 1969, Ideas and Integrities, MacMillan, New York, 318 pp.

Hammond, R., 1969, Modern Dredging Practice, Chapter 1, p 1-27, Fredrick Muller, London, 274 pp.

Inman, D. L. and R. W. Harris, 1971, "Crater-sink sand transfer system", Proc. Twelfth Coastal Engin. Conf., Amer. Soc. Civil Engin., New York, vol 2, p 919-933.

Inman, D. L. and E. B. Tunstall, 1972, "Phase dependent roughness elements", Thirteenth Int. Conf. Coastal Engin., Amer. Soc. Civil Engin., Abstracts Volume.

Knowles, M. and J. M. Rice, 1911, "Use of the water ejector for transporting sand", Jour. New England Waterworks Assoc., vol 25.

McKee, A., 1969, History Under the Sea, p 263, E. P. Dutton, New York, 342 pp.

ADDITIONAL REFERENCES OF INTEREST TO READERS

Diole, P., 1954, 4000 Years Under the Sea, Promenades d'archeologie sous-marine (trans. G. Hopkins) J. Messner, New York, 237 pp.

Frost, H., 1963, Under the Mediterranean: Marine Antiquities, Routledge and Kegan Paul, London, 278 pp.