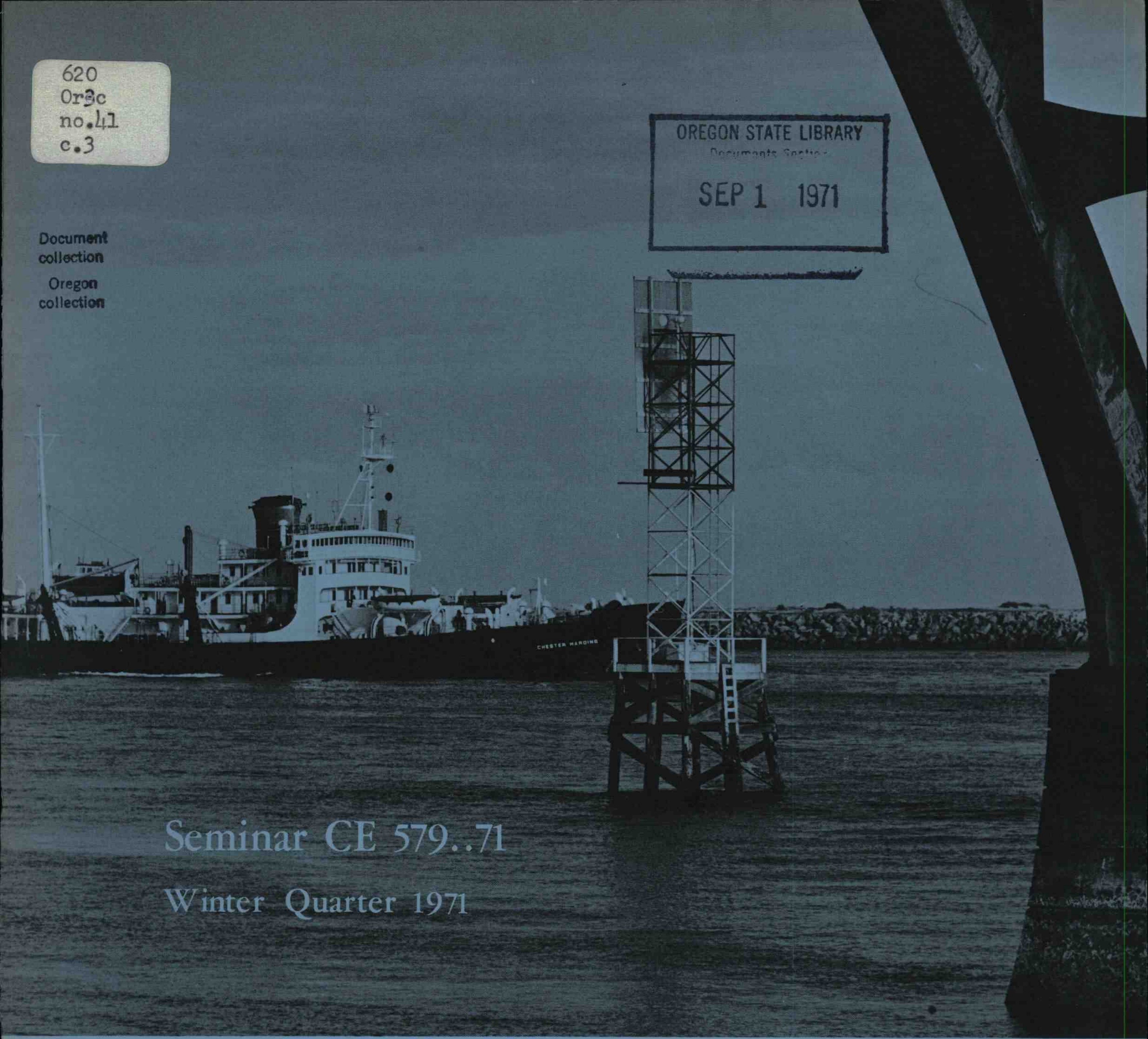

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Seminar Proceedings:

Topics in Ocean Engineering

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Preface

Ocean Engineering is a developing field where existing engineering technologies are being extended to effectively develop the resources of the marine environment. To promote greater understanding of Ocean Engineering techniques and to identify areas of needed research, a series of weekly lectures was arranged during the Winter Quarter of 1971 on the Oregon State University Campus.

Speakers were invited to give addresses to a wide range of technical and legal subjects dealing with problems involving the ocean and coastal environment. Students attending the seminars participated in exchanges with the speakers to hear about ocean engineering challenges and opportunities. It is hoped the reader will find the following papers interesting while reading of the efforts of leading professionals who have successfully dealt with marine and coastal problems.

The cooperative and enthusiastic support given by the speakers to the Ocean Engineering Seminar is gratefully acknowledged.

Larry S. Slotta
Director

Ocean Engineering Program

Oregon State University

Graduate study in ocean engineering is offered at Oregon State University through the School of Engineering. This program of study leads to the degree of Master of Ocean Engineering or Master of Science and Doctor of Philosophy degrees in Engineering with an emphasis on ocean engineering. These interdisciplinary programs are offered in cooperation with the Oceanography Department and other academic faculties with special interests in ocean science.

A student in ocean engineering, depending on his specific interests, is admitted to the Department of Chemical, Civil, Electrical, Industrial, or Mechanical Engineering. A program of study is then designed to fit the individual's professional objectives and to achieve a high degree of engineering competence applied to the ocean environment.

Some of the study and research areas in ocean engineering emphasized for development under the "Sea Grant" program are: Coastal and estuarine hydrodynamics and hydraulics, Marine water pollution control, Marine geotechnique, Coastal structures, Engineering materials and electrochemical processes, Marine systems design, Instrumentation, Simulation, Fluid measurements, Underwater acoustics, Biochemical engineering, and Marine bioacoustics.

Extensive facilities available to the ocean engineering program include numerous laboratories including: hydraulic, sanitary, photogrammetry, soil mechanics, structural engineering, engineering material, instrumentation, simulation, electrochemical, underwater acoustics, mechanical engineering, computing center, technical libraries, and oceanographic laboratories. In addition, Oregon State maintains field laboratories and has access to the facilities of several federal laboratories. These include the following: OSU Marine Science Center at Newport, Oregon; OSU oceanographic research vessels; OSU Netarts Bay research area; OSU Port Orford marine station; OSU Seafoods Laboratory, Astoria; and the Pacific Northwest Water Laboratory, EPA, in Corvallis.

Traineeships, research and teaching assistantships in Ocean Engineering are available for qualified students. Individuals involved in Ocean Engineering programs at Oregon State University work closely with industry and organizations off campus to help solve problems associated with the marine environment.

This information is published by Oregon State University as part of the National Oceanic and Atmospheric Administration Sea Grant program.

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Oregon State University's Sea Grant Program is partially maintained by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce.

Presented January 26, 1971, by Dr. William J. McNeil, Head of Pacific
Fisheries Laboratory at Newport, Oregon, Department of Fisheries and
Wildlife, Oregon State University.

Ocean Food Resources and the Future of Mariculture

The resources of the earth are finite, and man must find the means to arrest the growth of his population if catastrophe is to be avoided. Man technically can control his population without resort to fratricide, but social acceptance of population control will emerge slowly. For the immediate future it appears that man must face the prospect of a continued geometric population growth which presently doubles the number of humans in about 35 years.

The provision of an adequate food supply for a rapidly growing population has focused attention on the "green revolution" in agriculture and on ocean fisheries. These two developments can complement one another if applied wisely to assist man to "buy time" which can be used to seek solutions to the predicament of uncontrolled population growth.

The "Green Revolution"

My reference to "green revolution" relates to the high-yielding varieties of cereal grains recently developed by agriculturists. The new varieties have boosted yields per acre by 2 to 4 times, but the increased yields have certain associated "costs." Perhaps the most evident immediate drawback is a pronounced drop in protein content of the high-yielding grains. The protein content of certain high-yielding varieties of corn and wheat is, for example, only 62% to 63% of the protein content of the low-yielding varieties. Swine can be raised on low-yielding, high protein corn without protein supplements; but their diet must be supplemented with protein concentrates when they are fed the high-yielding varieties. Much of the supplemental protein found in farm animal feeds comes from ocean fish which are processed into meal and oil.

The nutritional requirements of man are similar to those of swine and other farm animals. Hence, the "green revolution" will not solve man's food problem without supplemental sources of protein. The critical dietary need of man today and into the immediate future is for additional protein.

The Need for Animal Protein

"Malnutrition" is not necessarily synonymous with "starvation." Cereal grains might supply the caloric needs of the human body to avoid hunger and starvation but a diet deficient in protein inevitably leads to malnutrition even in the absence of hunger. Furthermore, plant protein alone does not provide a nutritionally adequate diet for humans since plants typically lack certain amino acids which are the determinants for growth and repair of body tissues[1]. Up to 50% of the human population may be affected by protein deficiency today. Problems of protein deficiency are especially critical in under-developed countries where population growth is most rapid.

The need of animal protein has placed greater demands upon global marine fisheries resources. About 70% of the earth is covered by marine waters, and many people believe that the ocean is capable of feeding mankind. We should consider the reasonableness of this assumption.

Outlook for Ocean Fisheries

Landings of food fish and shellfish have increased about four-fold since the end of World War II. If we were to project recent annual geometric growth of ocean fisheries into the future, we would predict another doubling of landings by the early or mid 1980's (an eight-fold increase since World War II).

These projections are a source of comfort, because they suggest that the annual harvest of protein from the ocean is increasing three times faster than the human population. If we can sustain this difference for another two decades or longer, perhaps we will achieve a reasonable balance between the number of humans and their supply of protein. But can we sustain a continued rapid growth of ocean fisheries?

Fisheries analysts who have examined this question seem to agree in general that we might anticipate somewhere between a two- and a four-fold increase of today's ocean harvest. The calculations

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1) Ten amino acids are essential for normal growth and development--arginine, histidine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine.

are based on the assumption that technology will continue to place emphasis on the capture of wild stocks. This means that we may exhaust the major opportunities for increased harvest of food fish and shellfish in the 1980's. One then wonders about the possibilities for break-throughs in sea farming technology which would place food production in the ocean more under the control of man and make stocks of food fish and shellfish less dependent upon the vagaries of nature and less vulnerable to over exploitation.

Mariculture

Mariculture (marine aquiculture or sea farming) has been practiced for at least 4,000 years in Asia and 2,000 years in Europe. However, it has only been in recent times that man has been forced by exigency of population growth to consider the application of advanced methods for farming the oceans.

Production of wild fish stocks in the more productive marine water compares favorably with cattle on pasturelands (20 to 300 pounds per acre per year). By contrast, the culture of oysters in Japan has produced 46,000 pounds of meat per acre per year and of mussels in Spain 240,000 pounds. Such high yields are made possible by suspending shellfish from rafts and growing them in vertical columns where currents deliver a continuous supply of algae to the feeding animals.

High yields have also been obtained by raising fresh water fish in ponds and raceways on artificial diets. Raceways with flowing water are the most productive, with yields up to one million pounds per acre per year reported for carp and 70,000 pounds for trout. The yield of catfish raised in static ponds may be 2,000 pounds per acre per year, but this can be increased 50 percent or more by introducing small volumes of flowing water. Possibly the use of floating or submerged pens in the ocean or estuaries or the circulation of heated sea water from coastal steam electric stations through raceways will someday provide similar opportunities in mariculture.

One premise of mariculture is that higher levels of animal production are possible in water than on land. There are a number of reasons for this:

(1) Aquatic animals require less skeletal support than terrestrial animals since they live in a medium of approximately their own density. A higher percentage of their assimilated energy can therefore be devoted to production of edible musculature.

(2) Fish and shellfish are cold-blooded and do not expend a significant portion of their caloric intake to maintain a constant body temperature.

(3) When reared in brackish water approximately isotonic to their body fluids, fish and shellfish expend relatively little energy in osmoregulation.

(4) Sessile forms, such as oysters, expend relatively little energy in searching for food.

The more advanced systems in mariculture employ hatcheries to provide seed stock; whereas, the least advanced systems rely upon natural populations to supply juveniles to be raised under semi-controlled conditions. Before a food fish or shellfish can be raised successfully under the more advanced systems, the animal must exhibit certain characteristics:

(1) Adults should reproduce in captivity or semi-confinement or yield easily to manipulations that result in the production of their offspring;

(2) eggs and larvae should be hardy and capable of being hatched or reared under artificial conditions;

(3) food habits of larvae and young should be satisfied by operations which can increase natural food, or they should be able to take prepared feeds beginning with their early stages; and

(4) juveniles should gain weight rapidly and show a high conversion efficiency.

Mariculture requires substantial investments in equipment and facilities and much labor must be expended to maintain healthy stocks of fish or shellfish and to harvest and process animals. In the United States, the market value of products of mariculture must compare with the better cuts of beef if the producer is to realize a profit with present technology. Because mariculture is still in an early stage of technological advancement, we can anticipate innovations which will reduce the cost of production as science and technology begin to attack the problems.

Some of us can recall when broilers were a high-cost luxury food favored primarily for an occasional Sunday dinner. This changed in the 1950's and 1960's--the average price of broilers dropped 50 percent in the 15-year period 1949-64. The break in price was made possible only after serious disease problems and nutritional deficiencies were understood and methods of control were devised. Fast growing breeds of chickens were developed through selective breeding, and "factory" methods of production were adopted. The outcome is obvious in the market today where poultry ranks among the least expensive of our meats.

Fishery science is beginning to lay the biological groundwork in mariculture which someday might provide the foundation for technological innovations necessary for low-cost production of food fish and shellfish. The important biological problems have been categorized by a British scientist (Dr. J.D. Shelbourne) as primary and secondary limiting factors.

- (1) Primary limiting factors
  - (a) The provision of high-quality "seed stock"
  - (b) Food supplies for captive stock at different stages of development
- (2) Secondary limiting factors
  - (a) Physico-chemical conditions
  - (b) Stock-space relationships
  - (c) Disease
  - (d) Competition

Research in Mariculture at Oregon State University

The Oregon State University program currently places emphasis on Pacific salmon and oysters. Salmon and oysters enjoy a strong market demand and bring high prices. Knowledge of their life historie and ecological requirements is fairly complete. Both have been raised successfully in hatcheries.

Pacific Salmon

Of the five species of salmon which spawn in Northwest streams, three species (Chinook, coho, and sockeye) feed in fresh water as juveniles for several months before entering the ocean and two species (pink and chum) typically enter the ocean immediately as unfed fry. When young salmon enter the sea, they must maintain a proper balance of water and salts in their body fluids and tissues. To avoid dehydration while at sea, salmon drink water and excrete excess salts. Pink and chum salmon are able to excrete excess salts as young fry, but the other species must grow to a larger size before they are prepared physiologically to live in the ocean.

Oregon State University has constructed an experimental hatchery at Netarts Bay, Tillamook County, to produce young salmon for release directly into salt water. Land for the hatchery was donated by Mr. and Mrs. Victor A. Swanson. The Fish Commission of Oregon, the National Marine Fisheries Service, and the Sea Grant Program of the National Oceanic and Atmospheric Administration have provided financial support for the project.

Three groups of salmon (393,000 pink; 220,000 chum; and 75,000 Chinook salmon) were released from the hatchery in winter and spring 1970 in an effort to develop a source of seed stock for future salmon aquiculture. Releases of additional groups of fish (225,000 pink; 475,000 chum; and 40,000 Chinook salmon) are scheduled for completion in May 1971. Success of these releases will be judged by the number of spawners returning in later years.

Other experiments on salmon culture are underway at Port Orford, Curry County, where we have converted a former Coast Guard Station into a marine research laboratory. Young Chinook and hybrid salmon can be acclimated to live in ocean water by first raising them for several weeks in water of low (16%) salinity. Chinook salmon released into Netarts Bay in spring 1970 were acclimated to live in ocean water by this method.

Further studies are being planned to determine the effects of temperature and ration on growth of juvenile salmon in salt water. Under favorable conditions in nature, salmon will increase their body weight by two percent per day. A growth of 2.4 percent of body weight per day has been achieved in a Canadian Laboratory. If we knew how to achieve this rate of growth in heated sea water from coastal steam electric stations, we could produce a one-pound fish in 21 weeks.

Our immediate goals with salmon, then are:

(1) To develop a source of salmon seed stock to serve a future mariculture industry.

(2) To understand the role of temperature and ration on growth of salmon in thermally-regulated sea water.

Oysters

Oyster seed is usually collected from natural waters and raised under semi-controlled conditions. Considerable attention has been given in recent years to the production of oyster seed in hatcheries, and the Oregon State University pilot oyster hatchery is the first major facility designed for this purpose in the Pacific Northwest.

The pilot oyster hatchery was constructed with funds from the University, the Oregon Cooperative Oyster Marketing Association, and the Lincoln Development Corporation. The Association was organized with the help of the Lincoln Development Corporation to work cooperatively with Oregon State University to determine the feasibility of constructing a commercial hatchery on the Oregon coast. We are now in our second year of production of oyster seed from the hatchery. Several operational problems have been identified, and some have been solved. We hope soon to approach our target production of about 20 bushels of oyster seed per week (one bushel contains about 10,000 juvenile oysters attached to shell).

The hatchery has already proven to be a valuable asset to other research. Our study of oyster genetics, financed by the Hill Foundation, is made possible by the fact that we can crossbreed selected adult oysters with reasonable assurance that a substantial quantity of juvenile oysters will result. We also have Sea Grant supported work underway on physiology, feeding behavior, and settlement of oyster larvae. These experiments require substantial quantities of oyster larvae which are readily available from the hatchery throughout the year.

Juvenile oysters from a hatchery need to obtain early growth before they are transferred to growing grounds. This is especially important in autumn, winter, and spring, when the environmental conditions are apt to be most severe. The operation of a commercial oyster hatchery will require that juvenile oysters be held for several weeks in water having a temperature suitable for rapid growth. Heated discharge water from coastal steam-electric stations might be used for this purpose.

There might also be opportunities to link together the growing of salmon and oysters in a symbiotic "factory type" aquafarming system to enrich water for phytoplankton production. Other trace elements might be added along with an innoculum of plant cells to stimulate a rapid "bloom." Water would then be "filtered" through a bed of oysters which would convert the phytoplankton into valuable animal protein.

Conclusions

Development of high-yielding varieties of cereals and increased utilization of marine fisheries can provide only temporary relief for food shortages if man fails to arrest population growth. Major benefits will come from oceanic food resources because they supply critically needed animal protein.

Stocks of wild food fish and shellfish probably can sustain a substantial increased harvest for another decade or two. Major break-throughs in technology leading to large-scale mariculture will probably become necessary if man is to sustain increased production of animal protein from the ocean for longer than two more decades.

Research in mariculture at Oregon State University is presently emphasizing Pacific salmon and oysters. The projects involve the development of hatchery systems for producing seed stock and the raising of animals for market.

Presented March 9, 1971 by Professor Jon L. Jacobson, Oregon School of Law, University of Oregon.

Ocean Zones and Boundaries

An old joke has a couple on their first ocean voyage. She, looking out across the moonlit sea, sighs, "Oh, Henry, the ocean is so big." He: "Yeah, and that's just the top of it."

To an ocean scientist, at least, the joke is not so funny. To the extent that it contains any humor at all, it depends on the two dimensional view of the sea held by land-lubbers and ship-ravelers. The oceanographer, however, is trained to look at the ocean as a vast living mass with great depth as well as length and breadth. Henry is simply recognizing a basic truism.

This truism is coming to be recognized today by more and more people. Man's technology will soon make it possible for him to exploit much of the sea's natural resources and may, within the not-too-distant future, allow him actually to live for long periods of time within the ocean. As man increasingly descends into the sea and continues to travel its surface, he takes more and more of his society with him -- sort of like the early settlers of the Old West.

The extension of man's society outward from land and, now, into the depths of the ocean necessarily carries with it the laws and regulations which form the organization of that society. For example, consider that recent technological developments are enabling us to extract oil and other resources from the sea-bed farther out from dry land and deeper than ever before. The resulting ocean activities have shown an acute need for regulatory systems (sets of laws) for the exploration and exploitation of the ocean bottom. Various regulatory schemes for just this purpose are now being proposed and enacted.

It must be remembered, when considering legal rules for ocean activiities, that civilized man has traditionally placed the prime responsibility for the formal organization of his society in various sovereigns or governmental authorities. It therefore is very important to know or to decide which governmental authority, if any, has the power to regulate ocean activities in any given area.

It is not uncomplicated.

SURFACE ZONES: BACK TO TWO DIMENSIONS (MORE OR LESS)

Actually, of course, man has been using the ocean for a good many centuries for transportation of himself, his goods and his messages, for fishing, and for carrying out his interminable wars. During this time, he has found it necessary to delineate certain oceanic zones of authority. Because marine activities were for so long limited almost entirely to the surface, these established zones of authority tended, and still tend to "float" on the waves and show little more than a technical concern with the sub-surface.

The traditional surface zones are essentially three: (1) Internal waters, (2) territorial seas, and (3) high seas. Another surface zone of more recent creation will also be discussed: (4) the contiguous zone.

Internal Waters

The term "internal waters" refers not only to certain oceanic waters but also, and even more clearly, to lakes and rivers and streams. As the term implies, internal waters are those watery areas recognized to be entirely within the boundaries of a nation and completely subject to the nation's control. For example, Lake Tahoe - which straddles the border between California and Nevada - is subject to the control of no nation other than the United States. (Of course, there are some conflicts between the states of California and Nevada, but this is a non-international matter. Nevertheless, keep in mind the added complexities which our federal system of government presents.)

But Lake Tahoe is by no reasonable definition an "ocean" and we are supposed to be discussing ocean zones. So let's look at bays. Is a bay a lake or part of the ocean, or something different? Whatever a bay is physically, and whether you call it a sound, an inlet, estuary, or anything else, if it occupies a sufficiently deep indentation into a nation's coastline and presents a sufficiently narrow mouth to the open sea, it is legally internal waters. That is, it is subject to the exclusive control of the nation, like a lake. San Francisco Bay is a good example. A map of the California coast will show immediately that the Bay makes an exceptionally deep gouge into the coastline and meets the open sea at a very narrow mouth which we know as the Golden Gate. San Francisco Bay is, therefore, internal waters of the United States and, as to other nations, subject to the complete sovereignty of the U.S. Ships of other nations can enter the Golden Gate only with the permission of the U.S. and under any conditions the U.S. wishes to impose.

So internal waters are, in regard to the extent of governmental authority exercised over them, identical to the land territory of a nation: subject to complete sovereignty.

Territorial Seas

How do territorial seas differ from internal waters? Doesn't a coastal nation exercise complete sovereignty over its territorial sea? In a word, no.

The territorial sea is a belt of ocean bordering a nation's coastline. Its width (distance from shore to outer edge) varies among coastal nations; the U.S. territorial sea is three nautical miles. Many people are used to thinking of the territorial sea as the edge of a nation's existance - that the outer edge of the territorial sea is the outer boundary of the nation. To a large extent, this is true; but to the extent that this conception of the territorial sea leads one to believe that the waters within the territorial sea are subject to the same scope of governmental control as the nation's land or internal waters, it is not quite accurate. Actually, the only real difference between internal waters and territorial sea is that ships of other nations have the right of "innocent passage" through territorial seas. This basically means that a ship of one nation may "legally" (in the international-law sense) pass, in a non-hostile manner and for a non-hostile purpose, through the territorial sea of another nation without having first to ask permission or put up with any but minimal and reasonable conditions of passage. Except for this right of innocent passage, a nation's territorial sea is just like internal waters: the water and everything in, on, above, or beneath it is subject to the nation's complete sovereignty.

The historical development of the territorial sea concept (along with the concept of freedom of the high seas) is fascinating, if sometimes obscure. Unfortunately, there is hardly space here to go into it. Let us just say the territorial sea probably emerged originally to serve one or both of two purposes: (1) To assert the exclusive right of the nation claiming the territorial sea to fish in the claimed area; (2) To define in wartime the extent of a neutral country's neutrality. Especially with regard to this latter purpose, it is no doubt true that the range of the eighteenth-century land-based cannon (about three nautical miles) had something to do with establishing the width of the early territorial seas. This was the maximum width a nation could claim with any real authority. In fact, Thomas Jefferson, in asserting the young United States' claim to a three-mile territorial sea, referred to the "cannon-shot rule".

However, it is clear that in this day of intercontinental ballistics missiles the cannon-shot rule no longer serves as the justification for a nation's territorial-sea width. If it did, the U.S.'s territorial sea would, of course, encompass all bordering seas - and then some. Today the breadth of any nation's territorial sea depends on many complex factors, some more important to certain coastal nations than to others. For example, the U.S. continues to claim a rather narrow three-mile territorial sea largely because it is a sea and air power: it wants to discourage all coastal nations from claiming wider areas of the oceans so that the U.S. Navy and Air Force will have more non-territorial ocean space in which to maneuver. On the other hand, a nation which has great economic dependence on its coastal fisheries will want to claim a broad territorial sea for the purpose of excluding other nations from fishing off its shores. An extreme example is Peru, which claims sovereignty out to 200 miles (but this claim is generally not officially recognized as "legal" by the international community).

Though there is today no established agreement among nations on what the width should be, the definite trend is toward wider territorial seas. Two conferences of nations, one in 1958 and one in 1960, were called to attempt to establish some agreement on this problem; but in both cases, the delegates failed to reach any consensus on territorial-sea width. It was agreed, however, that any claims beyond twelve miles should not be recognized as valid. Partly as a result, more and more nations are claiming the maximum twelve miles as the breadth of their territorial seas. The United States itself may be well down the road to such a claim. But, as of this moment the official claim of the U.S. is that put forth by Thomas Jefferson: three miles.

The Contiguous Zone

The term "contiguous zone" has got to be one of the least descriptive terms in the English language. "Contiguous," of course literally means "adjoining" or "next to" - so we here have an ocean zone which is "next to" something. As might be guessed from the organization of this discussion, the contiguous zone is a zone next to or adjoining the territorial sea on the ocean side.

The contiguous zone pretty much originated in the agreement of coastal nations at an international conference on the Law of the Sea held in Geneva in 1958 (the same 1958 conference referred to above in the discussion of the width of the territorial sea). There were earlier similar concepts of international law, but the 1958 conference was responsible for both the name of the zone and its present accepted meaning.

A contiguous zone, according to the 1958 treaty, is a zone of the high seas,contiguous to a coastal nation's territorial sea, in which the coastal nation may excercise the control necessary to

(a) Prevent infringement of its customs, fiscal immigration or sanitary regulations within its territory or territorial sea;

(b) Punish infringement of these regulations committed within its territory or territorial sea.

Thus, a coastal nation has a recognized right to exercise its governmental authority to a limited extent outside its land territory or territorial sea. Remember that the territorial sea is, except for the right of innocent passage, subject to the complete sovereignty of the coastal nation and is therefore properly viewed as being within the nation's boundaries. On the other hand the contiguous zone lies <u>outside</u> these boundaries but is an area in which the coastal nation may exercise certain limited rights for special purposes. For example, a coastal nation could "legally" (under international law) carry out anti-smuggling operations outside its territorial sea and within the contiguous zone.

Which raises the next question: How wide is the contiguous zone? The 1958 treaty specifically states that a nation's contiguous zone may not extend more than twelve miles from the nation's coastline. Therefore, the United State's contiguous zone occupies a belt nine miles wide along the outer border of the three-mile territorial sea. It should be noted that nations which claim a twelve-mile territorial sea would of course have no right to claim a contiguous zone.

The High Seas

The high seas are all waters beyond the outer limit of the territorial seas. This again is a definition supplied by a treaty arising from the 1958 Geneva Conference of nations, although it is simply a restatement of a long-recognized concept. Notice that the definitions of both the high seas and the contiguous zone contemplate that the contiguous zone overlaps and is part of the high seas.

The high seas encompasses the vast majority of the waters of the world ocean. These are the waters outside the exclusive control of any nation and therefore not part of any nation's territory. For centuries, a concept called "freedom of the seas" has been recognized on the high seas. While freedom of the seas has many meanings in many contexts, it basically guarantees to all nations certain important rights to the use of the high seas without restriction or control by any other nation or authority. These rights include the rights to surface and air navigation; the right to fish; and the right to lay submarine cables and pipelines.

Of course, sea-faring nations may agree among themselves to certain restrictions and regulations concerning their own use of the high seas. Fishing treaties are a good illustration of these "contracts" between nations. For example, the North Pacific Fisheries Convention is a 1952 fishing treaty among Japan, Canada and the United States. Part of the agreement among these nations, all of whom fish extensively in the North Pacific, was that where one member-nation manages and fully utilizes a certain species of fish, the other members will abstain from fishing that particular stock of fish. Thus, the American salmon, spawned and developed in the U.S., could be fished only by U.S. fishermen if the salmon stock were "fully utilized" by the U.S. It must be noted, however, that such international agreements on the use of the high seas are binding only on the nations which are parties to the agreements. All other nations have the right to freedom of the seas, including the freedom to fish.

Today, as territorial seas tend to widen and as developed nations look increasingly to the deep sea and sea-bed as sources of food and mineral wealth, the concept of freedom of the seas is in jeopardy. Many of us will probably live to see the day when what we now refer to as the High Seas is subject to the control of a few nations or to the regulatory power of an international organization.

THE NEW "RESOURCE" ZONES

One of the many recent by-products of the post-World War II technological explosion has been the expanded capability of developed nations to exploit the sea's natural resources. Japan and Russia now have fishing fleets which roam the world, freezing and canning their catches in huge factory vessels. American companies drill for oil and gas on the world's continental shelves at depths undreamed of a few years ago. The relatively near future will see man begin to recover the vast mineral wealth from the deep sea bed itself, and he will gradually change from a hunter of wild fishes to a raiser and herder of domestic sea animals. Growing and farming microscopic plankton will someday become an economic reality.

Present and potential conflicts among nations over the control of the sea's natural resources have led to the rather recent creation of two ocean zones. These are (1) the continental shelf zone, and (2) the exclusive fishing zone.

The Continental Shelf Zone

A geologist would define the continental shelf as that extension of the continental land mass which underlies the sea from the shoreline out to the point where the land mass breaks sharply and plunges to the deep sea bed. This sharp break occurs at an average depth of about 200 meters (about 600 feet or 100 fathoms).

An international lawyer, when asked to define the continental shelf, would refer to yet another 1958 Geneva treaty and come up with a slightly different definition:

> "[T]he seabed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 meters or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas."

Two important points, which might tend to be obscured by the "legalese" of this treaty language, should be noted:

(1) This legal definition of the continental shelf has nothing to do with the geologist's definition, except that it borrows the average depth of all physical continental shelves to establish the initial 200-meter line probably seldom coincides with the actual edge of the geological shelf.

(2) <u>There is no definite outer boundary of the continental shelf</u>; the minimum 200-meter boundary is supposed to be pushed outward as man's capabilities for resource exploitation lead him deeper than 200 meters.

There are many complicated reasons - too many to go into here - why these two factors were built into the legal definition of the continental shelf. Both were the result of compromise, which seems to be the guiding principle for law-making on any level.

One more point should be made before we ask why the continental shelf zone exists: It is very important to realize that almost everywhere the continental shelf, as legally defined (that is, 200 meters), projects beyond the outer limits of the territorial sea. The 200-meter depth line may be anywhere from 0 to 800 miles from shore; the average distance is 42 miles. Most territorial seas are, as previously noted, 12 miles or less in width.

Now, to show why this is important, let's ask the crucial question: What is the continental shelf zone good for: It's not good for much of anything unless you happen to be a coastal nation -- if you are, it may be worth quite a bit. Again in the language of the 1958 treaty, the coastal nation " exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources." What this means is that a coastal nation owns the natural resources of its continental shelf to the exclusion of all other nations. It may sell those resources to others or sell the right to extract the resources from the seabed or subsoil of the shelf. The government of the United States does this by leasing sections of the shelf to developers for the purpose of taking oil and other minerals. Note that the right granted by the 1958 treaty encompasses <u>all</u> resources - living as well as mineral - which exist <u>on</u> or <u>under</u> the shelf itself.

The 1958 continental-shelf treaty does <u>not</u> effect the status of the waters above the shelf which are high seas and outside the boundaries of any nation. This is so because the treaty defines "continental-shelf" as the seabed and subsoil <u>outside the area of the territorial sea</u>, while the high seas are, as noted, all <u>waters</u> beyond the territorial sea, So we have the rather anomalous situation on the continental shelf where nations exclusively own and control valuable resources beyond the limits of their boundaries.

With the great increase in man's ability to recover these resources and the growing demand for them,the continental shelf zone is today taking on greater significance. However, mainly because of the fuzzy definition of the shelf's outer boundary, the 1958 treaty may soon be superseded by new, more specific language better suited to this ocean age.

<u>The Exclusive Fishing Zone</u>

The exclusive fishing zone is the most recently established U.S. ocean zone. It is also unique in at least one respect: it was not created or specifically authorized by any of the Geneva treaties.

The U.S. exclusive fishing zone and the contiguous zone are exactly co-extensive - they both occupy a nine-mile belt along the outer edge of the three-mile territorial sea. So the outer boundary of the exclusive fishing zone is twelve miles from the coastline.

Also, like the contiguous zone, the exclusive fishing zone is a "special purpose" extension of U.S. national authority into the high seas. That is, the fishing zone is not a claimed area of total U.S. sovereignty, as is the territorial sea (except, of course, for innocent passage).

The exclusive fishing zone was established by a 1966 act of the United States Congress which asserts to the world that the U.S. has the exclusive right to the living resources of the waters out to twelve miles from shore. According to the Congressional act, then, no other nation has a right to fish closer than twelve miles from the U.S. coast without U.S. permission. (There are exceptions for these nations who had traditionally fished in the new nine-mile zone prior to its establishment.)

The exclusive fishing zone is, along with the contiguous zone and the continental shelf zone, an extension of U.S. authority beyond the traditionally recognized sea boundary.

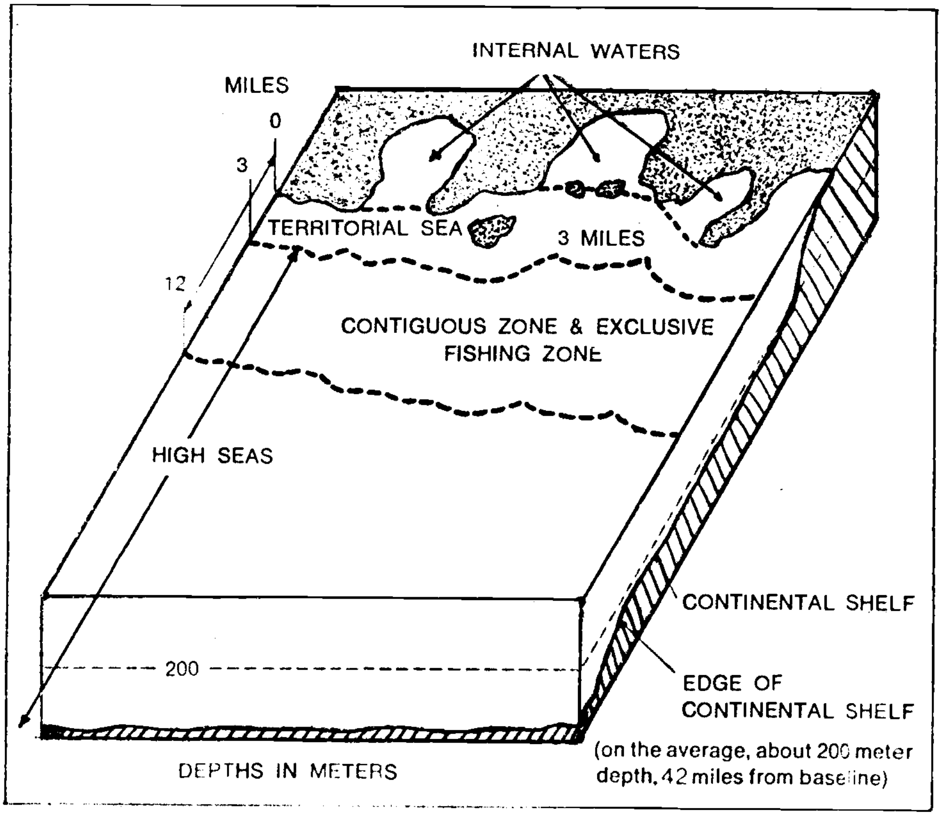
THE SPECIAL ROLE OF THE STATES

Several years ago, the U.S. Supreme Court caused quite a stir when it announced that all submerged lands under the territorial sea were owned by the federal government and not the states. Congress' response was the Submerged Lands Act of 1953, which deeded outright to the coastal states title to all submerged lands within three miles of their respective coastlines. (For historical reasons, Texas' and Gulf-side Florida's ownership extend nine miles from shore.)

Therefore, it is clear that each state has the exclusive right (as against the federal government) to sell the natural resources or sell the right to extract the resources of its offshore land areas, while the federal government has these rights as to the resources of the outer continental shelf. Naturally, this situation sometimes gives rise to boundary disputes between the federal government and the states. This kind of friction is not likely to decrease in the future.

SUMMARY

Now that each ocean zone has been outlined, let's put it together in diagram form:



Presented January 19, 1971, by Mr. Ogden Beeman, Department Manager, Marine and Industrial Development, The Port of Portland, Portland, Oregon.

Use of Estuaries for Navigation and Port Development

In an editorial entitled "Reconciling Progress with the Quality of Life" in Fortune magazine, the editors stated:

> "In a high technology society, the single-minded pursuit of any goal--even such a worthy one as feeding the hungry--is almost always bound to produce undesirable side effects on the environment. Unless we learn to watch for and prevent the side effects, all of our past and future efforts toward material progress and social justice will be futile."

That goal for the Port industry and navigation interests has been improvement of water transportation systems. There were some very significant reasons for pursuit of this goal.

Water transportation was the first of the systems to move people and goods in quantities. Its development preceded roads and railroads. It resulted in efforts to make the maximum possible inland penetration for deep draft ships; inland ports such as Portland, New Orleans and Philadelphia are examples of this inland penetration. Navigation was considered too important in early years that it was given special legislative and statutory privileges, without consideration that its single-minded expansion could, in time encroach on

(see the next page for rest)

other interests. Ironically, some of the special legislation written to protect navigation is now being used to prevent pollution of waterways.

Secondly, because water transportation is so cheap, especially for bulk, low-priced commodities, tremendous pressure was exerted to extend inland waterways systems to break railroad monopolies, exploit natural resources and bring about industrial expansion. Studies by the Tennessee Valley Authority show that a single waterfront industry can generate up to 18 complementary non-waterfront adjacent plants.

Thirdly, the waterways system became, in time, a key part of the transportation infrastructure of a nation. The railroads terminate at the major ports. Population grows at these key transportation points and waterways expansion becomes necessary to protect the tremendous investments of industry and transportation interests.

In order to realize the benefits of water transportation, the system must have channels capable of floating the ships, and docks and facilities capable of handling the commodities moving on the system. When waterways are developed to serve local markets or export resources indigenous to the region, it is, in my definition, a transportation system, and there is a ceiling on the growth of this system limited by the local market or the local exportable resources.

When the system is expanded to encourage industrial growth and expansion, it moves from the category of transportation to the category of industrial development. There is no limitation on the growth of this type of system -- except perhaps the availability of waterfront land. Often development of the transportation system makes possible (or inevitable) the industrial system that follows. The Lower Columbia River may be a case in point. The Houston Ship Channel is definitely an example of an industrial system surpassing the transportation requirements on the system.

The benefits to the community are different from these two levels of waterway development. The transportation system generally puts low demands on resources such as waterfront land. The industrial system, in theory, is infinitely expandable and can put tremendous demands on all resources.

With this background in mind, it is interesting to look at several examples of waterfront land use. In general, on the West Coast of the United States, the water frontage actually used for docks and wharves comprises an almost insignificant amount of total waterfront land. Our rough calculations show the following:

Figure 1
WATERFRONT LAND USE AS A PERCENT OF TOTAL

	Port Related	Industrial	Combined
Columbia River Estuary to Mile 23	5%	1%	6%
Columbia River Mile 23 to 106 (Vancouver)	2.5%	3.5%	6%
Columbia County, Oregon	less than 1%	5.5%	6%
Portland Harbor D/S Broadway Bridge (7 miles)			70%
Houston, Texas, Ship Canal (U/S 8 miles)			100%

The numbers in Figure 1 would change considerably if log storage areas were added. I have not included them, because they are interim land uses and do not preclude other land uses either simultaneously or at a later date. Also, I suspect the waterfront land use for highway and railroad right-of-way equals or exceeds that for navigation and Port interests.

Looking at Figure 1, it should not be difficult to understand why the citizen of Portland is more concerned about the uses of waterfront land than the citizen of Columbia County. The development coordinator of Aberdeen, Washington, was reported to have said recently:

> "Actually, only about 5 per cent of the private citizens who make up the Washington Environmental Council are aligned for battle on the seacoast issue. This 5 per cent seems to hail mainly from King County (Seattle), a fact which adds more kindling to the conflagration. There is that uneasy feeling that the cities, having smogged up their own environment, may be trying to take over the boondocks, whether the feeling is justified or not."

It is a serious mistake to overlook the difference between urban and rural, or small town, attitudes toward development.* We cannot expect the people in Columbia County, who have the opportunity to add 50% to the assessed valuation of the county with the addition of a single nuclear power plant, to be overly concerned about raising from 6 percent to 6.5 percent the county's developed waterfront.

In the competition for land and resources, the dredging necessary for navigation may consume more land and water resources than the terminals, docks or industrial land. Channel dredging and its problems vary with the waterway and the location along the waterway. On the Columbia River, it presents almost no problems. The material is clean sand; there are no pollutants in it;

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*See also "The Public's View of Environmental Problems in the State of Oregon," prepared for Pacific Northwest Bell by Harris, Lewis Associates, March 1970.

it can be discharged along the river banks to make recreation areas or Port-related sites. On the Columbia and Lower Willamette Rivers, most port facilities and industries are built on lands created or reclaimed during dredging operations for channel improvement. The area of the Columbia River estuary filled by channel spoils in the last 50 years is nearly insignificant.

However, the picture is considerably different in a coastal estuary where the material is silt, not sand, mixed with pollutants from years of uncontrolled disposal of industrial or municipal wastes. Spoil areas from channel dredging can gradually decrease the size of the estuary.

Even these problems are insignificant compared to harbors on the Great Lakes. Dredging problems, compounded by the existence of industrial wastes and the lack of upland disposal areas, are staggering.

It would be incomplete not to mention future ship size trends which will certainly influence future channel requirements. I refer you specifically to the excellent publication, "Merchant Vessel Sizes in U. S. Offshore Trades by the Year 2000," published by AAPA, in 1969. The following information is of interest.

1. Figure 2 shows the cost curve for hauling oil various distances in various size ships. Note the steep drop at the left-hand side indicating the tremendous economies of scale possible when vessel sizes are increased, say, from 15,000 to 80,000 dwt. Of greater interest, however, is that the curves tend to flatten out as the haul is shorter or as the vessel reaches a certain size. For the short trips the largest vessels are not practical. In fact, research shows that even by 1983 most of the world's tanker fleet

could use channels of from 40' - 45' deep. Certainly, the vessels in the coast-wise trade could use channels of 35' - 40'. The super tankers for the long international runs will require tremendous depths -- up to 75'. This quantam leap in vessel size is fortunate for many harbors such as Portland. We can simply decide never to be a crude oil importing area. However, areas such as Puget Sound must recognize the pressure to bring these vessels into the protected deep water and plan accordingly.

2. For dry bulk carriers (grain and ore), the economies of scale are not so available and only now are we seeing a few vessels drawing in excess of 40'. The world fleet will gradually increase in size to vessels of around 80,000 dwt, but established ports with depths of 40' - 45' should have no trouble handling nearly all of this fleet. Some ore carriers designed for special runs will draw more than 40' - 45', and, consequently, there will be pressure for land on extremely deep water areas, either for the processing plants or transfer of this ore to shore-side transportation systems.

3. It should be some comfort to know that all research indicates that the general cargo vessel has reached its maximum draft at around 35'. Break bulk, container, barge-carrying and special carriers for logs and pulps are, with few exceptions, being built with drafts of between 30' and 35' with no real change foreseeable in the future.

4. Ocean barging is also a very real factor in the future of ocean shipping. Present barges are generally of around 15' draft, although off-shore barging of bulk products will see development of barges

with over 20' draft. The advancement of barging technology will probably have the greatest impact on transportation uses in the numerous smaller estuaries on the Oregon Coast.

We have reached the end of the massive channel deepening projects of past years. Ports with 30' - 35' of water available will need little improvement to take the general cargo vessels of today and the future. Ports with 40' - 45' will be able to retain competitive position in dry bulks, but will lose certain commodities to other ports and to manufacturing facilities on very deep water. Naturally deep inlets will have land use pressures to provide facilities for the transfer and processing of liquid bulks such as crude oil and chemicals. Small coastal barge ports will try to increase depths to take advantage of somewhat larger barges, but the economies of the increased scale may be hard to prove when measured against the high cost and physical difficulties of deepening these channels and entrances.

In summary, future transportation requirements will not exert unusual demands on estuary resources. The industrial and population expansion which follows the transportation development has the potential of exerting tremendous requirements on all resources. How are we to deal with this problem? Let me discuss some of my thoughts about planning.

It has been said that if the population curves of the United States and the number of PhD degrees granted were both extrapolated, by the year 2035 every person in the United States would be a PhD. This story points up several very real problems for the planner.

1. Extrapolation of past events indicates that either we will be faced with some intolerable situations in the future or we will be faced

with some major discontinuities as the trend of past events is changed. Peter Drucker, in his book The Age of Discontinuity, says that discontinuities are the only things worth considering. He maintains that any fool can extrapolate past events into the future.

2. As professionals responsible for resource use and allocation, we must keep two things in mind.

   a. Where continuity or extrapolation indicates we will have serious problems, we must act decisively to break that continuity. A classic example is the work of the Bay Conservation and Development Commission in San Francisco. Continued land filling would destroy San Francisco Bay. BCDC was formed to break the continuity of that trend.

   b. Because we are unable to foresee the discontinuities of the future -- new life styles, new forms of transportation, new demands for resources -- we must plan for discontinuity by preserving options. Preservation of options for future discontinuities or unknowns is basic to survival. However, this can be used as an excuse for what I call "anti-planning". That is, preserve all future options by doing nothing with the resources. I cannot recommend this approach.

Using the concept of continuity as a framework for our thinking, the role of the planner (or technician) must be separated from the role of the politician.

As planners and technicians dealing with estuarine uses, we have two major roles. (See Figure 3 which is a graphic presentation of the development of an estuary.)

1. The first is to define survival requirements for all elements involved in the system. The ultimate loss of future options is the loss of survival. This is true whether we consider man, plant life, ducks, salmon or oysters. Man's survival may make great demands on the survival of other things. He must be fed, clothed, housed, educated, and employed to survive. He must also have challenge and the possibilities of leisure.

2. Definition of survival conditions must be made by the professional. Beyond that, the planner must define and compare choices. Realizing that optimizing one use in a closed system will be at the expense of another use, the planner must provide an array of choices. The economic, aesthetic, ecological and environmental benefits and tradeoffs of each plan must be identified. The planner (or technician) must be a great advocate when survival issues are at stake. When we have satisfied the survival requirements, however, we must contribute choices with facts on alternatives and test our own motives when advocating a position.

At that point, we move into the political arena. In the past, we have made it hard on our political leaders by presenting very difficult choices for them. This is particularly true of action for coastal zone preservation on the Oregon and Washington coasts. I think we have failed in presenting politicians with hard choices at the project level, not the conceptual level. If we could get the political leaders to go through the agonies on the concept (and do it only once), we could save them and ourselves the agonies of endless repetition of the classical arguments endlessly repeated as each project is examined.

After we, the planners and technicians, have done our job, the politician has several roles to play. They are:

1. Take action on the survival issues to assure the continued existence of all species and deal with the continuities that show we are going to be in trouble at some time in the future.

2. Select among the array of options presented by the planners and initiate action to achieve the selected goal. The option chosen should have ample allowance for future options and unknown requirements.

3. Give the planners feedback that allows them to do their job properly. An example of this is population. Land use, zoning, transportation, education, economic development and all other planning is based on population projections. A politican who suggested a population growth (or non-growth) plan for the next 30 years and then bent every legislative and administrative effort to achieve it would do more for proper planning than the sum total of planning legislation now being considered.

Estuary and coastal zone management is no different from resource management of other types. It has certain unique features. Survival problems are easier to identify. In a sense, guidelines should be easier to develop, because some of the survival issues are so clear.

We must distinguish between survival issues and amenities. When I say survival, I mean it in the broadest sense. There are economic survival issues just as there are species or ecological survival issues.

At the other end of the spectrum, we cannot use "economic survival" as an excuse. Industrial expansion is not necessary for survival -- it can be an amenity or a luxury we may or may not be able to afford. It is our job to define the measurements and preserve all resources required for survival and then help to allocate those resources left over for the best advantage of all the people in the United States.

Those of us gathered here today must identify the survival requirements, be they economic, agricultural, ecological, educational, or medical. We then must integrate all of this to define survival of the estuarine system.

We must remember that safeguarding future options is a survival issue. To that point, we must be advocates. Beyond that point, we must help the political process to work being ever careful of our own motives when our advocacy transcends our role in the political process.

In closing, let me quote again from Fortune magazine:

> "We know that isolated societies with very low levels of technology do not greatly damage their natural environments. We also know that our high-technology society is handling our environment in a way that will be lethal for us. What we don't know--and had better make haste to test--is whether a high-technology society can achieve a safe, durable, and improving relationship with its environment. This--and not a return to the pre-technological womb--is the only possibility worth investigating."*

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*"Reconciling Progress with the Quality of Life"; Fortune, February 1970.

Figure 1

WATERFRONT LAND USE AS A PERCENT OF TOTAL

	PORT RELATED	INDUSTRIAL	COMBINED
COLUMBIA RIVER ESTUARY TO MILE 23	5%	1%	6%
COLUMBIA RIVER MILE 23 TO 106 (VANCOUVER)	2.5%	3.5%	6%
PORTLAND HARBOR D/S BROADWAY BRIDGE (7 MILES)			70%
COLUMBIA COUNTY	<1%	5.5%	6%
HOUSTON, TEXAS, SHIP CANAL (U/S 8 MILES)			100%

Figure 2

THE RELATIONSHIP BETWEEN VESSEL SIZE
TRANSPORTATION COST
AND ROUTE LENGTH

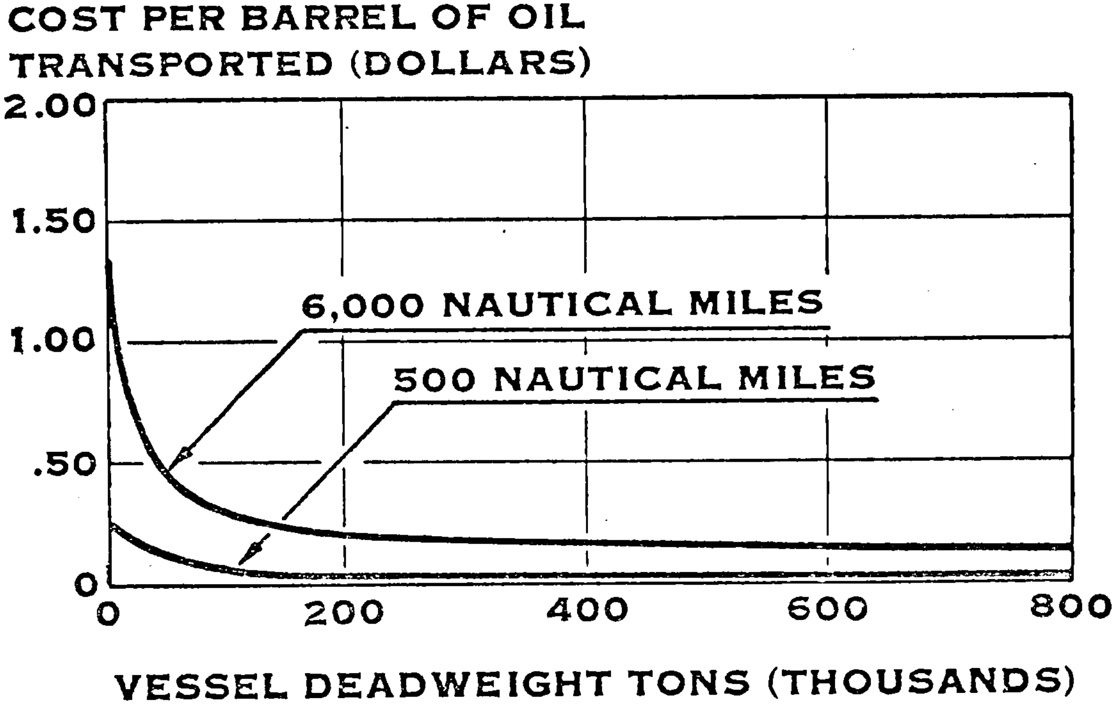
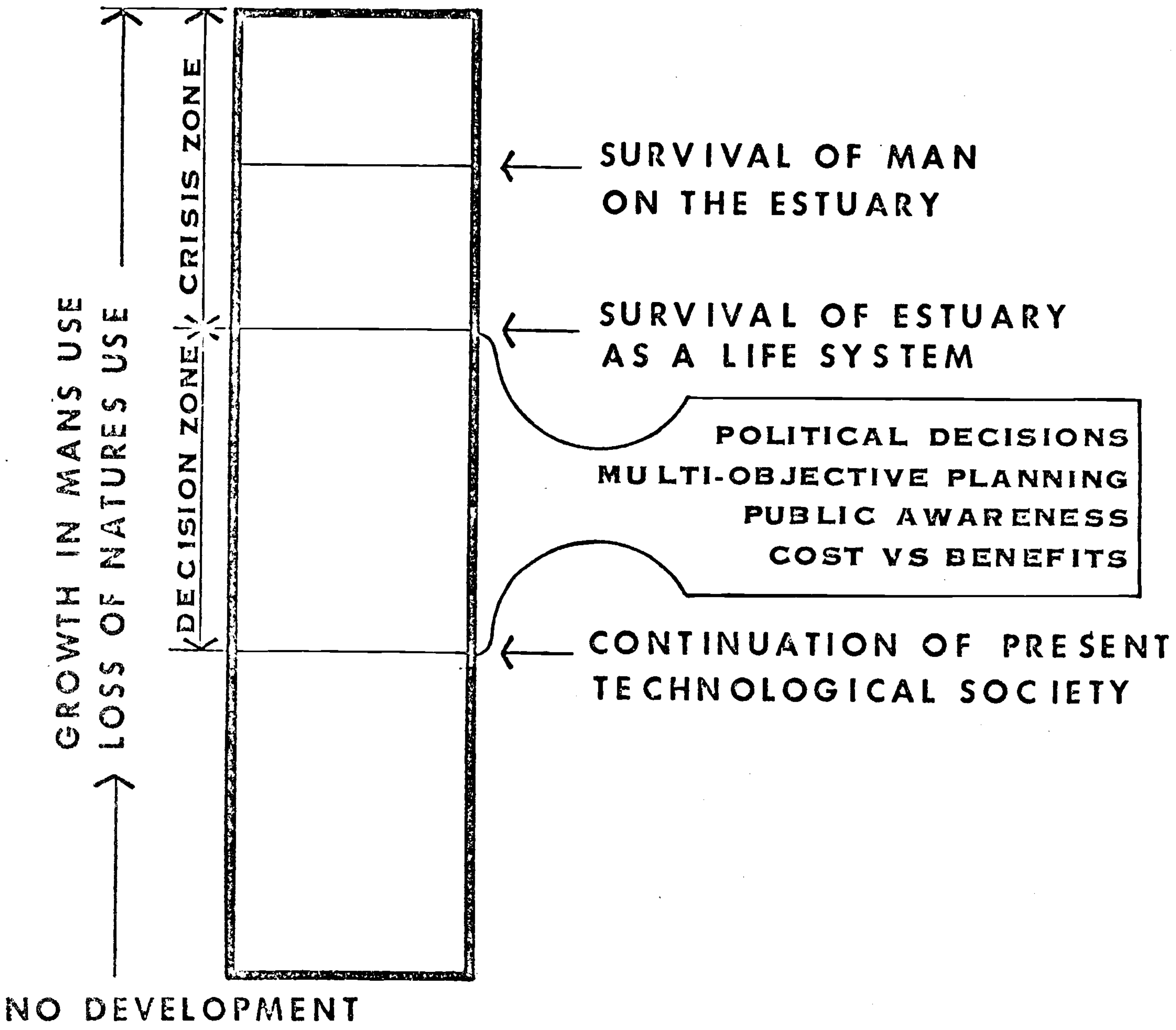


Figure 3

ESTUARY & COASTAL ZONE USE DIAGRAM



Presented March 16, 1971, by Robert J. Hopman, Portland District, U.S. Army Corps of Engineers.

Engineering in Navigable Waters

Before I begin on our subject matter I want to talk to you about a new ethic that is developing in American Science. I hope it is not a fad and will persist in future years. Primitive man took what he could from nature to stay alive, and he stood in awe at natural phenomena he could not understand. From this precarious beginning evolved a complex society which still takes from nature to fulfill its needs. In some quarters, man is now indicted for all his environmental ills; and yet in others, it is held that nature must be shaped as man requires it.

The ability to maintain an acceptable environment, however, can be hindered by failure to recognize fundamental earth processes. Environmental degradation is a natural procedure on earth; but man is beginning to contribute to that degradation in large measures in certain areas. Not all modification of our environment is degrading. Some alteration is acceptable. Hazardous changes must certainly be avoided. It is inexcusable that we should fail to predict responses of nature consequent to our own actions. Man has begun to develop an awareness that better housekeeping of the earth must be practiced as he continues to take from the earth the things he needs and uses.

Man is earth-bound. For some five billion years, the planet earth has revolved about the sun; and there is good reason to believe its journey will extend beyond another five billion years. Throughout this period, the earth has undergone constant change - mountains have risen where oceans formerly existed; animal and plant species have flourished and become extinct; earthquakes and volcanoes have always been with us; rivers and plains have appeared and reappeared; and glaciers have covered large segments of the planet many times. Although on earth but a few million years at the most, man has in the past 200 years unraveled a great deal of earth history and learned how to use the planet to meet his growing needs for survival.

As earth-bound residents, we look constantly, nevertheless, to other planets. The moon, satellite of the earth, has already been visited and found to be totally hostile to man. The surface of Venus is too hot for us, and Mars offers little, if any hope. The other planets are out of the question. Man, indeed, is earthbound and we must learn to accept this inescapable circumstance however great our expectations.

Resource needs of the United States. Let's take a look at the mineral resource needs of the society that makes up the United States of America. Within the life span of 200 million people now living in the United States, this nation will use from the earth:

6½ quadrillion gallons of water
7½ billion tons of iron ore
1½ billion tons of aluminum ore
1 billion tons of phosphate rock
100 million tons of copper
and so forth......... also, do not forget that a large share of these resources can and will be re-cycled again and again into usable goods.

In 40 years, our population will double. Just think of the added requirements of the next generation!
Water usage will triple by the year 2000.
Energy requirements will triple by the year 2000.
By the year 2000 we will have to construct as many houses and other facilities as now exist in the United States.

This staggering amount of natural mineral resources upon which the sustenance of the nation depends imposes a tremendous task of new discovery, and new development. How can we do this without changing the character of our environment; for society must also provide against excessive noise, excessive pollution, and excessive degradation of the landscape, water-scape, and sea-scape.

If this be the situation for the United States, certainly resource needs for the rest of the world command even greater attention. Developing nations seek fulfillment in health and economic betterment. The crust of the earth which provides these resources is worldwide and knowledge about it gained in one country can be used to good advantage by scientists and engineers in others. Does the crust of the earth have the potential to provide for man's needs? The problem for mankind is universal - planetary - not national. Wars must cease and man's society must one day be planetized if the species, homo sapiens, shall persist on earth.

If we must therefore take from the earth to provide for ourselves, we must employ value judgment and trade-off concepts in deciding how much to take from our environment, where to take it, and how to leave it in the taking and using. Take and use we must or we cannot survive as a species on earth.

Some myths about our environment. It is believed by many people in this country that it is man who is degrading and polluting his environment because of our modern industrial society. Some myths, however, need to be destroyed. Let me cite a few to demonstrate that natural processes are by far the principal agents in modifying our environment. Those individuals who speak about restoring our inherited environment of pure air, pure rain, pure rivers, pure lakes, and pure coast lines never had a course in geology.

It has been calculated that more than 100 million tons of fixed nitrogen in the form of ammonia and nitrates is annually transferred from the atmosphere to the surface of the earth as part of a natural precipitation process. In the United States alone, there falls upon the face of our land annually more than 4 million tons of calcium compounds - all in rain water. A recent news article stated that the waters flowing down from Mt. Fuji in Japan are so alakaline that photographs can be developed in it.

So nature itself pollutes the waters. We have long been led to believe that water issuing from natural springs is pure and beneficial to health because of its purity. The springs issuing into the Arkansas and Red Rivers carry 17 tons of salt per minute. In the Lower Colorado River, salt springs carry 1,500 tons of salt per day. The Lemonade Springs in New Mexico carry 900 pounds of sulphuric acid per million pounds of water (900 PPM) which is 10 times the acid concentration of most acid mine streams in the country. Hot Springs in Yellowstone Park is likewise many times more acidic than the typical acid stream in a coal-mining district. The Azure Yampah Spring in Colorado contains eight times the radium that the Public Health Service sets as a safe limit.

The lakes and ponds throughout geologic history have gone through a life cycle of birth, maturity, old age, and disappearance. No lake is truly permanent. The Great Salt Lake is nearing its dying stages. Once 20,000 sq. mi. in area, it is now only 950 sq. mi. in area. Many thousands of years ago it was essentially a fresh water lake, fed during the Pluvial Period of the Great Ice Age, and now is about 10 times as salty as sea water.

We frequently hear that Lake Erie is dead. This is pure rubbish. Lake Erie is the shallowest of the Great Lakes, was created 10,000 to 20,000 years ago and, barring another ice age, has several thousands of years yet to go before senility. The western part of the lake is an extremely shallow shelf and receives a large amount of natural organic material transported from the surrounding terrain. Here is where the algae growth has always been present. Lake Erie, according to J.E. Kinney, has continually produced about 50 percent of the fish catch of the entire Great Lakes system, consistently over the past 100 years. This is not a mark of a dead lake.

Green Bay, of Lake Michigan, so named by the first settlers because of the algae so prevalent on the bay is, like the western shallow part of Lake Erie, the source of a great amount of organic matter - and fish. The food supply for aquatic life is high in these environments. The oxygen supply, unfortunately, diminishes as algae growth increases, as this portion of the lake becomes more and more shallow and as organic material is swept into the water, whether natural or man-made, faces a similar life history. Shallow estuaries - likewise. This is the natural law.

The rivers of our nation are being called dirty because of the works of man. We must understand that rivers are the natural transport systems for sediment and humus (organic matter) washed downhill by the rains that fall upon the land.

It is estimated that the Mississippi River carries into the gulf a load of more than 2 million tons of sediment per day. This is equivalent to a daily load of 40,000 freight cars. The Paria River in Arizona is probably the dirtiest river in the world. It carries 500 times as much sediment as the Mississippi River per unit volume of water. This is a continuing condition year after year. Chemicals are also transported by streams in phenomenal amounts. The Brazos River of Texas, for example, transports 25,000 tons of disolved salt per day. Peace Creek in Florida carries twice the concentration of fluoride that is harmful to teeth. Many rivers and streams throughout the nation have natural qualities that do not meet the Public Health standards for drinking water.

A look to the future. It must be quite evident that although natural earth processes dwarf the actions of man in a total context, man can become a major geologic agent in a specific or local context. This inter-reaction of man with nature is without question a most important issue of future years. In a society that has reached maturity in the industrial sense, the issue of environmental alteration becomes more and more acute. It is within this framework that certain actions 100 or 200 years ago are now considered sinful. What are some solutions to our dilemma?

We find ourselves in the midst of a conflict between the need to develop the earth's resources and the desire to preserve the earth's environment - both, presumably, for the salvation of mankind. Industrial development has become synonymous with Wall Street: and American industry, envied around the world, is in trouble within its own country because of past abuses to the environment in the name of lowest cost. Profit has become an ugly word and the concept of science and engineering, once honored as a service to mankind, is now being ridiculed in many places.

Must one choose between the two concepts or can one seek balance as we move into the future? The first judgment must distinguish between danger and aesthetics; because change is inevitable in any developing society. The pace of change is a function of the choice of people as it should be, if the people will speak out.

I would like to begin by talking a little on the engineering and maintenance problems that we are confronted with in trying to provide the Columbia River as an open waterway.

The lower Columbia River navigation channel from the mouth of the Willamette River in the Portland-Vancouver area to the mouth of the Columbia River at the Pacific Ocean is an authorized project 40 feet deep by 600 feet wide.

The channel is 98.5 miles long and dredging of approximately 7,000,000 cubic yards of river sediment is required annually through 26 river bars whose total length approximates 50 miles. In addition to this an average of 2,200,000 cubic yards are dredged from the Columbia River entrance bar each year. However, the term river sediment is slightly misleading as the material dredged from the lower Columbia River consists almost entirely of fine to medium sand with very little silt to no clay. Absolute density of the material averages 2700 grams per liter. The average length of the 26 river bars is 8,200 feet; the shortest is 2,000 feet, while the longest is 14,000 feet. The other 48.5 miles of the channel under discussion is self-maintaining to river depths greater than 40 feet for a width of at least 600 feet. The river in its natural state had a controlling depth of 12 feet at St. Helens bar (mile 86) in 1885.

26 million tons of cargo move over this project annually and through MCR with more than 5000 vessel trips per year. I believe the prediction for 1990 is over 10,000 vessels and 50,000,000 tons of cargo.

Each year we remove about 9.2 million cubic yards of sediment from the Columbia River between the mouth and its confluence with the Willamette for about 3 million dollars.

This is quite small when one considers the maritime industry is the leading employer in Portland. Annual payroll directly attributable to Portland's maritime commerce is over $52 million. There are over 15,000 jobs that ultimately depend upon the activities of the port.

Portland district provides and maintains a channel in the Columbia River in many ways:

1. surveying and dredging.
2. channel constrictions - building of islands and pile dikes.
3. multiple purpose dams.
4. using existing channel alignment - bends in the river.
5. studying and learning the engineering and natural characteristics of its freshet and shoaling patterns.

Dredging - as mentioned earlier we remove about 9.2 million yards from Columbia - about 18 million yds. in the district for about 40¢/yd.

1. a. A bad shoal occurs - immediately mobilize p/l or hopper.

b. If not too severe - wait to regularly planned time or if a small severe shoal occurs use a hopper dredge enroute from repairs, etc.

(1) When a hopper dredge is used, spoil areas generally are only temporary. However, they may last many years contrary to some belief that as material is being dumped it instinctively rushes back to its original location in the channel. I might add we make a good effort to get material out of channel. Spoils are placed in:

(a) Areas where we feel material won't too readily get back into the stream - natural deeps in cross-overs - but not energy holes

- distance - economics, time
- identifiability
- safely - dump

(b) Sumps - what do we do with the millions of yards of sand each year removed from the Columbia River? The objective is to place the material by the most economical means to the government.

a. The Use of River Sediment Below Ordinary High Water. We tend to lose sight of the fact that river sediment can be and in many places is a most valuable natural resource. Effective usage of dredged sand depends upon the location and the foresight and planning of the engineers dealing with the sedimentation problem. In the Columbia River, dredge spoils are utilized for river control and constriction works, and development of recreational areas.

The use of sand for river control and constriction works certainly represents the highest and best use of sediment on the Columbia River project. The use of sand for constriction works has generally been in conjunction with the permeable groin building program.

Because of the permeability of these groins, it is almost always desirable to fill between the groins with dredge spoils to supplement natural accretion. The ultimate effect is like that of a long training groin following the desired curvature of the river and moving the bank line channelward. This is believed to be the most economical solution to the problem of dredge spoil disposal. However, when the spur groin method is used on sharp bends, excessive scouring and erosion of the toe of the slope of the sand fill presents a problem.

Constricting the river by placing sand fill without the benefit of spur groins has been fairly successful in some areas. However, to be fully effective, sufficient sand must be available to bring the fill to flood-free elevation and must be placed continuously channelward from normal high water line. Even then the toe of slope and the side of slope is endangered during subsequent freshets. What other uses are there for the spoils.

b. Government Agencies - these have a priority such as a highway department for road building or a county for road sanding in ice conditions.

c. Fish & Game Commissions. The Corps of Engineers has built every mile of beach along lower Columbia River by its spoil disposal practices.

d. Local Diking Districts. Sand is used to beef up flood control levees.

e. Recreation Beaches. Hundreds of thousands use the beaches each year.

f. Pressures - bank erosions.

g. Local People.

Local spoil disposal problems along the lower Columbia and Willamette Rivers fall generally into the following categories:

a. Disposal Below Ordinary High Water. Material placed below ordinary high water would not involve local costs or charges.

b. Disposal On-Shore Above Ordinary High Water. Disposal in this manner presents two different types of problems. One problem arises in areas where material cannot be retained below ordinary high water and it is necessary to utilize the closest on-shore disposal area available. There are cases where the property owners do not want the spoil as the land use is damaged rather than improved. In other cases, where the land is improved, property owners are not willing to absorb the filling charges. In these latter cases, the disposal area provides an economical location for placing dredge spoil and results in savings of cost to the government. It is therefore believed that, in these instances, the dredge spoil should be placed on these areas with no fill charges assessed against the property owners.

c. The other problem arises in areas where property owners desire the dredge spoil but an alternative area is also available for spoil disposal. In cases of this nature the government assesses a fill charge in recognition of the resulting improvement of land use. Such a charge can be determined.

I would like to talk now on

Advance Maintenance Dredging

Experience indicates that nearly all of the shoaling on the Columbia River takes place during the several weeks of the spring runoff. This means that after the river level returns to normal, there are parts of nearly 50 miles of river shoaled above project depth. This sometimes can present a critical situation from the standpoint of navigation as the deeper draft ships are forced to delay arrival and sailing times so high tides can be utilized. During low river stages tides affect the project channel approximately 8 feet at the seaward end 2.5 feet at Portland. Dredging capacity of the district is taxed immediately following the freshet in order to deepen the channel in the shortest possible time.

In the past it had been customary to dredge project depth plus 2 feet allowable overdepth or, let's say, to 42-foot depth on the lower Columbia River. Normal maximum shoaling during the average freshet is 6 feet, leaving a controlling depth of approximately 36 feet on some bars; this would require dredging every year. So that the channel may be at project depth the year around and in order that dredging may be scheduled on a year around basis, we, during the past several years, have been performing advance maintenance dredging. This means that rather than dredging to 42 feet, the channel is excavated to a depth of 45 feet to 47 feet and sometimes 49 feet which I will later explain 1.E., Project depth, plus five to seven feet of advance maintenance dredging, plus two feet or allowable overdepth dredging to allow for the inaccuracies of the dredging process.

It can be seen under this plan that after six feet of infill, there would still be left the project depth of 40 feet or better, and all shoaling would have taken place below project depth. The advantages of this plan are obvious. It is our ultimate intention of always providing a channel of at least 40 feet.

There is an advantage to advance maintenance dredging in addition to the benefits to navigation and economics. I won't mention B-C ratio. A large pipeline dredge requires a relatively deep infill bank for efficient dredging to assure an effecient dredging program. One means of doing this is to dredge advance maintenance and allow bars to shoal for one or more years. That is, a bar which normally shoals 2-3 feet per year could be dredged to 6 feet of overdepth every other year. The cross section would be slightly increased which would in turn increase the tendency of the bar to infill the following year. However, dredge production has been increased enough to more than offset this increased shoaling.

From the standpoint of dredging efficiency, it is unfortunate that shoaling does not take place by consistent and level build-up on river bars. The shoaling is mostly in sand waves and, therefore, a 37-foot sounding may be followed closely by one of 47 feet. It is obvious that this situation does not lend itself to pipeline dredging because P/L either has to dredge through the 47' sounding or fleet over it. The hopper dredge is one method of eliminating these waves. It is believed that, if available, trailing suction hopper dredges could be utilized to great advantage to remove the scattered high spots in a channel. This allows the remainder of the bar to build up towards a heavier bank which in turn assures greater efficiency in pipeline dredging.

The 49' Advanced Depth

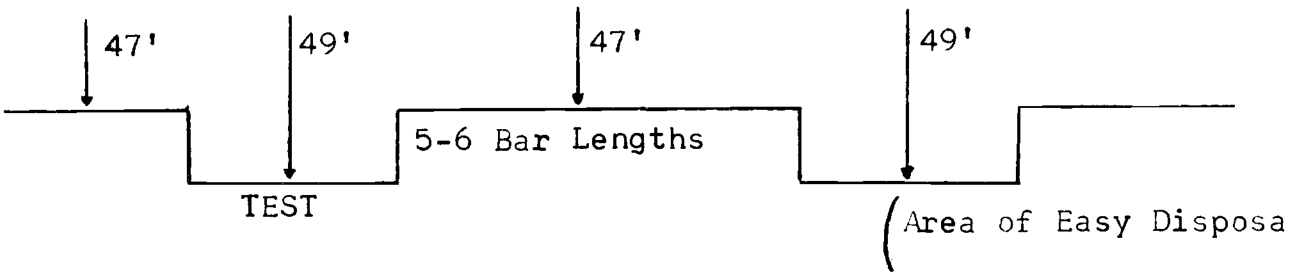
A. We are testing a new depth of 49' now
    1. 40' project depth
    2. 7' advance maintenance dredging
    3. 2' for inaccuracies of dredging

B. We only dredge extra deep to 49' where there are plenty of spoil areas such as where a highway department or private concern will haul the material away. We also go extra wide 50-100' to assure that the project width will remain so over a longer period of time.

C. We over-dredge in unusually fast and heavy shoaling areas for protective purposes, such as the fingers that occur at bifurcations.

D. Example of heavy shoaling or test area:
    1st year dredge to 49' - 6' shoal = 43' control
    2 nd year no dredging 43' - 6' shoal = 37' not critical but requires dredging

E. Test:



The Portland district has made great strides in improving and maintaining the navigability of the Columbia River during the past years. River constriction structures and the use of dredge spoils as well as advance maintenance dredging have brought about a marked improvement to the ship channel during the past several years.

There are several major problems remaining whose solution is not readily apparent, but sooner or later must be accomplished to insure continued improvement of the Columbia River navigation channel. These problems are:

1. Determination of a low-cost method for removing the peaks from the sand waves that develop in the ship channel and interfere with navigation.
2. A sound, harmless method of determining percentages of material which re-enters the navigation channel under various dredging disposal methods to allow logical derivation of costs of various dredging disposal procedures.
3. Determination of how much shoaling increases when a channel is over-dredged in depth but river width remains constant.

Solution of these problems will enable the Portland District to continue improvement in the navigability of the lower Columbia River.

Now, let's talk about other means of maintaining the coastal inlets. It seems at times we cannot provide a channel to deep draft traffic by the conventional operation of hopper dredging. Other schools of thought are available and one is the coastal inlet sediment bypassing approach to the problem of shoaling.

As wind-generated ocean waves approach the shoreline at an angle, break, and run up the beach face, they generate a longshore current. The wave crests bend (known as refraction) in an attempt to parallel the shoreline, never quite becoming parallel to the shore. The breaking action causes sand to become suspended and this sand is carried alongshore by the longshore current. Some sand is also dragged along the bottom by this current. In addition, after breaking, the wave runs up the beach face at an angle and back down the face in the steepest direction causing a "zig-zag" type motion of beach sand in the same direction as the movement caused by the current. Nearly all sediment transport thus occurs over a zone that extends from the wave breakers to a point above the mean high water line. Waves break when the water depth is approximately 1.3 times their height and often a longshore bar forms at this breaking point.

The rate of sediment transport (littoral drift) is primarily dependent on the longshore component of wave energy which, in turn, depends on the wave height squared and the angle between the wave crest and the shoreline.

Inlets are generally unstable and often must be stabilized by jetties that serve to fix the location and geometry of the inlet and to constrict tidal flow so the inlet does not silt up. Jetties interfere with the littoral drift which then accumulates on the updrift side. As a transport capacity still exists on the downdrift side of the jetties, beach erosion occurs in this area. The solution to this problem is to mechanically pass sediment past the inlet.

The material on the beach face and in the inlets, i.e. the material that must be moved past the inlet or harbor entrance, is sand. The median diameter of this sand may range from 0.15 mm up to near 1.0 mm for different areas along the Oregon Coast. The equivalent sieve sizes are 100 to 15.

The aim of any by-passing operation is to move 100 percent of the littoral drift being trapped. Often, in order to prevent sand from entering and clogging the inlet an attempt is made to trap all littoral drift approaching the inlet.

Several problems arise in the planning of a by-passing operation. Some of the major problems are discussed.

1. Littoral drift rates are very irregular. The peak daily rate will often be several times the annual average daily rate. The higher drift rate will generally occur during periods of higher waves when the by-passing operation may be shut down. A drift entrapment area large enough to handle peak transport rates and still accessible by the by-passing mechanism is needed.

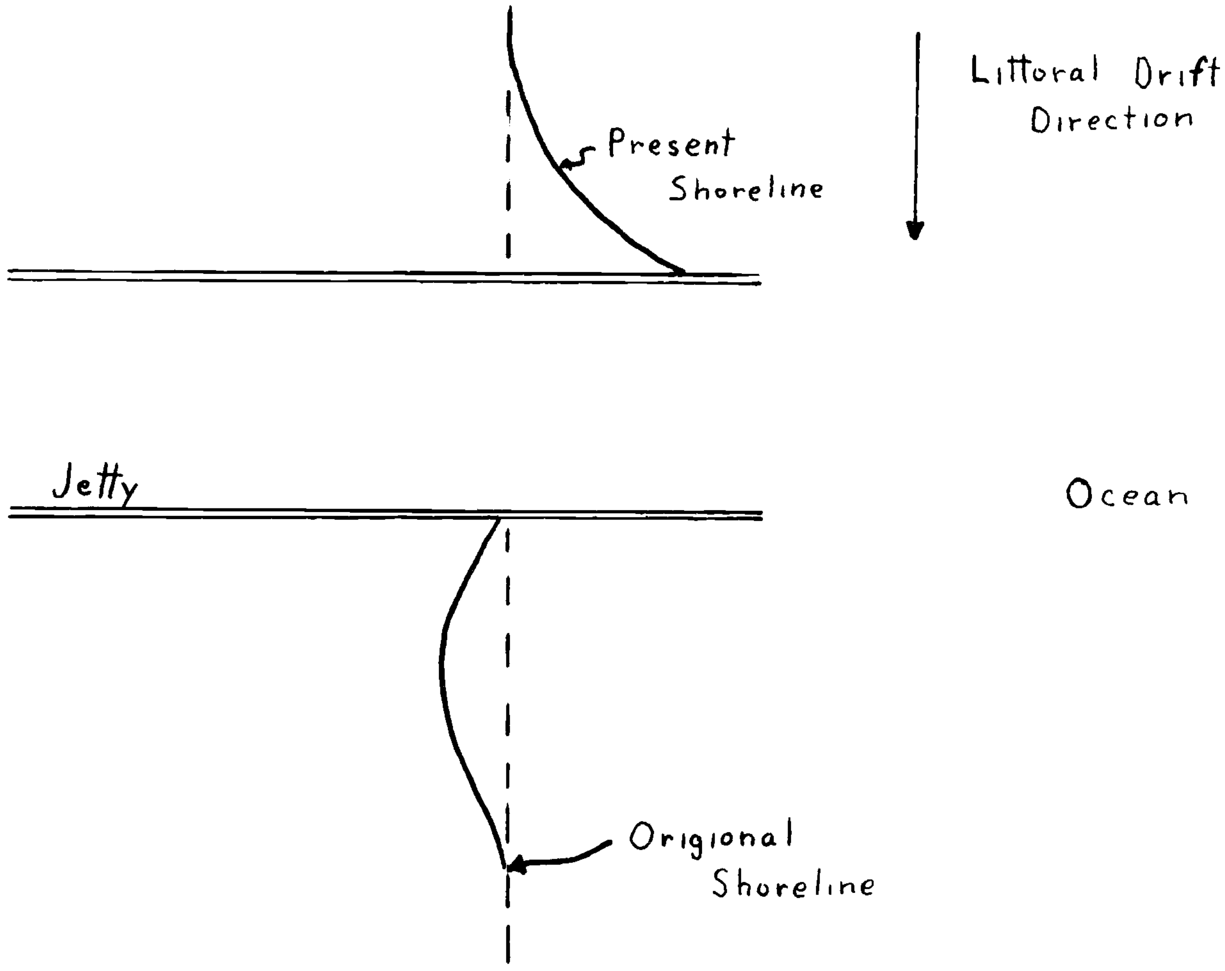
2. In some areas, due to the nature of wave conditions, large quantities of drift are moved in both directions along the shore. This is common, for example, during different seasons.

3. To date, there is no universal satisfactory technique for predicting drift rates. The rates are normally determined by surveying the volume of material trapped by a jetty or harbor breakwater. In many areas, only crude guesses of average annual rates can be made. Less is known of the day to day irregularity of drift rates.

4. To plan a by-passing operation one must also know the general width of the transport zone and where, over this width, most of the transport is occurring. This varies with the level of the tide and the height of the waves (which determines the location of wave breaking and the offshore bar).

A discussion of the most common sand by-passing problems and typical solutions are presented below.

The typical problem is a jettied inlet where sand is accumulating ahead of the updrift jetty.



One of the early attempts to solve this problem was at South Lake Worth Inlet, Florida. A fixed by-passing plant was constructed on the updrift jetty with an 8-in. suction line and a 6-in. discharge line 1200 ft. long. The discharge line crossed the inlet on a bridge and released the sand downdrift of the inlet. A centrifugal pump driven by a 65-hp diesel engine was used and the suction line was suspended from a boom that allowed the intake to swing in an arc. At present, the plant has an 8-in. centrifugal pump driven by a 300-hp diesel engine, a 10-in. intake on a boom with a 30-ft radius, and a 8-in. discharge line. The pump sits about 6 ft above mean sea level and, in calm weather, will remove all material within reach of the intake in 2 or 3 hours operation per day. With some storms the pump cannot keep up with the drift when operating continuously. The estimated capacity of the system is about 80 yards of sand per hour. It is estimated that the system handles about 1/3 of the drift (150,000 yards per year) the remainder passing the inlet or depositing on the bay shoal.

A similar plant was installed in 1958 at Lake Worth Inlet, Florida. The pump is set at -1 ft mean low water and, with a 12-in. suction line and 10-in. discharge line will handle 170 yards per hour. The pump is designed to handle 15 percent solids at 60 percent efficiency. The following features have been added to minimize the possibility of clogging the discharge line which crosses the inlet submerged.

(1) An alarm to warn operator of abnormal pressures so suction line can be raised.

(2) A device to admit clear water to suction line just ahead of pump when discharge pressure drops.

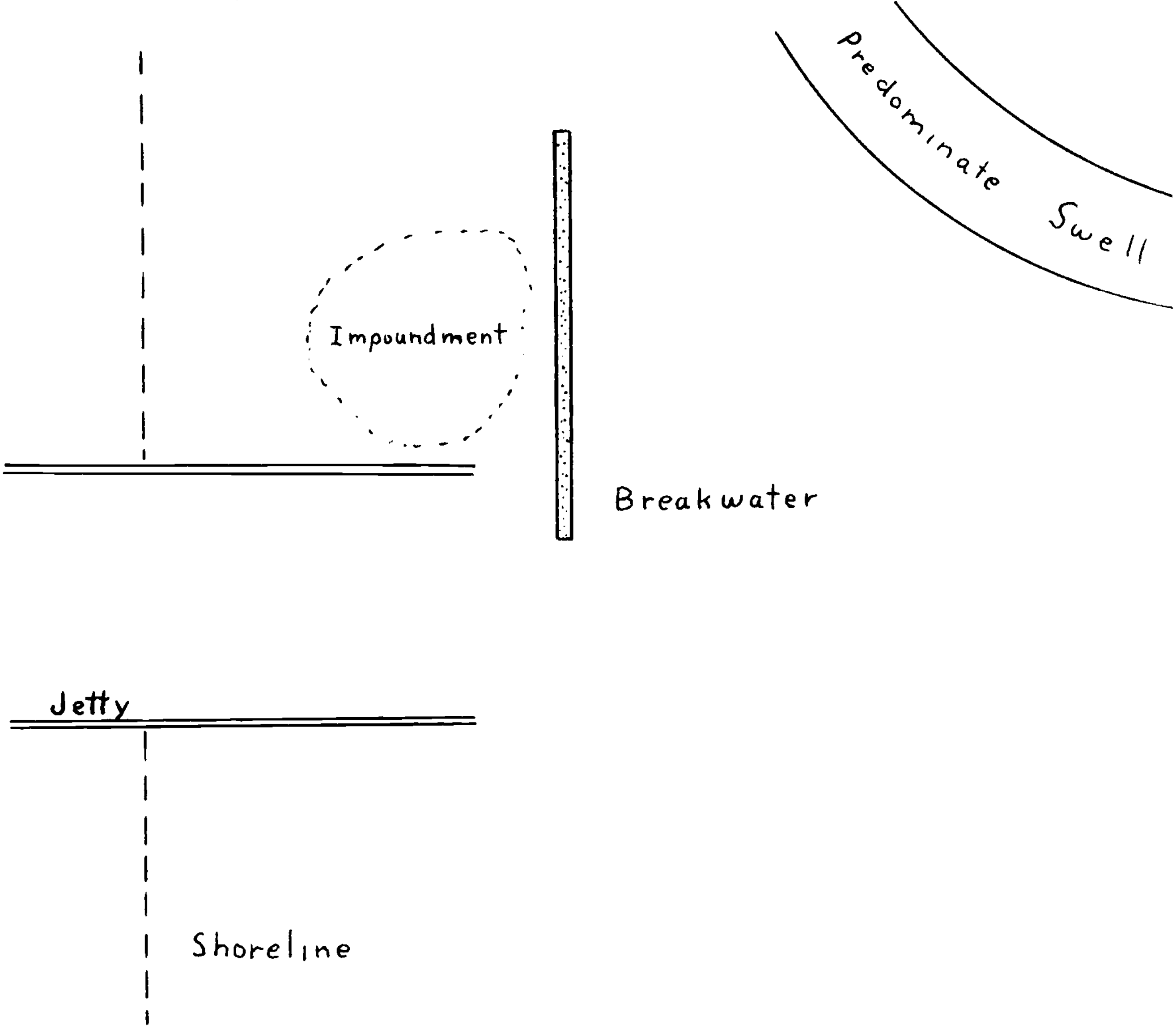
(3) A flush tank and air compressor to flush discharge line when needed.

(4) A gasoline driven 12-in pump to pump water into discharge line when flush tank is dry.

(5) A self propelling nozzle and sufficient hose to clean line (like sewer line cleaner).

The plant has an annual capacity of 100,000 yards, about half the annual drift at this location. Based on first operation and maintenance costs (5 months out of a year) over a 30 year period it will cost 50 cents a yard to by-pass material.

An improvement of the approach just discussed, is to construct an offshore breakwater that intercepts incoming waves and thus impounding littoral drift as shown. This also reduces wave action in the inlet channel and provides for favorable conditions in the impoundment area for a conventional hydraulic pipeline dredge to operate. This system will transfer 100 percent of the impounded drift, a major advantage.



This technique, or variations of it, appears to be the most promising and will be used to a great extent in the future. The best known application of this approach is at Port Hueneme, California.

Before World War II, a harbor with entrance jetties was constructed at Point Hueneme where the average annual littoral transport rate is 1,000,000 cubic yards. This caused the entrapment of about 300,000 cubic yards of sand each year and the diversion of about 700,000 cubic yards a year into the Hueneme Submarine Canyon which is located very close to shore off Port Hueneme. Also, very serious erosion commenced over several miles of shoreline downdrift of the jetties. At the most critical location the shoreline receeded 700 ft in ten years.

A temporary solution was achieved in 1953-1954 when 2,000,000 cubic yards were transported to the beach downdrift of the harbor as follows:

(1) A bulldozer and a dragline were used to cut out a small section of the beach just updrift of the harbor.

(2) A small hydraulic dredge was carried overland to this cut-section. This dredge dredged out a section 300 ft by 600 ft to -11 ft MLLW pumping the material to the downcoast beach.

(3) The small dredge then cut a channel through the beach to sea at a protected location near the jetty and a larger dredge was brought in to continue the by-passing operation until 2,000,000 cubic yards were transported downcoast.

A permanent solution was achieved in 1958-1961 when a small boat harbor (Channel Islands Harbor) was constructed a mile upcoast from Port Hueneme. Over 3,000,000 cubic yards of material were removed to form the harbor and were pumped to the beach downcoast of Port Hueneme. Jetties and a offshore breakwater were constructed and every two years 2,000,000 to 3,000,000 yards of sand are dredged from the entrapment zone and pumped along the beach, under the entrance to Port Hueneme to be deposited on the beach downcoast of Port Hueneme.

In the late 1960's a new approach to the inlet by-passing problem was attempted at Masonboro Inlet in North Carolina.

A low weir section acts as a "sand spillway" allowing littoral drift to accumulate and pass into the deposition basin located between the jetty and the channel. The weir section and other portion of the jetty inshore of the weir is made of concrete sheet piling driven to +2 ft MLLW (about mid-tide level) along the 1100 ft weir section. The 1700 ft of jetty seaward of the weir is a rubble mound structure to elevation +6 ft MLW. A pipeline dredge working in the protected deposition basin by-passes material downcoast to nourish Masonboro Beach. This project is designed to handle 100% of the littoral drift.

This concludes what I have to say. Briefly I've talked about our environment. We are not doomed to the filth of pollution as long as we strive for betterment in life's surroundings. I've talked about the engineering and maintenance problems of the Columbia River and I've talked a little on the sediment by-passing approach as a means of keeping the coastal inlet open a longer period of time.

Thank you for inviting me to speak to you today. I appreciate this opportunity to meet with you and share some of our ideas.

REFERENCES

1. Condensed speech delivered at George Washington University by William T. Pecora, Director of the United States Geologic Survey.

2. Speech delivered to the 68th meeting of the Committee on Tidal Hydraulics by Robert J. Hopman, Portland District, Corps of Engineers.

3. Coastal Inlet Sediment By-Passing, paper presented at Texas A & M University at the Dredging Theory and Applications Short Course of January 1971.

Presented February 2, 1971, by Commander Richard F. Malm, U.S. Coast Guard, Captain of the Port, Portland, Oregon.

Pollution: The Crime of the Times

The purpose of this discussion is to acquaint you with a problem - pollution of a vital resource - water, and to present a glimpse of the United States Coast Guard's functions in trying to arrive at logical and reasonable solutions.

The problem - pollution - and the solutions - prevention, abatement and elimination of pollution - are not simple, cheap, or going to be resolved overnight.

The principal ingredient in the problem is people - People as consumers and disposers.

The principal ingredient in the solutions is people - people cooperating to find answers, answers which will result in a viable environment, an essential element of life.

The United States Coast Guard is one of the policemen in the fight against this crime. Our main duties are to: receive reports, investigate, monitor clean up action, direct clean up where a spiller fails to do so properly, report the results of the investigation and clean up action, and when appropriate assess civil penalties or recommend criminal action to the United States Attorney.

Our area of principal jurisdiction is the Coastal Region which includes rivers, bays, inlets, sounds, etc. For example the operational area of the Captain of the Port, Portland, Oregon for water pollution control is the Oregon and Southern Washington coasts, the Columbia River to Bonneville Dam and the Willamette River as far up as the Falls at Oregon City.

Coast Guard forces are the first line in the Coastal Region because we are there. Our forces, normally on a 24 hour alert status for search and rescue and other functions, can respond and be deployed quickly in water pollution cases.

The principal law under which the Coast Guard operates in water pollution matters is the Federal Water Pollution Control Act, as amended. As you can see from Figure 1, this legislation first entered the scene in the 80th Congress in 1948. This original act has been amended six times, the latest one being the Water Quality Improvement Act of 1970.

Another law shown in Figure 1 is the Refuse Act of 1899. Although not administered directly by the Coast Guard, this Act has become, inspite of it's 72 year age, a powerful tool in combating pollution.

Both of these laws will be discussed further later.

Figures 2 and 3 delineate other important federal laws and documents as well as certain international conventions related to the control and elimination of water pollution.

I'm sure you are aware that these are not all of the pertinent laws, and certainly not the last which will address the subject.

The Federal Water Pollution Control Act, as amended, as it pertains to Coast Guard activities contains the following pertinent characteristics:

Administered by: Coastal Region - U. S. Coast Guard
Inland Region - Federal Water Quality Administration of the Environmental Protection Agency

Substances Covered: Oil in harmful quantities (Section 11)
Hazardous Polluting substances other than oil (Section 12)
Sewage from vessels (Section 13)

Salient Features:

General:

The principal impetus of this Act is clean up, preferably by the spiller. If the spiller does not clean up the Federal Government can remove or arrange for the removal of the polluting substance. The Federal Government can recover clean up costs.

A revolving fund in the amount of $35,000,000 is authorized for utilization by Federal activities in clean up where a spiller fails to do so properly. Monies recovered from a spiller are deposited in this account.

This Act prohibits the discharge of polluting substances into or on the navigable waters of the United States, adjoining shores or upon the waters of the Contiguous Zone.

National and Regional Oil and Hazardous Materials Pollution Contingency Plans are called for to provide efficient, coordinated, and effective action to minimize damage from discharges of polluting substances.

Notification of the U. S. Coast Guard is required as soon as the person in charge of a vessel or facility has knowledge of any polluting discharge from the vessel or facility.

The penalty for failure to notify the U. S. Coast Guard is a criminal one, namely a maximum fine of $10,000 and/or up to one year imprisonment.

This notification cannot be used against the spiller in any criminal case except for perjury or for giving a false statement.

Section 11 - Oil in harmful quantities:

Harmful quantities of oil are defined in 18 CFR 610. Essentially these regulations state that a discharge is harmful if:

> It violates applicable water quality standards, or if visible on the water surface or adjoining shores, or Causes a sludge or deposit beneath the surface of

the water or on the adjoining shores.

In essence - If you can see it or feel it the discharge is harmful.

To insure that spillers are financially able to assume the costs of clean up, vessels, onshore, and offshore facilities must establish evidence of financial responsibility as follows:

Vessels 300 gross tons and over (except dry cargo barges which carry no oil as cargo or fuel): $100 per gross ton or $14,000,000 whichever is the lesser.

The Federal Maritime Commission (FMC) has promulgated regulations (46 CFR 542) regarding the application for and issuance of Certificates of Financial Responsibility.

These regulations are applicable to all vessels, domestic and foreign.

Vessels without a valid certificate on or after 3 April 1971 can be denied entry into United States navigable waters and ports.

Onshore and Offshore Facilities: $8,000,000

Regulations have not yet been promulgated regarding application for and issuance of Certificates of Financial Responsibility for these activities.

For a knowing discharge of oil in harmful quantities a spiller can be fined up to $10,000. This is a civil penalty. In addition, if a vessel is involved its customs clearance may be withheld.

The Secretary of Transportation conducted a study (as directed by this Act) for transmission to the Congress and the President not later than 1 January 1971 regarding all aspects of financial responsibility and limitation of liability.

Section 12 - Hazardous Polluting substances other than oil:

Regulations are not yet fully developed or promulgated designating specific hazardous polluting substances other than oil.

On 1 November 1970 the President sent to the Congress a report with recommendations regarding the need for, and desireability of, enacting legislation to impose upon spillers liability for cost of removal of discharged hazardous polluting substances other than oil.

There are no penalties currently specified under this section.

Section 13 - Sewage from vessels:

Applicable to all vessels equipped with installed toilet facilities.

The Environmental Protection Agency, after consultation with the Coast Guard, will promulgate federal standards of performance for marine sanitation devices.

The Coast Guard will promulgate regulations, consistent with the standards and other maritime safety and navigation laws and regulations, governing the design, construction, installation, and operation of marine sanitation devices in vessels.

These standards and regulations, when they become effective, pre-empt all state and local statutes and regulations. However, a state may request that no sewage from vessels (treated or untreated) be discharged into certain waters of the state.

Initial standards and regulations become effective as follows:

For new vessels two years after promulgation, and
For existing vessels five years after promulgation.

Civil penalties authorized under this section are:

$5,000 for sale of a non-certified marine sanitation device or sale of a vessel without an installed, operative, certified marine sanitation device.

$2,000 for operating a vessel which is not equipped with a certified, operable marine sanitation device.

The Refuse Act of 1899 (Section 13 of the River and Harbor Act of 1899) contains the following especially germane features:

Administered by: U. S. Army Corps of Engineers.

Substances Covered: Any refuse matter of any kind or description ....except that flowing from streets and sewers, passing therefrom in a liquid state.....into any U. S. navigable water of any tributary or bank where the material may be liable to be washed into U. S. navigable waters by ordinary or high tides, storms, floods, or otherwise.

Penalties:

Criminal: Fine - $500 to $2500, imprisonment - 30 days to one year or both

Compensation for damages may also be required.

Recent Developments:

Executive Order 11574 of 23 December 1970 directs the implementation of a permit program under Section 13 of the River and Harbor Act of 1899 (Refuse Act of 1899) to regulate the discharge of pollutants and other refuse matter into the navigable waters of the United States .....

Implementing regulations will be issued by the Corps of Engineers under 33 CFR 209. A proposed rule making was promulgated on 31 December 1970. Comments, recommendations, or objections must be received not later than 14 February 1971.

These regulations apply to all present and future discharges whether or not they have a currently valid permit.

Public notices must be promulgated in each case of application for a permit.

Public hearings may be held if deemed advisable by the District Engineer of the Corps of Engineers.

Permits must be revalidated at least every five years.

Issuance or denial of a permit to discharge will be based on an evaluation of the impact of the discharge on:

Anchorage and navigation
Water quality standards
Fish and wildlife

The Environmental Protection Agency shall advise the Corps of Engineers regarding water quality standards.

Consultation is required with the Departments of Interior and Commerce, the Environmental Protection Agency, the agency exercising administration over wildlife resources and such other agencies and organizations as may be appropriate.

Denial of a permit to discharge can be based on one or more of the following conditions:

State or other certifying agency determines that the discharge will violate applicable water quality standards.

When the Environmental Protection Agency determines that the discharge will be inconsistent with water quality standards and related considerations.

Anchorage and/or navigation will be impaired.

Significant adverse impact on fish and wildlife resources will occur.

No permits will be issued for discharges or deposits of oil in harmful quantities.

The United States Coast Guard also engages in research and development activities in pollution control. Some of our principal activities in this area are listed below in the approximate order of priority.

An ocean barrier for seas up to five feet and winds up to 20 knots.

A surface recovery system with heavy weather capability.

Remote sensing for surveillance - to date RADAR appears to be the most promising.

Vessel (our own) air pollution reduction.

A baseline measurement system - what's there now and how clean is clean.

A National Pollution Response Information Center.

Among the systems developed by Coast Guard R & D is one called ADAPTS (Air Deliverable Anti-Pollution Transfer System). This system is designed to remove liquid polluting substances from stranded vessels. It consists of high capacity pumps (1000 tons per hour) and large bags into which the liquid can be transferred and transported. The bags continue to be a problem. Several pumping systems are being ordered and will be deployed to areas with the greatest pollution potential.

Figures 4 and 5 illustrate the monies authorized by the Federal Water Pollution Control Act and its various amendments. The total through fiscal year 1971 is just over 5 billion dollars.

It is emphasized that these figures represent authorizations not appropriations. For example - The Clean Water Restoration Act of 1966 authorized over 3 and ½ billion dollars for fiscal years 1967 through 1971. However, Congress appropriated just over 50% of the authorized amounts for fiscal years 1967 through 1970.

At the Captain of the Port Office of the Coast Guard in Portland, Oregon there is an increasing case load of water pollution investigations as evidenced by the information presented in Figure 6. The increase is probably due, in most part, to a vastly increased awareness of the operators and public of water pollution.

One recent case demonstrates the manner in which one type of water pollution situation should be handled. The case occurred on 13 January 1971 when the SS HOUSTON, a tanker struck the Shell Oil Company pier along the west bank of the Willamette River at Portland, Oregon. The collision resulted in the severing of one gasoline pipe line and the rupturing of two other lines (one gasoline, the other diesel fuel). No significant damage was done to the tanker. Between 300 and 500 gallons of gasoline gushed into the water. Here is a brief chronology:

Zero hour - 3:45 PM - The tanker SS HOUSTON struck the Shell Oil Pier.

Zero plus 5 minutes - The Shell Oil personnel notified the U. S. Coast Guard and the Portland Fire Department.

Zero plus 7 minutes - The Coast Guard notified the Portland Harbor Patrol and the Federal Water Quality Administration.

Zero plus 10 minutes - The Fire Department on scene.

Zero plus 17 minutes - The Coast Guard Marine Inspection Office notified by the Captain of the Port Office.

Zero plus 30 minutes - The Captain of the Port apprised of the situation by the Coast Guard Duty Officer.

Zero plus 35 minutes - The Captain of the Port established a security zone (closed the river) in the vicinity of the casualty.

Zero plus 51 minutes - The Coast Guard notified the Oregon State Department of Environmental Quality.

Zero plus 1 hour and 30 minutes - Booms in place, fire department flushing fuel from under the pier. Coast Guard marine casualty investigators on scene.

Zero plus 6 hours and 15 minutes - Fire Department advises that the majority of the spill is cleaned up.

Zero plus 7 hours and 15 minutes - The Captain of the Port terminated the security zone.

The Fire Department remained on scene overnight to protect against any continuing fire hazard. Coast Guard investigators returned to the scene at about 10:00 AM, 14 January 1971. At that time clean up was essentially complete with just a bare trace of pollutant noticeable. The case was closed just 18 hours and 15 minutes after it began.

As indicated previously - the Name of the Game is CLEAN IT UP - NOW! That is exactly what the Shell Oil Company did in this case.

PRINCIPAL FEDERAL LAWS RELATING TO WATER POLLUTION CONTROL

TITLE	LAW	APPROVED
WATER POLLUTION CONTROL ACT (Now entitled Federal Water Pollution Control Act)	80-845	06-30-48
AMENDMENTS:		
Water Pollution Control Act Extension of 1952	82-579	07-17-52
Water Pollution Control Act Amendments of 1956	84-660	07-09-56
Federal Water Pollution Control Act Amendments of 1961	87- 88	07-20-61
Water Quality Act of 1965	89-234	10-02-65
Clean Water Restoration Act of 1966	89-753	11-03-66
Water Quality Improvement Act of 1970	91-224	04-03-70
RIVER AND HARBOR ACT OF 1899 Section 13 of this Act has come to be known as the Refuse Act of 1899		03-03-99

FIGURE 1

OTHER FEDERAL LAWS AND DOCUMENTS RELATING TO WATER POLLUTION CONTROL

EXECUTIVE ORDER 11472 (05-29-69): Establishes the Environmental Quality Council and the Citizen's Advisory Committee on Environmental Quality.

NATIONAL ENVIRONMENTAL POLICY ACT OF 1969 (PL 91-190, Approved 01-01-70): To declare a National Policy . . . ; To promote efforts which will prevent or eliminate damage to the environment. . .; To enrich the understanding of . . . . ecological systems and natural resources. . .; To establish a Council on Environmental Quality.

EXECUTIVE ORDER 11288 (07-02-66) AND EXECUTIVE ORDER 11507 (02-04-70): Prevention, Control, and Abatement of Air and Water Pollution at Federal Facilities.

EXECUTIVE ORDER 11514 (03-05-70): Protection and Enhancement of Environmental Quality - The Federal Government Shall Provide Leadership . . .

ENVIRONMENTAL QUALITY IMPROVEMENT ACT OF 1970 (PL 91-224 (TITLE 11), Approved 04-03-70): There is a National Policy for enhancement of environmental quality; Primary responsibilities for implementation rest with State and local governments; The federal government encourages and supports implementation . . . .; Authorizes an Office of Environmental Quality.

EXECUTIVE ORDER 11523 (04-09-70): Establishes the National Industrial Pollution Control Council.

REORGANIZATION PLAN NO. 3 OF 1970 (10-06-70): Establishes the Environmental Protection Agency (EPA), effective 2 December 1970.

EXECUTIVE ORDER 11574 (12-23-70): Administration of Refuse Act Permit Program. Directs implementation of a permit program under Section 13 of the River and Harbor Act of 1899 (Refuse Act of 1899) to regulate the discharge of pollutants and other refuse . . . .

FIGURE 2

INTERNATIONAL DOCUMENTS RELATED TO WATER POLLUTION CONTROL

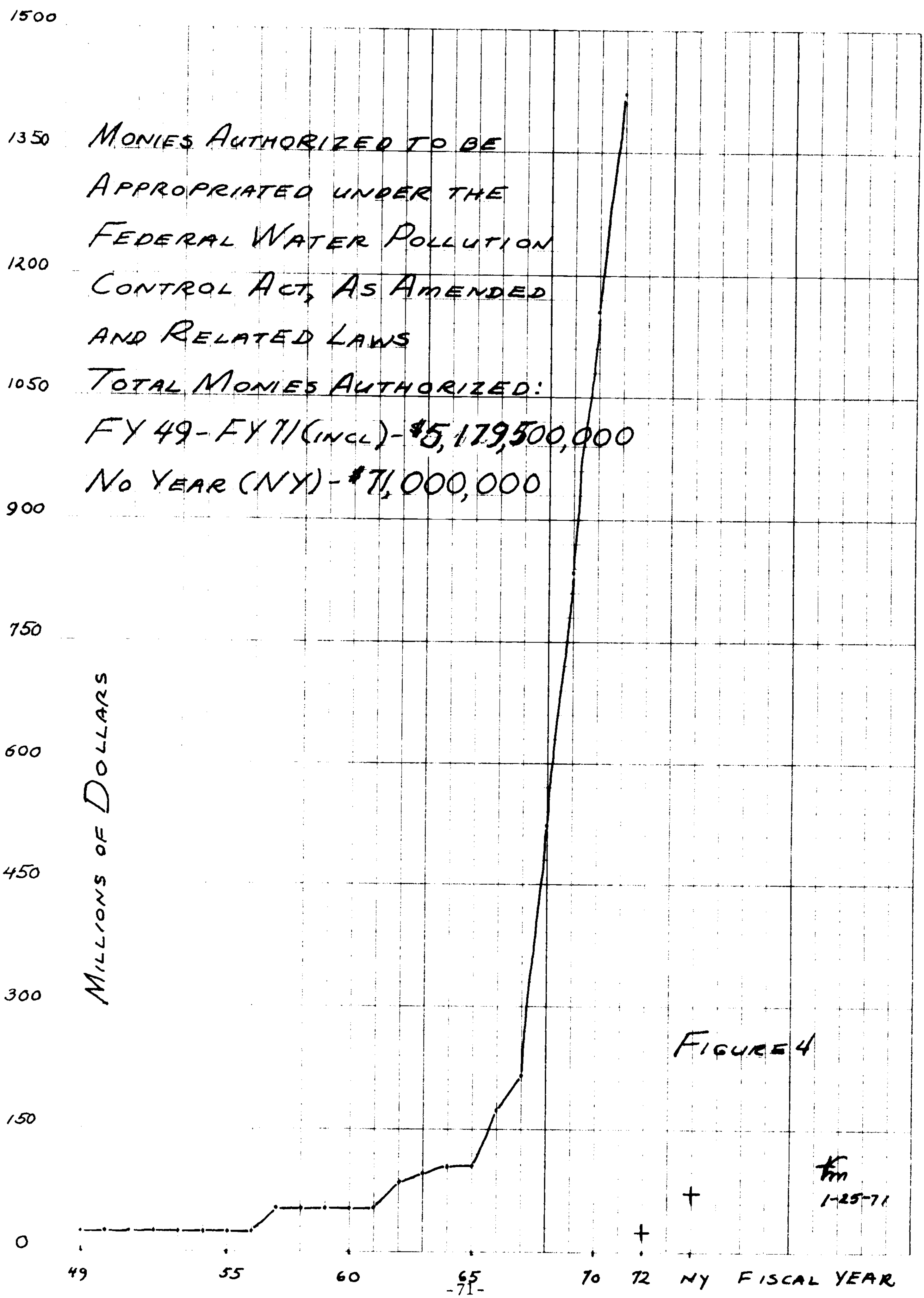
INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION OF THE SEA BY OIL, 1954: .....Action by common agreement to prevent pollution of the sea by oil discharged by ships .....; Establishes prohibited zones wherein the discharge of oil or oily mixtures is forbidden.....; Establishes an oil record book to be carried by ships.

INTERNATIONAL CONVENTION RELATING TO INTERVENTION ON THE HIGH SEAS IN CASES OF OIL POLLUTION CASUALTIES (1969): ....Parties.....may take such measures on the high seas as may be necessary to prevent..... danger to their coastlines.....from pollution or threat of pollution of the sea by oil.....

INTERNATIONAL CONVENTION ON CIVIL LIABILITY FOR OIL POLLUTION DAMAGE (1969): .....Adopts uniform international rules and procedures for determining questions of liability and providing adequate compensation.....

CONVENTION ON THE TERRITORIAL SEA AND THE CONTIGUOUS ZONE (1958): Delineates uniform rules for defining the territorial sea (in the United States - the "3 mile limit"); Defines a zone contiguous to the territorial sea where an administration may exercise control to prevent infringement of its customs, fiscal, immigration or sanitary regulations...; The maximum contiguous zone is the "12 mile limit".

FIGURE 3



MONIES AUTHORIZED TO BE APPROPRIATED UNDER THE FEDERAL WATER POLLUTION CONTROL ACT, AS AMENDED AND RELATED LAWS

TOTAL MONIES AUTHORIZED:

FY 49 - FY 71 (INCL) - $5,179,500,000

NO YEAR (NY) - $71,000,000

FIGURE 4

MONIES AUTHORIZED TO BE APPROPRIATED BY THE FEDERAL WATER POLLUTION CONTROL ACT, AS AMENDED AND RELATED LAWS (MILLIONS OF DOLLARS)

FY	CONSTRUCTION	R&D, ETC	TRAINING	OTHER	TOTAL
49	22.5	2.0		0.8	25.3
50	22.5	2.0		0.8	25.3
51	22.5	2.0		0.8	25.3
52	22.5	2.0		0.8	25.3
53	22.5	2.0		0.8	25.3
54	22.5	2.0			24.5
55	22.5	2.0			24.5
56	22.5	2.0			24.5
57	50.0		3.0		53.0
58	50.0		3.0		53.0
59	50.0		3.0		53.0
60	50.0		3.0		53.0
61	50.0		3.0		53.0
62	80.0		5.0		85.0
63	90.0		5.0		95.0
64	100.0		5.0		105.0
65	100.0		5.0		105.0
66	150.0	20.0	5.0		175.0
67	150.0	61.0	5.0		216.0
68	450.0	61.0	10.0		521.0
69	700.0	126.0	10.0		836.0
70	1000.0	126.0	29.5		1155.5
71	1250.0	126.0	45.0		1421.0
72			25.0		25.0
NY		36.0		35.0	71.0
TOTALS	4500.0	572.0	164.5	39.0	5275.5

FIGURE 5

WATER POLLUTION INVESTIGATIONS CONDUCTED BY THE COAST GUARD CAPTAIN OF THE PORT OFFICE, PORTLAND, OREGON

1969

Total Cases: 31

Number which resulted in fines or prosecution: 8 with 12 still pending.

Total dollar value of fines: $5600

Largest fine: $2500 against Fort Vancouver Plywood Company by the United States

Smallest fine: $250 against the vessel INDIAN MAIL by the United States

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1970

Total Cases: 101

Number which resulted in fines or prosecution: 16 with 25 still pending.

Total dollar value of fines: $2250

Largest fine: $500 against Zidell Explorations, Inc. by the City of Portland.

Smallest fine: $150 against the Trumble Asphalt Company by the City of Portland.

Cases investigated during October through December are either pending or the results are not yet available.

1971

Total cases: 17 (as of 28 January 1971)

ALL 1971 are still pending.

FIGURE 6

Presented March 2, 1971, by Mr. Michael Cruikshank, Research Supervisor,
U.S. Bureau of Mines, Marine Minerals Technology Center, Tiburon, California.

Reprinted from The Journal of Environmental Sciences, April 1969.

Environment and Technology in Marine Mining

Abstract

The marine mining environment consists basically of the ocean, and the seafloor including the subbottom. It is affected by the many socio-economic conditions prevalent in those adjacent areas under the influence of man. This natural environment is an uncontrollable complex of conditions to which technology must be adapted.

Marine mining technology is the application of controlled systems to the profitable exploitation of marine mineral resources. The major subsystems involved include extraction, transportation, beneficiation, and disposal.

The relationships between environment and technology vary markedly according to the type of mineral deposit, be it dissolved, consolidated, or unconsolidated, and its geographic location.

A major problem at present is the dynamics of the ocean water. Submergence of the equipment will obviate much of this problem but will involve new factors in technologic control and life support. Ground control will present new problems not generally associated with terrestrial deposits.

The ocean environment provides certain advantages in solids transportation whether in bulk or pipeline. The reduced solid/liquid density differential will alleviate many problems in handling and disposal. Temperature differentials and movement of water masses may also be utilized to advantage.

In summary it would appear that some of the more stable characteristics of the marine environment may present advantages to the mining engineer and could offer a more predictable medium in which to work than our gaseous atmosphere.

Environment and Technology In Marine Mining

One of the major program goals of the Bureau of Mines is to participate in the development of technology which will encourage the growth of a privately-owned-and-operated U.S. marine mining industry. This will be accomplished by (1) developing data, tools, and techniques necessary for characterizing marine mineral deposits and their environments, (2) and defining the mining systems requirements necessary for exploitation of these deposits and advancing the technology for their industrial development. The accomplishment of these objectives is the task of the Bureau of Mines' Marine Minerals Technology Center in Tiburon, Calif.

The three basic types of mineral deposits found in the marine environment, as illustrated in Figure 1, are:

1. Dissolved Deposits
2. Unconsolidated Deposits
3. Consolidated Deposits

The development of mining systems to successfully exploit these minerals centers on the complex relationship between two major subsystems, one involving the marine environment and the other involving the adaptation of technology to the environment. This breakdown is illustrated in Figure 2.

The marine mining environment consists basically of the ocean, and the seafloor including the subbottom. It is affected by the many socio-economic conditions prevalent in those adjacent areas under the influence of man. This natural environment is an uncontrollable complex of conditions to which technology must be adapted.

Marine mining technology is the application of controlled systems to the profitable exploitation of marine mineral resources. The major subsystems include extraction, transportation, beneficiation, and disposal. It is the purpose of this paper to discuss some of the problems and benefits created by the uncontrollable aspects of the marine environment and their relationship to the development of mining technology.

Since the environment changes with the type of mineral deposit and its geographic location, each deposit may require a new technology for identification and extraction. The development of these new technologies to extract minerals from the hostile environment of the ocean is a formidable task.

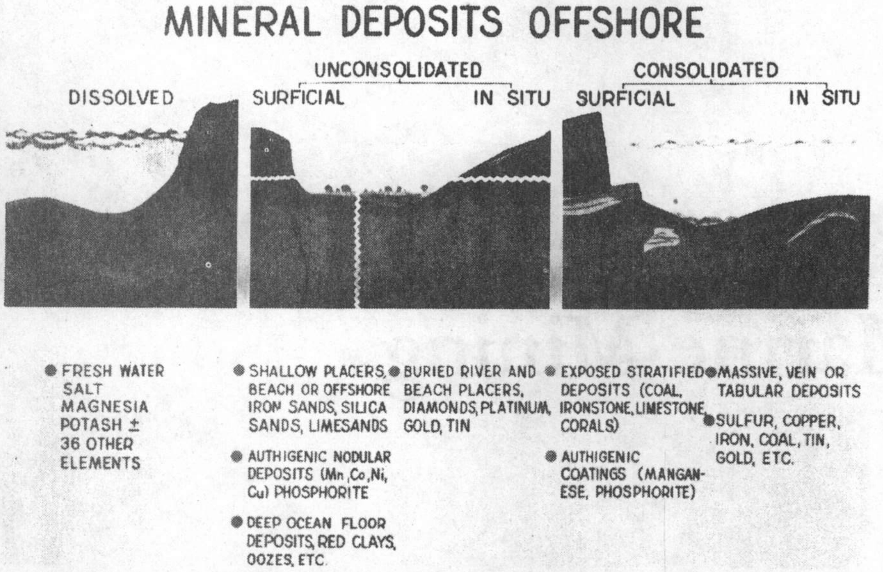

Figure 1. Classification of offshore mineral deposits.

Equally as formidable is the task of extending man's limited knowledge of the environment. Initially the Bureau of Mines is concentrating its attention on the minerals of the continental shelf with the concept that problems start at the beach and become more severe as one moves to sea. Thus the benefits of many years of experience in the working of similar deposits on shore can be applied. The United States continental shelf is nearly 900,000 square miles in areal extent and can be expected to contain ore bodies in generally the same distribution as geologically comparable land areas. The Bureau's first evaluation work on the shelf was accomplished during the summer of 1967 by the marine mining research vessel Virginia City off the coast of Nome, Alaska. Various sampling techniques were tested to determine their effectiveness in sampling the gold-bearing placer materials of Norton Sound. A similar program is planned for the summer of 1968 to investigate techniques for evaluating black-sand deposits off the coast of the Oregon-California coast and phosphorite deposits off the coast of southern California.

In addition to these efforts, much is learned about the marine environment and its effect on mining by observing other mining operations currently underway on the shelf in various areas of the world. These mining operations include tin dredging in Thailand and Indonesia in water depths of less than 150 feet, and diamond dredging in southwestern Africa in water depths of less than 100 feet. The major environmental problems facing these operations are the marine conditions: wind, waves, swells, and tides. These conditions must be critically evaluated so that procedures can be developed for predicting the degree of interference with mining. A systems analysis approach can then be taken to investigate possible modifications in mining techniques to allow longer periods of operation. These data and types of analyses can then be applied to other potential areas of operation so that predictions can be made regarding the economic feasibility of a proposed mining venture.

As a first step in making such an analysis, data were compiled for mining areas in Thailand, Indonesia, and southwestern Africa,[1] and for our own operation area in Norton Sound.[3] These locations are shown in Figures 3, 4, and 5.

The frequency of occurrence of different height waves (sea conditions) in days per year for the four areas is illustrated in Figure 6. The same type of presentation is made (Fig. 7) for swell height except that the length of the swell is also indicated. No breakdown was made between wave and swell condition in Norton Sound, and it is assumed the two conditions were combined in the available data. Waves are generally more irregular, are shorter in period, and exhibit a steeper crest than swells, which are waves that have traveled out of their generating area.

Wave and swell conditions have a major influence on dredge design and the type of dredging method employed. They also imposed restrictions on the exploratory drilling operations required for delineation of the offshore placers. To analyze the extent of sea-state influence on these factors, Table 1 was made up to show the frequency

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[1] Data obtained from the National Oceanographic Data Center

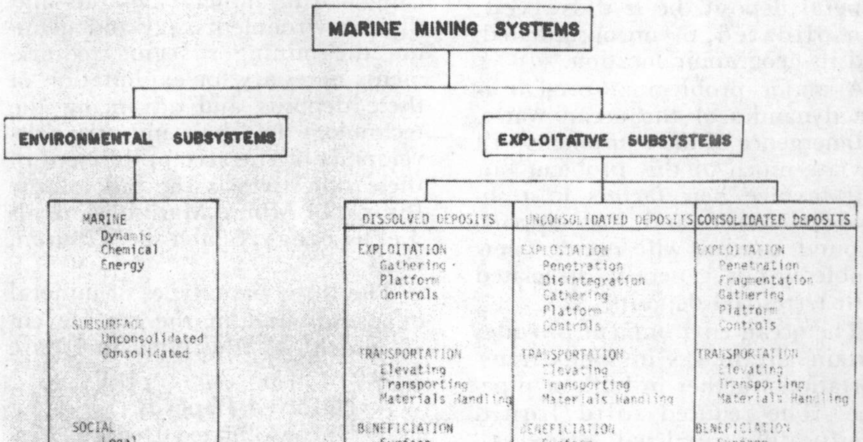

Figure 2. Classification of marine mining systems technology.

Table 1.–Frequency of Occurrence in Days Per Year of Seas Greater Than 5 Feet

Mining Areas	*Waves*	*Swells*
Phuket Island, Thailand	27	103
Singkep and Banka Is., Indonesia	9	57
Belitung Island, Indonesia	24	85
Southwestern Africa	57	267
Norton Sound, Alaska	89	(183 days of ice)

of occurrence of waves and swells greater than 5 feet. The 5-foot condition was selected because it represents a limiting state for operation of most conventional dredging and drilling techniques.

Under the worst conditions in Southeast Asia (see Table 1), waves and swells in excess of 5 feet occur during approximately 30% of the year. In southwestern Africa this condition exists during approximately 75% of the year. It is, therefore, apparent that drilling and dredging operations in southwestern Africa cannot be carried out by the conventional techniques employable in Southeast Asia. In Southeast Asia tin operators favor the conventional bucket-ladder dredge since it can remove large quantities of ground much more efficiently and with much better control than the suction dredge. Figure 8 shows one of the typical bucket dredges with a barge-type hull used in the Indonesian offshore tin operations. Mining operations have, for the most part, been successful, although there are some instances during storm periods where the dredges must be transported to the leeward of the islands to avoid rough seas. Even with these precautions, a number of accidents have occurred, at least one involving loss of life.[7]

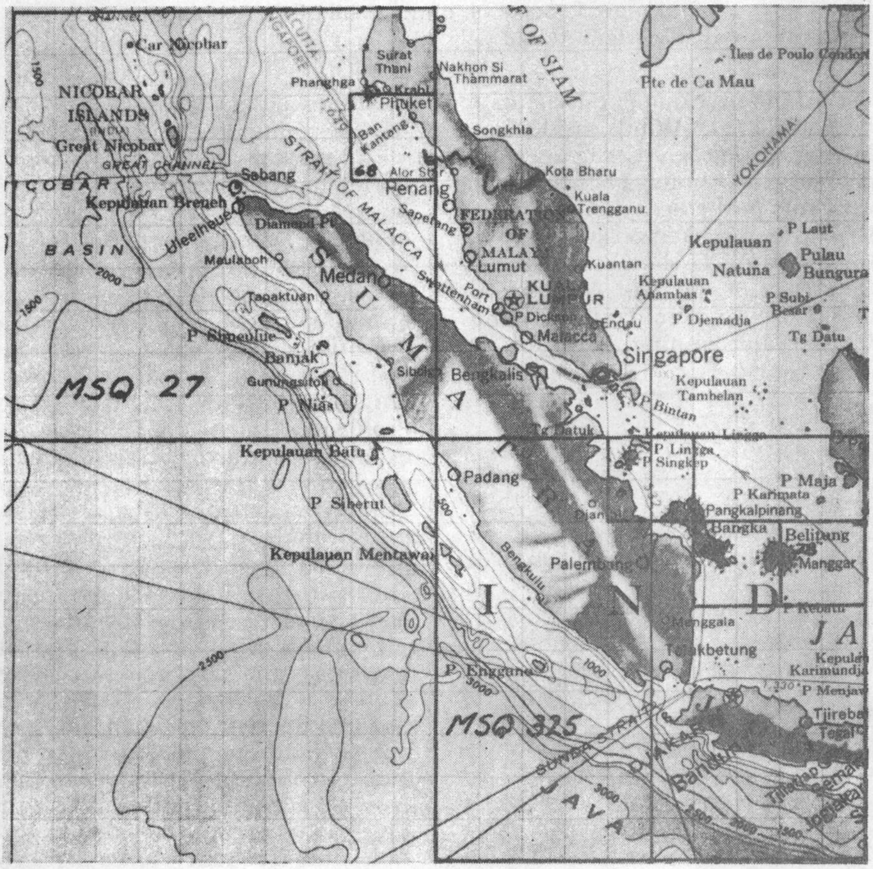

Figure 3. Location of offshore tin dredging operations

Even if the conventional bucket dredge were designed to withstand rougher seas (greater than 5 feet), a problem would still remain in keeping the bucket ladder in continuous contact with the seafloor and in preventing the possibility of severe damage due to impact with the bottom. For this reason conventional bucket dredges do not lend themselves to operation in the heavy seas characteristic of the southwestern African coast without a change in design. The same would be true for suction dredges having a rigid connection between the platform and suction head.

The severity of sea conditions off southwestern Africa has required mining operators to make certain innovations in equipment design. For exploration the use of a bumper-sub fitted to the bottom of the drill string allows exploratory drilling operations to proceed in swells up to 10 feet.[6] Equipment capable of working in a 10-foot sea gives 250% more drilling time than that limited to a 5-foot sea. For exploitation, dredges with the same barge-type hull as those employed in Southeast Asia have proven more suitable and less costly than conventional ship-type hulls.[12] Their advantages include greater structural strength, multiplicity of positive water-tight compartments, and greater safety in allowing dredging operations to be conducted closer to the water surface. Figure 9 from Webb [12] shows one of these barges making weather in a full gale.

Instead of the conventional bucket ladder or rigid suction line, the southwestern African dredges have employed a 16 or 18-inch dredge pump with a flexible hose attached through a swell-compensating mechanism to maintain suction contact with the seafloor. This compensating equipment consists of a counterbalance operating through a four-part line which suspends the suction intake in a vertical position and allows a rise and fall of some 40 feet. Figure 10 from Webb [12] shows the mining vessel Colpontoon with a girder structure over the foredeck housing the swell compensators.

Even though the present flexible-hose method of dredging in southwestern Africa is the only one that has proven practical, it has two

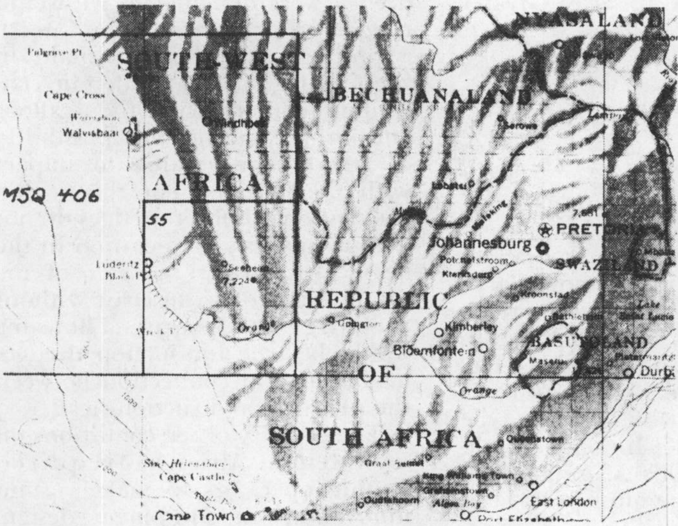

Figure 4. Location of offshore diamond dredging operations

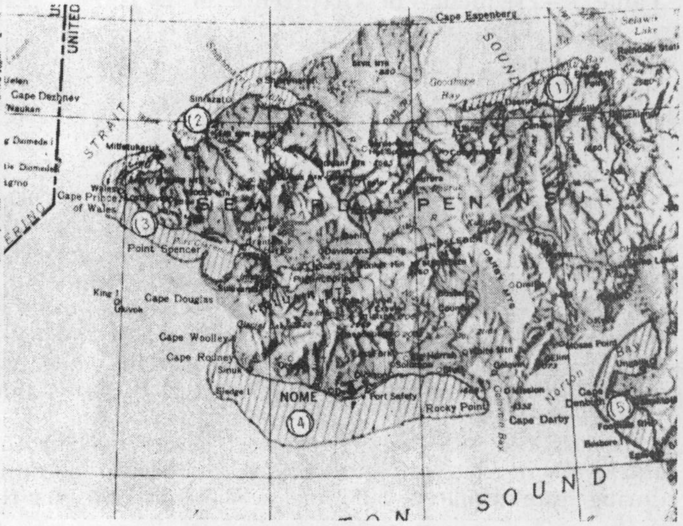

Figure 5. Location of potential offshore gold placers in western Alaska

major short-comings which have prevented these operations from being profitable. Dredging control is extremely poor, leaving a very irregular post-mining horizon with much of the deposit still in place. Also, there is little penetration to bedrock, where the diamonds are believed to be concentrated.[6]

Although the flexible suction dredges used in southwestern Africa can operate in 40-foot seas, it is believed that the addition of a swell-compensating mechanism on the bucket dredge could make it a strong competitor. Because of its increased efficiency, capacity, and control, even a small increase in its operating capabilities in heavy seas would make the bucket dredge extremely attractive.

In Norton Sound off Nome, Alaska, ice exists over 50% of the year and during the remainder of the year there are only 3 months with seas less than 5 feet. A conventional dredge with a 5-foot sea limitation could hardly operate economically under such conditions. If technology could improve the seaworthiness of these dredges so they could function in 10-foot seas, the time available for operation would be doubled. Alternatively, if a means were developed for operating continuously either above or below the ice, the available operating time would be tripled.

In addition to sea and swell conditions, winds and tides are also important environmental factors to be considered. Winds, aside from having an effect on sea, tide, and current conditions, play a significant role in the design of the superstructure of a fixed or floating platform. Figure 11 shows the monthly frequency of different wind speeds and their predominant directions for the same mining areas; for the Nome area, data are presented only for the summer months. As with sea conditions, the winds in South Africa and Alaska are much more severe than in Malaysia and Indonesia. During September in Nome, the winds are predominantly from the north, where there is a minimal fetch. Although the sea conditions may permit operation, wind tides can cause strong currents which result in anchoring problems. One of the major delays experienced during last summer's Alaskan drilling operations was ship movement due to anchor slippage. Under severe conditions, combined coastal wind and tidal currents in the Nome area can reach velocities up to 4 knots.

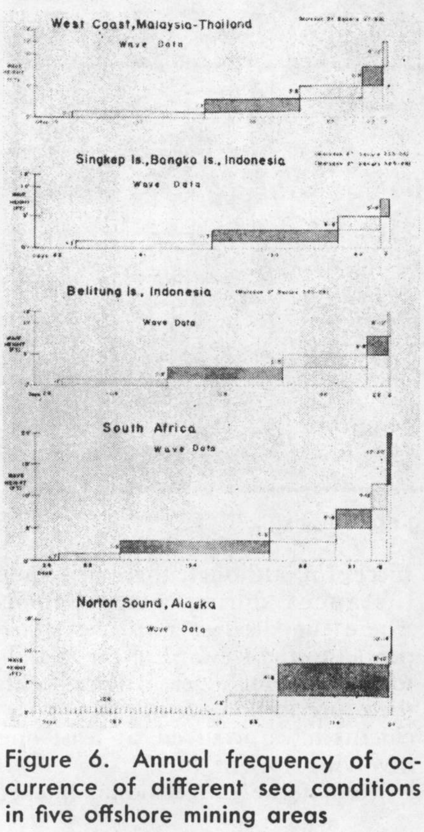

Figure 6. Annual frequency of occurrence of different sea conditions in five offshore mining areas

Figure 12 illustrates typical tidal fluctuations in the five offshore mining areas. Accurate knowledge of these fluctuations is an absolute necessity during the exploration and exploitation phases of mining. Not only are the tides a major cause of current, but the magnitude and frequency of changes in water depth are a controlling factor in dredge design. Also the success of geophysical profiling is dependent on an accurate accounting of tidal fluctuation at the exact time and place of operation.

It can be seen from figure 12 that a variety of tidal conditions can exist. The tides off Bangka Island, Indonesia, have a maximum range of 6.3 feet and are diurnal; that is, one complete cycle

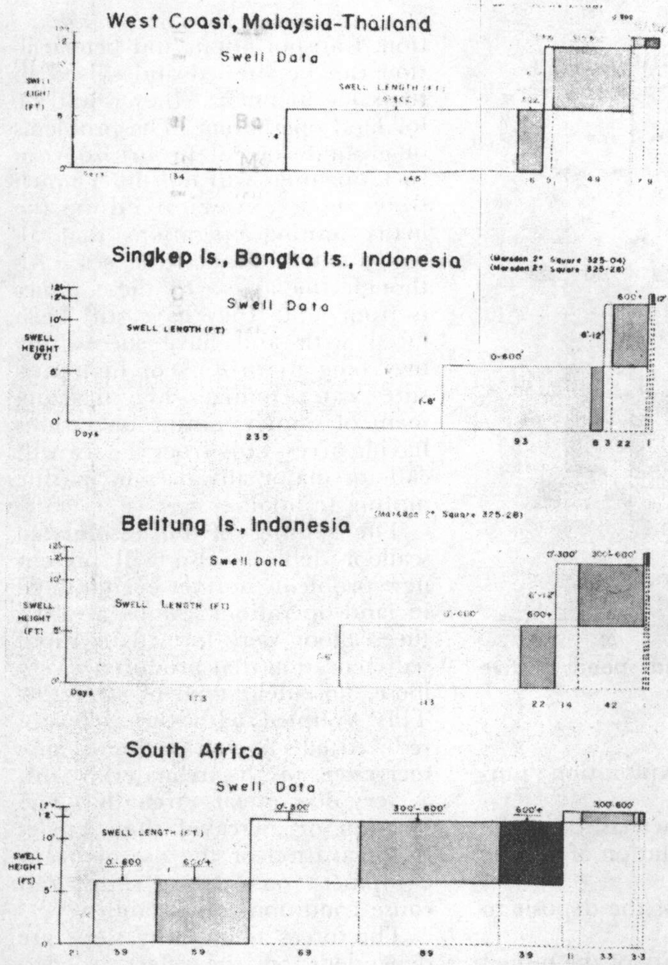

Figure 7. Annual Frequency of occurrence of different swell consitions in four offshore mining areas.

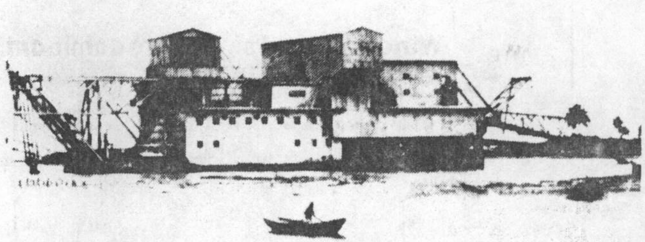

Figure 8. Typical bucket-ladder dredge with barge hull used in Indonesian offshore tin operations (photograph courtesy of C. M. Romanowitz).

Figure 9. Southwest African dredge in Heavy seas.(12)

Figure 10. Southwest African dredge "Coloontoon" with girder structure over foredeck housing the swell compensators.(12)

per lunar day of 24 hours and 50 minutes. The tides off Phuket Harbor, Thailand, and Capetown, South Africa have a maximum range of 8.5 and 5.4 feet, respectively, but they are semidiurnal with two complete cycles per lunar day. The tides off Nome, Alaska, are mixed, having periods of fluctuation which range between diurnal and semidiurnal. With tide tables available on almost every section of the world, it might appear that tide prediction was a simple matter. That this is not the case can be seen from the tide graph of Nome, Alaska. The dotted line which covers the 4-day period July 11-14, 1967, was plotted from measurements obtained by the University of Washington. Whereas the tide tables predict a maximum range of about 2 feet, actual recordings show a range over the 4-day period of about 5.5 feet. The discrepancy is caused by the strong effect of winds on the tide changes in this area. Tides of 14 feet above and 3 feet below mean-lower-low water have been recorded in Norton Sound. Similar deviations, although possibly not as pronounced, can be expected in almost any area of the world, thus complicating the task of tide prediction.

The problems of marine environment which we have discussed so far have their major effect on mining technology when considering the floating-type platform. Submergence of the equipment would obviate many of these problems. It has been estimated [8] that a submerged drilling platform, which would require less engineering for wind and wave stress and eliminate the use of an expensive tender-derrick complex, could be constructed for less than half the cost of an above-water platform.

In some areas the feasibility of a successful mining venture may be directly dependent on the development of a submerged mining system which can avoid the dynamic aspects of the air-water interface. Although many new factors in technologic control and life support must be considered, they command a high priority in planning future technologic development.

The marine mining environ-

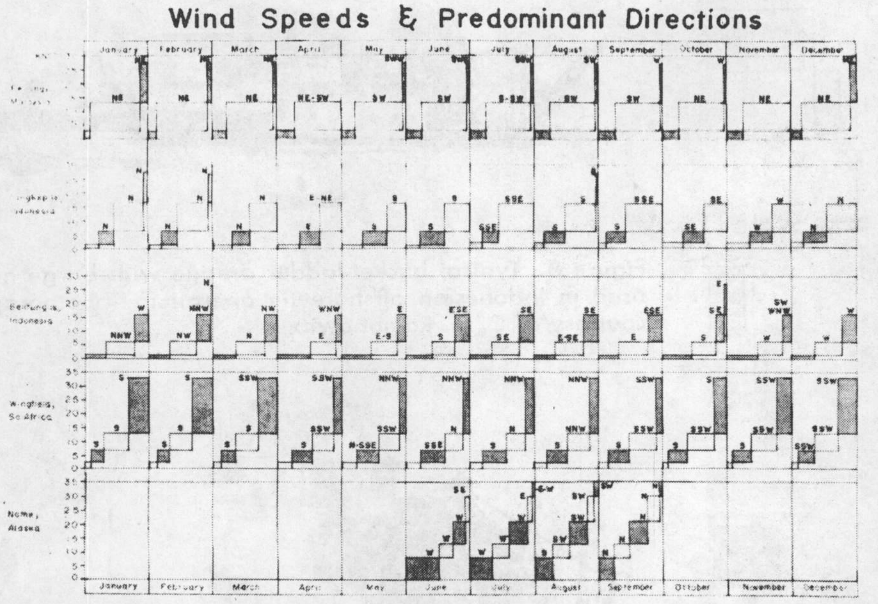

Figure 11. Monthly frequency of occurrence of different wind speeds in five offshore mining areas

ment, in addition to the sea, includes the seafloor and its subbottom. Although the problems of adapting to this aspect of the environment may not be as great as those associated with the sea, the seafloor and its subbottom present a much greater unknown to us.

The economic feasibility of an undersea mining venture depends on two factors: (1) The extent and value of mineralization present and (2) the cost of exploring and exploiting this mineralization. With existing technology, resolution of these factors is an expensive and extremely crude process. Although suitable techniques have been developed for obtaining representative samples of the first few feet of the unconsolidated seafloor, sampling to greater depth (to 200 feet) is more of an art than a science. This is especially true where undisturbed samples are required.

Assuming representative core recoveries and a minimum of ore migration, the extent and value of mineralization can be determined by techniques of disturbed sampling. To determine the cost of exploring and exploiting the deposit, however, there are a number of unknown factors which must first be evaluated. These include the following:

1. Amenability of the deposit to penetration for exploration purposes.
2. Velocity characteristics of the deposit for interpretation of seismic profiles.
3. Amenability of the deposit to excavation.
4. Transportability of the mined material.
5. Ground control problems resulting from excavation, such as ground support, slope stability, and bearing capacity.
6. Methods of beneficiation suitable to the type of ore and deposit characteristics.
7. Methods of waste disposal which will be necessitated.

Each of these factors represents an engineering phenomenon which requires for its evaluation a basic knowledge of the intrinsic engineering properties of the deposit material. Unfortunately these properties cannot be determined from disturbed samples. In the final analysis, therefore, techniques of undisturbed sampling to great depths must be perfected in order to completely evaluate the economic feasibility of a marine mining operation.

Based on the successful delineation of ore values and engineering properties, design of the various mining subsystems can proceed. Problems of penetration, excavation, transportation, and beneficiation can be studied and solved in the same manner as they would be for land operations. The problems of ground control in subbottom rock openings will not differ much from those experienced in the many mining operations that already extend under the sea. Although the access to these mines is from land, they have still been faced with and have successfully overcome problems of high-pressure water influx. The development of similar mining operations having access only from the sea will call for major advances in marine mining technology.

The mining of unconsolidated seafloor deposits also will present new problems not yet encountered in land operations. Many areas of the seafloor were formed by rapid sedimentation that produced a very loose, flocculent type of structure. This, coupled with the factor of reduced effective stress due to submergence, results in material with a very low shear strength. The creation of increased slope angles by excavation or the use of heavy equipment on existing slopes can cause conditions of instability.

The forces acting on a slope are dependent on the effective overburden pressure acting over a plane of potential shear. This pressure can be divided into two components, a shear component directed along the plane and a normal (direct) component acting at an angle i to to the vertical pressure; the angle i is the angle between the horizontal and the plane of the slope. If a Mohr's diagram is made of these stresses and a strength envelope is plotted as in figure 13,[9] the stability of the slope may be determined. If the angle of the slope is less than the angle of internal friction, the sediment should be stable to any thickness. If, however, as in figure 13a, the angle of internal friction ϕ is less than the slope angle i, the lines cross at some point F, and F^1 is the effective normal stress at which failure occurs. Figures 13b[5] and 13c[4] give two examples of slope stability analyses made for submarine sediments in two coastal areas of the United States. An increase in the slope angle of 4° for the case in figure 13c would lead to incipient failure at some critical depth.

In areas of existing submarine canyons and gullies, conditions of pending slope failure may already be present, and extreme caution must be exercised during excavation or in the use of bottom-resting equipment. A slope failure on the outer periphery of an undersea stripping operation, aside from the safety hazards which may be involved, could cause contamination of the ore zone with waste material and significantly increase operation costs. Control of the slope angle when dredging from a surface platform can be very difficult. All of these factors being considered, it is imperative that the environmental parameters of the seafloor and its subbottom be accurately defined.

One of the most serious problems facing a marine mining operation is waste disposal. Unlike land operations where mine tailings can be retained in specially prepared areas or returned back to the original excavation, waste disposal in the ocean is much less controllable and will often have a greater effect on the surrounding environment. Not only can these wastes contaminate the new ore but they may have a major effect on the ecology of the area, especially if toxicants are utilized in the ore beneficiation process. Past studies on the effects of mining on marine biological life have been retrospective in nature, being initiated after the damage was already done. Future studies will involve the measurement of the ecosystem before any activity is commenced, so that causal effects may be continually monitored as mining progresses. It is of the utmost importance that exploitation of one natural resource does not involve the destruction of another.

So far, we have discussed numerous problems presented by the marine environment which will confront the development of a marine mining technology. Despite its hostility, the marine environment also offers technologic advantages not found in comparable land areas. There are, in fact, many mineral resources which owe their commercial importance or even their origin to the ocean environment. The much-publicized deep sea manganese nodules, which are found distributed throughout the major oceans of the world, are continually forming on the seafloor. On the Pacific ocean floor alone, it is estimated that these nodules are forming at the rate of 10 million tons annually. Various metals constituting these nodules such as magnesium, vanadium, manganese, cobalt, and zirconium are agglomerating at a rate which currently exceeds the U.S. rate of consumption.

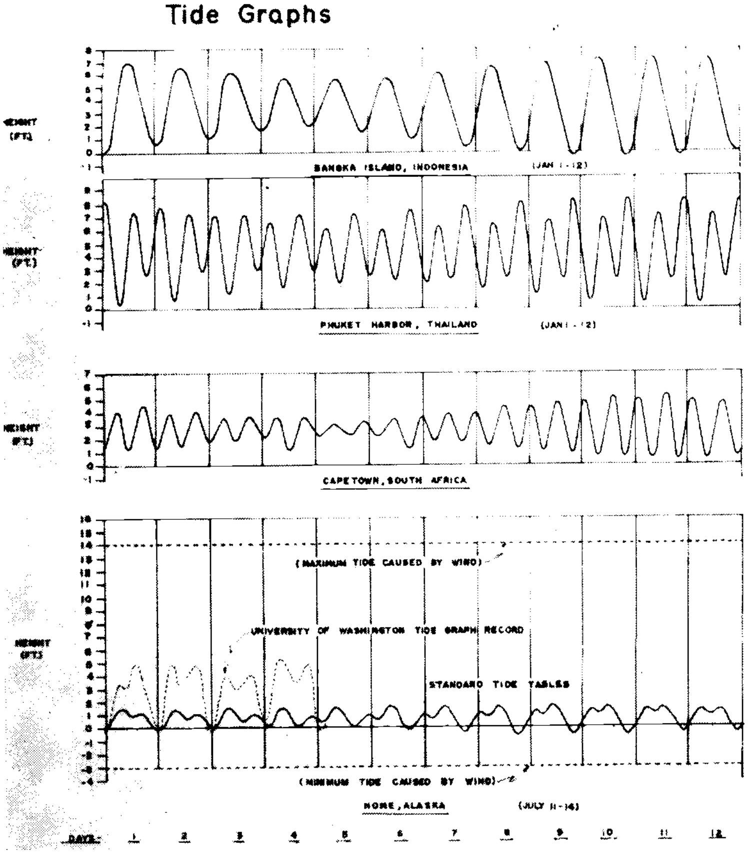

Figure 12. Typical tidal fluctuations in four offshore mining areas

The Government-owned cement plant at Akranes, Iceland, produced over 120,000 metric tons of cement in 1966, using shell sand dredged from the sea.[10] There are no known deposits of limestone on the mainland. Deposits of suitable shell sand, 10 miles offshore in Faxa Bay, southwest of Akranes, were discovered in 1949. West of the deposits, the sea bottom has a rich growth of marine mollusks. During the winter, heavy seas from the Atlantic transport the dead shells toward the east to deeper water, where they again settle to the bottom. The sand makes a slope 800 to 1,200 yards wide from the point of origin to a depth of 130 to 140 feet. On the eastern side of the slope, the tidal current runs from north to south and carries the sand particles to the south. The gradient of the slope, which is 10 to 12 miles long, is balanced, and the sand is constantly replenished.

Similar types of replenishment action are common to many offshore heavy metal deposits. On the northeast coast of Ceylon, black sands containing ilmenite (TiO_2) and zircon (ZiO_2) are recovered by a walking dragline operated from land.[11] During the monsoon seasons fresh washings of the black sands help to maintain a constant reserve, making close control of the mining operation unnecessary.

The rich gold deposits recovered from the beaches at Nome, Alaska, at the turn of the century owe their origin to the sorting and concentrating action of the sea. Numerous offshore sand and gravel deposits found throughout the world have assumed commercial importance because of the sea's natural classification processes. Other marine seafloor deposits which may someday have commercial significance are phosphorites, glauconites, red clays, and calcareous and siliceous oozes.

There is also a vast quantity of dissolved minerals contained in the sea. Although only sodium, magnesium, calcium, and bromine have been commercially extracted as metals or salts, future technological and economic changes could alter this picture. The discovery of four mineral-enriched "hot spots" in the Rift Valley of the Red Sea[2] could materially affect the economic aspects of dissolved mineral recovery. Tests at the newest site indicated a salt concentration of 27%, almost eight times that of normal ocean water. The concentration of such elements as iron, manganese, copper, lead, and zinc ranges from 1,000 to 50,000 times that of normal ocean water. Although these phenomena have not been discovered in other areas of the ocean, they may nevertheless exist.

In addition to the beneficial role the marine environment plays in the formation of mineral deposits, it also can offer numerous technological advantages for the exploitation of these deposits. Utilization of the ocean's waves, tides, and currents to produce power has been given much consideration.

Temperature differential between water layers and between water and air offers another potential for power production. Such systems are particularly feasible in the polar and equatorial ocean areas of the world, where differentials of greater than 25°F are found.

Ocean currents can also assist in the extraction of dissolved minerals by substituting for giant pumps. Studies have demonstrated the feasibility of extracting uranium using ion exchange resins in areas combining a substantial residual drift and high uranium content, such as the west coast of Norway or the Japan and Florida Straits.[1] It was estimated that the flow through the Florida Strait would carry over 1 million tons of uranium past the production line each year.

Another important technological advantage of the marine environment is reflected in the unique systems of geophysical prospecting that are used for sea-floor and subbottom featural analyses. Subbottom profiling operations using a ship-towed energy source can delineate large areas of the ocean bottom in much less time and at less cost than comparable land-operated equipment.

The ocean environment will also provide certain advantages in solids transportation, thereby alleviating many of the problems connected with the handling of ore and the disposal of waste. In pumping materials from the ocean floor, either vertically or horizontally, the reduced slurry density resulting from submergence will significantly reduce the power requirements.

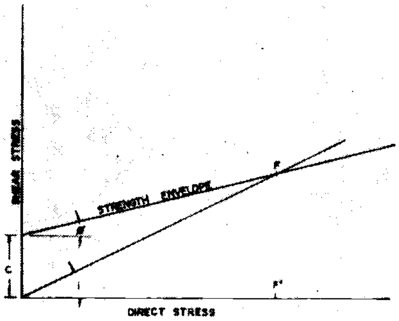

FIGURE 13a - DETERMINATION OF SLOPE STABILITY FROM SLOPE INCLINATION AND ANGLE OF INTERNAL FRICTION (AFTER TAYLOR, 1948)

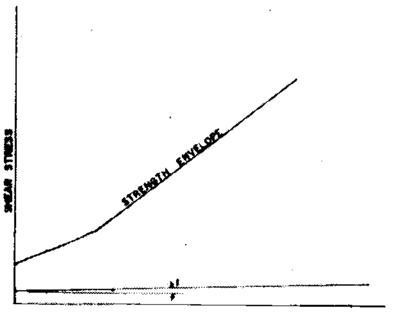

FIGURE 13b - STABILITY ANALYSIS TEXAS SHELF AREA (AFTER MORELOCK, 1967)

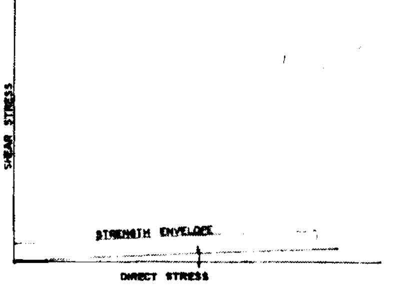

FIGURE 13c - STABILITY ANALYSIS CALIFORNIA SLOPE AREA (AFTER INDERBITZEN, 1965)

Figure 13. Stability analysis by infinite slope theory

Submergence may also provide certain propulsion advantages for future underwater vehicles used in the transportation of ore. Research on new hull designs and frictional drag reduction techniques for high-speed underwater vehicles has shown that speeds attainable in the relatively calm waters of the subsurface ocean may be several hundred percent greater than those achieved by comparable surface vessels.

The problems associated with water turbidity and waste disposal may also have their positive side. Informed opinions have been expressed that seafloor activity may release large amounts of nutrients previously unavailable to plant and animal life in these areas, so that mining the seafloor may have the same beneficial effect as plowing land.

The water-seafloor interface offers a more stable and more predictable environment than the air-land interface. For this reason, many of the parameters which must be considered in the design of a land-based mining operation do not have to be accounted for in the ocean. In evaluating problems of slope stability and bearing capacity on the seafloor, the effects of changing water table, heavy rain, freezing, thawing, or extreme drying need not be considered. In determining the effectiveness of a drill or excavation tool in various consolidated or unconsolidated materials, we do not have to specify whether the material is dry, partially saturated, or saturated. The assured presence of a predictable fluid medium will in some respects make the task of mining systems development an easier one.

In summary it can be said that the successful development of a marine mining technology will require knowledge not only of the problems arising from the marine environment, but also of the advantages inherent in it. Research at the Bureau of Mines' Marine Minerals Technology Center is being directed toward all phases of marine mining systems development. By necessity, therefore, we are studying better ways to define the environment in which these systems must work. As the marine environment is delineated, we are confident that a suitable technology can be adapted to it. ●

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Mining and Mineral Recovery 1969

"IF MANKIND in generations to come will be forced to look beyond the continental land masses for the bulk of its metal and mineral needs, then it seems more reasonable to surmise that prior attention by the world's extractive industries will be given to the ocean deeps, rather than to the heavens" (M. J. Aug 69).*

Several events of 1969 may in the future be regarded as milestones in the development of undersea mineral resources. An American company, Deepsea Ventures, Inc., has been formed and financed for the purpose of mining manganese nodules from the deep ocean at depths to 18,000 ft., and has begun conversion of a prototype mining ship (Hy Jan 70 lb, p 3); the Russians have suddenly put great public emphasis on the need to tap "nature's undersea mineral resources" (Bakke)[1] and have followed this up with reports of exploration and discovery in many of the world's oceans; discoveries made during the Deep Sea Drilling Project indicate some new and potentially important sources of mineral resource under the sea, and have initiated considerable technical advancements in deep sea exploration (Peterson). In general, the year has been one of progress, and despite fiscal setbacks and legal quagmires, the fledgling offshore mining industry has become more of a reality and less of a fantasy dreamed up by gold diggers on the oceanography bandwagon. Kruger (1969) states this reality succinctly in his paper "Mining: A Business for Professionals Only" which should be required reading for all aspirants into the glamorous world of ocean minerals.

A number of papers (Askevold, Moyal, Wakefield, Medford) have reviewed the existing ocean mining industry with conclusions that confirm steady but positive development. Medford (1969) has studied the problems of marine mining in Great Britain from a mathematician's viewpoint and concluded that the greatest contribution from research and development at this time is likely to be in exploration and evaluation rather than in improvements in mining methods, a conclusion which is borne out by present activities in the field.

Environment

Three new terms, environment, pollution and ecology, have been added to the layman's vocabulary this year. The environment for marine minerals is scarcely known and major programs for inventory of national and world resources have been proposed by a number of groups. The hypothesis of ocean floor spreading (Orowan) has economic portents when the nature of rift valleys and associated hydrothermal emanations such as those in the Red Sea are considered. If emanations of this type are associated with young continental rifts as suggested, then the residual deposits so formed should be sought on the outer edge of the continental shelf or slope rather than in contemporary mid-ocean ridges. A number of writers have expressed views on the part played by the marine environment in ore genesis (Brongersma-Sanders, McGinnis, Kharkar *et al,* Curtis & Spears, Oberc & Seri Baturin *et al,* and White), whi others (MacDonald) showed intere in the trace element content of natural waters as a means of prospec ing for ore deposits.

While no new types of miner deposit have been added to the li of resources (Table I and McIlher ney), McKelvey and Wang (1969 compiled a very excellent set c preliminary subsea mineral resourc maps at a scale of 1:40.000.000. Th most significant point these map make is that all but the continenta rise, and a few small areas of th Central Pacific and Indian Ocean are conceivably favorable locally fo mineral deposits. This potential ha not been stated quite so forcefull elsewhere. Other aspects of the environment receiving attention are th need for good engineering data t vastly improve and quantify ou knowledge of the fundamental character and properties of the rocks an minerals of the sea floor (Corp) an for measuring and forecasting ocea data (Ives).

Pollution has suddenly taken o ominous new meaning, but minin companies have always lived wit this threat, along with their other environmental problems, sometimes facing it grudgingly and ineptly, othe

TABLE I—TABULATION OF MARINE MINERAL RESOURCES

OFFSHORE MINERAL DEPOSITS				
Dissolved	**Unconsolidated**		**Consolidated**	
	Surficial	**In Situ**	**Surficial**	**In Situ**
Metals and salts of, Magnesium Sodium Calcium Bromine Potassium Sulphur Strontiun Boron Uranium and about 30 other elements **Fresh water**	**Shallow beach or offshore placers,** Heavy mineral sands Iron sands Silica sands Lime sands Sand and gravel **Authigenic deposit,** Manganese nodules (Co, Ni, Cu, Mn) Phosphorite nodules Phosphorite sands Glauconite sands **Deep ocean floor deposits** Red clays Calcareous ooze Siliceous ooze Metalliferous ooze	**Buried beach and river placers** Diamonds Gold Platinum Tin **Heavy minerals may include,** Magnetite Ilmenite Rutile Zircon Leucoxene Monazite Chromite Scheelite Wolframite	**Exposed stratified deposits** Coal Ironstone Limestone **Authigenic coatings** Manganese oxide Associated Co, Ni, Cu Phosphorite	**Disseminated massive, vein, or tabular deposits** Coal Iron Tin Gold Sulphur Metallic sulfides Metallic salts

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*Abbreviations are listed at the bottom of Table II.

[1] Reference listing is arranged alphabetically at end of this chapter.

times sparing on expense to resolve the problems to everyone's satisfaction. From now on, however, there will be no ignoring it, and counter measures to avoid pollution will take a prime place in any mining evaluation studies in or near the ocean. Despite the fact that certain operations may have a beneficial effect on the environment (Cruickshank *et al*, O.S.N., 17 Jan 69, p. 3), public opinion is such that the very suggestion of possible disturbance of the environment will lead to voluble criticism and expensive constraints (E.M.J. Dec 69). Anticipation of these effects is the subject of a major program initiated by the Bureau of Mines at their Marine Minerals Technology Center in Tiburon. This program is one of many in the Department of the Interior, dealing with marine resources development and environmental quality (U.S. Dept. of Interior).

The third of the trilogy, ecology, really combines the other two, and yet in a broader sense involves the total cycle of human life and mineral supply and demand. Four factors are cited by Askevold (1969) in support of increased investment in ocean mining: (1) an anticipated acceleration of demand for mineral commodities resulting in an accelerating depletion of land reserves; (2) a need for strategic independence; (3) allowance for the lengthy time lag which occurs between the discovery of any mineral deposit and the mining and processing phases; and (4) the fact that certain ocean mining operations are already profitable and can compete with land based operation. As a proponent of the first factor, Park (1968) makes some chilling forecasts which also should be required reading for the enquiring investor.

Exploration

New or ongoing exploration programs reported in the past year number over 65 and include operations in three major oceans and off the shores of 20 different countries (Table 2). The major emphasis has been on tin, titanium minerals, and gold, all in nearshore, relatively shallow areas, but there have been selective projects in deep water to sample manganese nodules in the Atlantic and Pacific Oceans and metalliferous muds in the Red Sea.

New technology for exploration has been slow in coming, and there are still many gaps to be filled (Wang & Cruickshank). However, systems for determining position for survey and navigation on the surface have been perfected to give accuracies which are more than adequate for the data collected. Lasers have been used for extreme accuracy in line of sight surveys (Walker 1969), and for short range work, Decca and Hastings Raydist (Barnes) have been widely used. Satellite navigation has been given thorough and successful testing during the *Glomar Challenger* drilling project.

The analogy between airborne and seaborne survey is very close, but remote sensing from space is a new tool now under study for mineral exploration. A Remote Sensing Center has been established at Texas A&M (Offshre, Oct 69), and one project uses photographs from space craft to obtain data on shallow water mineral placers. Airborne detection of deeply buried deposits using low frequency radio transmissions is employed by Barringer Research Ltd. of Canada under the trade name Radiophase. Other potential applications of this technique in the marine environment include the mapping of water conductivity to determine the extent of pollution, and the location of faults, shear zones and other mineral traps.

Another unusual airborne electrical method known as Teltran utilizes the ground current effects generated by lightning from tropical storms many hundreds of miles distant (Australian Mining). Methods for measuring the potential generated by an oxidizing ore body submerged in the ocean are being developed under a joint research project between the U.S. Bureau of Mines at Tiburon and the University of California at Berkeley (Corwin et al). A number of organizations are working on the improvements of subbottom profiling systems, considered by many to be one of the most useful developments to date for mineral delineation beneath the sea, although its utility in the delineation of heavy minerals placers is questioned by some experts (MMTC). Side scan sonar is being developed for sea floor mapping (Livesy), and at least two companies, Westinghouse (U.S.) and Geomecanique (France), already have commercial models available.

Much effort is being put into the development of *in situ* mineral analyses techniques using neutron activation (Sandquist & Matsura) with a potential for remote use in the sea floor. Sentfle *et al* (1969) describe encouraging results using californium-252, an isotope recently offered for sale by AEC (E.M.J. Dec. 68) at $450 billion per pound, or more realistically, $100 for one-tenth of a microgram. Rapid geophysical and radiometric methods of locating phosphate concentration in the sea bed are described by Tooms (1969) with reference to the North West African shelf, and delineation techniques for phosphorite off Southern California have been described by Barnes (1969).

There have been few developments in submarine sampling hardware, (Table 3) and despite some encouraging claims (Libby & Horton) sampling of detrital deposits of heavy minerals is still a major problem, and the representative sampling of offshore gold placers is still a questionable art. Until there are production operations with which to compare and confirm the grades obtained by present sampling techniques, any evaluation of gold placers offshore must remain highly speculative. Research on marine placer sampling is being carried out by a number of organizations including the U.S. Bureau of Mines at Tiburon (Cruickshank & Collins).

Dissolved Minerals

Despite development in extractive processes, no new minerals have been produced from sea water sources, although several new plants have been put into operation for magnesia and fresh water (Table 4). Current trends favor the use of sea water magnesia rather than conventional land sources, and the closure of the mine and plant of Northwest Magnesite Company has further increased the dependence of American manufacturers of basic refractories on sea water. In an opposite vein, Dow closed down their Freeport seawater bromine plant and will use inland wells as the future source of brine. This was strictly a question of economics. As to the age old question of gold from sea water, Russian scientists at the Irkutsk Institute of Rare Metals report the culture of a mold fungus which extracts 98 percent of the gold in some solutions, covering itself with gold in the process, while Rosenbaum *et al* (1969) of the U.S. Bureau of Mines, after a thorough examination of the facts and fancies, conclude "We know of no procedure now, nor do we see anything on the horizon, that can recover gold economically from sea water".

Unconsolidated Minerals

Mining operations using dredges offshore are being carried out by at least twenty companies in various parts of the world (Table 5) for the recovery of diamonds, gold, tin, heavy mineral sands, calcareous

TABLE II—MARINE MINERAL EXPLORATION ACTIVITIES 1969

Location	Coverage	Purpose of Exploration	Company	Status Reported	Equipment	Reference
Deep Seas						
Atlantic Ocean, Blake Plateau	Not specified	Manganese nodules	Deepsea Ventures Inc.	Active	R/V Prospector	MMTC
Pacific Ocean	Area SE of Hawaii 1700 km S of Los Angeles	Manganese nodules	Sumitomo Shoji Co.	Completed tests, 1 ton sample obtained	Tokai Daigaku Maru, converted with endless bucket line dredge	M.J. 7/69
	Not specified	Manganese nodules	Deepsea Ventures Inc.	Active	R/V Prospector TV drag line	Oc 11/69
Red Sea	Approx. 21°N 38°E	Metalliferous muds	International Geomarine Corp., Ocean Science & Engineering Inc.	Active sampling	R/V Wando River	OSN 2/69 MMTC
Europe						
United Kingdom	Southern Irish Sea off Welsh Coast; N. Wales and Lancashire	Not specified	Seismograph Svc (U.K.), Institute of Geological Sciences, Univ. of Wales	Active	Borehole drill	M.A.R. 6/69
United Kingdom	50,000 acres, off Yorkshire coast	Potash	Yorkshire Potash Ltd. (Rioeinto Zinc Corp.)	Planning permission applied for	N.S.	M.A.R. 6/69
United Kingdom	Continental Shelf	Mineral assessment	Institute of Geological Science	In process	N.S.	M.J. 10/69
Cornwall	North Coast	Tin	Alpine Geophysical Assoc.	Active	Drilling	M.A.R. 6/69
U.S.S.R.	Baltic Sea Coast	H.M. sands, rutile, ilmenite, zircon	USSR Federal Research Inst. for Marine Geology	Discovery report	Dredger Vyborgsky	O.S.N. 12/68 Of 12/69
	All seas	All minerals	All-Union Scientific Research Institute for Ocean Geology & Geophysics	Active	17 research vessels, seismic, magnetic & electrometric equipment	M.J. 7/69
	Black Sea, Kalamit Bay, New Yevpatoria, Sea of Azor	Fe, Mn, H.M. sands	Marine Geology Lab, Moscow University	Under development	Unmanned submarine laboratory	E.M.J. 7/69 Of 12/69
	Kamchatka & Sakhalin Islands	Au, Sn	N.K.	Discovery report, commercial grade	R/V Tura, drilling equipment & pumps	M.J. 7/69
	Sea of Ohkotsk	N.K.	N.K.	Operating	R/V Mirny	M.J. 7/69
	Kamchatka, Chukotka, Kirvele Islands, Sakhalin	Cu (Coastal?) Titanomagnetite	N.K.	Discovery report		M.J. 12/69 Of 12/69
	Sea of Japan, Siberian Coastal Waters	Au, H.M. sands	N.K.	Discovery report in 82′ water	Drilling	Of 12/69
	Laptev & East Siberian Seas	Tin	N.K.	Discovery report	N.S.	Of 12/69
Sweden	Gulf of Bothnia	All types of mineral ore excluding oil, gas and salt	Boliden A.B.	Sole rights to exploit applied for 3-year $580,000 program planned	Geophysical N.S.	M.J. 7/69
Greece	Sea bed of coastal zone	Mineral resources	Hellenic Govt.	Being undertaken	N.S.	M.A.R. 6/69
Asia & Far East						
Japan	N.S.	Underwater mineral surveys	Hitachi Shipbuilding & Engineering Co., Mitsubishi Heavy Ind. Ltd., Mitsubishi Electric Co., Nakamura Tekkosho Co.	Plans announced for mobile submarine base	N.S.	M.J. 12/68
	Japan Continental Shelf	Mineral resources	Oceanographic Science & Technology Council	Recommended crash program	N.S.	O.S.N. 7/69
India	Chavara in Quiton District of Kerala, beaches	Monazite	A Calcutta company in collaboration with American, Canadian, Japanese & French interests	Will shortly undertake exploitation	N.S.	M.A.R. 6/69
Malaysia	Malacca, five mile strenth of coast	Sn	Placer Ltd. (Canada) Sharikat Lombangan dai Perusahan Melayu (Malaysia)	Discovery of rich deposits announced. Cost of survey $M400.000. Work ceased pending decisions on rights.	N.S.	M.J. 4/69
	i. Perlis & Kedah ii. Perak, Selangor, Penang. iii. Malacca, Johore, Negri Sembilan	Sn	i. Ocean Mining (U.S.) ii. Conzinc Rio Tinto iii. Billiton	Confirmed previous declaration of interest by Govt. to award lease rights.	N.S.	M.J. 6/69 7/69 11/69

(continued on next page)

TABLE 11—MARINE MINERAL EXPLORATION ACTIVITIES 1969

Location	Coverage	Purpose of Exploration	Company	Status Reported	Equipment	Reference
	Malaysia West Coast, between Kuantan and Pulan Tioman, 6,000 m²	Sn, sand and gravel	Royal Malaysian Navy, University of Malaysia, Imperial College (London)	18-day survey completed	N.S.	T.I. 10/69
Thailand	Offshore N.S.	Mineral resources	U.S. Naval Oceanographic Office ECAFE	Preliminary survey completed	R/V F. V. Hunt	T.I. 11/69
	West coast Ranong	Sn	Siamese Tin Corp.	Applied for license to prospect	N.A.	T.I. 8/69
North America						
Canada	Canadian continental shelf	Mineral resources	Canadian Dept. of Energy, Mines & Resources	One-year program (Hudson 70) scheduled to begin Nov. 69	C.S.S. Hudson	M.T.N. 7/69
Central America						
Puerto Rico	South & S.W. Coast. 1,500 M² continental shelf	Heavy minerals	Industrial Development Admin., P.R. U.S. Geological Survey	Being undertaken	N.S.	M.A.R. 6/69
Panama	Panamanian Coast, Bay of Montijo	Rutile, Au, Hg.	North American Resources Corp.	Concession rights obtained	N.S.	M.J. 10/69
Panama	Rivers	Au	Sandia Metals Corp.	Active	38′ Darian Queen, drilling rig, portable dredge, geophysical N.S.	Of 6/69
United States of America						
Maine	Long Island in Casco Bay	Mineral N.S.	King Resources Co.	Establishing base	N.K.	O.S.N. 11/68
New England	Long Island and New Jersey Continental Shelf	Sand & gravel	Woods Hole Ocean. Inst., U.S. Geological Survey	Report	N.S.	M.J. 12/68
Michigan	Green Bay, Lake Michigan	Mn	Michigan Technological University	Samples retrieved, 5 tons	Dredge	M.J. 9/69
	Eagle Harbor, ¼ mi. offshore	Native Cu	Quincy Mining Co.	5.5 tons native Cu retrieved from 72′ outcrop	Divers	M.C.J. 12/69
Louisiana	165,000 acres offshore	Sulphur	Bureau of Land Management	Lease sale of 119 tracts scheduled May 69	N.A.	E.M.J. 2/69
Georgia	64 m² offshore marshlands	Phosphate	Kerr McGee Corp., Georgia Dept. of Mines, Mining & Geology	Under dispute due to pollution potential. Study completed. Deposits valued at $16 billion	N.K.	E.M.J. 12/69
California	Oregon Calif. border, Eel River,					
	60m² offshore	Au, Pt, monazite, chromite, magnetite	Bultes Gas & Oil Co.	N.K.	N.K.	MMTC
	Off Point Reyes	Au	N.S.	Leases applied for	N.K.	MMTC
Alaska	Offshore 4 miles W. of Nome 22,000 acres	Au	Shell Oil Co., American Smelting, Mining & Refining Co.	Drilling from the ice winter 1969	Becker drill	O.O.W. 1/69
	Goodnews Bay	Pt	U.S. Geological Survey	Active summer 1969	Subbottom profilers, bottom samples	O.M.G.H.
	Eastern Bering Sea	Au, heavy minerals	U.S. Geological Survey, Coast & Geodetic Survey, University of Washington	Active summer 1969	Geophysical profiling, USS Surveyor and R/V Thomas	O.M.G.H.
	Chukchi Sea	Mineral resources	U.S. Geological Survey, U.S. Coast Guard	Active summer 69	USS Storis. Seismic & magnetometer profiles	Hy 12/69
	Goodnews Bay, 20,000 acres offshore	Pt	Apco Corp., Inlet Oil Corp.	Discovery report from 7 of 50 holes. Will resume 1970	Drilling	M.J. 10/69
South America						
Uruguay	Aguas Dulces, beach, 280 km N. of Montevido	Ilmenite, rutile, monazite	Administration Nacional de Combustibles, Alcohol y Portland (ANCAP)	Formation of national/foreign companies authorized for development	N.A.	MTN 6/69
Eastern Pacific						
	Selected areas N.S.	Tin, Au, chromite, Fe	Marine Resource Consultants Inc.	Active	Subbottom profiling	E.M.J. 12/68

(continued below)

TABLE II—MARINE MINERAL EXPLORATION ACTIVITIES 1969

Location	Coverage	Purpose of Exploration	Company	Status Reported	Equipment	Reference
	Beaches in Malaysia, Korea, Taiwan, Philippines	H. M. sands	Private consultant, ECAFE	Active	N.S.	E.M.J. 7/69
Indonesia	Selected areas offshore, Belitung & Bangka	Tin	Ocean Sc. & Eng. Inc. (US), Amerada Petroleum Corp. (US), Kathleen Investments (Aust.) UK, Dillingham Ocerseas Corp. (US), Signal Oil & Gas Co. (US)	Draft No. 2 under study	N.S.	M.J.N. 1/69
	Riau, and N. West Singkep offshore	Tin	Rio Tinto Zinc Corp. (UK), Bethlehem Steel Corp. (US)	Draft No. 1 under study	N.S.	M.J.N. 1/69
	Offshore between Billiton and Singkep and off coast of West Kalimantan (Karimata)	Tin	N.V. Billiton, Maatschappij	Exclusive contract to explore & develop	M/V Bison, subbottom profile, drill	W.M. 6/69
	Offshore areas of Central & South Sumatra, Kalimantan & Sulawesi	Heavy minerals	Ocean Mining Inc.	Contracts under discussion	N.S.	W.M. 8/69
	Offshore Bangka & Billiton	Tin	United Nations, Indonesian State Mines	Active	Platform drills, Bangka and others	MMTC
Pacific Islands						
	3 major archipelagoes in 3 million m^2 of ocean	Resource mapping	U.S. Geological Survey, Territorial Governments	Reported planned	N.S.	M.J. 1/69
Fiji	Selected areas	Mineral survey	Barringer Research (Canada)	$2 million agreement with Fiji Govt. signed	N.S.	M.J. 4/69
	Offshore Viti Levu & Varua Levu	Au and other	Crawford Marine Specialists	Active	N.S.	M.A.R. 6/69
New Guinea	Deltas & offshore Gulf of Papua 2000 m^2	Magnetite sands	James Wallace Exploration Pty. Ltd. (Aus.)	Application subject to approval	N.S.	M.J. 11/69
New Zealand	East Coast Banks Peninsula to Rangitata River 100 m	Au	Kaiser Aluminum and Chemical Corp.	Permit approved	N.S.	M.J. 6/69
	W. Coast, S. Island, 150 x 10 miles, Teremakau River to Waiho River	Au	Marine Mining Corp.	Commenced test drilling, seismic completed	N.S.	M.J. 6/69
	N. Island between Waverley and Patea	Iron sands	Adaras Developments Ltd., for Marcona Developments (NZ) Ltd., Subsidiary of Marcona Corp. (U)	Work in progress, 60 to 100 million tons concentrate estimated	N.S.	M.J. 6/69
New Zealand	Golden Bay area, Westport, Parapara Inlet to Pakawau, including Aorare River, 8,600 acres	60 minerals of interest	Kaiser Mining & Development Ltd.	Applied for prospecting	N.S.	M.J. 11/69
	Otago Coast	Au	Alpine Geophysical Associates	Survey in program	N.S.	O.S.N. 1/70
Australia West Australia	Beaches near Bunbury	H.M. sands	Coastal Titanium Pty., Ltd.	Will explore	N.S.	M.J. 5/69
	William Bay, 760 acres	H.M. sands	Hill 50 Consolidated, Haoma Gold Mines, North West Mining Co.	To prospect	N.S.	M.J. 11/69
	Shark Bay, 2 million acres	Potash & other	Magellan Petroleum Australia, Ltd.	Drilling commenced	N.S.	E.M.J. 10/68
Queensland	Burdekin River area beaches, 30 miles, to be 1,700 m^2	Au	Amad N. L., Vam Ltd.	To prospect. Scout drilling completed. 0.33 dwt/yd^3	Drilling and pilot plant	M.J. 7/69
	Offshore Port MacQuarie to Hat Head	Rutile	Laser Electronics Pty., Ltd. for Planet Metals Ltd.	Completed initial program. Drilling will follow	Subbottom profiling, navigation by laser	M.J. 11/69
	Point Plomer & Crescent Head	H.M. sands	Planet Metals Ltd.	Scout drilling completed	N.S.	M.J. 11/68
	S. Queensland & North N.S.W.	H.M. sands	Offshore Research and Development Pty., Ltd., for Planet Metals, Inc.	Drilling in progress. 120 line rules SBP completed	Subbottom profiling, drill N.S.	M.J. 11/69

(continued on next page)

Location	Coverage	Purpose of Exploration	Company	Status Reported	Equipment	Reference
Queensland	Cape York Peninsula, coastal	Tin sands	Consolidated Mining Industries, Ltd.	320 holes drilled, 21 million cu. yd. indicated, 13 oz./yd.	Auger drill	OI 8/69
	Great Barrier Reef	Minerals N.S. (Coral)	Queensland Govt.	Investigating	N.S.	M.M.E. 8/69
Tasmania	Selected offshore areas	Tin	Ocean Mining A.G.	Phase II completed. Phase III in preparation	MV Wando River, Subbottom Profiler, Horton Sampler	M.M. 9/68

Abbreviations

E.M.J.	Engineering & Mining Journal
M.J.	Mining Journal
W.M.	World Mining
M.A.R.	Mining Annual Review
M.C.J.	Mining Congress Journal
MMTC	Marine Minerals Technology Center
M.P.B.	Mining & Petroleum Bull. (ALASKAN Div. of Mines & Minerals)
N.K.	Not known
N.S.	Not specified
N.A.	Not applicable
P.Q.	Pit & Quarry Engineering
Oc	Oceanology Weekly
Of	Offshore Magazine
O.O.W.	Ocean Oil Weekly
OMGH	Office of Marine Geology & Hydrology
Hy	Hydrogram
S.B.P.	Subbottom profiling
Bro	Brown, G.A. 1967
MME	Mining & Minerals Engineering
OSN	Ocean Science News
SFE	San Francisco Examiner
MIB	Minerals Industry Bulletin
USGS	U.S. Geological Survey
TI	Tin International
UN	United Nations
IMM	Institution of Mining & Metallurgy Transaction
PC	Personal communication

Note: Under equipment, numbers separated by an oblique stroke refer to depth of water in ft/, depth of penetration in ft

sands, and sand and gravel. Gold dredging has been strictly of an exploratory nature. Operations in Alaska by the Aurora Mining Co. ended in disaster in November when a storm caused the beaching of the dredging barge, loss of two auxiliary vessels, and heavy damage to a third.

An operation in Nova Scotia was carried out during 1969 using a suction dredge to block out reserves in two deposits in an area where previous surveys had indicated three potential deposits totalling 42 million cubic yards (Libby). To date there has been no successful mining operation using a suction dredge to recover gold (Cruickshank), so the results should be of interest from this point of view alone.

Tidal Diamonds (SWA), owned one-third by Getty Oil Co. and two-thirds by Consolidated Diamond Mines of S.W. Africa Ltd., has laid off all mining dredges except the Pomona and during the year a number of improvements have been made in the methods used to dredge the diamondiferous gravels from the sea bed. The dredge head of the Pomona has an 18" suction intake and utilizes high pressure water jets to disintegrate compacted sediments. The head is traversed systematically across the deposit using two anchor shieves in front of the dredge and a three-drum scraper hoist on board which allows the head to be moved about 25 ft. on either side of the center line of the barge. The fundamental problem remains the same however, that of recovery of diamonds covered by 10 to 50 ft. of coarse sediment in the violent seas common to the Skeleton Coast.

As in land deposits, the diamonds are generally concentrated in or near the bedrock, which may be badly broken or gullied. This presents a very difficult mining problem for which there is, as yet, no satisfactory solution. Additionally, as on shore, some of the areas are overlain by a cemented conglomerate which may render the operation in these parts quite uneconomic. Most of the cost so far has been subsidized by mining of the foreshore above the low water mark. This operation utilizes large dikes up to 100 ft. wide, built of overburden from the upper part of the beach. Experiments are now being made using 14-ton concrete blocks cast on site in an attempt to mine the surf zone. With waves as much as 30 ft. high, this could pose some major problems (M.A.R., June 69, p. 273). The Terra Marina Co., after some disappointing trials with the suction hopper dredge Ontginner I, did extensive research into new techniques and recovery equipment before moving to a new area around Plumpudding Island. Results were "exceptionally successful" and because of unusually low operating costs, profits in October and November amounted to $166,000. Net profits amounting to over $1 million annually were forecast by the chairman of Bonaskor, one of the major shareholders (Johannesburg report).

Tin dredging operations at sea have continued actively in Thailand and Indonesia, forecasting a bright and important future for offshore mining in South East Asia. The new suction dredge working the shallow deposits of Southern Kinta Consolidated, at Takuapa, continued to operate profitably throughout its second monsoon season. Recovery in the concentration plant on board has been satisfactory, but improvement is still needed on the mining technique to reduce the proportion of material left behind on the sea bed (T.I., Oct. 69, p. 280). The other three offshore dredges in Thailand, operated by Aokam Tin Ltd. and Tongkah Harbour Tin Dredging Ltd., are all bucket ladders, but Thailand Exploration and Mining Co., jointly owned by Union Carbide Corp. and Eastern Mining Development Co., recently has ordered a cutter suction dredge with a capacity of 1 million cubic yards per year, which should be in operation by mid 1970. A similar 5-million-cubic-yard dredge has been ordered for delivery in 1971. In Indonesia eleven bucket line dredges are still operating but dwindling reserves and worn out equipment have called for an urgent program to delineate new deposits and rehabilitate some of the dredges. The United Nations and the U.S. Agency for International Development are both now reported to be involved in programs to this end. Operations for tin offshore in Cornwall, England, are still very much in the pilot stage.

Heavy minerals of which rutile, zircon, monazite and ilmentite are the most important are mined from beach and dune sands in the U.S., New Zealand, Ceylon, Africa, India, and Australia. Deposits are indicated offshore in several areas, notably New South Wales, but as yet there are no dredging operations taking place in the open sea. The growth rate for heavy mineral production has been dramatic during the last ten years and expansion in the 70's is expected to set an even faster pace, which will undoubtedly involve the development of deposits seaward of the present low water mark.

TABLE III—RECENT DEVELOPMENTS IN SUBMARINE SAMPLING HARDWARE*

Name	Manufacturer	System	Depth of water	Depth of hole	Dia. of hole	Power req.	Platform	No. of opr.	Type of ground
Amdril 10-6	Alluvial Mining & Shaft Sinking Co. (U.K.)	hydropneumatic jetting, continuous	150′	25′	8″	200 HP	bottom	3	gravel 6″
Geodoff 1/5	Conrad-Stork (Neth.)	electric vibratory	200′	22′	3″	10	bottom	2	sediment
Contra Flush	Hydraulic Drilling Equipment Ltd. (U.K.)	rotary reverse flush	200′	200′	6″	N.K.	ship or barge	3	coarse alluvials
Gun corer	U.S. Navy Patent No. 3,477,525	Explosive impulse	N.S.	N.S.	N.S.	Expl.	bottom	1	hard sediment
Divcor	Descon Engineers Inc. (U.S.)	Diver operated hydraulic rotary	600′	300/100′	3¾″-24″	N.K.	bottom	N.S.	rock
Beach cor	American Undersea Co. (U.S.)	Hand held jetted pipe with liner	Beach	6/10′	4″	<10	handheld	2	sand
TARC-3F	Tsurumi-Seki Kosakusha Co. Ltd. (Japan)	Free fall rocket corer	1000′	3′	<2½″	Expl.	free	1	hard sediment

*Not previously listed in the handbook.

TABLE IV—PLANTS FOR EXTRACTION OF MINERALS FROM SEA WATER IN OPERATION 1969

Mineral	Location	Company	Process	Raw Materials	Annual Production	Value	% Domestic Production
Magnesium metal	U.S.A.	Dow Chemical Co. Freeport	Precipitation	Sea water & dolomite, electric power	106,000 tons	$708/ton	61% world production
	Norway	Norsk Hydro Electric, Heroga	Precipitation	N.K.	70,000 tons		
Magnesium compounds	World-wide	Over 25 plants	Precipitation	Sea water, carbonate rock	N.K.		
	Canada	Sea Mining Corp. Ltd.,[1] Aguathuna, NF	Precipitation	Sea water, limestone	36,500 tons		
	Eire	Quigley Co. Inc.,[1] Dungarvan	Precipitation	Sea water, dolomite	75,000 tons		
	U.S.A.	Dow Chemical Co. Freeport, Texas	Precipitation	Sea water & oyster shells	690,000 tons	$665/ST	74%
	U.S.A.	F.M.C. Corp. Newark, Calif.	Precipitation	Bitterns			
	U.S.A.	A. P. Green Refractories Freeport	Precipitation	Sea water & oyster shells			
	U.S.A.	Kaiser Refractories Moss Landing, Calif.	Precipitation	Sea water & dolomite			
	U.S.A.	E. J. Lavino Co. Freeport					
	U.S.A.	Merck & Co. San Francisco	Precipitation	Sea water & carbonate rock			
	U.S.A.	Michigan Chemical Corp., Port St. Joe	Precipitation	Sea water & carbonate rock			
	U.S.A.	H. K. Porter Co. Pascagoula					
Sodium chloride	U.S.A.	Leslie Salt Co. San Francisco	Solar evaporation	Sea water	1.25 million tons	$23/Ton	29%
	Japan			Sea water	0.9 million tons		100%
	Colombia	Instituto de Fomento Industrial	Solar evaporation	Sea water,	300,000 tons		
Bromine	U.S.A.	Ethyl Dow Chemical Co., Freeport, Texas	Chlorine displacement	Sea water	102,000 tons	$3/lb.	70%
	U.S.A.	Westraco Chem. Div. of F.M.C. Corp. Newark, Calif.		Sea water bitterns			
Fresh water	World-wide	Over 150 plants	Various	Sea water	150 million gal.	36¢/ton[3]	
	Holland	Dutch Government	Epansion evaporation	Sea water	30,000 m^3/day		
	Mexico	Aqua Chem Inc. Rosarito, Mexico		Sea water	800 l/su		
Heavy water	Canada	Glare Bay, Nova Scotia	N.K.	Gulf Stream water	73,000 tons	N.K.	100%

[1] New plants
[2] Closed down 1969
[3] McIlhenny (1969) values rounded

Mining of calcareous sands or relict oyster shells for cement production and other uses continues to be widespread. The proximity of dredging operations to beds of living shellfish has caused some real concern among environmentalists (Laycock) and portends the need for intensive study of all such operations, both ongoing and proposed, where there may be an incompatability with the interests of others. In the Bahamas, extensive offshore deposits of aragonite will be developed by Ocean Industries, Inc., in a dredging operation involving the construction of a number of artificial islands (Oc Oct. 69, p. 125).

Sand and gravel are moved in large tonnages by dredges for clearance of waterways and for production of aggregate. A survey in Great Britain recorded 76 sites where sea dredged aggregates were delivered along side a wharf. Of these, 63 were from offshore and 13 from tidal estuaries and harbors. The current annual production of marine sand and gravel was estimated to be around 12 million tons produced by 55 suction dredges (Chapman & Roeder). The authors concluded that salt and shell content of sea dredged aggregates were not as great a problem in concrete manufacture as had been originally feared, and that there was a pressing need for a more adequate method of reserve estimation, a need that is common to most offshore mineral resources.

Deepsea Ventures, Inc., a Tenneco subsidiary, reported excellent progress in its multi-year program to develop the technology for finding, recovering, and processing sea floor manganese nodules (Flipse). The purchase of a 7,500-ton, 322-foot cargo vessel for conversion to a prototype suction mining dredge to work in 3000 ft. of water initiated a new phase of a program started in 1962. Extensive studies and pilot opera-

TABLE V—SELECTED DREDGING OPERATIONS OFFSHORE 1969

DREDGE DATA								OPERATING DATA (selected)						
Name of dredge	**Dredge type**	**Hull type**	**Tonnage**	**Depth range**	**Mooring**	**Rated capacity**	**Capital cost $**	**Period**	**Operating depth**	**Deposit type**	**Monthly throughput cu. yds.**	**Cost/yd**	**Deposit value $/yd**	**Remarks**
DIAMONDS														
Tidal Diamonds (S.W.A.)														
Pomona	5x18" suction	Barge 285x60	4800 T	<150′	anchor	15,000 T/day	2,100,000	7/64-6/65 1/68-6/68	100 ft. 70 ft.	Diamond gravel	18,450 8,940	$41.6 $36.2	39.6 33	All dredges crew 114
Terra Marina														
Ontginner I	14" hymatic jet lift & jet cutter	Tanker 200x39x15		<150′	4 anchor	15,000 T/day	1,400,000	9/66	70 ft.	Diamond gravel	n.k.	n.k.	n.k.	
GOLD														
Aurora Mining Co. Bluff, Alaska	Suction	Barge	500	110′	N.K.	N.K.	N.K.	Aug. 68	110′	Gold placer	N.K.	N.K.	N.K.	Beached in storm
Matachewan Canadian Gold, Ltd., Nova Scotia	Suction	N K.	N.K.	60	N.K.	150 yd^3/hr	N.K.	1969	60′	Gold placer	N.K.	N.K.	.30	Blocking out reserves summer 1969
TIN														
Aokam Tin Mining Ltd. (Thailand) No. 2 Dredge	**14 cf. bucket line**	**Barge**	**n.k.**	**110′**	**6 anchor**		**2,560,000**	1968	**85′**	Tin alluvial	226,000	n.k.	1.75	
Aokam Tin Berhad Phuket No. 3 Dredge	15-cubic-foot bucket	Barge	N.K.	117′	6 anchor	650 yd^3/hr	N.K.	1969		Alluvial tin	N.K.	N.K.	2±	Completed Oct. 68
Southern Kinta Consolidated Ltd. Taknapa, Thailand	Side trailing suction	**Barge 200x50**	n.k.	<50′	n.k.	n.k.	1,650,000	1969	N.K.	Tin alluvial	N.K.	N.K.	Operating throughout 1969	
Tongkah Harbour **Tin Dredging Ltd. (Thailand) "Sea Dredge"**	**15 cu ft bucket line**	**Barge 230x72x12**	**2,500 T**	**100**	**6 anchor**	**18,000 T/day**		**1966**	**<100′**	**Tin alluvials**	**171,000 yd**	**22¢**	1.10	
Thailand Exploration & Mining Company	Suction	N.K.	N.K.	N.K.	N.K.	N.K.	6 million	1971 expected	<100′	Alluvial tin	5 million yd^3/yr			
Indonesian State Tin Mining Enterprises	1x7 cu ft	bucket dredge line	n.k.		6 anchor			1959-61	100-130′	**Tin alluvial**	**150,000**	**31.0¢**		
Bangka, & Sinkep	8x14 cu ft	bucket barge line	n.k.		6 anchor			1959-61	100-130′	**Tin alluvial**	**300,000**	**31.0¢**		
"Bangka I"	**18 cu ft bucket line**	**Barge 300x80x16**		131	6 anchor	**26,000 T/day**	**10,000,000**	**1966**	**82′**	Tin alluvials				
Coastal Prospecting Ltd. Cornwall, U.K.	3-inch suction	Ship	25	65′	4 anchor	250 gpm	N.K.	1967	15-40′	Alluvial tin	N.A.	N.A.	N.K.	Pilot operation
HEAVY MINERAL SANDS														
Titanium & Zirconium Industries Pty. Ltd.	Suction dredges (2)	Ocean going	n.k.	n.k.						H.M. sands beach dep.				**Details n.k.**
CALCAREOUS SANDS AND SHELLS														
Iceland Govt. Cement Works (Iceland)	24" hydraulic suction	Ship 150′	1,100 T	140′	Free	9,600 T/day	n.k.	1964	130′	Shell sand	10,000 MT	n.k.	n.k.	
Southern Industries Corp. (La. USA) "Mallard"	18" hydraulic cutter	Barge 200x50′	1,239 T	55′	Spuds & 2 anchor	36,000 T/day	n.k.	1964	50′/55′	Oyster shell	600 y.p.l.		n.k.	
Ideal Cement Work (S. F. U.S.A.) Texas	16" hydraulic cutter	Barge		30′	Spuds & 2 anchor			1966	27′	**Oyster shell**	625,000	n.k.	**n.k.**	
Ocean Industries Inc. Bahamas	Suction	N.K.	N.K.	N.K.	N.K.	N.K.	N.K.	Under development		Aragonite				**Reserves 575 million**

SAND AND GRAVEL														
U.S. Corp of Eng. (Coastal U. S.)	Hydraulic dredges 8"-20" (20)	Ship	—	<55'	Free	20,000 T/day	±630,000		0-50'	Sands & clays		10.9¢	n.k.	
United Sand & Gravel Co. (S. F. Bay) "Sandpiper"	16" hydraulic	LSM Conversion	n.k.	80'	Free	6,000 T/day	n.k.		n.k.	Gravel fill			n.k.	
U.S. Corps of Engineers, Texas "McFarland"	Twin suction	Ship	N.K.	60	Free	1,500,000 yd³/month	17 million	1967-1969	45'	Sand & clay	1,000,000	22.6¢	N.A.	
Sand & Gravel Association Great Britain (63 Locations)	Suction (55 dredges)	Hopper dredge	Various	<150'	Free	100-2500 tons	N.K.	Present	<155'	Sand & gravel	1 million	N.K.	N.K.	
Hall & Company Lumber Kingdom AA Raymond	28" hydraulic suction	270x46x23 Hopper dredge	5,400 T	50'	Free	15,000 T/day	n.k.	1967	n.k.	Gravel	60,000		n.k. n.k. n.k.	
Monterey Sand Co. Monterey, Calif.	Fixed dragline	N.A.	3-3500	12'	Buoy	45 T/hr	N.K.	June 68	Surf zone 150' offshore	Coarse silica sand	1,000,000 yd/yr		4.50	
MANGANESE NODULES														
Deepsea Ventures Inc., U.S.A.	24-inch suction	332' ship	N.K.	3000'	Dynamic	N.K.	N.K.	1970	3000'	Mn nodules (Blake Plateau)	N.K.	N.A.		Scheduled pilot operation

tions using models and full scale replicas of the dredge components in laboratories and in a flooded mine shaft appear to have given the company every confidence that their system, which is similar to concepts described by Mero (1958), will operate successfully. Other large metal mining companies are maintaining interest in the development of deep ocean mining.

Technological interchange between the dredging and other associated industries has been noticeably accelerated by mutual interests in marine minerals. A useful survey by Alderice (1969) points out an existing capability in the U.S. for submarine mining, with many dredging companies already involved in the production of mined products.

There is a definite trend toward the use of cutter suction dredges for mining operations, where only the bucket line has been considered in the past. IHC Holland of Rotterdam (T.I., August 69, p. 205) cite a number of problems involving increased depths and disposal of tailings which can be overcome by the use of suction dredges. Davis and McKay (1969) make authoritative comparisons of the two types. Already one suction dredge, the Takuapa, is in operation in the Southeast Asian offshore tin fields, and at least two more have been ordered. It is claimed that the dewatering problem which arises through use of a hydraulic dredge can be overcome by use of the Cleaveland circular jig (Cleaveland) although none have yet been installed in an operating dredge.

Another trend has been to submersible earth moving equipment. Most significant has been the trial operation of the first, manned underwater dredge, developed by Ocean Dredging, Inc. for the Corps of Engineers beach replenishment program (Oc v.7, n.3, p. 17). A similar dredge is in the design phase at Reynolds Submarine Services, Inc. Other underwater work units tested during the year include a manned, 48-ft., 44-ton, four-wheeled "work horse" built for Cammell Laird (Sea bed engineering) Ltd., and capable of operation at depths of 600-ft. on tasks such as drilling, cable laying, surveying, and salvage (Offshore, May 69); and a first generation unmanned, underwater bulldozer capable of working in 33-ft. of water, built by Japan Development & Construction Co., Ltd. A pneumatic dredge has been developed in Italy for which a capability of pumping a 60% solids ratio is claimed (D. & H.A. 50 (584): 78-80, June 69). Work is being carried out in the U.S. Bureau of Commercial Fisheries to develop dredges for bottom shell fish (O.S.N. v. 11, n. 45, p. 5) and the similarity of problems in recoverying clams and manganese nodules suggests a fruitful field for cooperative research.

Consolidated Minerals

Although having a tremendous resource potential for the future, new activities in the mining of consolidated deposits offshore have been limited (Table 6). According to Investors Guardian (Feb. 69, p. 556), Cleveland Potash, formed by Charter Consolidated Corp. and Imperial Chemical Industries will develop offshore reserves of potash in Yorkshire, England, by solution mining, and in the same area, Yorkshire Potash, a subsidiary of Rio Tinto Zinc Corp. plans to use conventional underground methods. At the Levant Tin Mine in Cornwall the sealing of the breach in the sea bottom and its isolation from the rest of the old mine workings was successfully completed in January 1969. Due to changing supply and demand, Freeport Sulphur Co. temporarily closed the $25 million Camenada Mine, which had been producing sulphur from offshore for less than a year (Wall Street Journal 21 Feb 69). In Alaska a new operation for extraction of barite from vein deposits exposed beneath the sea at Castle Island is being undertaken by Alaska Barite Co., a wholly owned subsidiary of Inlet Oil.

Technology advances which may eventually have profound effects on hard rock mining offshore have been made on leaching processes, using ion exchange resins (E.M.J. Nov 69, p. 35) and bacterial leaching for gold (M.J. 5 Sep 69), and acid cyanide leaching and solvent extraction for copper (W.M., Nov 68, p. 17). The need for innovation in solution mining of uranium is discussed in a paper by Smith and White (1969). Advances in non-explosive rock breaking (M.A.R. 6/69, p. 271) and shaft boring rates of up to 15 ft. per hour (E.M.J. Jan 69, p. 88) will help to reduce the technologic restraints on mining far offshore.

Affairs

Conferences on marine affairs have been more prolific this year, but there is no question that the most informed technical discussions on marine minerals will be shared in future between the highly successful Offshore Technology Conference, the first of which was held in Houston in May 69, and the World Dredging Conference held last year in Brussels,

TABLE VI—MINING OPERATIONS IN CONSOLIDATED DEPOSITS OFFSHORE 1969

Name of Mine	Location	Company	Minerals	Depth below SL	Max. Dist. from shore	Access	Method of Working
Collieries (5)	Nova Scotia	Dominion Coal Co. Ltd.	Coal	300'-1000'	5 miles (reserves)	Adit on shore	Room & Pillar 300-1000'
			5'-7' seam at 4-24°				Longwall below 1000'
Chien Chi Coal Mine	Taiwan	Chien Chi Coal Mine Co.	Coal 0.3-3.3m at 9-47°	0-1500'	9000'	Adit on shore	Longwall
Kozlu Coal Mine	Turkey	Eregli Coal Mines Ltd.	Coal 19 seams @ 45° 3-60'	15,000'	1000 m	Vert. shaft on shore	Stepped longwall
Collieries (19)	Japan	Nittesu Mining Co. Ltd.	Coal				19 operating mines
Collieries (31)	U.K.	National Coal Board	Coal	300'-8800'	5 miles	29 shafts on shore 1 natural island 1 artificial island	Longwall
Lotaschwager	Chile	Lotaschwager Coal Co.	Coal	3000 feet	4 miles	Shaft on shore	N.K.
Jusarro Gruva	Finland	Oy Vuoksenniska Ab	Magnetite quartz banded iron ore	30 meters steep dipping	1000 m	Shaft on shore	Shrinkage stoping
Levant Mine	Cornwall, U.K.	Greevor Tin Mines	Tin. Vert. lodes	holed through	1 mile	shaft on shore	Underhand stoping
Grand Isle Mine	U.S.A. La.	Freeport Sulphur Co.	Sulphur 220-425' dome	2000'	5 miles	drill holes	In situ Frasch process
Camenada[1]	U.S.A. La.	Freeport Sulphur Co.	Sulphur	—	—	drill holes offshore platform	In situ Frasch process
Castle Island	Alaska	Alaska Barite Co.	Barite	50 feet	1 mile	Sea surface	Blast and dredge
Yorkshire Potash*	England	Rio Tinto Zinc Corp.	Potash	3500 feet	5 miles	Shaft on shore	Room and pillar
Goderich	Canada, Ont.	Sifto Salt (1960) Ltd.	Rock salt 75' 0.2°	1170'	2500'	Vert. shaft on fill	Room & Pillar

[1] Closed temporarily, 1969.
*Under development. Production scheduled 1970.

and scheduled for 1970 in Singapore. Ninety organizations in the United Kingdom interested in undersea engineering have agreed in principle to set up a cooperative research scheme in conjunction with the Construction Industry Research and Information Association. In Japan, Ocean Systems, Inc., The Sinjen Co. and Sumutoma Shoji, Kaisha Ltd. have formed a new company, Ocean Systems (Japan), Ltd., to offer a broad range of ocean engineering capabilities including mining. Columbia University has created a new graduate degree program in ocean engineering headed by an international authority in mineral engineering, mining and mineral economics.

One of the most striking things about 1969 was the ambitious and optimistic report by the President's Commission on Marine Science, Engineering and Resources, "Our Nation and the Sea—A Plan for National Action," published in January, and followed by a year of confusion, pessimism, and restraints. Even the International Decade of Exploration which seemed such a great idea the year before made little if any progress. The U.S. Bureau of Mines, Marine Minerals Technology Center at Tiburon, suffered two reductions in force, and although the second cut in funding was restored, it was too late to prevent the loss of some valuable projects and personnel. The House Subcommittee on Oceanography's Panel on Marine Engineering and Technology now finds that while a crash program in marine minerals is not needed "a substantial and continuing national effort" is.

Two subcommittees of the United Nations Committee on the Peaceful Uses of the Sea Bed and Ocean Floor Beyond the Limits of National Jurisdiction, the Legal Subcommittee, and the Economic and Technical Subcommittee, have been heavily involved with subsea minerals. Major areas of discussion are the rights of access, the use of resources, pollution, safety, and technical progress in minerals development. A moratorium on exploitation of deep sea minerals proposed in the U.N. was not passed and the laws still remain obscure. Disconcerting differences in opinion are noted, between nations, within the assembly, and even between our own executive branches (Burke 70), and orderly development of the oceans and their resources is still a doubtful issue. Meanwhile, many states are passing laws to cover the development of mineral resources within their offshore jurisdictional boundaries.

In retrospect, 1969 has been a year of strengthening for the fledgling marine minerals industry. Much of the glamour has worn off; there is a realization that the billions of dollars worth of minerals under the sea will cost just a little less than that to bring to market; and the professionals are accepting the challenge.

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Presented February 23, 1971, by Dr. John Nath, Department of Oceanography, Oregon State University.

Some Considerations for Buoys and Their Moorings

Introduction

Within the last twenty years the design of moorings has evolved from that of a rough "rule of thumb" approach to that of a fairly sophisticated "systems" type of analysis. Current research in many sections of the United States is very active in finding answers to this very complex design problem. The motivation for the research comes from current need to moor large vessels in all ocean depths and from a National Data Buoy Development Program which proposes to establish a large number of buoys off our coasts for gathering oceanographic and meteorological data.

The previous paper in this seminar series, by Prof. Wiegel, presented the design approach generally taken, and some of the theory behind, Wave Forces on Structures. Some similar or analogous concepts arise for the subject of moorings. The major differences come about from the types of structures. Professor Wiegel's work was focused on non-yielding, fairly rigid structures where the structural motions are small with respect to the motion of the fluid. Moored structures, on the other hand, are often compliant and have considerable motion when acted upon by the forces of Nature.

Some types of moored structures are listed below:

1. Ships and boats - moored to piers, in deep water for drilling purposes, in shallow water to transfer oil cargo
2. Platforms - for drilling for hydrocarbons
3. Mines - National defense
4. Nets - For fishing, usually towed, various trawls
5. Towed targets (a type of mooring)
6. Buoys - discussed in detail below

One type (extreme example) suggested by John Isaacs of Scripps Institution of Oceanography (with tongue in cheek) would be a synchronized orbiting platform with a mooring line attached, reaching to an anchor on the ocean floor with various sensors on the line.

The vehicle for illustration for this lecture will be buoys and their moorings. The forces that act on them and the responses of the buoys and moorings will be discussed.

The environments and the missions generally determine what types of buoys are used. For example, most interests for moored buoys in deep water are concerned with making oceanographic and meteorological measurements. Consequently, two distinct types of buoys are currently being utilized in the northern Pacific Ocean by ONR with Scripps Institution of Oceanography. They are the large disc with a diameter of forty feet and a thickness of seven and a half feet and the bumble-bee buoy of Scripps which is a covered catamaran about eight feet wide and sixteen feet long. For intermediate water depths many types are used, such as boat hulls, toroids, discs and spars, such as FLIP and TOTEM. A commonly seen buoy in shallow water is the Aid-To-Navigation buoy of the U.S. Coast Guard. The latter is probably the one you have had most experience with -- black and red in the harbors. Black on the port side for entering a harbor. They are very valuable because life often depends on the efficacy of ATN buoys. In some cases very large buoys have been used to replace light ships.

The design problems for a buoy and mooring system range from straight forward "easy" type problems to those requiring a high sophistication of mathematics. Certainly the problem of corrosion and quality of materials is a major one. This paper will focus on the problems of determining the nature of the forces acting on a selected system and the response of the system to the forces. As the concepts of wave forces were illustrated by discussing wave forces on a cylinder, this paper will illustrate buoy and mooring problems by discussing only a single point mooring. The problems for such a mooring are considerable. One must determine the static and dynamic forces acting. They may be regular, or periodic, but more often consideration must be given to the random nature of the processes involved, particularly waves. Thus the reliability of the moorings may be required. For example, a question the designer may desire to answer is "What is the probability that the buoy and mooring will survive for one year in that particular location". Many items are involved in calculating an answer to such a question -- such as the stress-strain, hysteresis and fatigue characteristics of the components of the mooring line, the reliability of each of the operational units of the buoy, weather and wave statistics, theft, vandalism, well meaning return of the buoy to its owner, etc.

This lecture will be mostly on deterministic loads on the system and the corresponding responses. The presentation will be organized into two major sections, one dealing with buoys and the other dealing with the mooring itself.

(A word on the use of the words "moor" and "mooring"; "moor" is a verb transitive as used here, e.g. we will moor the buoy. "Mooring" is the noun, e.g. the mooring of the buoy is located in the estuary.)

Buoys

The loads or forces acting on buoys come from many sources. They will be discussed in accordance with the sources.

Gravity is perhaps the most important source of forces acting on a buoy. The basic dead load weight and the payload are included as well as the static buoyancy forces. Most buoys are designed with a fairly large reserve buoyancy for safety against sinking.

The wind force can constitute the major steady horizontal force acting on a buoy. Wind is composed of a steady component and a fluctuating component as shown in Fig. 1.

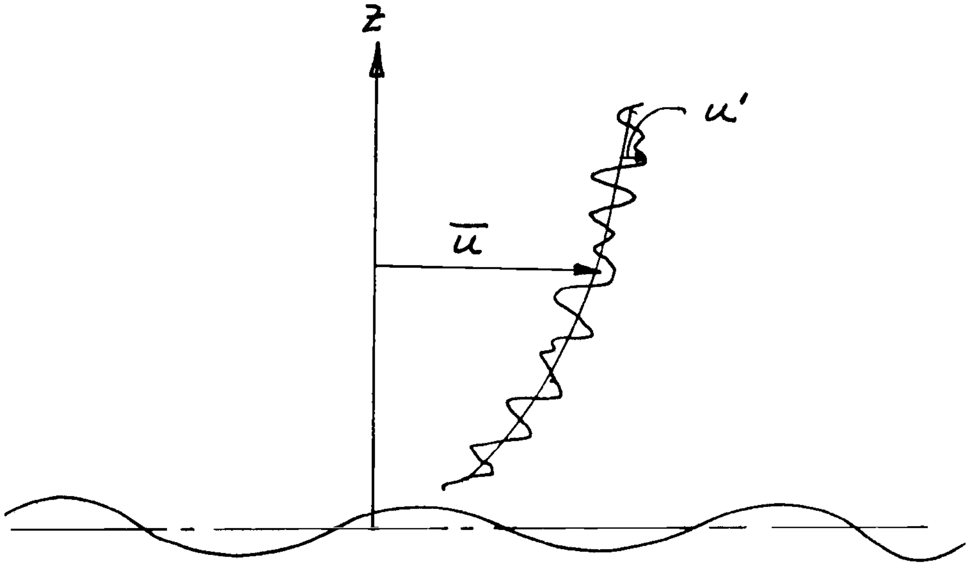


Figure 1

That is, the velocity can be expressed as

$$u = \bar{u} + u' \qquad (1)$$

wherein $\bar{u}$ is the mean velocity and u' is the turbulent fluctuation about the mean. The mean velocity profile is usually considered to be a logarithmic one. That is something like

$$\frac{\bar{u}}{u_*} = \frac{1}{k} \ln \frac{z}{z_o} \qquad (2)$$

wherein u_* is the friction velocity, k is the von Korman constant and z_o is the aerodynamic roughness. The friction velocity is expressed as:

$$u_* = \sqrt{\frac{\tau_o}{\rho}} \qquad (3)$$

where τ_o is the friction shear resistance and ρ is the mass density of the air. Usually (but not always) a buoy is subjected to only a small portion, vertically, of the velocity profile. Thus the wind velocity can be considered as:

$$V = \bar{V} + V' \qquad (4)$$

The mean velocity, $\bar{V}$ is usually taken from 80 to 150 knots for design work, depending on location. The fluctuation velocity, V', has not been considered in most designs to date, but recent evidence by Nath (1970) indicates the fluctuations are large and they occur at the same frequency as the waves. The drag force on the buoy is determined from

$$F_w = \frac{C_{DW} A_B \rho V|V|}{2} \qquad (5)$$

where C_{DW} is a composite drag coefficient for the wind and A_B is the projected area of the buoy.

From the wind and other causes a steady current will act on the buoy. The drag force from the current is determined by an equation similar to Equation 5. Plate (1970) shows that the surface drift current from the wind can be expected to have a magnitude of about 3% of the wind velocity. Thus, for a design wind velocity of 150 knots, the surface current would be expected to be about 4.5 knots. The Coriolis effect would direct the current 45° from the wind, but this is rarely if ever taken into account. Vertical current velocity profiles are usually assumed by the designer and one possible one is shown in Fig. 2. It is generally felt that the shape of the velocity profile is similar to the temperature structure in the ocean.

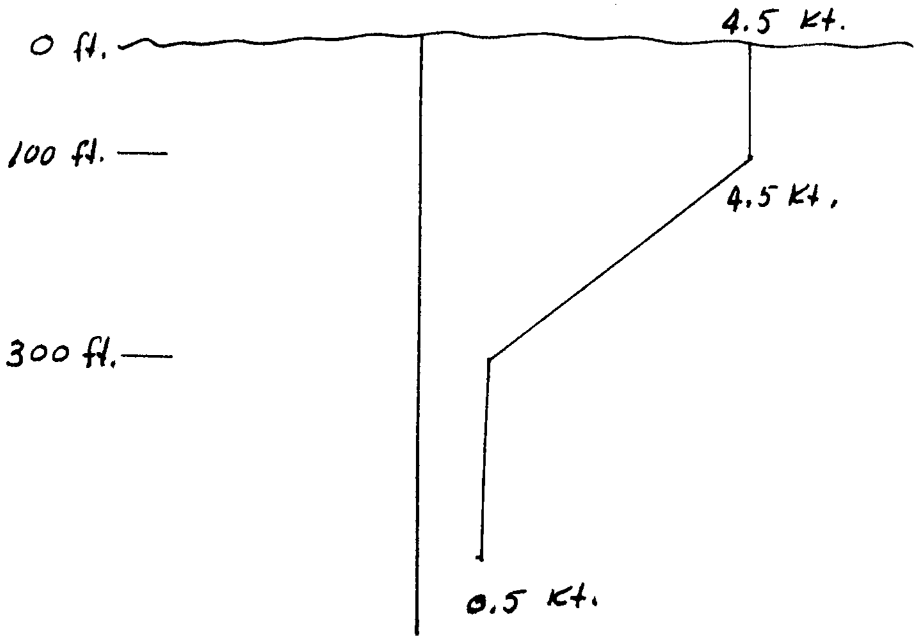


Figure 2

The forces from waves evolve from fluid dynamic drag and fluid acceleration concepts similar to those that were presented by Professor Wiegel. Considerable complications arise, however, because of the motion of the buoy. In general the motion of the buoy has six degrees of freedom. Figure 3 shows a schematic of the buoy axes.

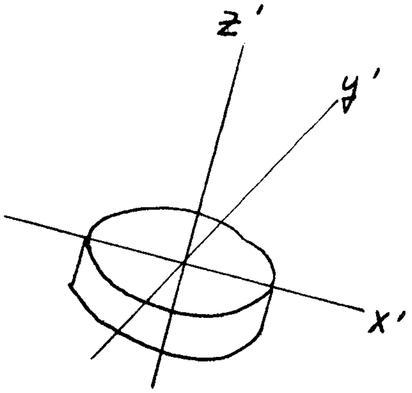


Figure 3

The buoy will translate along and rotate about the three primed axes which are fixed to the buoy. In addition, the buoy reference system will be in motion with respect to the earth, or some other reference inertial system. Usually designers concern themselves with two-dimensional motion, or three degrees of freedom of the buoy.

The equations of motion of the buoy must be concerned with the forces acting on it. These forces are expressed similarly to, but not equal to, those illustrated in Professor Wiegel's lecture. Both force and moments must be considered, but force only will be shown here for illustration. The wave force in some given direction is expressed as:

$$F = \frac{\overbrace{C_D\ A\ \rho\ V|V|}^{\text{drag}}}{2} + \overbrace{C_I V \rho a_R + V \rho a_W}^{\text{acceleration}} \qquad (6)$$

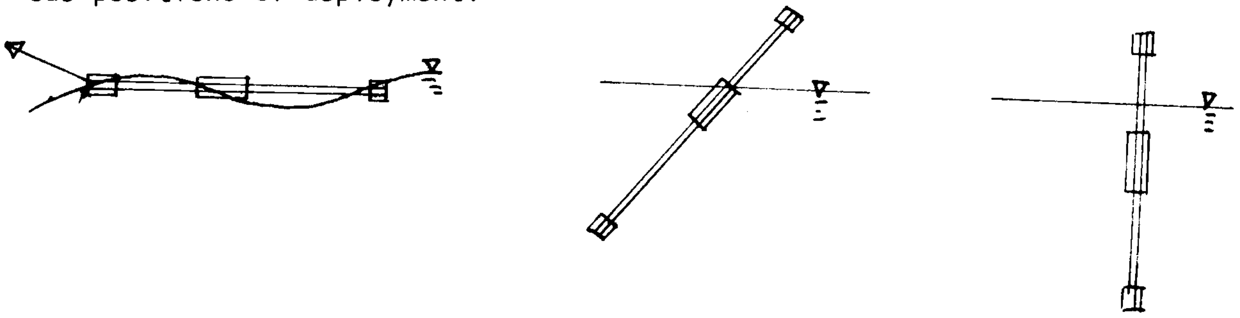
wherein the drag term looks the same as before but the acceleration term now has two terms. However, the velocity term, V, in the drag portion refers to the relative velocity between the buoy and the wave. For the acceleration portion the first term includes an inertia or added mass coefficient and a_R is the relative acceleration between the fluid and the buoy. The second part of the acceleration term represents the pressure distribution that acts on the buoy by virtue of the fact that the water is accelerating so that a_W is the acceleration of the water. In passing -- the pressure as calculated by small amplitude wave theory must be modified so that zero pressure is obtained at the water surface.

The ATN buoys are sometimes caught in the surf due to storms sending in such long period waves that the breaker line moves outward. The basic equations of the forces acting on the buoys remain the same but little is known about the coefficients. Practically none, if any, research has been accomplished in determining the coefficients in surf.

One very important force acting on the buoy is the mooring line. It is possible for waves, current, gravity, etc., to act on the mooring line in a very complex way such that the attachment force acting on the buoy is very difficult to determine. This subject will be presented in the next section of this lecture.

The last important forcing condition on the bouy for consideration is that from handling, transportation, and mooring of the buoy. For example, consider a disc buoy. The hydrodynamics are such that the buoy tends to submerge when being towed if a critical speed/length ratio is exceeded. The speed/length ratio is a Froude number and is equal to $V_k/\sqrt{D}$, where V_k is in knots and D is the diameter of the buoy. Obviously, the larger the buoy, the faster the allowable tow speed.

For spar buoys one has to consider the erection procedure. As the buoy is towed into position it is subjected to tow loads and wave loads that do not occur while it is in operation. Figure 4 shows a spar buoy in various positions of deployment.



Towing Erection Operating Position

Figure 4

Buoys are fairly concentrated masses and can be treated as such. Each buoy type has a unique frequency response curve in heave and pitch. Consider Figure 5 as a frequency response curve in heave:

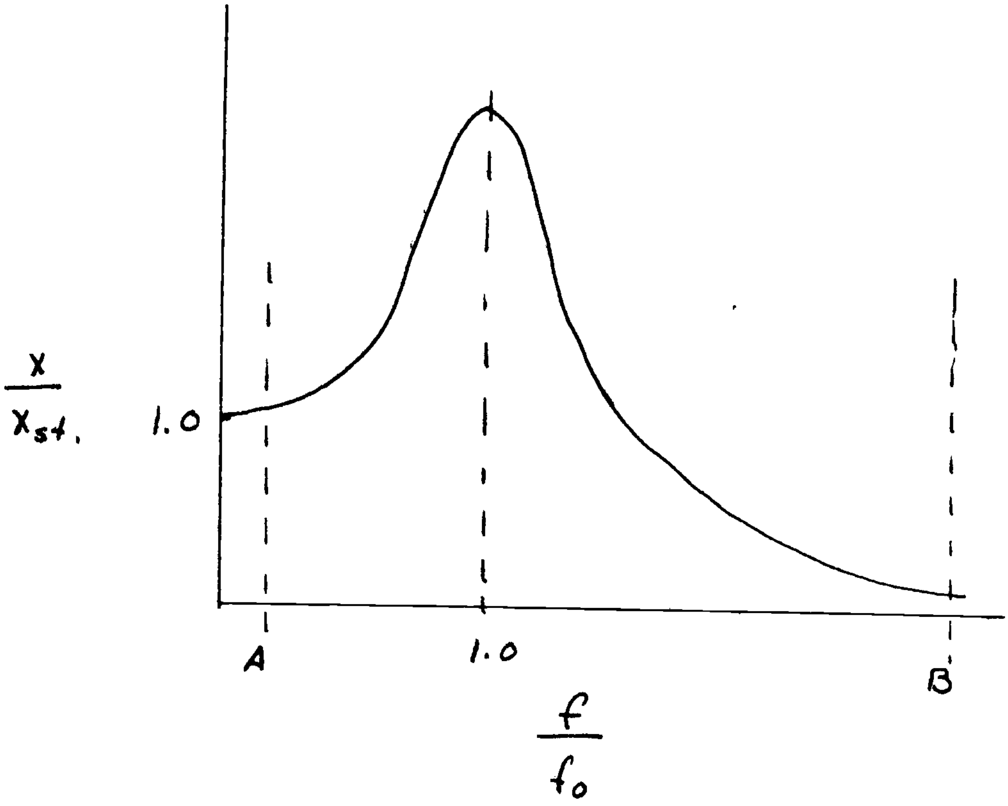


Figure 5

The frequency response curve can be used very effectively for selecting the various types of buoys. For example, one would want to avoid the resonance peak almost at any cost. Disc buoys, toroids, spheres, etc. have frequency response curves such that the waves in the ocean all occur at values less than, say, A . Thus, surface following buoys have a dimensionless heave response characteristic equal to 1.0 . For spar buoys the ocean waves occur at frequencies higher than B so that the dynamic displacement divided by the static displacement is close to zero. It looks like all buoys should be spars. The hitch is that, to be quite motionless, they must be about 300 feet long. TOTEM was 181 feet long. They are difficult and expensive to handle and they have high drag characteristics in water, current and wind, which exert large forces on the mooring system. Disc buoys, on the other hand, are easy to deploy, are less expensive, have more reserve buoyancy and have very low drag characteristics. But, they heave and pitch a lot and your measurements must be able to tolerate the motion. Some measurement can not tolerate the motion and so a spar-type buoy must be used.

Thus, for close design work, one must have adequate testing to determine all the drag and added mass coefficients of the buoy. This usually requires hydraulic model testing that can be performed with Froude similitude relationships.

Moorings

In this section we will consider the anchor line that connects the buoy to the anchor. (Recall that we are considering only one-point moorings in order to keep things as simple as possible.) The design of mooring lines is still more of an art than a science, but big advances have been made in the last five years. The types of lines vary greatly from chain through steel wire rope to nylon, polyester and polypropylene lines. Hemp is used only rarely and for very short term, or temporary moorings. In some cases a combination of materials is used effectively. For example, in some oceans shark bite is a big problem, but it is often found to occur in the upper portions of the line. Therefore, one will often find steel wire rope used for the upper few feet and then nylon or dacron below. Nylon is a desirable rope because of the damping characteristics, etc.

Fortunately, recent work is underway to determine more carefully the elastic and inelastic characteristics of steel wire rope. I suspect that a great deal of future work will be devoted to other types of ropes. For example, we have very little idea how much the diameter of rope changes under stress. It was found by Laura et al. (1970) that the effective Poisson ratio was well over 0.5 . Values of 1.5 to 2.5 were determined, depending on the type of rope.

To make a science of rope selection is tough. For example, it is likely that the physical characteristics of nylon rope change with the temperature and humidity at the time the rope is woven.

In considering the loads acting on the mooring line, usually two basic conditions are considered -- the loads from steady state forces and those from dynamic forces. In some cases the dynamic loads are negligible with respect to static loads but hardly ever. Practically never can one ignore the static loads and devote full attention to the dynamic loads. The degree of severity of the dynamic loads depends a great deal on the water depth, the scope, and the steady state loads. Scope is the length of mooring line divided by the water depth.

Consider that both longitudinal and transverse waves travel down a line. If the period of travel of either wave is within the periods of surface waves that are present in the ocean, a resonant condition can exist, depending on the degree of damping in the system. If the line is very short, resonance is not a problem and the design from waves can proceed in a pseudo-dynamic manner. That is, the various positions of the buoy on the wave can be considered from a static viewpoint.

Of the forces acting on the line it is difficult to single out any that are most important. Therefore the following discussion is not in any particular order. Gravity acts on the line, of course, both in terms of the dead load on the line and the buoyancy forces of the water on the line. In some cases a neutrally buoyant or positively buoyant line is desired for ease in handling during deployment procedures. Then a polypropylene line or a steel line with flotation units is used.

The water current is an important force. If the water is deep, a very small current (0.5 knots) can create very large forces. If the depth is small, as in estuaries, very large currents can occur. The usual drag expression is used to estimate the current forces acting on a line. However, very little information exists on what the coefficients are. Usually one resorts, with misgivings, to data on circular cylinders - both smooth and rough. One point of contention is how the force actually acts. Consider Fig. 6.

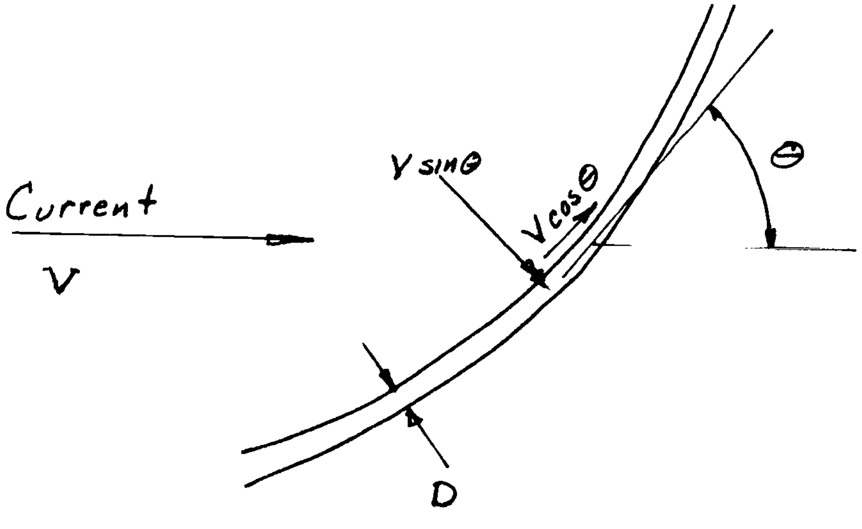


Figure 6

Usually the drag force on the cable is considered to be resolved into the normal and tangential components, due to the normal and tangential components of velocity. Thus the normal drag force, per foot of line, is

$$F_N = \frac{C_{DN} D \rho (V \sin \theta)^2}{2} \tag{7}$$

and the tangential component is

$$F_T = \frac{C_{DT} D \rho (V \cos \theta)^2}{2} \tag{8}$$

Be aware that other approaches exist. The tangential coefficient is about 2 orders of magnitude smaller than the normal coefficient. Thus for large θ the tangential component can be ignored. Likewise, the normal component can be ignored if θ is small.

For certain Reynolds numbers vortices are shed which cause the line to vibrate at high frequencies. This is called strumming and can be a problem for some measurements. The range of Reynolds numbers is usually from about 10^2 to 6×10^5. In this range the Strouhal number is about 0.2. The Strouhal number is

$$S = \frac{fD}{V} \tag{9}$$

wherein f is the frequency of shedding of eddies, D is the diameter of the cylinder and V is the water velocity.

Waves create drag and acceleration forces on the line in a manner similar to Equation 6, including the definitions of the symbols that are given there. If the water is very deep (say, 20,000 feet), then the direct wave action on the line may be negligible. However for shallower water, the wave action may be very significant.

Of course, the buoy action is very significant. It matters a great deal what kind of buoy is used as to what forces can be expected on the line. As previously stated, if the buoy is a spar, large drag forces will result in steady current and tow-under is possible. Figure 7 illustrates the tow-under danger.

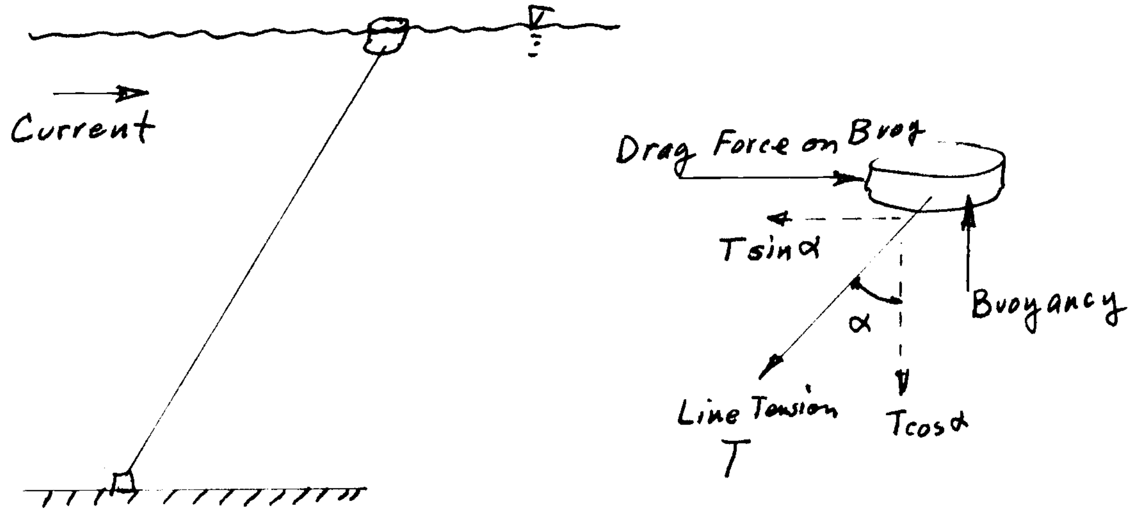


Figure 7

If drag is large and α is small, then the line tension, T, will be large because

$$T = \frac{\text{Buoy Drag}}{\sin\alpha} \tag{10}$$

Obviously this can create large line tension. In addition the required buoyancy is

$$\text{Buoyancy} = \frac{T}{\cos\alpha} \tag{11}$$

So, if the reserve buoyancy is low (as it is for spars), then the buoy can easily submerge for high currents. Other methods of mooring are then required for a spar buoy. However, a disc or boat-shape hull, with low drag, is ideal for such one-point moorings.

Other significant forces on the line can be from the deployment procedure. Occasionally the mooring line itself will be used for towing the buoy (not a good practice). Frequently the buoy is launched with the "anchor last" procedure. That is, the anchor is dropped after the buoy has been deployed.

Mathematically the dynamic tensions in the line are attainable in the time domain with conventional methods of fluid and solid mechanics. Solutions can be made in the frequency domain, after linearization procedures, with conventional concepts of random vibrations, spectral analysis, etc. To give you an idea of the mathematics involved, by considering all forces acting on a small element of the line, and considering Newton's second law of motion, conservation of mass, the geometric continuity of the line filament and after including certain simplifying assumptions, the following set of partial differential equations evolve:

$$
\begin{bmatrix}
1 & 0 & -v_r^{(1)} & -\dfrac{1}{C_a^{(1)}\mu} \\
1 & 0 & -v_r^{(1)} & +\dfrac{1}{C_a^{(1)}\mu} \\
0 & 1 & (v_a^{(1)} - C_r^{(1)}) & 0 \\
0 & 1 & (v_a^{(1)} + C_r^{(1)}) & 0
\end{bmatrix}
\begin{bmatrix}
v_a^{(2)} \\ v_r^{(2)} \\ \theta^{(2)} \\ T^{(2)}
\end{bmatrix}
=
\begin{bmatrix}
f_1 \\ f_2 \\ f_3 \\ f_4
\end{bmatrix}
\quad
\begin{array}{|c|}
\text{On the characteristic curve} \\
\dfrac{ds}{dt} = \\
\left(\dfrac{AE}{\mu}\right)^{\frac{1}{2}} \\
-\left(\dfrac{AE}{\mu}\right)^{\frac{1}{2}} \\
\left(\dfrac{T}{M}\right)^{\frac{1}{2}} \\
-\left(\dfrac{T}{M}\right)^{\frac{1}{2}}
\end{array}
\tag{12}
$$

Wherein the f terms represent the forcing functions on the line. The superscript 2 stands for the values at $t + \Delta t$ and the superscript 1 stands for the values at time t. That is, the coefficient matrix contains the values of v, etc., at time t. In Equation 1,

$$C_a = \left(\frac{AE}{\mu}\right)^{\frac{1}{2}} \tag{13}$$

and

$$C_r = \left(\frac{T}{M}\right)^{\frac{1}{2}} \tag{14}$$

where A is the cross-sectional area of the line, E is the modulus of elasticity, or the slope of the tangent to the stress-strain diagram of the line, μ is the saturated mass density of the line in slugs per foot and M is the virtual mass of the line per foot (the actual mass plus the hydrodynamic added mass). For completeness, the forcing functions will be listed below.

$$f_1 = -\Delta t\ g\ (1 - \frac{1}{G})\sin\theta + v_a - v_r\theta - \frac{T}{C_a\mu} - \frac{C_aQ}{E}\Delta t\ \frac{\partial^2\varepsilon}{\partial t^2} \tag{15}$$

$$f_2 = -\Delta t\ g\ (1 - \frac{1}{G})\sin\theta + v_a - v_r\theta + \frac{T}{C_a\mu} + \frac{C_aQ}{E}\Delta t\ \frac{\partial^2\varepsilon}{\partial t^2} \tag{16}$$

$$f_3 = \Delta t \left[\frac{C_D}{\pi D} \left(\frac{2}{C_I + G} \right) V \left| V \right| + \left(\frac{1 + C_I}{G + C_I} \right) \left(A_z \cos\theta - A_x \sin\theta \right) - \left(\frac{G - 1}{G + C_I} \right) g \cos\theta \right] + v_r + (v_a - C_r)\,\theta \tag{17}$$

$$f_4 = \Delta t \left[\frac{C_D}{\pi D} \left(\frac{2}{C_I + G} \right) V \left| V \right| + \left(\frac{1 + C_I}{G + C_I} \right) \left(A_z \cos\theta - A_x \sin\theta \right) - \left(\frac{G - 1}{G + C_I} \right) g \cos\theta \right] + v_r + (v_a + C_r)\,\theta \tag{18}$$

In the above equations, g is the acceleration of gravity, G is the specific gravity of the saturated line, Q is the damping coefficient which will be described later, ε is the strain in the line, C_D is the drag coefficient perpendicular to the line, D is the line diameter, C_I is the added mass coefficient (which is equal to 1.0 for a smooth circular cylinder), V is the relative velocity between the line and the water in the radial direction and A_Z and A_X are the accelerations of the water particles in the z and x directions. The values of the variables in Equations 4 through 7 are determined at time t by an interpolation procedure from the s-t grid intersection points as described in Ref. 12. The second derivative of the line strain was determined simply with the finite difference approximation,

$$\frac{\partial^2 \varepsilon}{\partial t^2} \cong \frac{\varepsilon_3 - 2\varepsilon_2 + \varepsilon_1}{(\Delta t)^2} \tag{19}$$

where the subscripts represent the preceding values of strain. Solution of the above equations is by numerical methods, using the method of characteristics. Figure 8 shows the grid type of solution and more details one given in Nath (1970-A).

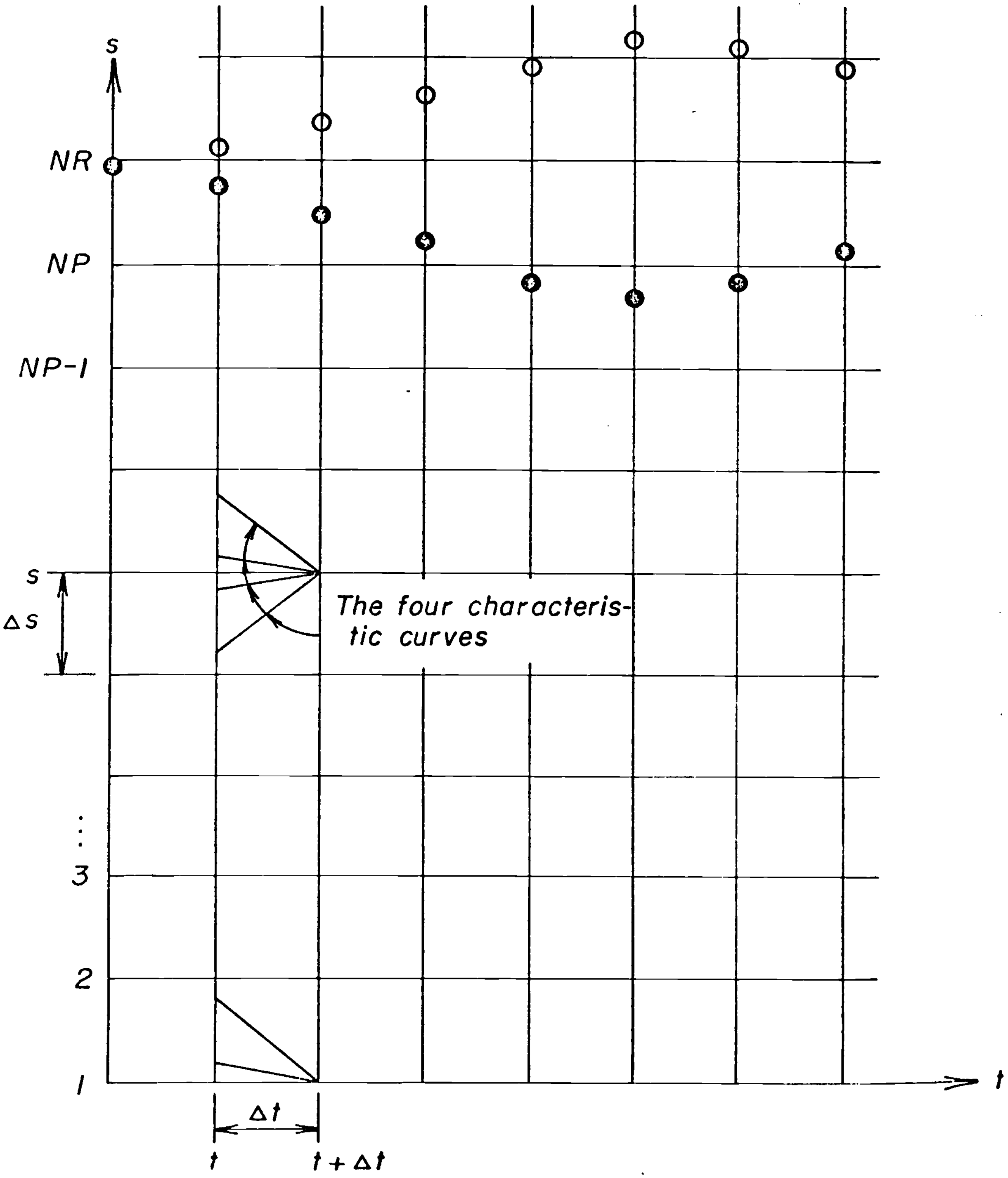


Figure 8 The s-t Grid

However, for much work in deep water moorings a simplification can be made by considering the lines to be straight. For illustration, we will simplfy even further to considering a line that is perfectly straight as shown in Fig. 9.

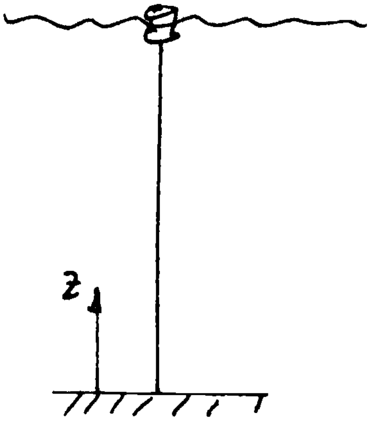


Figure 9

Without going through the full derivation, suffice it to say that the solution for the line tension is governed by the classical vibrating string and rod boundary value and initial value problem solutions in partial differential equations. If the boundary condition at the top is one of enforced displacement, then the solution is:

$$T(z,t) = AEz_o \frac{\omega}{c} \frac{1}{\sin \frac{\omega L}{c}} \cos \frac{\omega z}{c} \sin \omega t \tag{20}$$

where T is the line tension, A is the cross-sectional area of the line, E is the linearized modulus of elasticity, z_o is the amplitude of the displacement at the top of the line, ω is the radian frequency of the enforced displacement and c is the celerity of an elastic wave in the line such that

$$c = \left(\frac{AE}{\mu}\right)^{\frac{1}{2}} \tag{21}$$

with μ the mass per foot of the line. However, if the top boundary condition is described as an oscillating force the solution for line tension is:

$$T(x,t) = F_o \frac{1}{\sin \frac{\omega L}{c}} \cos \frac{\omega z}{c} \sin \omega t \tag{22}$$

The important thing to notice between Equations (20) and (22) is that an infinite, or resonant tension occurs for the first case at

$$\frac{\omega L}{c} = n\pi , \quad n = 1, 2, 3, \ldots \tag{23}$$

and for the second case at

$$\frac{\omega L}{c} = \frac{n\pi}{2}, \quad n = 1, 3, 5, \ldots \tag{24}$$

For illustration, consider two types of buoys that may conceivably be moored to nearly vertical mooring lines at the air-water interface. One buoy is a surface following large disc and the other is a non-surface following, or relatively stable, spar. For a flexible mooring line the large disc will impose a displacement at the upper end of the line as it closely follows the undulations of the water surface whereas the spar buoy will impose a time varying force on the line as the waves pass the spar. For a particular wave frequency the resonant length of line for the disc mooring will be

$$L = n\frac{\pi c}{\omega}, \quad n = 1, 2, 3, \ldots \tag{25}$$

For the spar buoy, the resonant length of mooring line will be

$$L = n\frac{\pi c}{2\omega}, \quad n = 1, 3, 5, \ldots \tag{26}$$

For other buoy types, such as the aid-to-navigation buoys used by the U.S. Coast Guard, some conditions between Equations (25) and (26) will exist. In addition, many wave frequencies exist at sea and all resonant conditions with respect to the entire wave frequency spectrum should be investigated.

Consider a common ocean wave period of seven seconds. The frequency will be 0.90 radians per second. Assume that a one-inch diameter nylon line (that is nearly neutrally buoyant) is used and that it is pre-stressed to 2200 pounds. The modulus of elasticity may be about 7.5×10^6 psf and the saturated density of the line will be about 0.0118 slugs per foot. Thus the celerity of a longitudinal elastic wave in the line will be approximately

$$c = \left(\frac{0.00547 \times 7.5 \times 10^6}{0.0118}\right)^{\frac{1}{2}} \tag{27}$$

or

$$c = 1860 \text{ fps} \tag{28}$$

For the disc buoy, the resonant lengths of mooring line will be 6,500 feet, 13,000 feet, etc. For the spar buoy, the resonant lengths of line will be 3,250 feet, 9,750 feet, etc. This emphasizes that all wave frequencies should be examined for the resonant lengths of the line and the type of buoy. The above arguments can be presented in terms of the transfer function, which gives the spectrum of the response as a function of position on the line, given the wave spectrum.

Similar developments can be obtained for the transverse motion of the line in the x direction at the buoy. However, the longitudinal, or z direction, produces the most severe action on the line.

Now, for slack lines we need to find a way to organize our data. An approach is to display data in dimensionless form so that it will be most useful for various conditions. One suggestion from Nath (1970-A) is to plot a dimensionless tension vs. a dimensionless frequency as shown in Figure 10.

The line tension is divided by a representative wave acceleration times total line mass. The wave frequency is divided by the first mode natural undamped frequency as determined from Equation (23). The interesting results show the various modal frequencies of the system.

An attempt has been made to show only a few of the modern tools to help a designer select materials. The approach has been to look at a stress and motion analysis. The materials themselves, of course, are very important. Usually a chain is used near the anchor to reduce chaffing of the line on rocks and sand. If the analysis shows it is feasible, a wire rope is used as the major mooring link because of its small size (thus reducing drag forces) and low cost. However, twisted rope tends to untwist itself and once it is strained to over 30% or 40% of the ultimate load, and then the load removed, the rope develops kinks, and the rope will break when the load is reapplied. Even no-twist steel ropes twist to some degree. To circumvent these troubles, usually braided or plaited nylon or dacron rope is used. An additional advantage is gained from the increased amount of damping (the amount is unknown presently).

SUMMARY

A brief overview has been given of some design techniques that are being used to solve problems on moored buoys. It has been shown that even for a one-point mooring the computational procedures can be quite complex. The problem is definitely coupled at the attachment point to the buoy, meaning that the buoy motion is influenced by the force of the mooring line on it and the motion of, and the tensions in, the mooring line are influenced greatly by the motion of the buoy, which in turn depends on the type of buoy used.

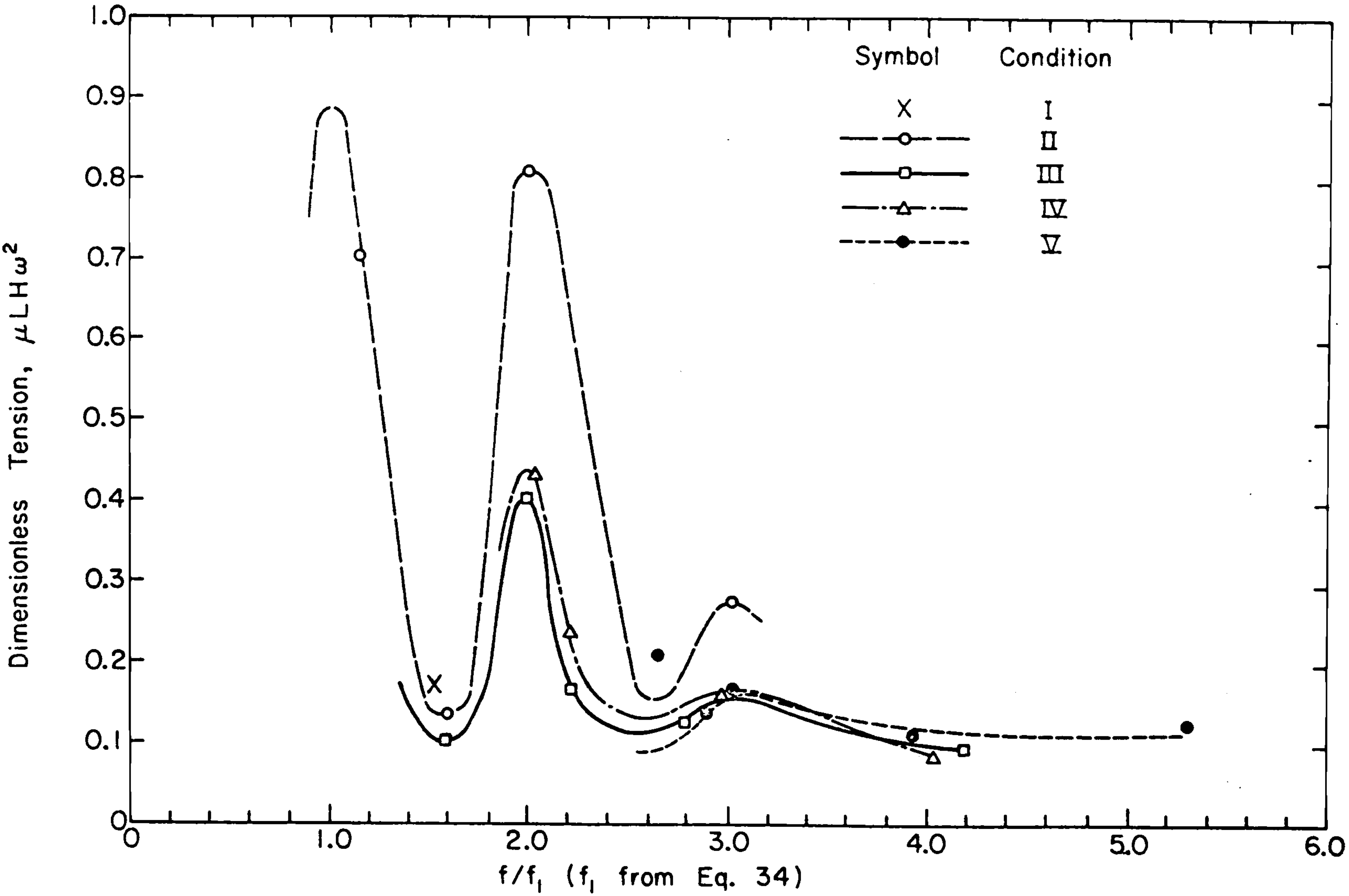


FIG. 10 ESTIMATED FREQUENCY RESPONSE CURVES FOR LINE TENSION AT THE BUOY. DEPTH = 20,000 FT.

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Waves and Their Effects on Pile Supported Structures

SUMMARY

Three methods of presenting wave data are discussed: the significant wave (including the "design wave" concept), the wave spectrum, and the directional spectra. Their use in calculating wave forces on pile supported structures is described, with a discussion of the relative usefulness of the linear versus the non-linear approach. The concept of virtual mass is described, and how this leads to a type of non-linearity which is of great importance in the reversing flow field associated with wave motions.

INTRODUCTION

We are all aware of the tremendous forces exerted by hurricane and gale generated water waves on structures in the ocean. Man, since ancient times, has been constructing boats, breakwaters, and docks in a manner which he has hoped would be adequate to withstand these forces, often with success, but often failing. In recent years our knowledge of the physics of the phenomenon has been developed rather rapidly, permitting us to make better designs now than previously. Some concepts and details of the present state of our knowledge will be presented in this lecture.

Wind blowing over the ocean's surface drags water along with it, thus forming a current, while at the same time it generates waves. Many of the waves grow so steep that they become unstable and break, and in this breaking process they generate a substantial amount of turbulence. One of the most noticeable features of these waves is their irregularity, both in time and in space. Owing to the nature of the wind, the waves generated by the wind blowing over the water surface move in a continuous spread of directions, as measured from the direction of the mean wind velocity. Once the waves leave the generating area, they become smoother in appearance and are known as swell. Due largely to dispersion and angular spreading, the energy density decreases with distance travelled from the storm.

Three methods have been developed to represent these waves. The simplest method is to use the concept of a "significant wave" designated by a height (H_s), period (T_s) and direction (see Wiegel, 1964). Another method utilizes a "one-dimensional spectrum," that is, the wave energy density as a continuous function of both component wave frequency and direction. Both the one-dimensional and directional spectra are based upon the concept of linear superposition of component waves and assuming the statistical independence of phase angles amongst the frequency components. Although most of the wave data that are available have been obtained using the significant wave concept, a substantial amount of data is becoming available in the form of one-dimensional spectra.

Almost no directional spectra of ocean waves are available. Obtaining information of this type requires an array of wave gages, the use of an electronic analog to digital converter, and the use of a high-speed digital computer. Furthermore, the mathematical techniques necessary to obtain reliable directional spectra are difficult to use at the present time from a practical standpoint. However, it is expected that in the future many designs will be made which are based upon directional spectra, with the spectra being a few generalized types.

There are two principal reasons, beside the availability of data, which make the significant wave concept useful to the design engineer. One has to do with the problem of the conception of a design in the mind of an engineer, which, because of the large number of variables involved, requires a rather simple visualization of the variables. The second reason is that water waves are not a linear phenomenon, and in relatively shallow water where many structures are built, certain non-linearities are of controlling importance; the significant wave height, period and direction can be used together with the most appropriate non-linear theory for calculations. A variation of this concept is the use of the "design wave," a wave which has been estimated to be the most extreme which will be encountered during the life of a structure. Ultimately, it is expected that the mathematics of non-linear superposition will be developed sufficiently for the directional spectra concept to be used even in shallow water.

It is necessary to have information on the "wave climate" in the area of interest for the planning and design phases, and synoptic wave data for the construction and operation phases. Traditionally, the wave climate has been represented by "wave roses" or tables which have been obtained from visual observations, from wave recorders, or from hindcasts from weather maps. It would be of much greater benefit to the engineer to have wave data in the form of cumulative distribution functions in order to be able to make an economic design based upon the numerical probability of occurrence. In addition, it would also be better to have wave data in another form for use in planning construction and other operations; in the form of continuous observations, measurements, or hindcasts so that the statistical properties could be determined of the number of consecutive days the waves will be less than, or greater than, some safe or economic combination of height, period and direction. Continuous records would also permit the calculation of "wave spectra," and if an appropriate array were used, it would permit the calculation of "directional spectra" for a site.

Finally, a design philosophy is needed. Owing to the lack of statistical information, details of the forcing functions, and our inability to predict in advance our changing needs, it is usually necessary to develop a "plateau" type of design, rather than attempting to design for a sharply tuned optimum design.

LINEAR THEORY FOR PROGRESSIVE WAVES

Linear Wave Theory

The coordinate system usually used is to take x in the plane of the undisturbed water surface and y as the vertical coordinate, measured positive up from the undisturbed water surface. The undisturbed water depth is designated as d. Sometimes the vertical coordinate is taken as measured positive up from the ocean floor, being designated by S.

The wave surface is given by

$$S_s = y_s + d = \frac{1}{2} H \cos 2\pi \left(\frac{x}{L} - \frac{t}{T}\right) + d \qquad (1)$$

where H is the wave height, L is the wave length, T is the wave period, t is time, and the subscript $-_s$ refers to the wave surface. The wave length, L, and wave speed, C, are given by

$$L = \frac{gT^2}{2\pi} \tanh \frac{2\pi d}{L} \qquad (2)$$

$$C = \frac{gT}{2\pi} \tanh \frac{2\pi d}{L} \qquad (3)$$

where g is the acceleration of gravity. The horizontal component of water particle velocity, u, the local acceleration, $\partial u/\partial t$, and the pressure, p, are given by

$$u = \frac{\pi H}{T} \frac{\cosh 2\pi S/L}{\sinh 2\pi d/L} \cos 2\pi \left(\frac{x}{L} - \frac{t}{T}\right) \qquad (4)$$

$$\frac{\partial u}{\partial t} = \frac{2\pi^2 H}{T^2} \frac{\cosh 2\pi S/L}{\sinh 2\ d/L} \sin 2\pi \left(\frac{x}{L} - \frac{t}{T}\right) \qquad (5)$$

$$p + \rho g y = \frac{1}{2} \rho g H \frac{\cosh 2\pi S/L}{\cosh 2\pi d/L} \cos 2\pi \left(\frac{x}{L} - \frac{t}{T}\right) \qquad (6)$$

where ρ is the mass density of the water.

Similar expressions are available for the vertical components, and expressions are available of the water particle displacements (see Wiegel, 1964).

Wave Forces on Piles

In a frictionless, incompressible fluid the force exerted on a fixed rigid submerged body may be expressed as (Lamb, 1945, p. 93)

$$F_I = (M_o + M_a)\ f_f = \rho B C_M f_f \qquad (7)$$

where F_I is the inertia force, M_o is the mass of the displaced fluid, M_a is the so-called added mass which is dependent upon the shape of the body and the flow characteristics around the body, and f_f is the acceleration of the fluid at the center of the body were no body present. C_M has been found theoretically to be equal to 2.0 for a right circular cylinder by several investigators (see, for example, Lamb, 1945). The product of the coefficient of mass, C_M, the volume of a body, B, and the mass density of the fluid, ρ, is often called the "virtual mass" of a body (i.e., $M_o + M_a$) in an unsteady flow (Dryden, Murnagham and Bateman, 1956, p. 97). C_M is sometimes expressed as

$$C_M = 1 + C_a \qquad (8)$$

where C_a is the coefficient of added mass.* The mass of the fluid displaced by the body enters into Eq. 7, with one part of the inertial force being due to the pressure gradient in the fluid which causes the fluid acceleration (or deceleration). This force per unit length of cylinder, F_p, is given by

$$F_p = \oint p\,dy = \rho \frac{dU}{dt} \int x\,dy = \rho A_o \frac{dU}{dt} \tag{9}$$

in which A_o is the cross sectional area of the cylinder and $\oint$ is a contour integral (McNown, 1957) which follows from the well-known relationship in fluid mechanics for irrotational flow

$$-\frac{1}{\rho}\frac{dp}{dx} = \frac{dU}{dt} \tag{10}$$

where dp/dx is the pressure gradient in the fluid in the absence of the body. In many papers on aerodynamic studies using wind tunnels F_p is called the "horizontal buoyancy" (see, for example, Bairstow, 1939). The added mass term, expressed by $C_a \rho A_o$ per unit length of cylinder, results from the acceleration of the flow around the body caused by the presence of the body. As the fluid is being accelerated around the body by the upstream face of the body (which requires a force exerted by the body on the fluid), the fluid decelerating around the downstream face of the body will exert a smaller or larger force on the downstream face, depending upon whether the flow is accelerating or decelerating. This concept can be seen more clearly for the case of a body being accelerated or decelerated, through a fluid. The force necessary to do this is proportional to the mass per unit length of the cylinder, M_c, plus the added mass, M_a,

$$F_I = (M_c + C_a \rho A_o) \frac{dU}{dt} = (M_c + M_a) \frac{dU}{dt} \tag{11}$$

The leading face of the cylinder pushes on the fluid causing it to accelerate, and the fluid decelerating on the rear side of the cylinder pushes on the cylinder (with the equivalent reaction of the cylinder). In accelerated motion, the reaction at the front must be greater than the reaction at the rear as the fluid decelerating at the rear was not accelerated as much, when it was at the front, as the fluid in front is being accelerated at that instant.

It is unfortunate that the terms added mass and virtual mass have entered the literature as they tend to confuse our concept of the phenomenon. MacCamy and Fuchs (1954; see also Wiegel, 1964, p. 273) solved the diffraction problem of waves moving around a vertical right circular cylinder extending from the ocean bottom through the water surface, using linear wave theory. They solved for the potential, obtained the distorted pressure field from this potential, and integrated the x-component of force around the pile which resulted from this pressure field. In our coordinate system, their solution is

$$F_{Ih}(S) = \frac{\rho g H L}{\pi} \frac{\cosh 2\pi S/L}{\cosh 2\pi d/L} f_A\,(D/L) \sin\left(-\frac{2\pi t}{T} - \beta\right) \tag{12}$$

where

$$f_A\,(D/L) = \frac{1}{\{[J_1'\,(\pi\,D/L)]^2 + [Y_1'\,(\pi\,D/L)]^2\}^{\frac{1}{2}}} \tag{13}$$

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*In many papers the term virtual mass is used for the term added mass. Owing to this, care must be exercised in reading the literature on the subject.

in which J_1 and Y_1 are Bessel functions of the first and second kinds, respectively, and the prime indicates differentiation. β is the angle of phase lag, and will not be shown here as $\beta < 5°$ for values of $D/L < 1/10$, although it is very large for large values of D/L. When $D/L \to 0$, $f_A(D/L) \to \frac{1}{2}\pi\ (\pi D/L)^2$, and

$$F_{Ih}(S) \to 2\ \frac{2\pi^2 \rho H}{T^2}\ \frac{\pi D^2}{4}\ \frac{\cosh\ 2\pi S/L}{\sinh\ 2\pi d/L}\ \sin\ (-\ \frac{2\pi t}{T} - \beta) \tag{14}$$

Neglecting β for small values of D/L, it can be seen that this is the commonly accepted equation for the inertial force, with $C_M = 2$.

In a real fluid, owing to viscosity, there is an additional force, known as the drag force, F_D. This force consists of two parts, one due to the shear stress of the fluid on the body, and the other due to the pressure differential around the body caused by flow separation. The most common equation used in the design of pile supported structures is due to Morison, O'Brien, Johnson and Schaaf (1953), and is:

$$F\ =\ F_D + F_I\ =\ \frac{1}{2}\,C_D\ \rho_w\ A\ |V|\ V + C_M\ \rho_w\ B\ \frac{dV}{dt} \tag{15}$$

where A is the projected area and B is the volume of the pile. As V and dV/dt vary with position, it is better to use the following equation where $F_h(S)$ is the force per unit length of a circular pile. Consider the case of a pile installed vertically in water of depth d, extending from the bottom through the surface. The water particles move in an orbit due to the waves, with both horizontal and vertical components of velocity and acceleration, u, v, du/dt and dv/dt, respectively. The horizontal component of wave induced force, per unit length of pile, is given by

$$F_h(S)\ =\ \frac{1}{2}\,C_D\ \rho_w\ D\ |u|\ u + C_M\ \rho_w\ \frac{\pi D^2}{4}\ \frac{du}{dt} \tag{16}$$

Here, du/dt is

$$\frac{du}{dt} = \frac{\partial u}{\partial t} + u\,\frac{\partial u}{\partial x} + v\,\frac{\partial u}{\partial y} + w\,\frac{\partial u}{\partial z} \tag{17}$$

If we consider only linear theory, the convective acceleration (the last three terms on the right-hand side of Eq. 17) can be neglected, leaving only the local acceleration; i.e., $du/dt \approx \partial u/\partial t$. u and $\partial u/\partial t$ are given by Eqs. 4 and 5. It can be seen that the drag and inertia forces are in quadrature, so that the maximum total force "leads the crest" of the wave. The larger the drag force relative to the inertia force, the closer will be the maximum total force to the passage of the wave crest past the pile. As will be pointed out in a later section, there is a relationship between C_D and C_M, so that Eq. 16 is quite complicated, although it is not usually treated as such.

If a circular structure is placed at an angle to the waves, the vertical component of wave induced force can be treated in a similar manner, using v and $\partial v/\partial t$ as well as u and $\partial u/\partial t$.

If strictly linear theory is used the total horizontal component of wave force acting on a vertical circular pile can be obtained by integrating $F_h(S)\ dS$ from 0 to d. Very often in practice, one integrates $F_h(S)$ from 0 to S_s, obtaining results which are somewhere between the results for linear wave theory and those for second order wave theory. A digital computer program for this operation is available for this purpose, as are graphs and tables of results (Cross, 1964; Cross and Wiegel, 1965).

Much time and money have been spent in obtaining prototype and laboratory values of C_D and C_M. Most of the work has been done by private companies and is not available.* Some data which are available for C_D are given in Fig. 1 (Wiegel, Beebe and Moon, 1957). It is evident that there is a considerable scatter of both C_D; this is also true for the values of C_M. One of the main reasons for this is that the analysis of the data was based upon two simplifications: First, that linear theory could be used to reduce the basic data, and second, that each wave (and force) of a series of irregular waves could be analyzed as one of a series of uniform waves having the height and period of the individual wave in the record.

Agerschou and Edens (1966) reanalyzed the published data of Wiegel, Beebe and Moon (1957) and some unpublished data of Bretschneider, using both linear theory and Stokes Fifth Order theory. They concluded that for the range of variables covered, the fifth-order approach was not superior to the use of linear theory. They recommended for design purposes, if linear theory is used, that C_D should be between 1.0 and 1.4, and that C_M should be 2.0, these values being obtained for circular piles 6-5/8, 8-5/8, 12-3/4, 16 and 24 inches in diameter. (It should be noted here that the theoretical value of C_M for a circular cylinder in potential flow is 2.0.) Wilson (1965; see also, Wilson and Reid, 1963) report average values of $C_D = 1.0$ and $C_M = 1.45$ for a 30-inch diameter pile. At a recent conference, one design engineer stated he used values of C_D ranging from 0.5 to 1.5 and C_M from 1.3 to 2.0, depending upon his client (Design and Analysis of Offshore Drilling Structures: Continuing Education in Engineering Short Course, University of California, Berkeley, California, 16-21 September 1968). The results reported above were obtained either as values of C_D and C_M at that portion of a wave cycle for which $F_D = \max$ and $F_I = 0$, and vice-versa, or for the best average values of C_D and C_M throughout a wave cycle, assuming C_D and C_M to be constant. Both of these methods of obtaining and reporting the coefficients should be refined, as the coefficients are dependent upon each other, and are also time dependent as well as dependent upon the flow conditions.

In the significant wave approach, the significant wave height, H_s, and significant wave period, T_s, are substituted for H and T in the above equations, treating the significant wave as one of a train of waves of uniform height and period. In the design wave approach, the chosen values of H_d and T_d are used in a similar manner.

One Dimensional Wave Spectra Approach

Recently there have been several papers published on the study of wave forces exerted on circular piles, using probability theory. In these studies it was assumed that the continuous spectrum of component waves could be superimposed linearly, that the process was both stationary and ergodic, and that the phase relationship among the component waves was Gaussian.

Some years ago the author obtained both the wave and force spectral densities for a pile installed at the end of the pier at Davenport, California, as shown in Fig. 2. It was not evident why the form of the two spectral densities should be so similar considering the fact that the product $|u|\,u$ occurs in Eq. 16. Professor Leon E. Borgman (1966) studied this problem in detail and developed the following theory.

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*It appears that the results of a long term prototype study of wave forces on piles, by a consortium of oil companies, will be released at the Offshore Technology Conference, to be held in Houston, Texas, 19-21 May 1969.

The basic wave force equation is Eq. 16, which may be expressed as a function of time as

$$F(t) = C_1 |V(t)| V(t) + C_2 A(t) \tag{18}$$

Here F(t) is the time history of the horizontal component of force per unit length of circular pile at an elevation S above the ocean floor, and

$$C_1 = \frac{1}{2} \rho_w C_D D \tag{19a}$$

$$C_2 = \rho_w C_M \pi D^2/4 \tag{19b}$$

The theoretical covariance function for F(t) using ensemble averaging with the Gaussian random wave model is

$$R_{FF}(\tau) = C_1^2 \sigma^4 G\left[R_{VV}(\tau)/\sigma^2\right] + C_2^2 R_{AA}(\tau) \tag{20}$$

where $R_{VV}(\tau)$ and $R_{AA}(\tau)$ are the covariance functions of the horizontal component water particle velocity, V(t), and local acceleration A(t) (i.e., u and $\partial u/\partial t$), where

$$\sigma^2 = 2 \int_0^\infty S_{VV}(f)\, df \tag{21}$$

and

$$G(r) = [(2 + 4r^2)^2 \text{ arc sin } r + 6r \sqrt{1 - r^2}]/\pi \tag{22}$$

in which $G(r) = G(R_{VV}(\tau)/\sigma^2)$, and f is the frequency of the component wave ($f = 1/T$).

The covariance function $R_{VV}(\tau)$ and $R_{AA}(\tau)$ are calculated from the spectral densities $S_{VV}(f)$ and $S_{AA}(f)$ by use of the Fourier transforms

$$R_{VV}(\tau) = \int_{-\infty}^{\infty} S_{VV}(f)\, e^{i2\pi f\tau}\, df \tag{23a}$$

$$R_{AA}(\tau) = \int_{-\infty}^{\infty} S_{AA}(f)\, e^{i2\pi f\tau}\, df \tag{23b}$$

where

$$S_{VV}(f) = \frac{(2\pi f)^2 \cosh^2 2\pi S/L}{\sinh^2 2\pi d/L} S_{\eta\eta}(f) = T_V(f)\, S_{\eta\eta}(f) \tag{24a}$$

$$S_{AA}(f) = \frac{(2\pi f)^4 \cosh^2 2\pi S/L}{\sinh^2 2\pi d/L} S_{\eta\eta}(f) = T_A(f)\, S_{\eta\eta}(f) \tag{24b}$$

and

$$(2\pi f)^2 = \frac{2\pi g}{L} \tanh 2\pi d/L \tag{25}$$

The functions $T_V(f)$ and $T_A(f)$ are called transfer functions. The fundamental quantity $S_{\eta\eta}(f)$ is the spectral density of the water waves, and is obtained from the Fourier transform

$$S_{\eta\eta}(f) = \int_{-\infty}^{\infty} R_{\eta\eta}(\tau)\, e^{-i2\pi f\tau}\, d\tau \tag{26}$$

in which $R_{\eta\eta}(\tau)$ is the averaged lagged product of $\eta(t)$ (i.e., average of $\eta(t)\,\eta(t+\tau)$) where $\eta(t)$ is the time history of the wave motion at the location of the pile (i.e., $\eta(t) = y_s(t)$).

Borgman found that Eq. 22 could be expressed in series form as

$$G(r) = \frac{1}{\pi}\left[8\,r + \frac{4r^3}{3} + \frac{r^5}{15} + \frac{r^7}{70} + \frac{5r^9}{1008} + \dots\right] \tag{27}$$

and that the series converges quite rapidly for $0 \leq r \leq 1$. He found that for $r = 1$, the first term $G_1(r) = 8r/\pi$ differed from $G(r)$ by only 15%, and that the cubic approximation $G_3(r) = (8r + 4r^3/3)/\pi$ differed from $G(r)$ by only 1.1%. Substituting the first term of the series into Eq. 20 results in

$$R_{FF}(\tau) = \frac{C_1^{\,2}\,\sigma^4}{\pi}\left[\frac{8\,R_{FF}(\tau)}{\sigma^2} + \dots\dots\right] + C_2^{\,2}\,R_{AA}(\tau) \tag{28}$$

The Fourier transform of this is:

$$S_{FF}(f) = \frac{C_1^{\,2}\,\sigma^4}{\pi}\left[\frac{8\,S_{VV}(f)}{\sigma^2} + \dots\dots\right] + C_2^{\,2}\,S_{AA}(f) \tag{29}$$

which is the desired force spectral density.

Borgman made a numerical analysis of the situation shown in Fig. 2. The numerical integration of $S_{VV}(f)$ gave $\sigma^2 = 1.203$ ft^2/sec^2 and a least square fitting of the theoretical covariance of $F(t)$ against the measured force covariance gave estimates of $C_D = 1.88$ and $C_M = 1.73$. The transfer functions $T_V(f)$ and $T_A(f)$ were calculated and plotted; it could be seen that $T_A(f)$ was nearly constant in the range of circular frequencies ($2\pi/T$) for which most of the wave energy was associated. The calculated and measured force spectral densities are shown in Fig. 3. The reason for the excellent fit is that for the conditions of the experiment $T_V(f)$ was nearly constant and the linear approximation to $G(r)$, $G_1(r)$, was a reliable approximation.

Jen (1968) made a model study of the forces exerted by waves on a 6-inch diameter pile in the 200 ft. long by 8 ft. wide by 6 ft. deep wave tank at the University of California, Berkeley. In addition to using periodic waves, irregular waves were generated by a special wave generator using as an input the magnetic tape recording of waves measured in the ocean. The dimensions of the waves relative to the diameter of the pile were such that the forces were largely inertial. Jen found for the regular waves that $C_M \approx 2.0$, and using Borgman's method to analyze the results of the irregular waves tests found $C_M \approx 2.1$ to 2.2. The reason for this close agreement between theory and measurement of C_M is probably due to the small value of H/D, which resulted in quasi-potential flow (This will be discussed in a subsequent section).

Equation 29 permits the calculation of the force spectral density at a point. This is useful but the design engineer usually needs the total force on a pile, and the total moment about the bottom. In addition, the total force and the total moment on an entire structure is needed. These problems have been considered by Borgman (1966; 1967; 1968) and Foster (1968). In obtaining a solution to this problem, the integration of the force distribution is performed from the ocean bottom to the still water level as this is in keeping with linear wave theory. There is no difficulty in obtaining the solution for the inertia force, but cross product terms appear in the solution for the drag force.* Borgman made use of the linearization of G(r) by restricting it to the first term of the series given by Eq. 27 to obtain the approximate solution for the total force spectral density $S_{QQ}(f)$.

$$S_{QQ}(f) \approx S_{\eta\eta}(f) \left\{ \frac{8}{\pi} \left[\frac{2\pi f\ C_1}{\sinh 2\pi\ d/L} \int_o^d \sigma(S) \cosh(2\pi S/L)\ dS \right]^2 + \left[\frac{(2\pi f)^2\ C_2}{\sinh 2\pi\ d/L} \int_o^d \cosh(2\pi S/L)\ dS \right]^2 \right\} \tag{30}$$

in which

$$\int_o^d \cosh(2\pi S/L)\ dS = \frac{\sinh 2\pi d/L}{2\pi/L} \tag{31}$$

The first integral in Eq. 30 cannot be prevaluated, but must be calculated for each sea-surface spectral density used.

The total moment about the bottom is

$$S_{MM}(f) \approx S_{\eta\eta}(f) \left\{ \frac{8}{\pi} \left[\frac{2\pi f\ C_1}{\sinh 2\pi\ d/L} \int_o^d S\ \sigma(S) \cosh(2\pi S/L)\ dS \right]^2 + \left[\frac{(2\pi f)^2\ C_2}{\sinh 2\pi d/L} \int_o^d S \cosh(2\pi S/L)\ dS \right]^2 \right\} \tag{32}$$

in which

$$\int_o^d S \cosh(2\pi S/L)\ dS = \frac{1}{(2\pi/L)^2} \left[1 - \cosh 2\pi d/L + (2\pi d/L)\cosh 2\pi d/L\right] \tag{33}$$

As in the case of Eq. 30, the first integral cannot be prevaluated.

Borgman (1967; 1968) has found this linearization of the drag term to be the equivalent of using $(V_{rms} \sqrt{8/\pi})\ V(t)$ in place of $|V(t)|\ V(t)$ in Eq. 18; the physical reason for this is not clear, however. It should be pointed out here, that another linearization has been used by nearly every investigator in the past, with essentially no discussion; that is, the use of $\partial u/\partial t$ rather than du/dt (see Eq. 17). Work is needed to determine the size of error introduced by this linearization compared with the size of the error introduced by the linearization of the drag term.

A relatively simple transfer function has been obtained by Borgman (1966; 1967) to calculate the total force and overturning moment the pile array of an offshore platform, and the reader is referred to the original work for information thereof.

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*A solution to this problem has been obtained by A. Malhotra and J. Penzien, University of California, Berkeley, California, and is to be published soon.

One Dimensional Wave Spectra

There have been a number of papers published on one dimensional wave spectra (see, for example, National Academy of Sciences, 1963), and a large number of measured wave spectra have been published (see, for example, Moskowitz, Pierson and Mehr, 1963). There are several possible ways of using actual spectra, one being a simulation technique (Borgman, 1968) for a large number of spectra, or a large number of wave time histories reconstituted from spectra. Another way to use spectra is to develop a "standard" set of spectra. There have been a number of such standards suggested. One of these has been given by Scott (1965), who re-examined the data of Darbyshire (1959) and Moskowitz, Pierson and Mehr (1963), and then recommended the following equation as being a better fit of the ocean data

$$S(\omega)/H_s^2 = 0.214 \exp - \left[\frac{(\omega - \omega_o)^2}{0.065\,\{(\omega - \omega_o) + 0.26\}}\right]^{\frac{1}{2}} \tag{33a}$$

$$\text{for} \quad -0.26 < (\omega - \omega_o) < 1.65 \tag{33b}$$

$$\text{and, } = 0, \text{ elsewhere} \tag{33c}$$

where $\omega = 2\pi f$ (in radians per second), ω_o is the spectrum peak frequency, H_s is the significant wave height (in feet), and the energy spectral density $S(\omega)$ is defined by

$$S(\omega) = \frac{1}{\pi} S_{\eta\eta}(f)$$

It is also defined by

$$S(\omega) = \frac{1}{2} \sum^{\delta\omega} a_i^2/\delta\omega \tag{34}$$

in which the summation is over the frequency interval ω, $\omega + \delta\omega$, and a_i is the amplitude of the i^{th} component, with

$$y_s = \sum_{i=1}^{n} y_i = \sum a_i \cos(\omega_i t + \phi_i) \tag{35}$$

in which ϕ_i is the phase angle of the i^{th} component. The factor $\frac{1}{2}$ enters as $\sum^{n} a_i^2/2$ is the mean value of ${y_s}^2$ during the motion. The term $a_i^2/\delta\omega$ is used, as the concept of a_i tends to lose physical significance (i.e., $a_i^2 \rightarrow 0$) as $n \rightarrow \infty$, whereas $a_i^2/\delta\omega$ does not; hence the value of using the energy density as a function of frequency.

Scott also found, using linear regression, that

$$1/f_o = 0.19\, H_s + 8.5 \tag{36a}$$

$$1/\omega_o = 0.03\, H_s + 1.35 \tag{36b}$$

$$T = 0.085\, H_s + 7.1 \tag{36c}$$

where T is the average period (in seconds) of all waves in the record, and can be shown to be

$$T = 2\pi \, (m_o/m_2)^{\frac{1}{2}} \tag{37}$$

where

$$m_k = \int_o^\infty \omega^k \, S_{\eta\eta}(\omega) \, d\omega \tag{38}$$

For k = 0, we have the "variance," m_o, and for a narrow (i.e., "Rayleigh" spectrum) we have

$$H_s = 4 \, m_o^{\frac{1}{2}} \tag{39}$$

Using quadratic regression, Scott found

$$f_o = (0.501/T) + (1.43/T^2) \tag{40a}$$

$$\omega_o = (3.15/T) + (8.98/T^2) \tag{40b}$$

It is of considerable importance to the engineering profession to develop means by which the spectral approach can be studied in the laboratory. In studying some of the problems, it is necessary to know the relationship between the one-dimensional spectra in the ocean and the spectra generated in a wind-wave tank (Plate and Nath, 1968). Comparison of a number of wave spectra measured in the ocean, in lakes and in wave tanks have been made by Hess, Hidy and Plate (1968). Their results, shown in Figure 4, are fully developed seas wind-wave energy density spectra. The high frequency portion of the spectra all tend to lie close to a single curve, with energy density being approximately proportional to ω^{-5} as predicted by the Phillips' equilibrium theory (see Wiegel and Cross, 1966, for a physical explanation of this). A close inspection of these data by Plate and Nath (1968) led them to conclude that the high frequency portion of the energy spectral density curve varies from the ω^{-5} "law," being proportional to ω^{-7} near the spectral peak, and being proportional to about ω^{-4} in the highest frequency range of the spectra. It would appear from the one example of Wiegel and Cross (1966), Figure 5, in which they compared a normalized measured laboratory wind-wave energy density spectrum with one calculated by use of Miles' theory, together with other physical reasoning, that a theoretically sound basis exists for the development of a "standard" set of spectra.

The argument for the high frequency portion of the energy density spectra being proportional to $\omega^{-5}$is as follows (Wiegel and Cross, 1966). For a train of uniform periodic progressive waves, the maximum wave steepness is generally considered to be

$$\frac{H}{L} \approx \frac{1}{7} \tanh 2\pi \, d/L \tag{41a}$$

which, for deep water, reduces to

$$\frac{H}{L} = \frac{H}{(g/2\pi) \, T^2} \approx \frac{1}{7} \tag{42b}$$

and

$$H^2 \approx \frac{4\pi^2 g^2}{49(2\pi f)^2} \qquad (43)$$

from which

$$H^2/\omega = H^2/2\pi f \approx \frac{4\pi^2 g^2}{49(2\pi f)^5} = \frac{4\pi^2 g^2}{49\ \omega^5} \qquad (44)$$

If the energy spectral density is proportional to $(H/2)^2/\omega$, then it must also be proportional to ω^{-5}.

In order for the design engineer to use with confidence the work of the type proposed by Borgman, it would be desirable to measure $S_{VV}(f)$ and $S_{AA}(f)$ as a function of $S_{\eta\eta}(f)$ in both the ocean and in the laboratory to see how reliable the linear transfer functions are for different sea states.

Directional Wave Spectra

Before directional spectra can be used in the design of structures in relatively deep water it is necessary to have measurements of such spectra, and to understand them sufficiently to be able to choose a "design" directional spectra. Two sets of measurements have been made in the ocean (Chase, et al., 1957; Longuet-Higgins, Cartwright and Smith, 1963), a few in a bay (Stevens, 1965) and a few in the laboratory (Mobarek, 1965; Mobarek and Wiegel, 1967; Fan, 1968).

Mobarek (1965) checked several methods that had been suggested for obtaining the directional spectra from an array of wave gages, and found none of them too reliable. However, making use of simulated inputs, he was able to choose the most reliable method and to devise correction factors. Some of his measurements are shown in Figure 6. Values in the ordinate are in terms of the wave energy, E, rather than the energy density, $S_{\eta\eta}(f)$. When normalized, his laboratory results were found to be similar to normalized values of the measurements made in the ocean by Longuet-Higgins, et al. (1963), as can be seen in Figure 7. At the suggestion of Professor Leon E. Borgman, Dr. Mobarek compared the circular normal probability function (the solid curve in Figure 7) with the normalized data and found the comparison to be excellent.

The probability density of the circular normal distribution function is given by (Gumbel, 1952 and Court, 1952):

$$P(\alpha, K) = \frac{1}{I_o(K)} \exp(K \cos \alpha) \qquad (45)$$

where α is the angle measured from the mean $(\theta_m - \theta)$, K is a measure of the concentration about the mean, and $I_o(K)$ involves an incomplete Bessel function of the first kind of zero order for an imaginary argument. The larger K, the greater the concentration of energy; it is analogous to the reciprocal of the standard deviation of the linear normal distribution.

It has been found that much useful information on directional spectra can be obtained from the outputs of two wave recorders, through use of the co-spectra and quadrature spectra to calculate the linear coherence and the mean wave direction (Munk, Miller, Snodgrass and Barber, 1963; Snodgrass, Groves, Hasselman, Miller, Munk and Powers, 1966). It appeared to the author that if the directional spectra were represented by the circular normal distribution function it should be possible to obtain the necessary statistical parameters in a similar manner. It was believed that such a simplified approach could provide data of sufficient accuracy for many practical purposes. As a result of discussions with Professor Leon Borgman, a theory was developed by Borgman (1967) to do this, and tables were calculated to provide a practical means to obtain the required information.

Borgman (1967) used a slightly different representation of the directional spectra

$$S_{\eta\eta 2}(f, \alpha) \;=\; S_{\eta\eta 1}(f)\ \exp[-K \cos(\theta - \theta_m)]/2\pi I_o(K) \tag{46}$$

where the 2π in the denominator indicates an area under the curve of 2π rather than unity, f is the component wave frequency in cycles sec, and $S_{\eta\eta 1}(f)$ is the one-dimensional spectral density. The estimation of the parameters $S_{\eta\eta 1}(f)$, $K(f)$ and $\theta_m(f)$ is achieved by cross-spectral analysis based on a sea surface record at two locations. $S_{\eta\eta 1}(f)$ and the co- and quadrature spectral densities for the two recordings are computed by the usual time series procedures. The theoretical relations between measured and unknown quantities is

$$\frac{C(f)}{S_{\eta\eta 1}(f)} = \int_o^{2\pi} \frac{\exp[K \cos(\theta - \theta_m)]}{2\pi I_o(K)} \cos[k\overline{D} \cos(\theta - \overline{\beta})]\, d\theta \tag{47}$$

$$\frac{Q(f)}{S_{\eta\eta 1}(f)} + \int_o^{2\pi} \frac{\exp[K \cos(\theta - \theta_m)]}{2\pi I_o(K)} \sin[k\overline{D} \cos(\theta - \overline{\beta})]\, d\theta \tag{48}$$

where $\overline{D}$ is the distance between the pair of recorders, k is the wave number ($2\pi/L$) and β is the direction from wave recorder #1 to wave recorder #2. For a given frequency, all quantities are known except θ_m and K. Hence these two equations represent two nonlinear equations with two unknowns. Borgman has prepared tables which enable one to solve for θ_m and K, given $C(f)/S_{\eta\eta 1}(f)$ and $Q(f)/S_{\eta\eta 1}(f)$. Two solutions, symmetric about the direction between the pair of recorders result. This ambiguity may be eliminated by using three wave gages instead of two, or in many applications using other information regarding the main direction of the directional spectra. The relationship between the parameter K and the directional width of the spectrum can be seen in Figure 8.

Using simulation techniques devised by Professor Leon Borgman, Dr. Fan (1968), continuing the work of Mobarek, made an extensive study of the effects of different lengths of data, lag numbers, wave recorder spacings, filters, and different samples on the calculation of directional spectra, using several methods, using a known circular normal distribution input. An example of the effect of gage spacings, relative to the component wave length, on the estimates can be seen in Figure 9. He then used the "best" combination to obtain the directional spectra of waves generated in a model basin by wind blowing over the water surface. As a result of this study it appears that, for the case of waves being generated in a nearly stationary single storm, the directional spectra can be approximated by two parameters and should be tested for use in the design of an offshore structure.

The results were sufficiently good to encourage Borgman and Suzuki to develop a new method for obtaining useful information on directional spectra by measuring the time histories of the x and y components of wave induced force on a sphere mounted a few feet above the ocean bottom, together with the wave pressure time history at the sphere. The results of this work (Suzuki, 1968) indicated that a practical method is available to the engineer for measuring the approximate directional spectra of ocean waves.

NON-LINEAR PROBLEMS

There are several types of non-linearities involved in the problem of wave induced forces on offshore structures. One, which is due to the term $|u|\,u$ of Eq. 16, is important in the wave spectra approach; a method of overcoming the handicap has been described in a previous section. A second enters through the term du/dt in Eq. 16, which has been linearized through the use of $\partial u/\partial t$ in place of du/dt. A third non-linearity enters through the generation of eddies, and will be discussed subsequently.

The most commonly considered non-linearity is associated with non-linear wave theories. Two of these are the Stokes and the Cnoidal wave theories (see, for example, Wiegel, 1964). The first is best used for relatively deep water, and the second is best used for relatively shallow water. No attempt will be made to describe these theories in detail herein; rather a few equations will be given to indicate the general nature of the difference between these theories and the linear theory.

To the third order, the Stokes' (Stokes, 1880; Skjelbreia, 1959) wave profile is given by

$$\frac{y_s}{L} = A_1 \cos 2\pi \left(\frac{x}{L} - \frac{t}{T}\right) + A_2 \cos 4\pi \left(\frac{x}{L} - \frac{t}{T}\right) + A_3 \cos 6\pi \left(\frac{x}{L} - \frac{t}{T}\right) \qquad (49)$$

where the coefficients A_1, A_2 and A_3 are related to the wave height by

$$H/d = (L/d)\,[2A_1 + 2\pi^2 A_1{}^3 \cdot F_3\,(d/L)] \qquad (50)$$

where

$$A_2 = A_1{}^2 \cdot f_2\,(d/L), \quad A_3 = \pi^2 A_1{}^3 \cdot f_3\,(d/L) \qquad (51)$$

with f_2 (d/L) and f_3 (d/L) being functions of d/L.

The waves have steeper crests and flatter troughs than linear waves, and there is a mass transport of water in the direction of wave advance. The equations for water particle velocities and accelerations will not be presented herein as extensive tables of functions are needed for their use (or the availability of a high speed digital computer).

When the wave length becomes quite long comapred with the water depth, about L/d > 10 (the value depending upon H/d as well), the Cnoidal wave theory is perhaps a better approximation than is the theory of Stokes waves. The theory was originally derived by Korteweg and de Vries (1895). To the first approximation the wave profile is given by S_s, measured from the ocean bottom

$$S_s = S_t + H\,\mathrm{cn}^2\,[2\,K(k)\,(x/L - t/T),\,k] \qquad (52)$$

where cn is the "cnoidal" Jacobian elliptical function and K(k) is the complete elliptic integral of the first kind of modulus k, S_t is the elevation of the wave trough above the bottom, and is given by

$$\frac{S_t}{H} - \frac{d}{H} + 1 = \frac{16\ d^3}{3L^2\ H}\ \{K(k)\ [K(k) - E(k)]\} \tag{53}$$

where E(k) is the complete elliptic integral of the second kind of modulus k. The wave length is

$$L = \sqrt{\frac{16\ d^3}{3H}} \cdot kK(k) \tag{54}$$

and the period is related to the modulus k through

$$T\sqrt{\frac{g}{d}} = \sqrt{\frac{16d}{3H}} \left\{ \frac{kK(k)}{\sqrt{1 + \frac{H}{d}\left[-1 + \frac{1}{k^2}\left(2 - 3\,\frac{E(k)}{K(k)}\right)\right]}} \right\} \tag{55}$$

The equation for water particle velocities and acceleration and graphs which permit the use of the Cnoidal wave theory have been prepared by Wiegel (1964; see Masch and Wiegel, 1961 for tables of functions). .

Professor Robert Dean (1968) has made analytical studies of the wave profiles predicted by these and other theories, including his "stream function wave theory," in order to determine the probable useful ranges of the theories. His results are shown in Figures 10 and 11.

It is necessary to be able to calculate the height of the wave crest above the water surface in order to determine the deck height on an offshore platform, and the work of Dean cited above is useful for this purpose. It is also important to be able to estimate the regions of reliability of the several theories in the prediction of water particle velocities and accelerations. Dr. Bernard Le Méhauté and his co-workers (Le Méhauté, Divoky and Lin, 1968) have made careful laboratory studies of the water particle velocities of "shallow water waves" for several values of H, T, and d and compared their measurements with predictions made using a number of linear and non-linear wave theories. An example of their results is shown in Fig. 12. They concluded, that while no theory was found to be exceptionally accurate, the Cnoidal wave theory of Keulegan and Patterson appeared to be most adequate for the range of wave parameters and water depths studied. It appears that much more work of this type is needed.

The water particle velocities and accelerations given by the most valid non-linear theory are used in Eq. 16 to calculate the force on a pile. These velocities and accelerations are usually calculated for the so-called "design wave," which is usually the wave considered by design engineers to be the largest wave the structure might encounter during its useful life.

Another reason for the variability of the data is associated with the wake. The formation of eddies in the lee of a circular cylinder in uniform steady flow has been studied by a number of persons. It has been found that the relationship among the frequency (cycles per second) of the eddies, f_e, the diameter of the cylinder, D, and the flow velocity, V, is given by the Strouhal number, N_S,

$$N_S\left(1 - \frac{19.7}{N_R}\right) = \frac{f_e\ D}{V} \approx N_S \tag{56}$$

where N_R is the Reynolds number. Except in the range of laminar flow, the Reynolds number effect can be neglected. For flow in the sub-critical range

($N_R <$ about 2.0×10^5), $N_s \approx 0.2$. For $N_R > 2.0 \times 10^5$, there appears to be a considerable variation of N_s; in fact, it is most likely that a spectrum of eddy frequencies exists (see Wiegel, 1964, p. 268 for a discussion of this). The most extensive data on N_s at very high Reynolds numbers, as well as data on C_D and the pressure distribution around a circular cylinder with its axis oriented normal to a steady flow, has been given by Rosko (1961), some of which are shown in Figure 13.

What is the significance of N_s for the type of oscillating flow that exists in wave motion? Consider the horizontal component of water particle velocity as given by Eq. 4. For deep water, the equation is approximately

$$u = (\pi H/T) \cos 2\pi t/T \tag{57}$$

at x - 0. Then, using an average of u to represent V; i.e.,

$$V_w \approx u_{avg} \approx \pi H/2T \tag{58}$$

where V_w is the "average" horizontal component of water particle velocity due to a train of waves of height H and period T. For at least one eddy to have time to form it is necessary for

$$T > 1/f_e \approx 2DT/\pi H\ N_s \tag{59a}$$

And, if $N_s \approx 0.2$

$$H > 10\ D/\pi \tag{59b}$$

Keulegan and Carpenter (1958) studied both experimentally and theoretically the problem of the forces exerted on bodies in an oscillating flow. The oscillations were of the standing wave type in which the wave length was long compared with the water depth so that the horizontal component of water particle velocity was nearly uniform from top to bottom. Furthermore, the body was placed with its center in the node of the standing wave. They found that C_M and C_D depended upon the number $u_{max}\ T/D$ where $u = u_{max} \cos 2\pi t/T$. They observed that when $u_{max}\ T/D$ was relatively small, no eddy formed, that a single eddy formed when $u_{max}\ T/D$ was about 15, and that numerous eddies formed for large values of the parameter. It is useful to note that this leads to a conclusion similar to Eq. 59. For example, if one used the deep water wave equation for $u_{max} = \pi H/T$, then

$$u_{max}\ T/D > \pi H/D > 15 \tag{60}$$

and

$$H > 15D/\pi \tag{61}$$

It appears from the work described above that a high Reynolds number oscillating flow can exist which is quite different from high Reynolds number rectilinear flow unless the wave heights are much larger than the diameter of the circular cylinder. It would appear that the Keulegan-Carpenter number is of greater significance in correlating C_D and C_M with flow conditions than is Reynolds number (Wiegel, 1964, p. 259), and that the ratio H/D should be held constant to correlate model and prototype results, or at least should be the appropriate value to indicate the prototype and model flows are in the same "eddy regime" (see Paape and Breusers, 1967, for similar results for a cylinder oscillating in water).

When the Keulegan-Patterson number is large enough that eddies form, an oscillating "lift" force will occur with a frequency twice that of the wave frequency. For a vertical pile the "lift" force will be in the horizontal plan normal to the direction of the drag force. Essentially no information has been published on the coefficient C_L for water wave type of flow. In uniform rectilinear flows it has about the same numerical value as C_D.

Photographs taken of flow starting from rest, in the vicinity of a circula cylinder for the simpler case of a non-reversing flow, show that it takes time for separation to occur and eddies to form. The effect of time on the flow, an hence on C_D and C_M has been studied by Sarpkaya and Garrison (1963; see also Sarpkaya, 1963). A theory was developed which was used as a guide in analyzing laboratory data taken of the uniform acceleration of a circular cylinder in one direction. Figure 14 shows the relationship they found between C_D and C_M was found which was dependent upon ℓ/d, where ℓ is the distance traveled by the cylinder from its rest position and D is the cylinder diameter. They indicated the "steady state" (i.e., for large value of ℓ/D) values of $C_D = 1.2$ and $C_M = 1.3$.

The results shown in Figure 14 are different than those found by McNown and Keulegan (1959) for the relationship between C_D and C_M in oscillatory flow, Figure 15. They measured the horizontal force exerted on a horizontal circular cylinder placed in a standing water wave, with the cylinder being parallel to the bottom, far from both the free surface and the bottom, and with the axis of the cylinder normal to the direction of motion of the water particles. The axis of the cylinder was placed at the node of the standing wave so that the water particle motion was only horizontal (in the absence of the cylinder). Their results are shown in Figure 15. Here, T is the wave period and T_e is the period of a pair of eddies shedding in steady flow at a velocity characteristic of the unsteady flow. In their figure, the characteristic velocity was taken as the maximum velocity. They found that if T/T_e was 0.1 or less, separation and eddy formation were relatively unimportant, with the inertial effects being approximately those for the classical unseparated flow, and if T/T_e was greater than 10, the motion was quasi-steady.

Studies in a hydraulic laboratory have been made by Bidde (1970) for the case of "deep water" and "transitional water" waves acting on a vertical "rigid" circular cylinder which extended from near the bottom through the water surface. For this case the undisturbed water particle motion was not simply a rectilinear back and forth motion, but the water particles moved in an elliptical orbit in a vertical plane. Furthermore, any eddies that formed were affected by the free surface at the interface between the air and water. One of the most crucial factors in oscillating flow of this type is the fact that the wake formed during one portion of the cycle becomes the upstream flow in another portion of the cycle.

During the first stages of the study, immiscible fluid particles with the same specific gravity as the water were made of a mixture of carbon tetrachloride and xylene, with some zinc oxide paste added to make the particles easily visible. After the mixture was made, it was injected into the water by means of a long glass tube which had a rubber bulb mounted at one end. The other end of the tube was heated and drawn to make the tip opening the desired size. After some experimenting approximatley spherical globules of the proper size could be squeezed out into the water. Stereophotographic sets were taken of the trajectories of these tracer particles, and a computer program (Glaser, 1966) was used to calculate the space position of them. However, it was found too difficult and lengthy a job to pursue.

Owing to the difficulty described briefly above, a description of the wake regime was developed which was based upon its surface characteristics. The procedure was as follows. The wave generator was set for a given period and wave height, and magnesium powder was sprinkled on the water surface in the vicinity of the pile. The wave generator was started, and the wake characteristic was observed. An example of the relationship between the wake characteristic and the wave height, with the wave period being held constant is given in Table 1, together with the values of Reynolds number and Keulegan-Carpenter number. Similar tables were constructed for a number of wave periods. It was found that the Keulegan-Carpenter number correlated reasonably well with the different regimes of the surface wake characteristics. The relationship is shown visually in Fig. 16. When the Keulegan-Carpenter number was about 3, one or two eddies formed, when its value was about 4 several eddies formed and shed, having the appearance of a von Karman vortex street, when its value was in the range of 5-2 the wake started to become turbulent, and when the Keulegan-Carpenter number was larger than 7, the wake became quite turbulent, and the turbulent mass of water swept back and forth past the pile. It can be seen from this study that the von Karman vortex street formed when the wave height was about equal to the pile diameter. A few experiments made with a pile with a diameter nearly four times the size showed similar results when the wave height was about the same size as the pile diameter.

When eddies form, in addition to their effect on the longitudinal drag and inertial forces, lift forces are also exerted on the cylinder. For a vertical cylinder these lift forces act horizontally, but normal to the longitudinal forces (longitudinal being in the direction of wave motion). Examples of waves, lift forces and longitudinal forces are shown in Fig. 17 for three different values of the Keulegan-Carpenter number (3.23, 6.23 and 10.2). The terms top and bottom associated with the lift and longitudinal forces refer to the forces measured by the top and bottom strain gages on the transducer; the total lift and total longitudinal forces are the sums of the top and bottom values.

There is considerable agreement between the visual observations described previously and the force measurements. Figure 17a shows a set of records for a Keulegan-Carpenter number of 3.2. The lift force has just begun to be non-zero. For this value of the Keulegan-Carpenter number the first eddies develop and shed. The eddy strength is probably very small so that the lift force recorded is negligible. The lift forces for this case have a frequency which is about the same as the wave frequency. This might be due to the fact that the flow is not perfectly symmetrical. The horizontal component of velocity in one direction (wave crest) are slightly different from those in the opposite direction (wave trough), and for the threshold condition the eddies only shed for one direction of the flow. The Keulegan-Carpenter number is 6.2 for the run shown in Fig. 17b. The eddy shedding is distinct, and the frequency of lift forces is approximately twice the frequency of the waves. This shows that there is time only for two eddies to shed in each direction. The lift forces are about 25% of the longitudinal force. The wake is not yet completely turbulent, and the lift force records show a more or less regular pattern. The Keulegan-Carpenter number for the run shown in Fig. 17c is 10.2. The wake is fully turbulent. The transverse ("lift") force record appears to be random. The ratio of maximum lift to maximum longitudinal force is about 40%.

An equation for lift forces is

$$\text{Lift force} = F_L = \frac{1}{2} C_L \rho u^2 A \tag{62}$$

TABLE 1

Water depth = 2.0 ft

Cylinder diameter = 1-5/8"

Wave period = 2.0 seconds

(From Bidde, 1970)

Run Number	Wave height (feet)	Surface Reynolds Number	Surface Keulegan-Carpenter Number	Observations
1	0.028	850	0.9	No separation, no eddies (Amplitude of motion does not reach cylinder diameter)
2	0.04	1,220	1.3	
3	0.055	1,680	1.8	Small separation
4	0.07	2,140	2.3	Very weak v. Karman street
5	0.08	2,450	2.7	Clear v. Karman street
6	0.095	2,920	3.2	Wake of prior semicycle, when swept back gives rise to additional eddies
7	0.105	3,230	3.5	
8	0.120	3,700	4.0	
9	0.135	4,180	4.6	Eddies swept back by the time they are formed
10	0.155	4,810	5.2	
11	0.180	5,610	6.1	
12	0.20	6,250	6.8	
13	0.22	6,900	7.5	Becoming highly turbulent
14	0.24	7,550	8.2	
15	0.27	8,530	9.3	Extremely turbulent, no more eddies visible
16	0.30			
17	0.32			
18	0.34			
19	0.35	11,200	12.2	

where C_L is the coefficient of lift, u is the horizontal component of water particle velocity, ρ is the mass density of water, and A is the projected area of the cylinder. Use of this equation leads to difficulties as the time history of the force does not necessarily vanish when u goes through zero. Owing to this, very large values of C_L can be calculated from the laboratory measurements. This difficulty can be largely overcome by defining the relationship of Eq. 62 only for maximum values of the force,

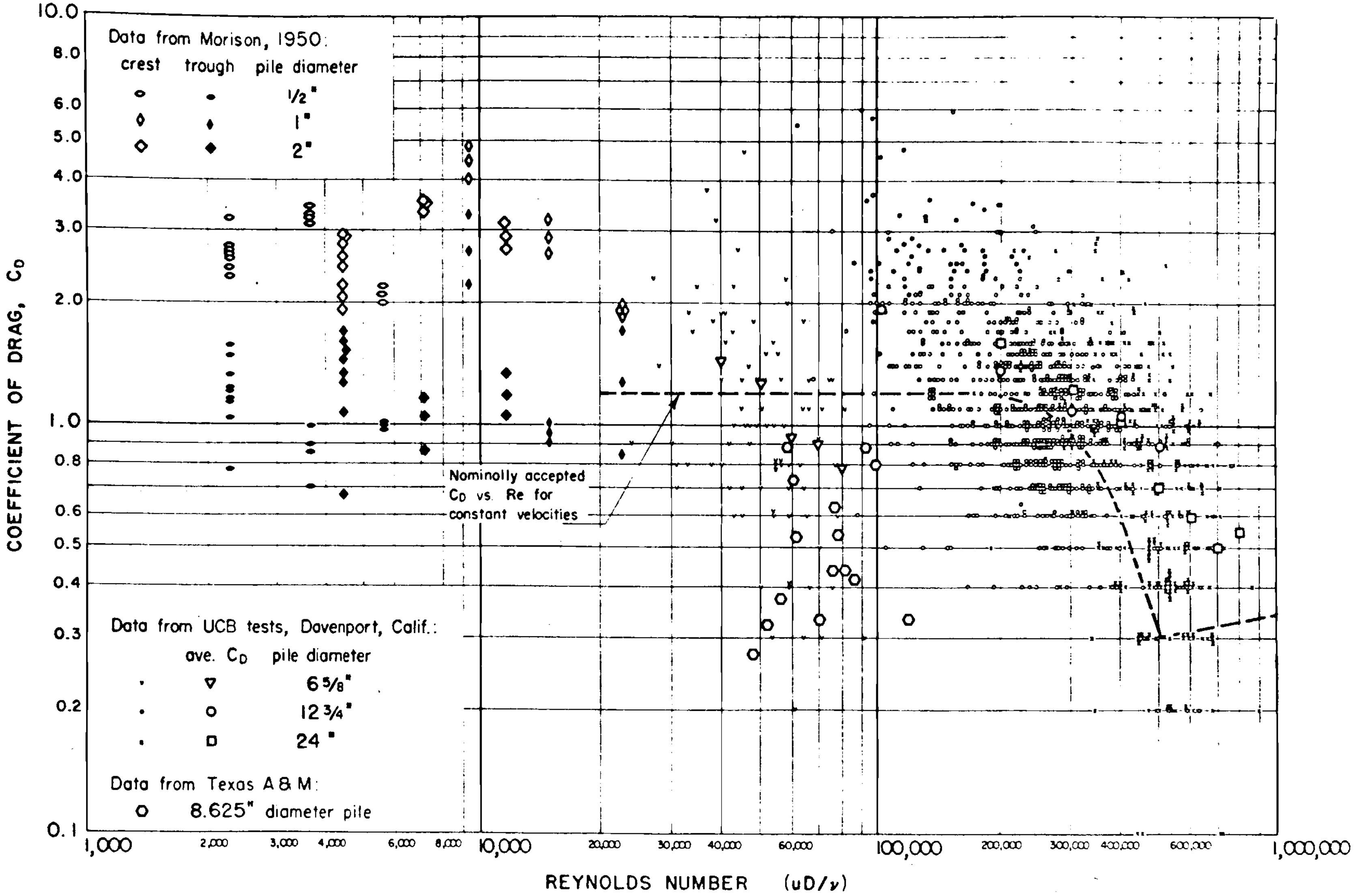
$$F_{L_{max}} = \frac{1}{2} C_{L_{max}} \rho u^2_{max} A \tag{63}$$

In this study the ratio of lift to longitudinal force was used as a basic parameter rather than C_L as this parameter is comparatively less sensitive to any systematic errors in the instrumentation used to measure the forces, as similar errors would be present in both lift and longitudinal force measurements, and these errors would have a certain tendency to cancel out. Some of the data are shown in Fig. 18 on the relationship between the wave height and the ratio of lift force to longitudinal force. The relationships between the Keulegan-Carpenter number and the Reynolds number and the ratio of lift force to longitudinal force are shown in Fig. 19.

The limitations of the wave-generating equipment, the flumes and the force meters with which Bidde was working were such that tests could not be made with waves higher than the ones shown. The runs made with the highest waves show a slight tendency for the ratio of lift to longitudinal force to decrease. The ratios of lift to longitudinal force vs. the Keulegan-Carpenter number and the Reynolds number are plotted in Fig. 19. This graph indicates that the lift forces start at a Keulegan-Carpenter number of 3 to 5, and then increase steadily with increasing values. At a Keulegan-Carpenter number of about 15 the ratio of lift to longitudinal force shows a slight tendency to stop increasing. For the smaller diameter pile, the Reynolds number appears to be as good a parameter for correlation purposes as the Keulegan-Carpenter number. However, the Reynolds number fails to correlate the ratio of lift to longitudinal force when the values of the larger pile are compared with those of the smaller pile. For the smaller pile the value of the Reynolds number for eddies to form is about 0.5×10^4, whereas it goes up to 2.5×10^4 for the larger pile. For the same conditions the Keulegan-Carpenter number is 3 to 5 for both the piles.

The work described above was for uniform periodic long crested (regular) waves. In the ocean waves are irregular. So a few tests were made in the laboratory using irregular waves. Figure 20 presents samples of wave-force records for a random wave input. In Fig. 20b lift forces can be seen for the cases when the waves have a Keulegan-Carpenter number above a certain value. As an approximation, the results for the case of regular waves can be extended to the case of random waves. For example, the highest wave in Fig. 20b has a height of 0.3 ft. Using linear theory, the Keulegan-Carpenter number for this wave (assuming $T \approx 1.1$ sec.) can be calculated:

$\frac{u_{max} T}{D} \approx \frac{\pi H}{D} \approx 7.0$. The lift force for this wave is approximately 15 to 20% of the longitudinal force (cf lift and longitudinal forces for comparable waves in Figs. 20a and 20b).



Coefficient of Drag for Circular Cylindrical Piles of Various Diameters

(from Wiegel, Beebe and Moon, 1957)

FIGURE 1

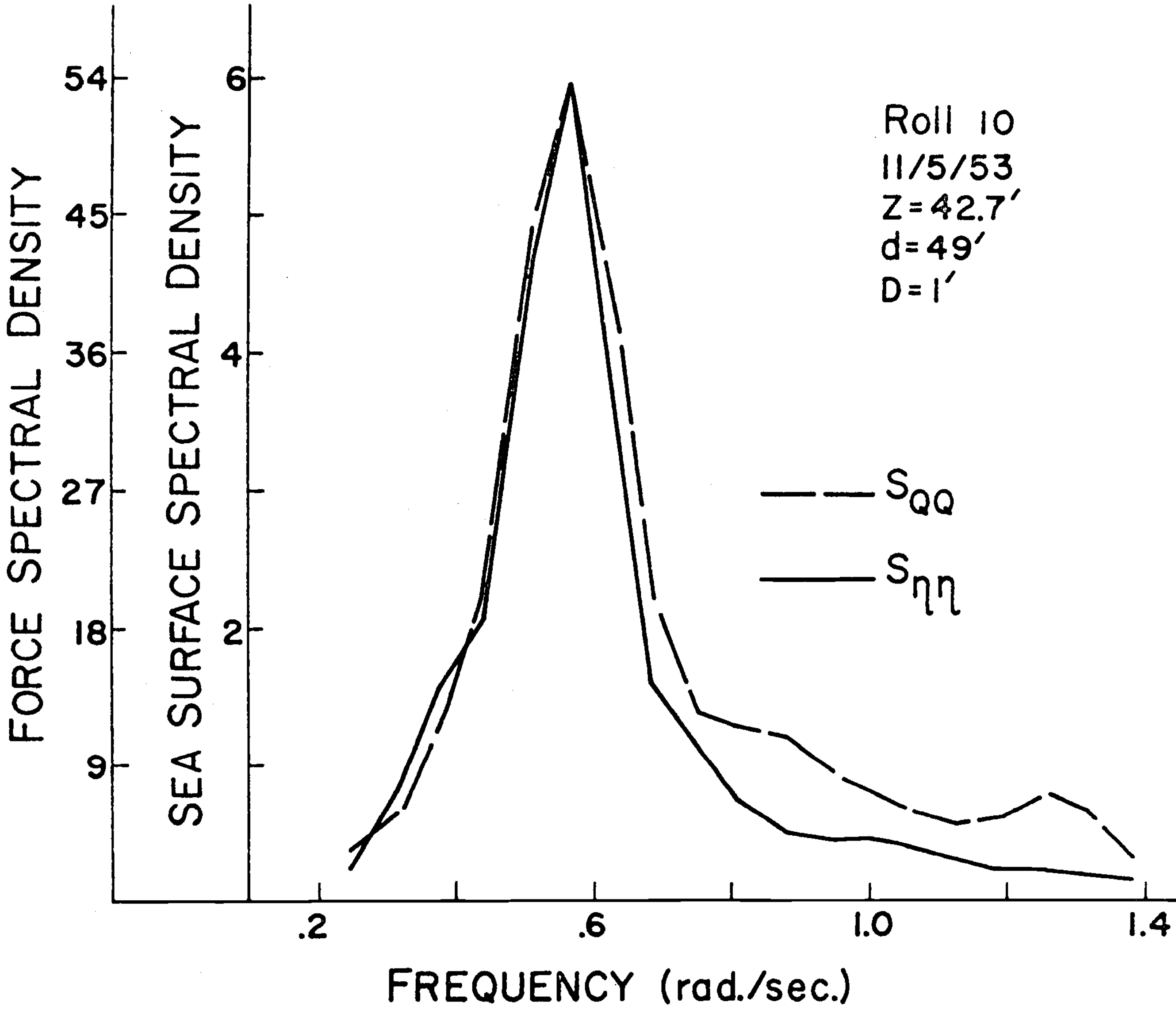


Figure 2. A comparison of force and sea-surface spectral densities for roll 10, Davenport data.

(From Borgman, 1966)

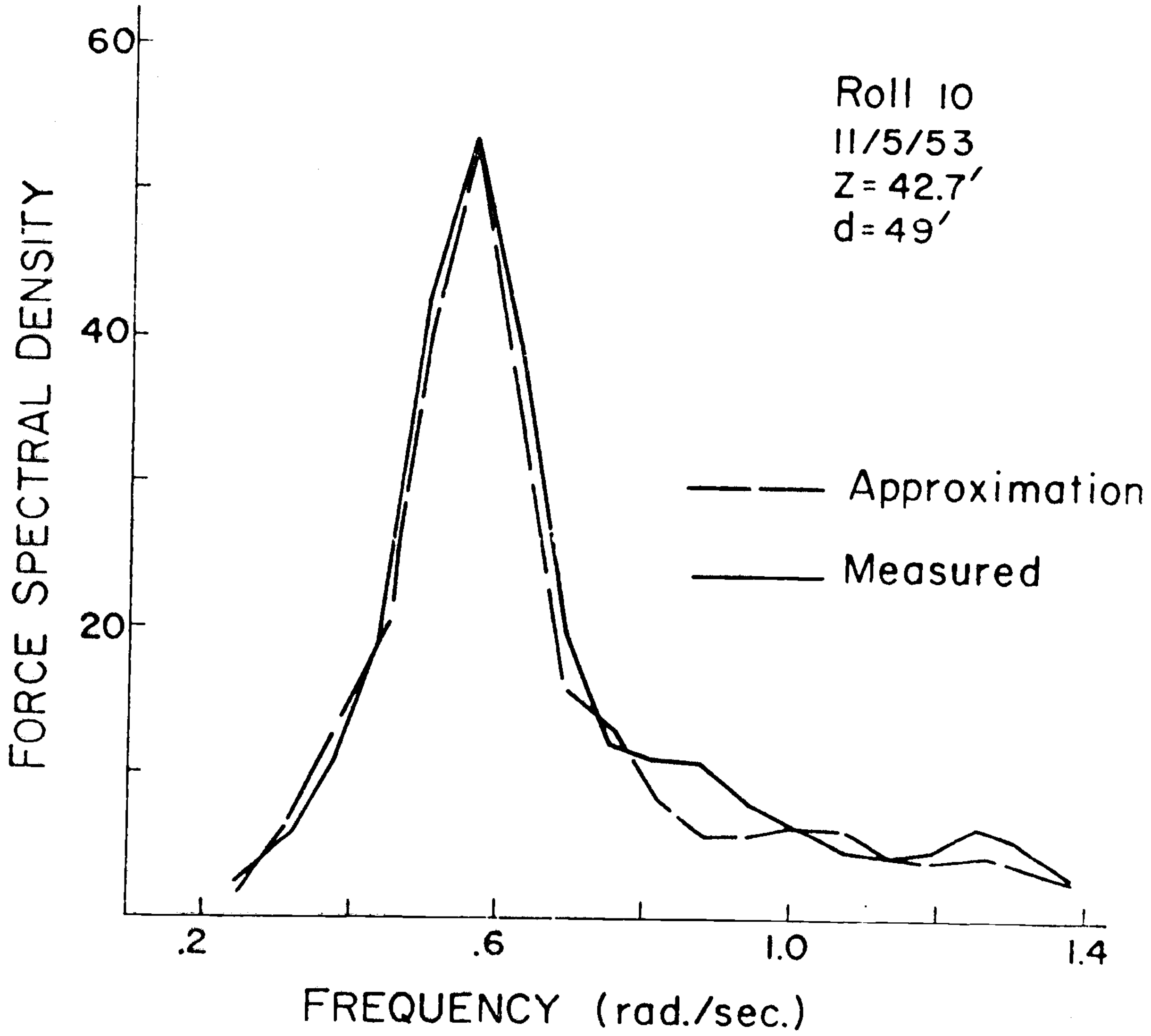
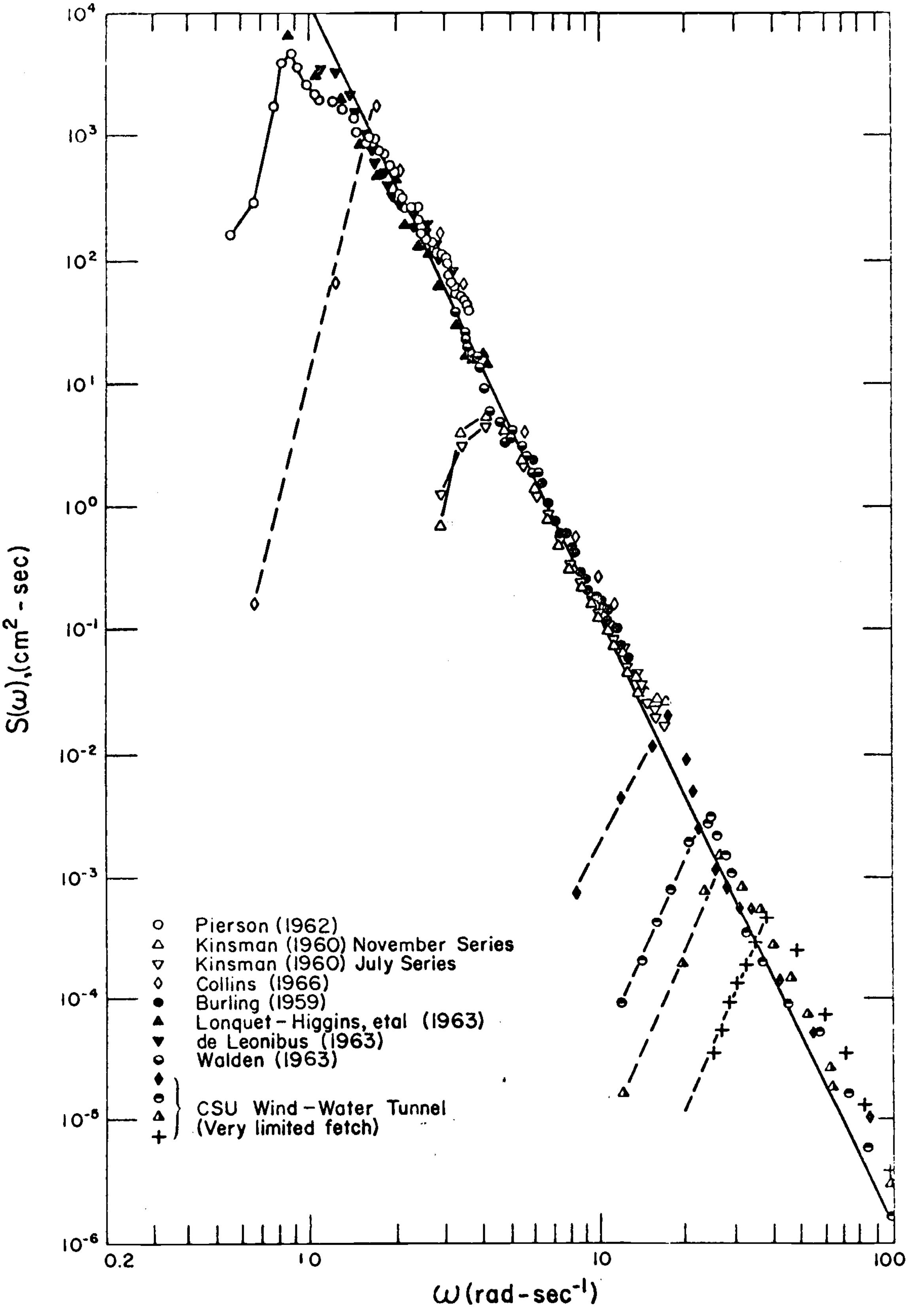


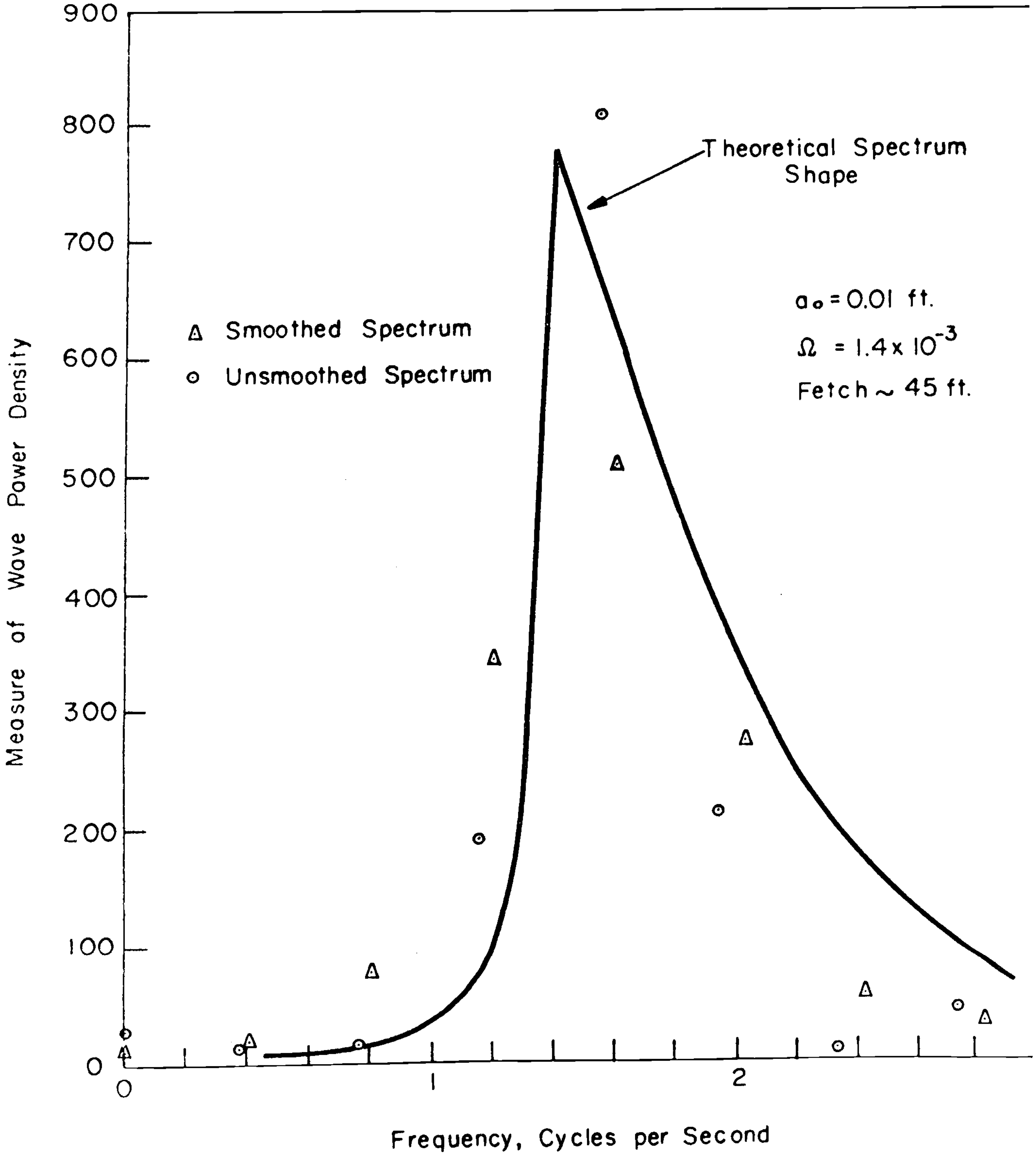
Figure 3. A comparison of the measured and computed force spectral density for roll 10, Davenport data.

(From Borgman, 1966)



(from Hess, Hidy and Plate, 1968)

Figure 4



COMPARISON OF SMOOTHED AND UNSMOOTHED WAVE POWEF SPECTRA WITH SHAPE OF THEORETICAL SPECTRUM

(from Wiegel and Cross, 1966

H-9426-A

FIGURE 5

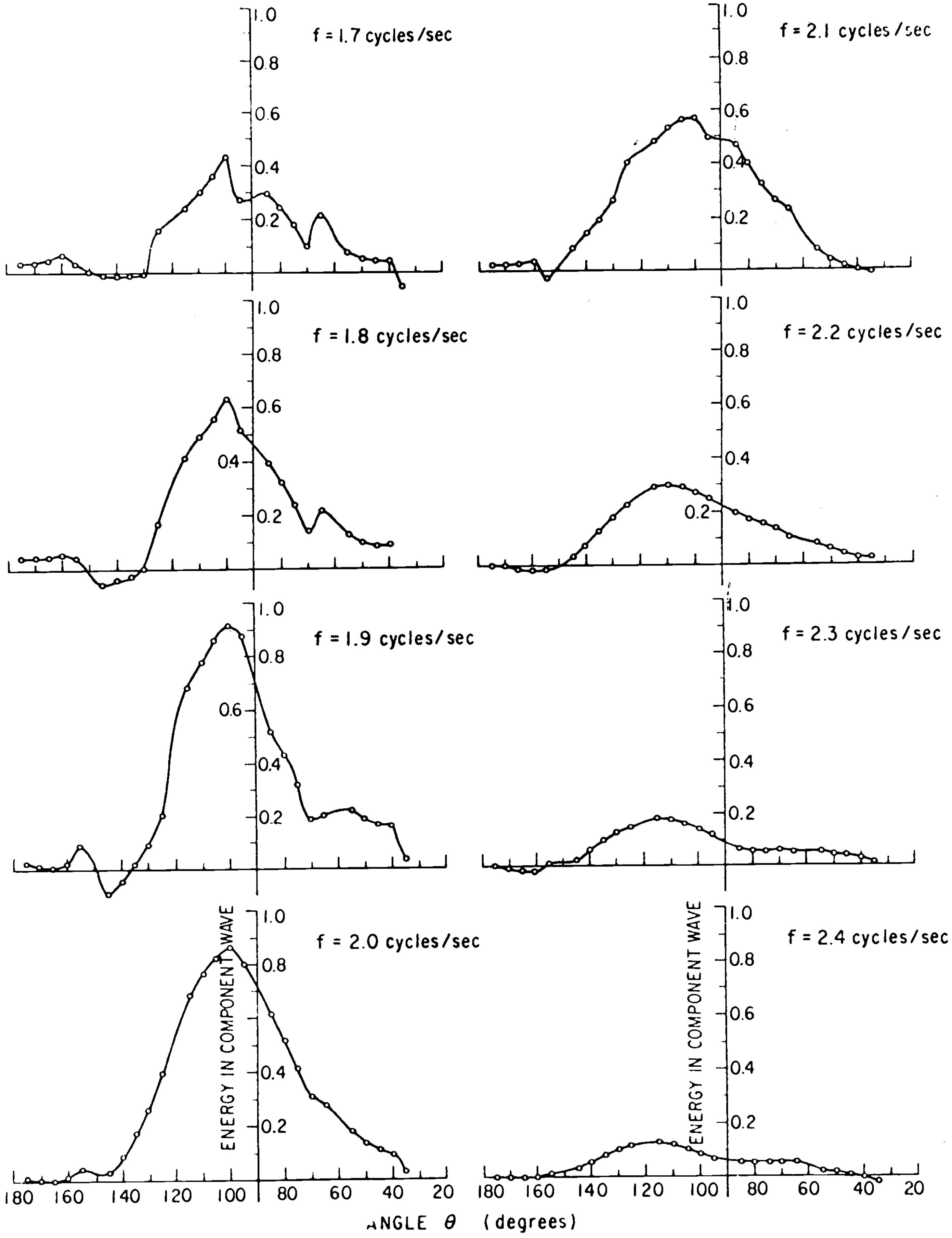


FIG. 6 DIRECTIONAL SPECTRA, DISCRETE ENERGY METHOD
(FROM MOBAREK 1965)

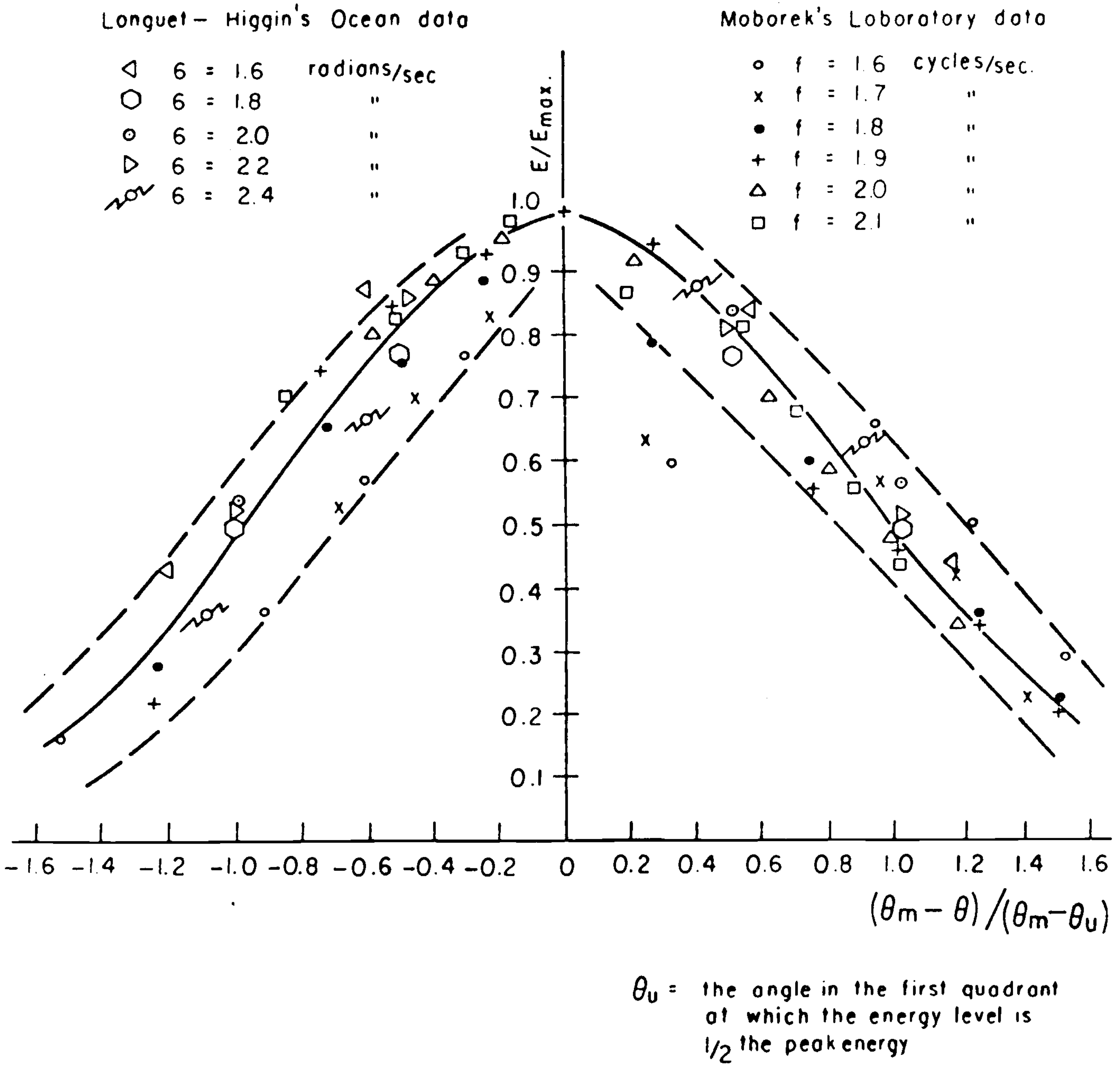


FIG. 7 NORMALIZED PLOT OF DIRECTIONAL SPECTRA
(FROM MOBAREK, 1965)

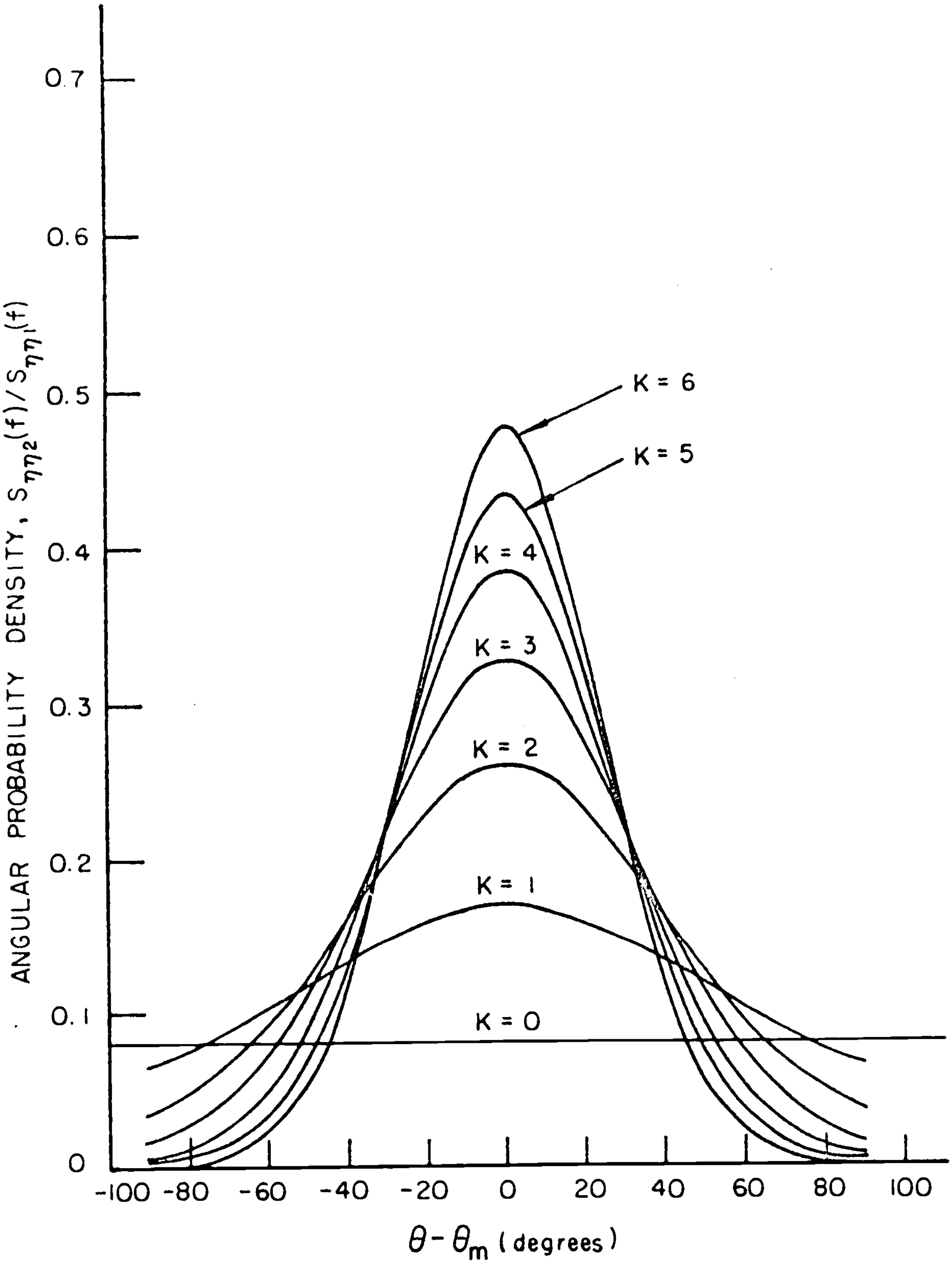


FIG. 8 THE CIRCULAR NORMAL DISTRIBUTION

(from Fan, 1968)

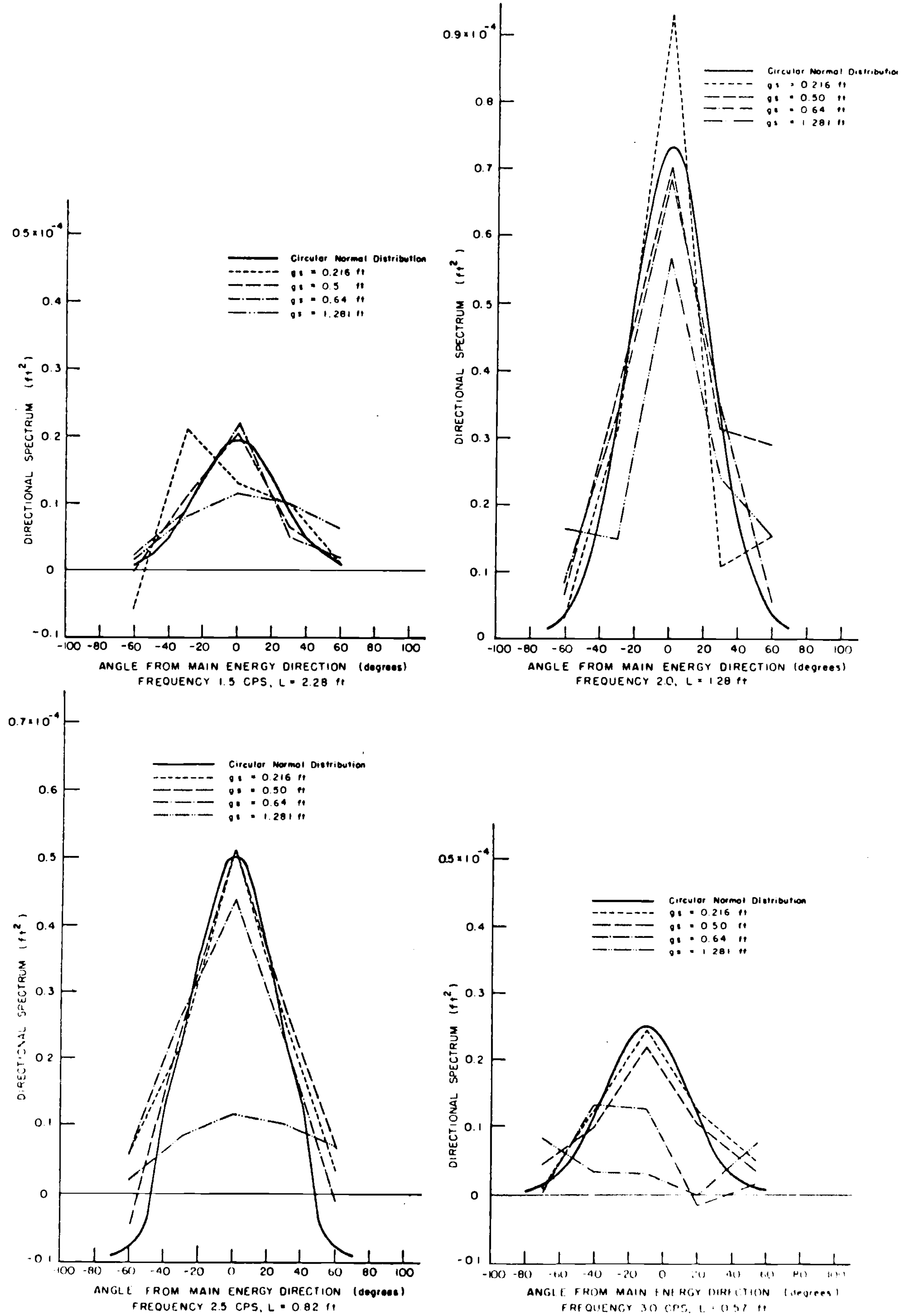


FIG. 9 COMPARISON OF DIRECTIONAL SPECTRAL ESTIMATES FOR VARIOUS GAGE SPACINGS
(from Fan, 1968)

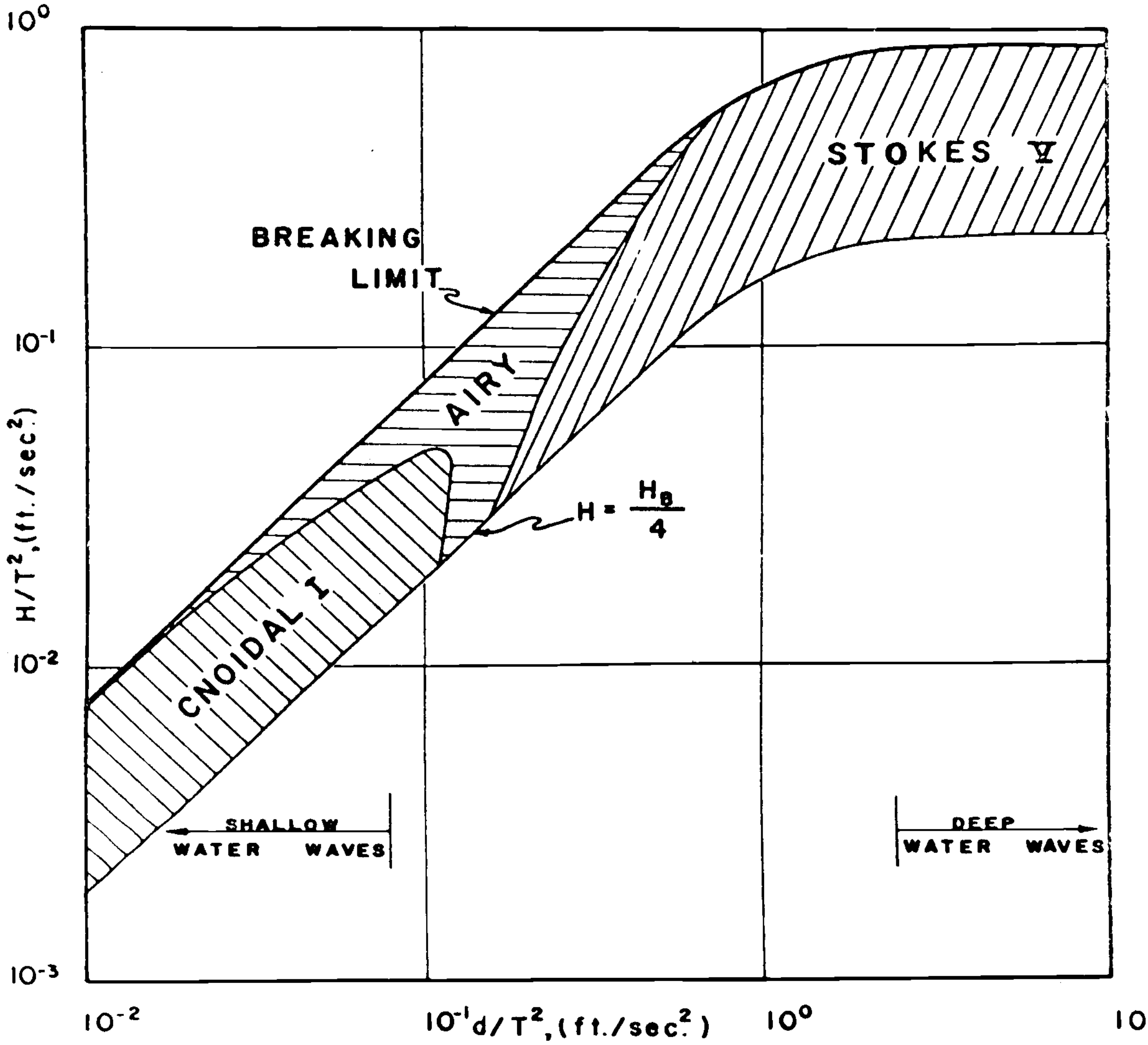


FIGURE 10
PERIODIC WAVE THEORIES PROVIDING BEST FIT TO DYNAMIC FREE SURFACE BOUNDARY CONDITION (ANALYTICAL THEORIES ONLY)
(FROM DEAN, 1968)

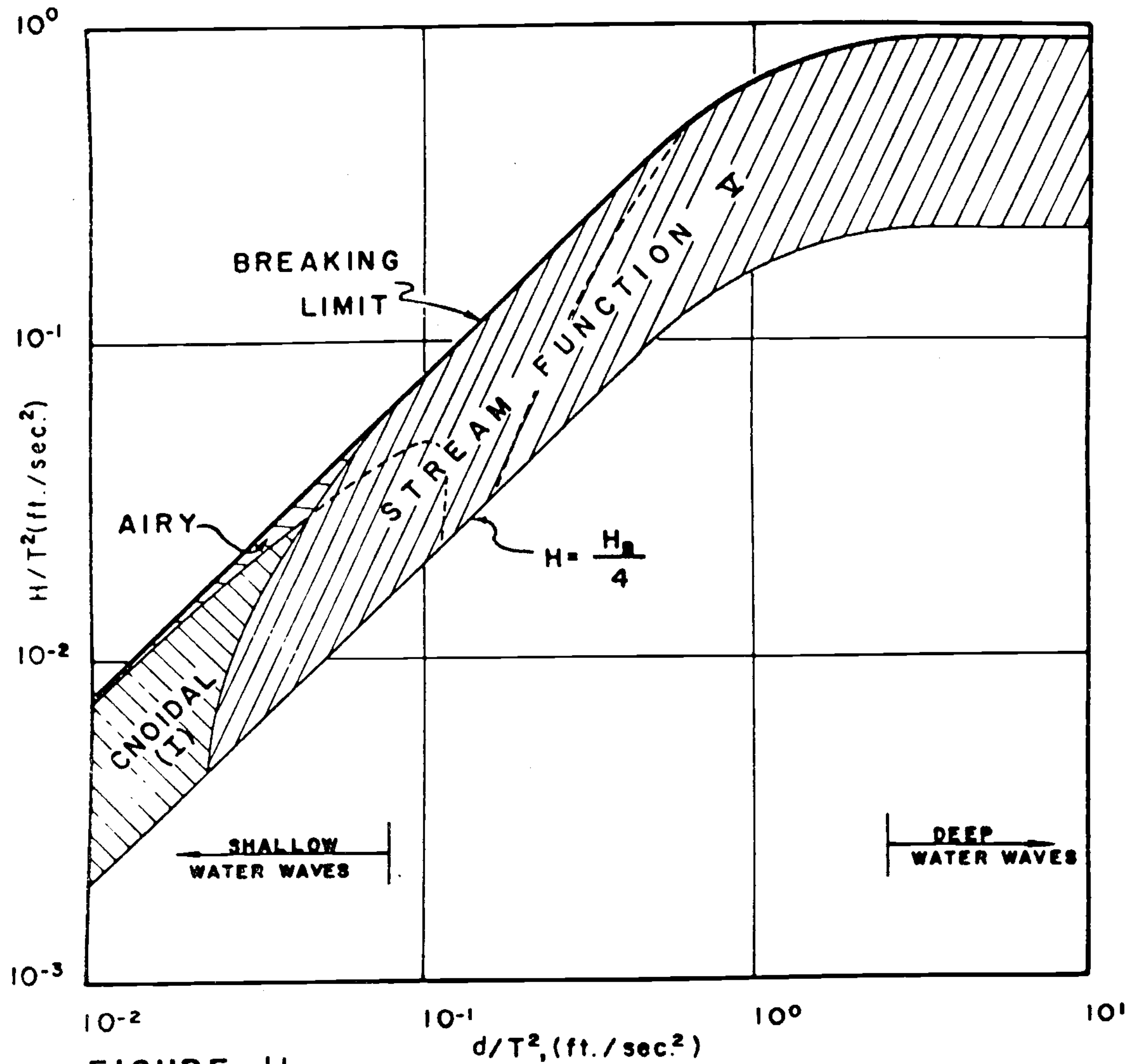


FIGURE 11
PERIODIC WAVE THEORIES PROVIDING BEST FIT TO DYNAMIC FREE SURFACE BOUNDARY CONDITION (ANALYTICAL AND STREAM FUNCTION V THEORIES)
(FROM DEAN, 1968)

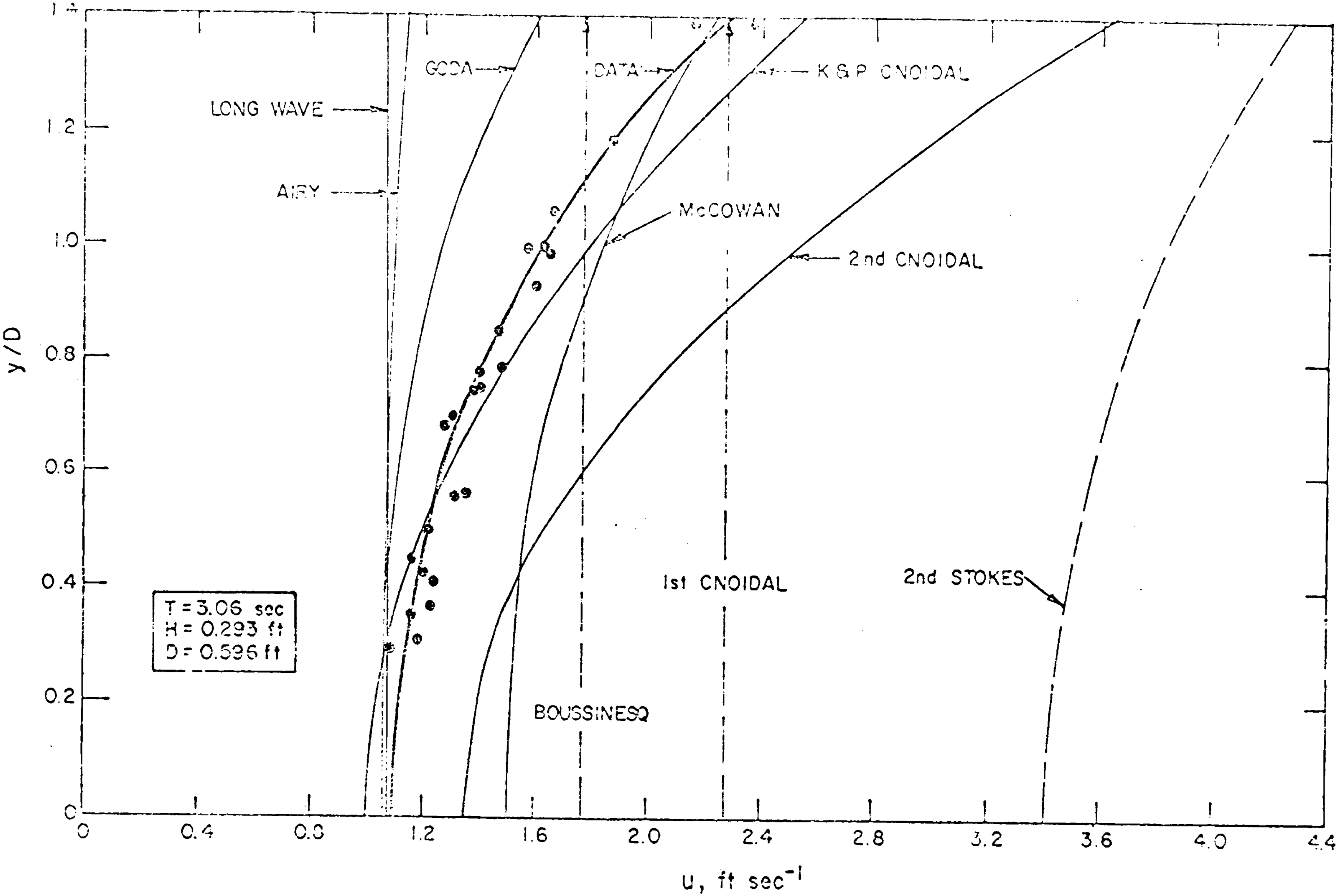
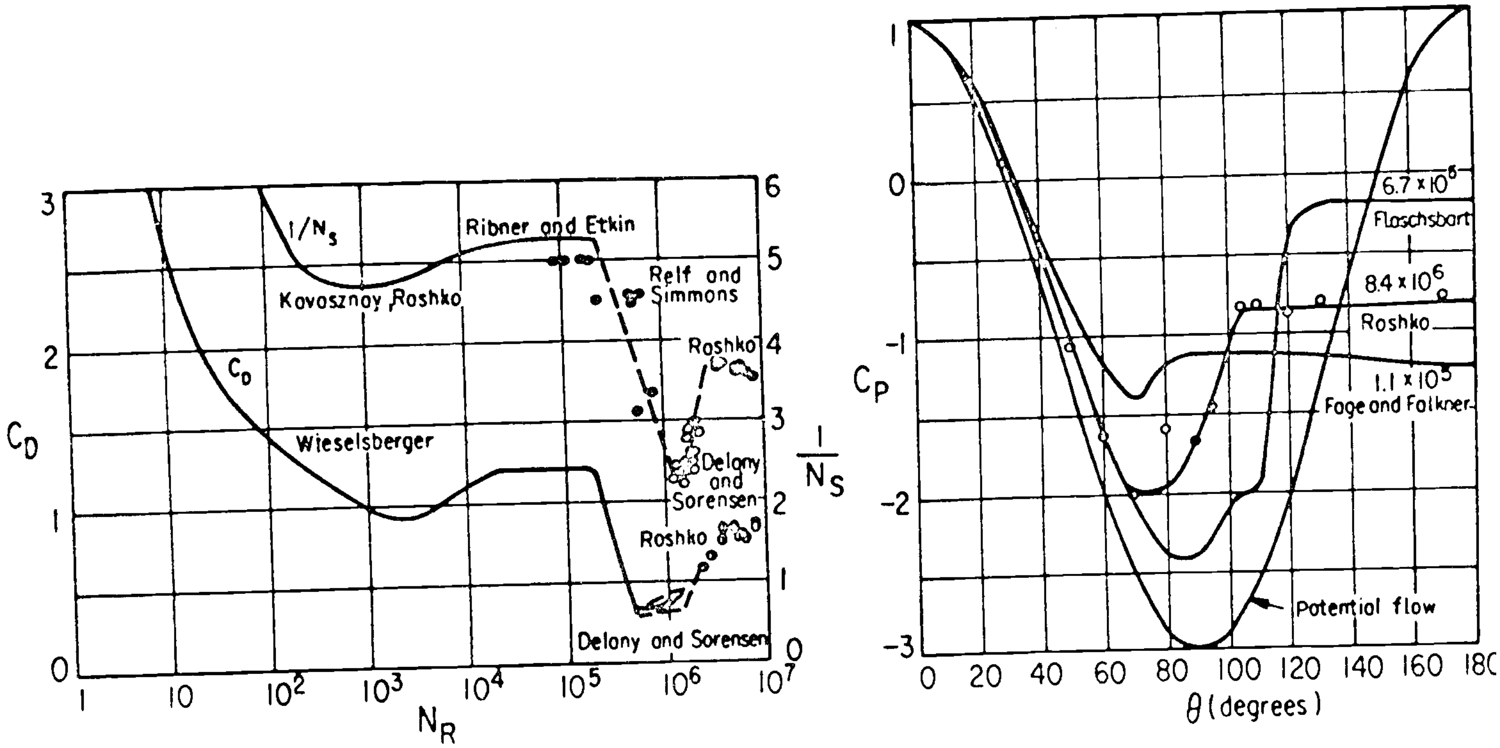
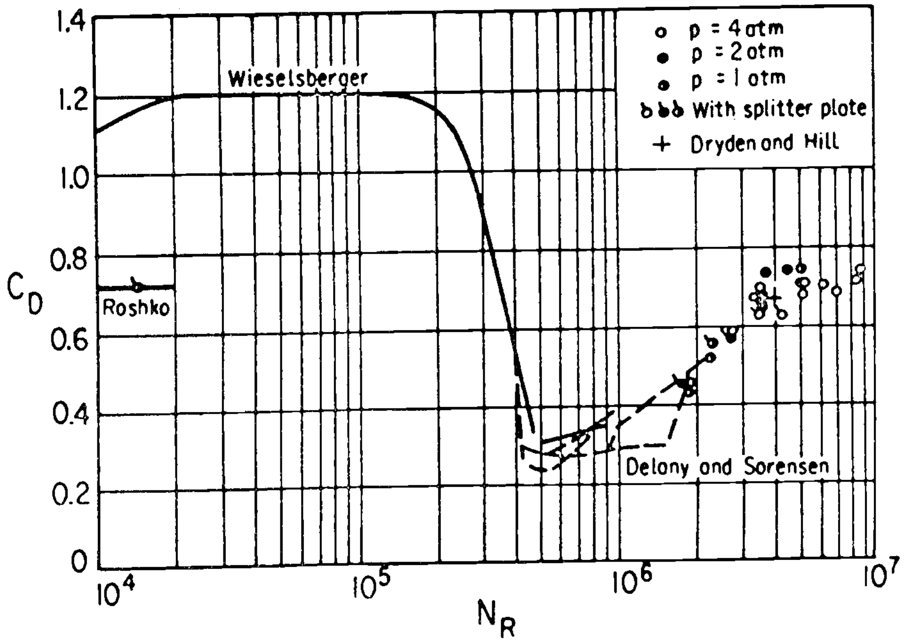


Figure 12 Horizontal Particle Velocity under the Crest - NEAR-BREAKING WAVE
(FROM LÉ MEHAUTÉ, DIVOKY AND LIN, 1968)



(a) Drag coefficient and reciprocal of Strouhal number

(b) Pressure distributions



(c) Drag coefficient

FIG. 13 STROUHAL NUMBER, DRAG COEFFICIENT AND PRESSURE COEFFICIENT AT HIGH REYNOLDS NUMBER FOR A CIRCULAR CYLINDER.

(From Roshko 1961)

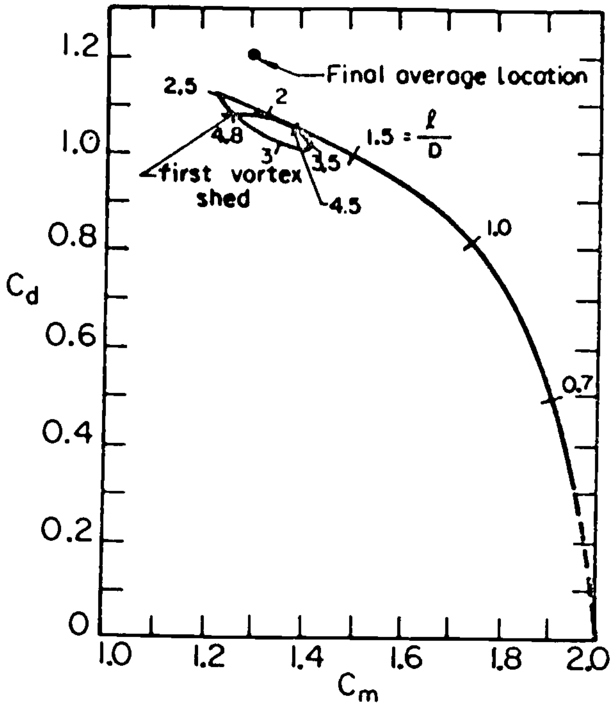
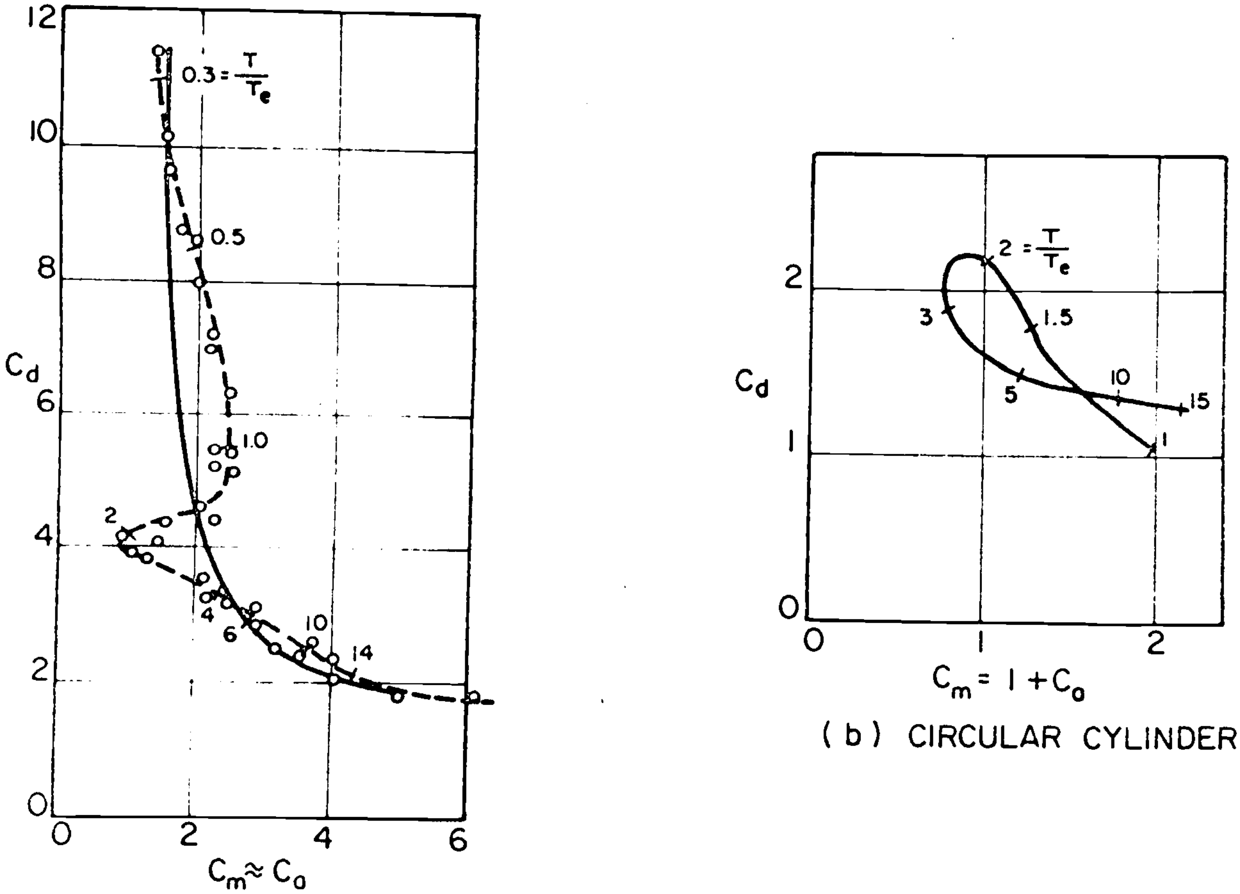


FIG. 14 CORRELATION OF DRAG AND INERTIA COEFFICIENTS
(From Sarpkaya and Garrison , 1963)



(b) CIRCULAR CYLINDERS

(a) PLATES

FIG. 15 INTER-RELATIONSHIP BETWEEN COEFFICIENTS OF COEFFICIENTS OF DRAG AND OF VIRTUAL MASS FOR (a) FLAT PLATES AND (b) CIRCULAR CYLINDERS (From Mc Nown and Keulegan , 1959)

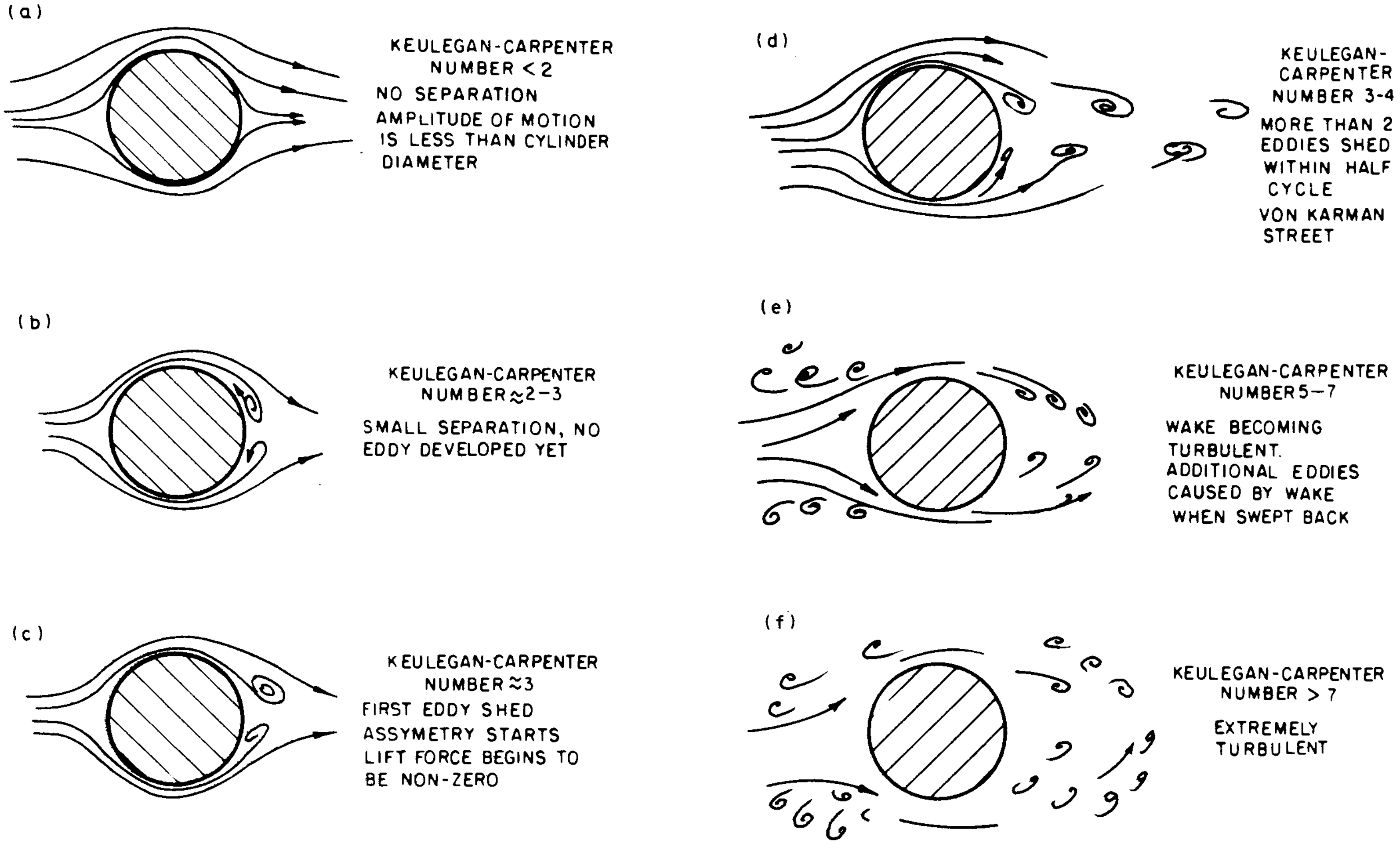


FIG. 16 WAKE CHARACTERISTICS AS A FUNCTION OF THE KEULEGAN-CARPENTER NUMBER (BIDDE, 1970)

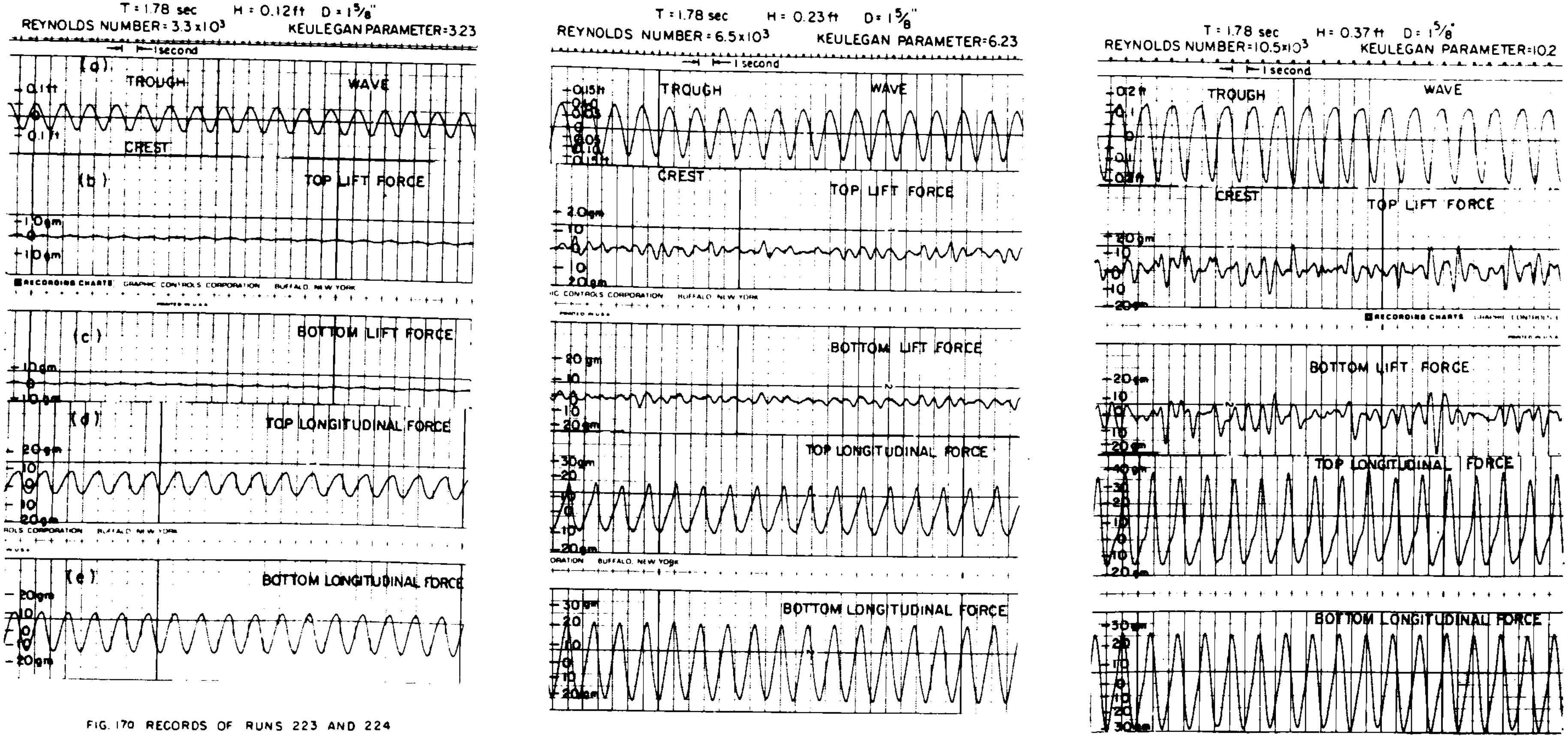


FIG. 17a RECORDS OF RUNS 223 AND 224

FIG 17b RECORDS OF RUNS 217 AND 218

FIG 17c RECORDS OF RUNS 209 AND 210

FIG. 17 SAMPLE WAVE AND FORCE RECORDS, UNIFORM PERIODIC WAVES (BIDDE, 1970)

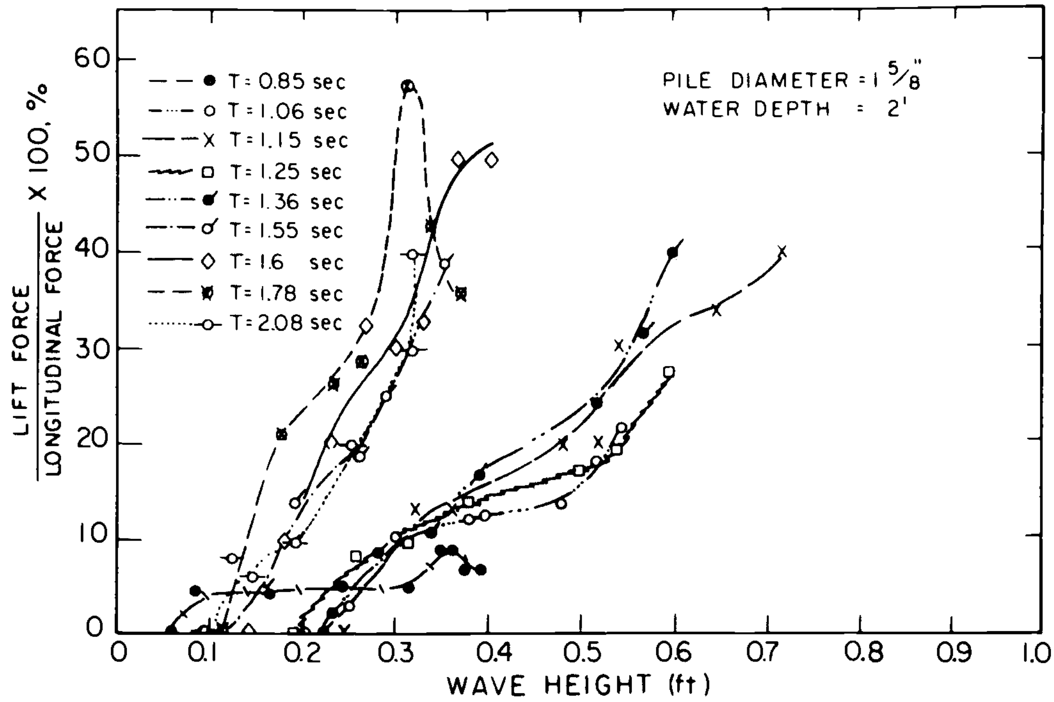


FIG. 18a PILE DIAMETER = 1 5/8" AND WATER DEPTH = 2 FT, RUNS 69 TO 244

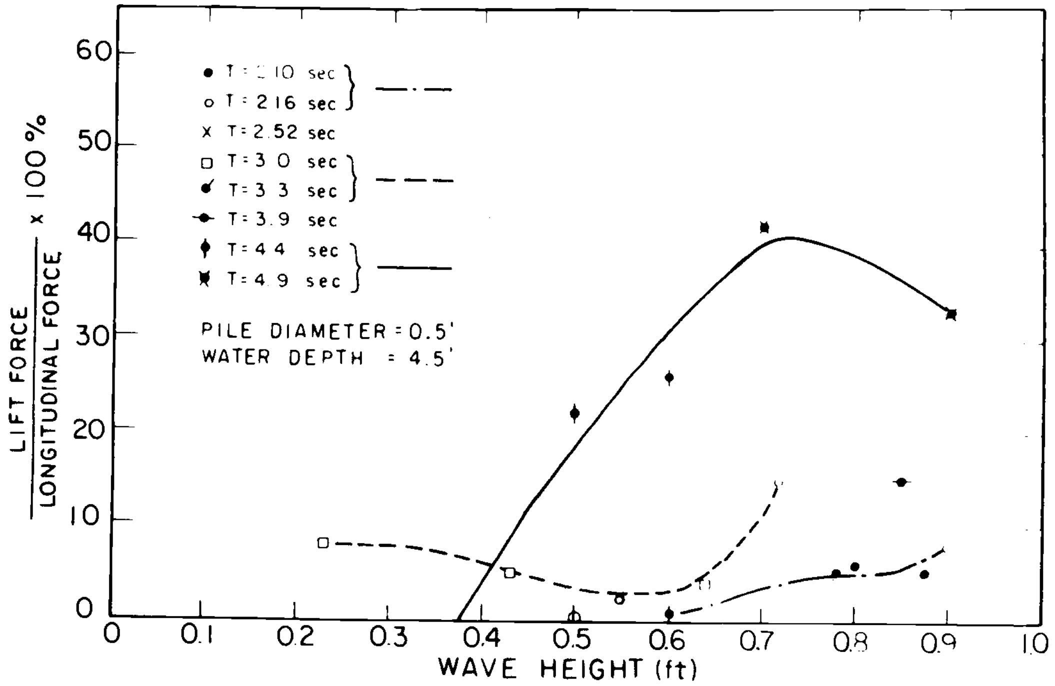


FIG. 18b PILE DIAMETER = 0.5 FT AND WATER DEPTH = 4.5 FT, RUNS 313 TO 348

FIG. 18 RELATIONSHIP BETWEEN RATIO OF LIFT TO LONGITUDINAL FORCE AND WAVE HEIGHT

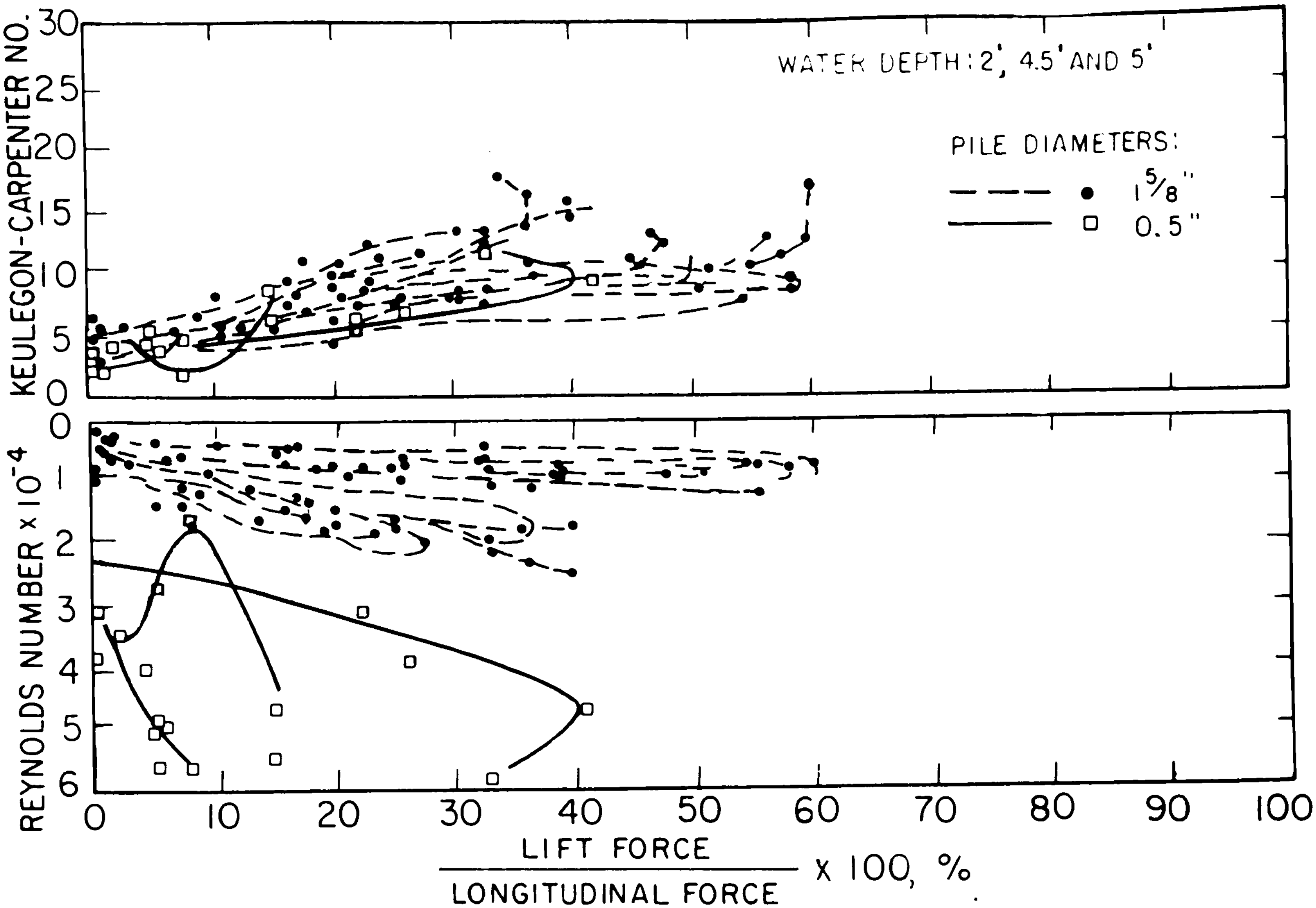


FIG. 19 KEULEGAN-CARPENTER NUMBER AND REYNOLDS NUMBER vs RATIO OF LIFT TO LONGITUDINAL FORCE, ALL RUNS

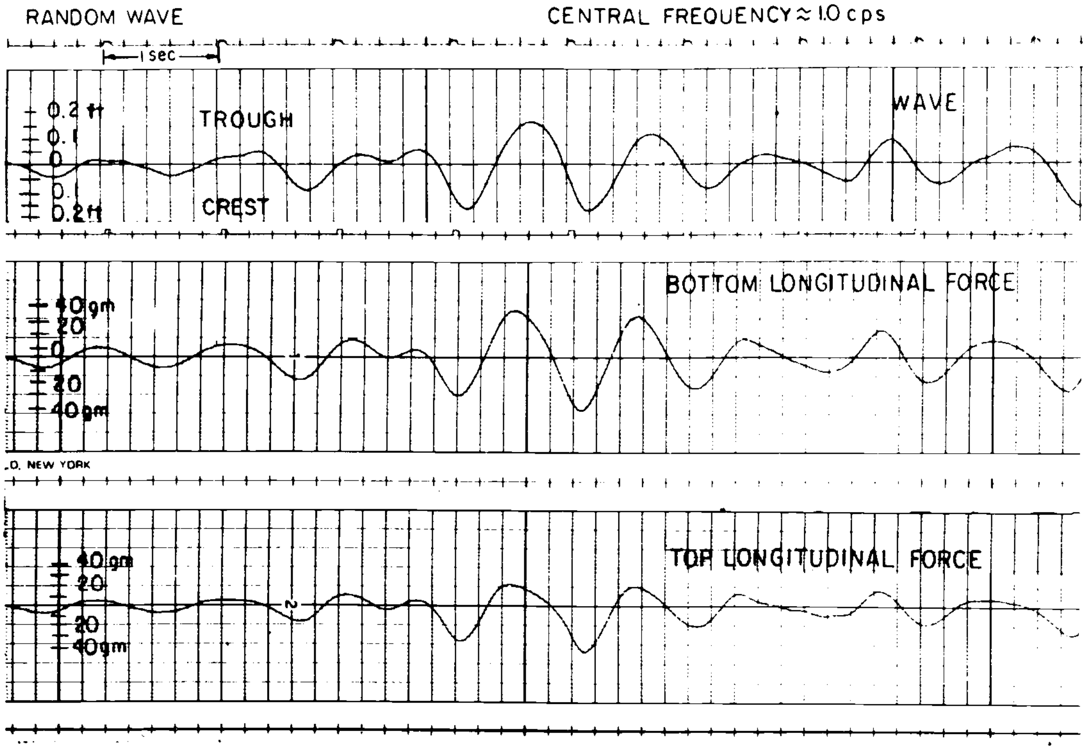


FIG 20a RECORDS OF RUN 366

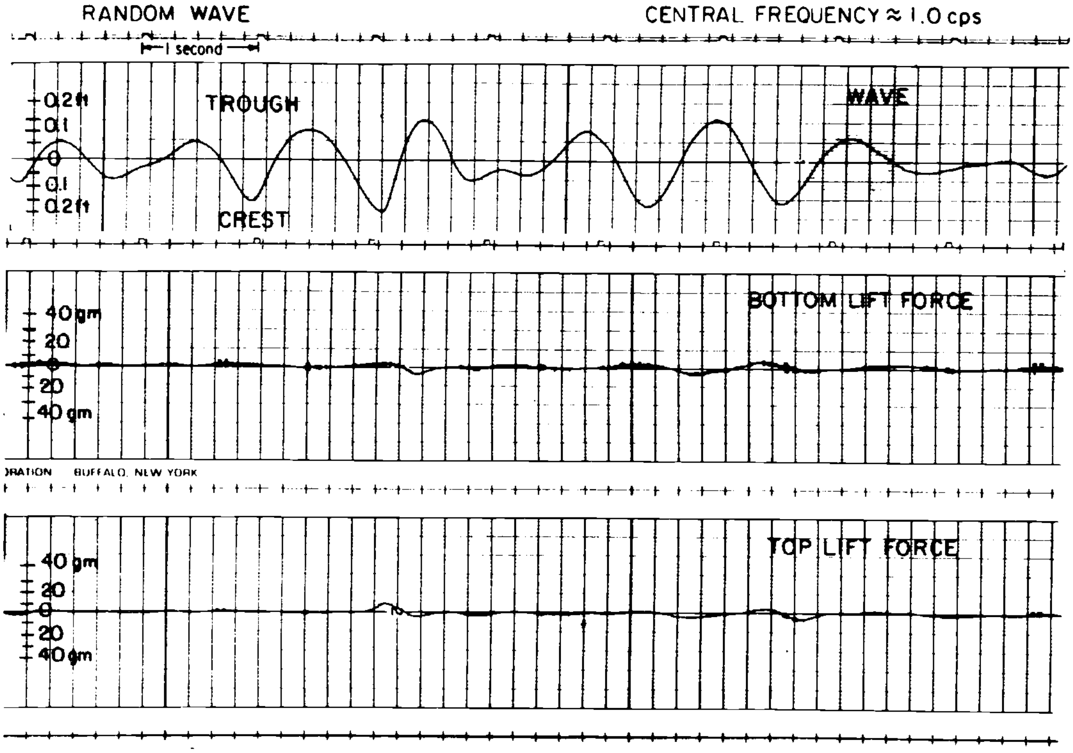


FIG 20b RECORDS OF RUN 365

FIG. 20 SAMPLE WAVE AND FORCE RECORDS, IRREGULAR WAVES (BIDDE, 1970)

LIST OF SYMBOLS

a_i = Amplitude of wave component, feet

A = Projected area, feet^2

A_o = Cross sectional area of cylinder, feet^2

A_1, A_2, A_3 = Coefficients in Stokes' third order wave theory, dimensionless

B = Volume of submerged body, feet^3

cn = Jacobian cnoidal elliptical function, dimensionless

C_1 = $\frac{1}{2} \rho_w C_D D$; pound-second^2/feet^3

C_2 = $\rho_w C_m \pi D^2/4$, pound-second^2/foot^2

$C(f)$ = Co-spectra, feet^2-second

C_a = Coefficient of added mass, dimensionless

C_D = Coefficient of drag, dimensionless

C_m = Coefficient of mass, dimensionless

d = Water depth, with no waves present, feet

D = Diameter of pile, feet

$\overline{D}$ = Distance between a pair of wave recorders, feet

dp/dx = Pressure gradient, pounds/foot^3

du/dt = Horizontal component of water particle total acceleration, feet/second^2

dv/dt = Total acceleration, feet/second^2

$E(k)$ = Complete elliptic integral of the second kind of modulus k, dimensionless

f = Wave frequency, 1/T, cycles/second

f_2, f_3 = Functions in Stokes' third order wave theory, dimensionless

f_e = Eddy frequency, cycles/second

f_f = Acceleration of fluid in general case of unsteady flow, feet/second^2

f_o = Wave component frequence for which spectral density peak value occurs, 1/second

F = $F_D + F_I$, total force, pounds

$F(t)$ = Horizontal component of force, per unit length of pile, statistical theory, pounds/foot

F_D = Drag force, pounds

$F_h(s)$ = Horizontal component of force on a vertical pile, pounds

F_I = Inertia force, pounds

F_{Ih} = Horizontal component of inertia force, pounds

F_p = Integrated pressure force, pounds

g = Acceleration of gravity, feet/second^2

$G(r)$ = Defined by Equation 22, dimensionless

$G_1(r)$ = First term of series representing G(r), dimensionless

H = Wave height, feet

H_d = Design wave period, seconds

H_s = Significant wave period, seconds

$I_o(k)$ = Incomplete Bessel function of the first kind of zero order for an imaginary argument, dimensionless

J_1 = Bessel function of the first kind, dimensionless

k = integer, dimensionless

K = Measure of concentration about the mean, circular normal distribution function, dimensionless

$K(k)$ = Complete elliptic integral of the first kind of modules k, dimensionless

L = Wave length, feet

l = Distance traveled by cylinder from position of rest, feet

m_k = Statistical moment, defined by Equation 38, feet^2-ω^k

m_o = m_k for $k = 0$, variance of wave surface time history, feet^2

M_a = Added mass, slugs

M_c = Mass per unit length of cylinder, slugs/foot

M_o = Mass of a submerged body, slugs

N_s = Strouhal number, dimensionless

p = Pressure due to wave, at some point x, y, z in the water, pounds/feet ^{2}

$P(\alpha,K)$ = Circular normal distribution function, dimensionless

$Q(f)$ = Quadrature spectra, feet^2-second

r = In $G(r)$, $r = R_{VV}(\tau)/\sigma^2$, dimensionless

$R_{AA}(\tau)$ = Covariance function of the horizontal component of water particle acceleration, feet^2/second^4

$R_{FF}(\tau)$ = Covariance function of the horizontal component of force, pounds^2/foot^2

$R_{VV}(\tau)$ = Covariance function of the horizontal component of water particle velocity, feet^2/second^2

$R_{\eta\eta}(\tau)$ = Covariance function of wave surface, feet^2

S = Vertical coordinate, measured from the ocean bottom (i.e., $S = 0$ at ocean bottom), feet

$S_{AA}(f)$ = Wave water particle horizontal component of water particle local acceleration spectral density, feet^2/second^3

$S_{FF}(f)$ = Wave force per unit length of pile (horizontal component) spectral density, pounds^2-second/feet^2

$S_{MM}(f)$ = Total wave induced moment about pile bottom (horizontal component) spectral density, foot^2-pounds^2-second

$S_{QQ}(f)$ = Total wave force (horizontal component) spectral density, pounds^2-second

S_s = Vertical distance from the ocean bottom to the water surface, feet

S_t = Elevation of wave trough above ocean bottom, feet

$S_{VV}(f)$ = Wave water particle horizontal component of velocity, feet^2/second

$S_{\eta\eta}(f)$ = Wave surface spectral density, feet^2-second

$S_{\eta\eta 1}$ = One dimensional wave energy spectral density in directional spectra theory, feet^2-second

$S_{\eta\eta 2}$ = Directional wave energy spectral density, feet^2-second/radian

$S(\omega)$ = Wave spectral density, $S_{\eta\eta}(f)/\pi$, feet^2-second

t = time, seconds

T = Wave period, seconds

T_Λ = Transfer function, Equation 24b, 1/second^4

T_d = Design wave period, seconds

T_e = Eddy period, second

T_s = Significant wave period, seconds

T_V = Transfer function, Equation 24a, 1/second^2

U = Horizontal component of water particle velocity, feet/second

V = Velocity, feet/second

V_{rms} = Root mean square value of V, feet/second

V_w = An "average" horizontal component of water particle velocity, feet/second

x = Horizontal coordinate, $x = 0$ at wave crest, feet

y_s = Vertical distance from the undisturbed water surface to the water surface when waves are present, feet

Y_1 = Bessel function of the second kind, dimensionless

α = Angle measured from the mean, degrees

β = A phase angle, diffraction theory for wave force, radians

$\overline{\beta}$ = Direction between a pair of wave recorders, degrees

$\delta\omega$ = Circular frequency interval, cycles/second

θ = Horizontal angle in directional spectra, degrees

θ_m = Direction angle of peak value of directional wave energy spectral density, degrees

ρ = Mass density of a fluid slugs/foot^3

ρ_w = Mass density of water, slugs/foot^3

σ^2 = $2 \int_{-\infty}^{\infty} S_{VV}(f)df$, feet^2/second^2

τ = Lag in covariance function, seconds

ω = Circular frequency, $2\pi/T$, radians/second

ω_o = Circular frequency at which peak value occurs in wave spectrum, radians/second

$\partial u/\partial t$ = Horizontal component of water particle local acceleration, feet/second^2

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Presented January 12, 1971, by Dr. Roderick Mesecar, Oceanography Department, Oregon State University, Corvallis, Oregon.

A Brief Review of the Moored Instrumentation Platforms Used for Oceanographic Research at Oregon State University

One of the most persistent problems of the deep-sea oceanographer is how to get long-term time series data of the ocean parameters he is interested in.

The Oceanography department operates two seagoing research vessels: the R/V YAQUINA and the R/V CAYUSE. These vessels cost from 2,200 to 1,500 dollars per day to operate and are in heavy demand. Economics and their lack of availability generally eliminates the use of these vessels for this type of research.

To circumvent this problem, the Oceanography department started to investigate the use of moored instrument platforms for air-sea research. In 1965, a research buoy based upon the catamaran concept was purchased from Scripps Institution of Oceanography. The buoy as seen in figure 1, was 8 feet wide and 12 feet long and could easily be transported on a 2-1/2 ton flat bed truck. The pontoons were rigid plastic foam with a fiberglass shell. Bridging for the buoy deck was common lumber and marine plywood. The mooring point was at the geometric center of the buoy bridging structure. Free flooding compartments are located to the outside of the pontoons for added stability during high wave condition. This buoy was held on station with a taut line mooring of 3/4-inch nylon line under an average tension of 300 pounds.

The buoy was moored in the following manner: the buoy was set adrift from the ship with the correct length of mooring line attached for the station water depth. The free end of the mooring line was then attached to a concrete anchor still attached to the ship. Once the ship was maneuvered over the mooring site, the anchor was cut loose to free fall to the bottom. The falling anchor quickly pulled the buoy on location.

The instrumentation package was contained in a light and water-tight case on top of the buoy. Inside the case was a panel of analog instruments displayed similar to those in an aircraft cockpit for measuring seawater temperatures at seven positions below the surface, wind speed and directions, compass heading, mooring line tension, air temperature and time. The data recording media was film. A 16 mm camera with a fixed open shutter was focused on the instrument panel. Under clock control, a light would flash exposing the film and advance the camera. The film could only be retrieved in a calm sea without fear of taking a wave over the open instrument case.

This buoy was moored 13 miles west of Yaquina Head for about six months, which showed the mooring system could be successfully used in the Oregon coastal areas. Later developments of this buoy by Scripps are the "bumble bee" series currently being used in the Pacific as satellite buoys to the large Convair Ocean Data Station buoy.

The catamaran buoy is basically a sea surface follower and is not adaptable to some research problems. About two years ago, Dr. Stephen Pond developed a buoy for air-sea interaction studies. The requirement for his buoy was that it should be as free as possible of sea surface motion and easily deployed at sea with minimum personnel. An instrumentation platform to meet these requirements is shown schematically in figure 2. The tower is modularized so that tower sections can be added to in 10 foot sections and buoyancy can be added in 400 pound increments. The main stem is made up of 10 foot sections of galvanized radio antenna tower for a total of 60 feet. Buoyancy is provided by multiple toriod floats that are plastic foam covered with fiberglass. Mounting brackets are moulded into the fiberglass casing so that additional toriods can be stacked together for additional buoyancy. Figure 3 shows the bellmouth at the bottom end of the buoy with the buoyancy toriods mounted on the frame.

Dr. Pond's tower can be used in the bay or deep ocean. When it is used in the bay, a large anchor is put in place and then the tower is winched down to operating level with a steel cable through the bellmouth. Additional guy lines can be strung from the tower to satellite anchors if more rigidity is necessary. For some work, the tower is used free floating as a stable platform. In that case the tower is towed to sea by the bellmouth end which has had an extra 1,000 pounds of ballast added to it. When the towing end is released, the tower uprights itself and is ready for use. In figure 4, the tower is ready for righting. In its present configuration this tower has a 1,000 pound pay load and can be climbed by the researcher. Six watertight canisters, 10 inches in diameter by 35 inches high, house the power supply and instrumentation. These canisters are located just above the buoyancy toriods and just below the water surface. Wind speed and direction, wet and dry bulb air temperature, inclinometers, compass, and wave staff have been some of the sensors used on the tower.

Conditioned signals from the tower are transmitted over an electric cable to the ship where they are recorded on a 14 channel analog tape recorder. The analog tapes are then returned to the laboratory and digitized for data processing on the CDC-3300 computer.

A much larger buoy with sophisticated electronics is being developed by the Themis program at Oregon State University. An artist's rendering of this buoy is shown in figure 5. This buoy is 180 feet long with a dead weight of 60,000 pounds and a pay load of 5,000 pounds. It extends out of the water about 30 feet with areas for mounting instruments along its entire length. The buoy is towed in a prone position and then righted at the mooring site by flooding some of its buoyancy tanks. A two point mooring has been used on this buoy in ocean depths of 1,600 feet in the following manner. Anchors are placed about 2,100 feet apart with a line up from each anchor to a subsurface spring float directly above it and 75 feet below the sea surface. Tether lines are then run from the spring buoys over and attached to the buoy at a point 30 feet below the surface. This type of buoy has been in moored service almost two years.

For additional details on the mooring of this buoy, refer to an article by Dr. Stephen Neshyba in the April 1970 issue of Oceanology, page 22.

The tremendous potential of the buoy is in its instrumentation flexibility. It is outfitted with line-of-sight, full duplex radio transmitters-receivers for the transmission of data at fixed intervals or on demand basis to a Corvallis based shore station. The shore station consists of telemetry equipment coupled to a PDP-15 Digital Equipment Corporation computer which is used as a controller for the data link. Under program control, the controller can handle data on a 24-hour basis with the possibility of using an adaptive control concept for changing data rates during a more interesting recording period.

Some data reduction and presentation will be done on the PDP-15; however, eventually a cable data link will be established with the University CDC-3300 computer for large analysis programs as illustrated in figure 6.

Some transducers planned for the Themis buoy are wind speed and direction, wave heights, winching system for measuring water temperature in a continuous profile up to 500 meters below the surface and line tensions on the mooring lines.

A combination of batteries and propane electric power generation on board the buoy gives the instrumentation abour five months sea life before it needs fuel service.

Although these descriptions of buoys used by the Oceanography department at Oregon State University are brief, I hope they tend to illustrate the trend of efforts to fill the platform requirements needed for the acquisition of spacial time series oceanic data. Please feel free to contact me for additional information.

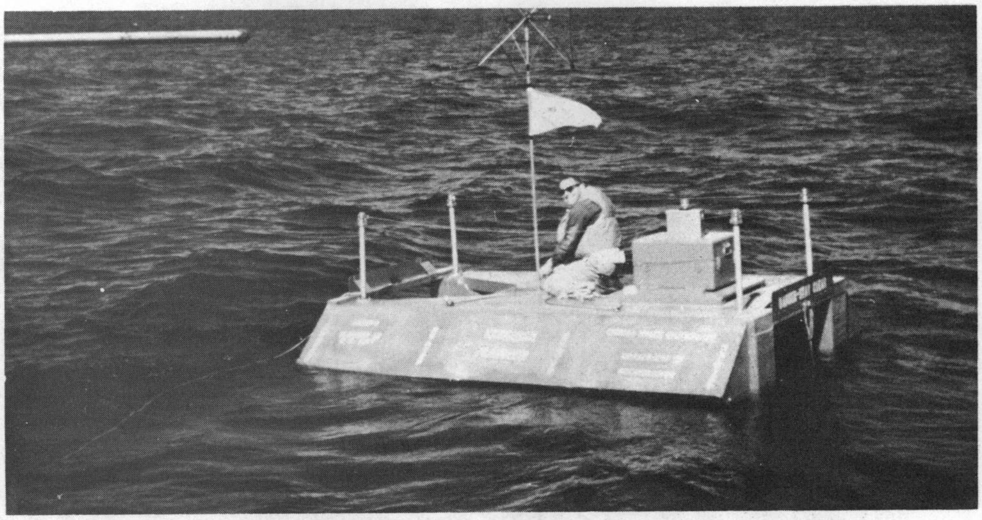


Figure 1

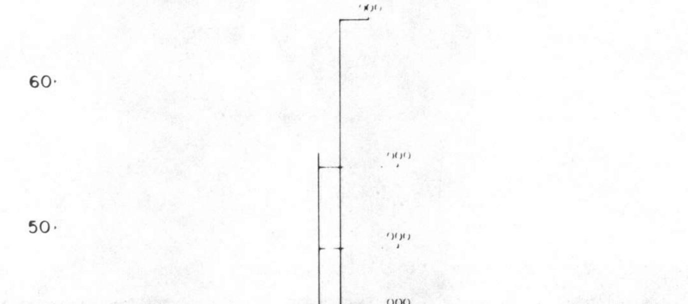


Figure 2

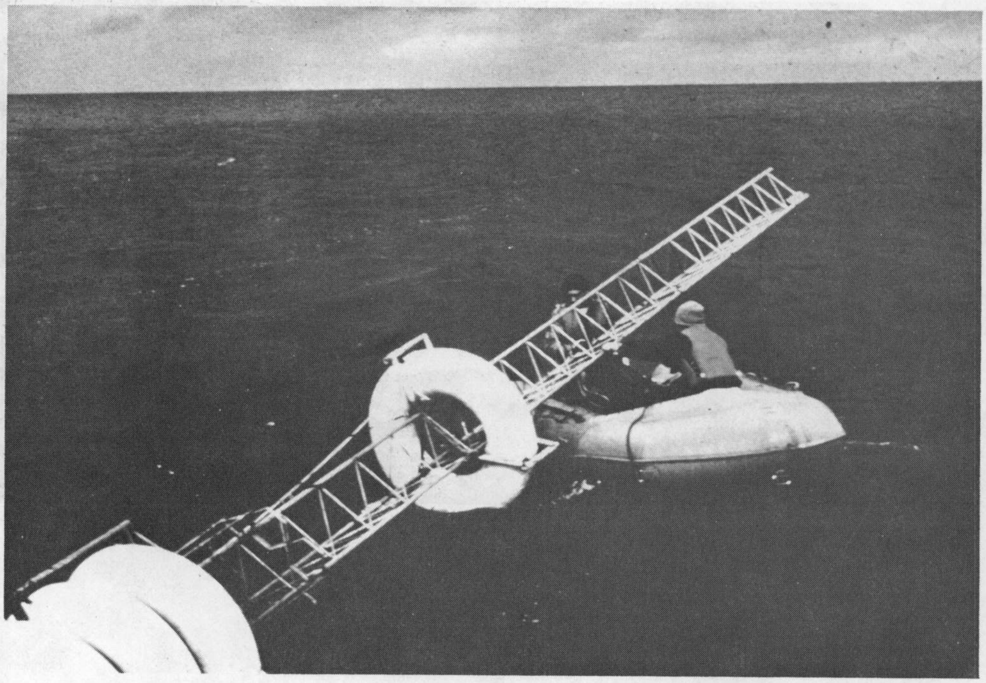


Figure 3

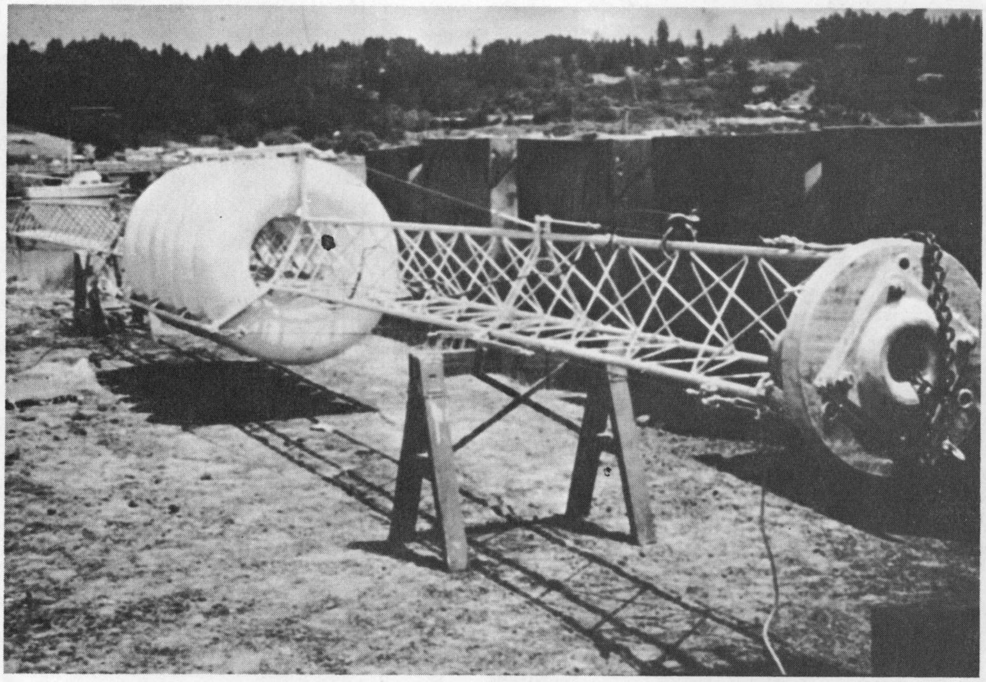


Figure 4

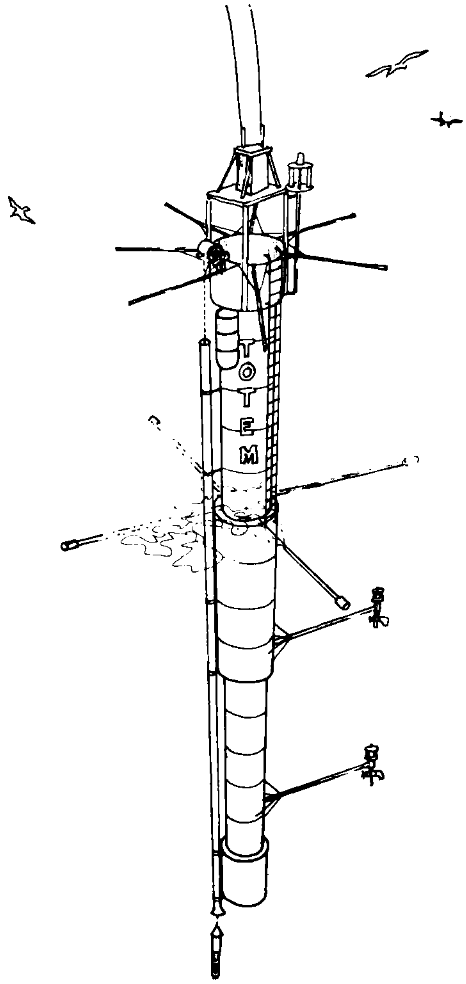


Figure 5

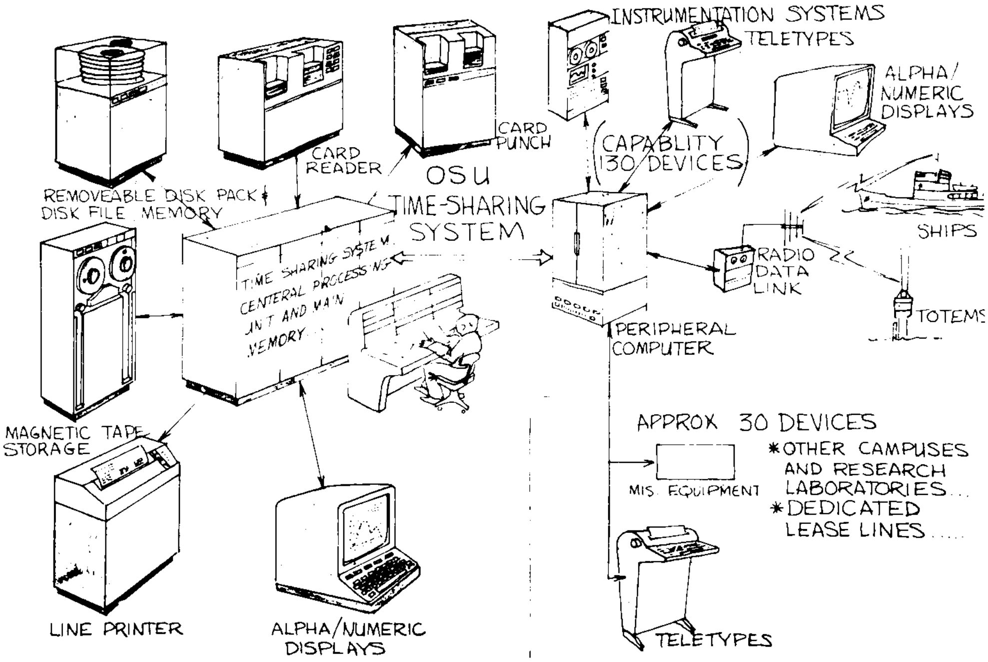


Figure 6

Presented January 5, 1971, by Dr. William D. McMullen, Department of Metallurgical Engineering, Oregon State University.

Corrosion in the Marine Environment

INTRODUCTION

This paper will be primarily concerned with the corrosion of metals. Corrosion is a major materials problem in the marine environment. There is considerable literature available on corrosion; much on corrosion in the sea (several references are given at the end of this paper). However, information on a specific corrosion problem tends to be scattered through the literature, or, because of the great varieties of metals, alloys, plastics, and the many types of corrosion problems, information for a specific problem is not available. To give you some idea of the problems, it must be realized that there are over 20,000 commercially available steels alone.

The marine environment is a beautiful media in which to study corrosion. Corrosion is an electrochemical process which normally takes place in an electrolyte. The ocean is a good electrolyte, containing chloride ions and oxygen which are particularly bad for many materials. The effect of the ocean on corrosion is not limited to the water itself but extends to the marine atmosphere on shore where moist, salty air rapidly attacks many metals. In fact, one of the most rapidly attack regions of steel pilings is not in the water itself but in the area just above the high tide level in the so-called splash zone where the metal is alternately wet and dry. Basically, the ocean is a very large electrolytic cell, in which rapid corrosion can be expected.

TYPES OF CORROSION

Many authors divide corrosion into various forms, all are more or less related and the division is somewhat arbitrary, but useful (1,2). I will follow Fontana and Greene's approach in discussing the various forms of corrosion (2).

General Corrosion or Uniform Attack

Uniform attack is the common type of corrosion. The electrochemical rate of attack is more or less uniform over the entire surface. The general rusting of steel is an example of this form of corrosion. The rate of uniform corrosion can readily be established in the laboratory and quite accurate predictions can be made of the expected lifetime for a given material in a given environment. This is the best form of corrosion since the unexpected does not occur. In general, the more reactive a metal is, the faster the corrosion rate, or zinc corrodes at a much, much faster rate than platinum in sea water. The standard electromotive force (EMF) series can be used as a general indication of the activity of a metal. The EMF series is obtained under specific laboratory conditions and should be used with caution.

A better indication would be to use a galvanic series in sea water under temperatures, pressures, etc., used in service. Such a series is listed below in Fig. (1). These series should not be used in predicting general corrosion rates but do give general trends. There are many exceptions and specific corrosion data should be used.

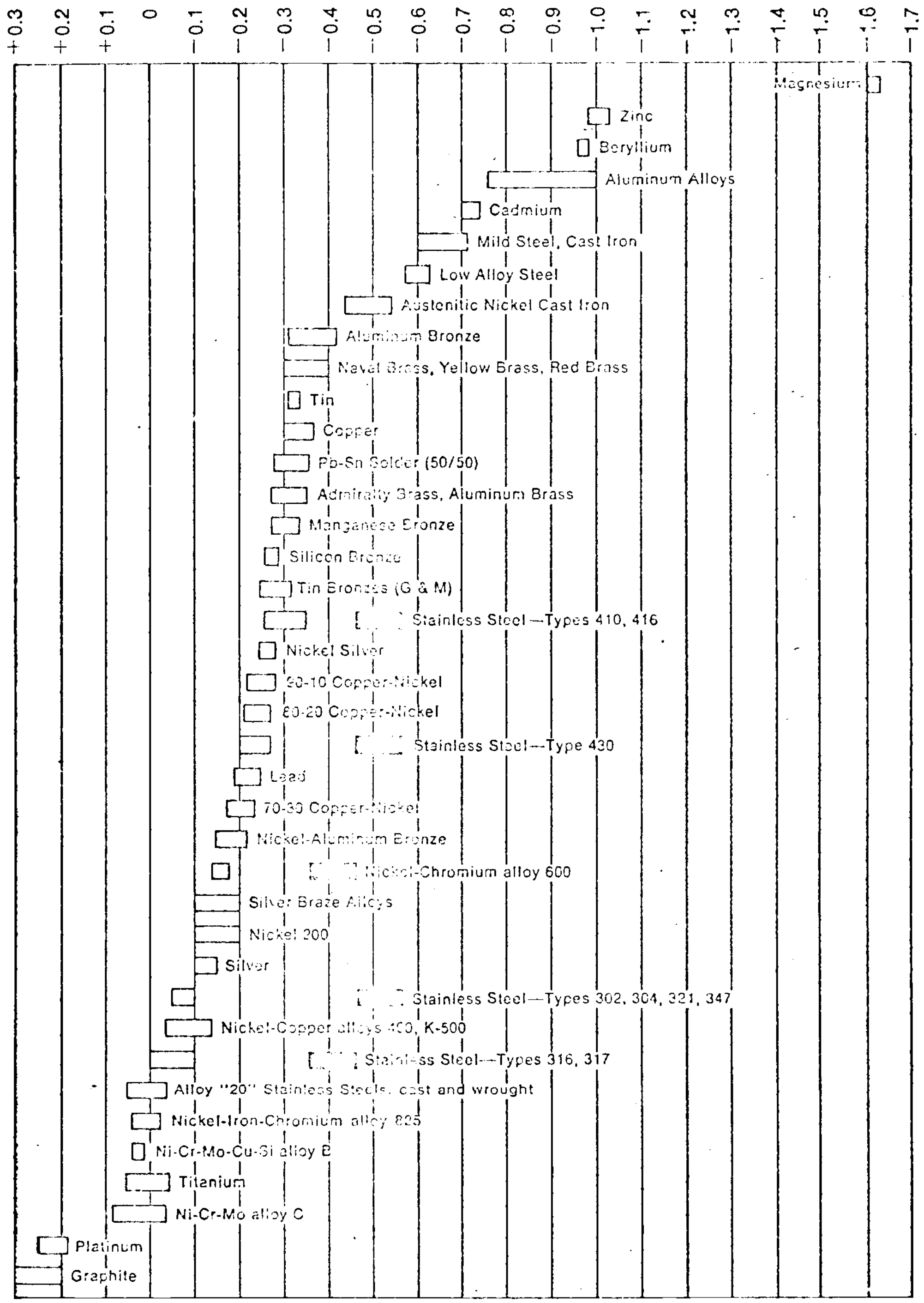
The remaining forms of corrosion normally are a more localized attack and, considerable more difficulty is encountered in predicting when a part will fail. The actual failure is often sudden, and is usually unexpected. Many of the more general corrosion resistant metals are susceptible to the one or more of the following forms of corrosion.

Galvanic Corrosion

Galvanic corrosion occurs when dissimilar metals are in electrical contact and in an electrolyte. The more reactive metal is attacked and goes into solution (becomes the anode); the more noble metal becomes the cathode and tends not to corrode. An example of this type of corrosion is a galvanic cell or a battery. A voltage developes between the two metals and an electric current flows between the metals. The farther the metals are apart in the galvanic series, the higher the potential between the two and the faster the active metal corrodes. The corrosion is most rapid near the junction of the metals, but does tend to occur over the entire area of the active metal. A more noble metal fastener (bolt, etc.) connecting large, more active metal plates is a much better arrangement than the reverse combination. The former arrangement tends to spread out the attack while the latter concentrates the attack in a small area and leads to rapid failure. This is a common problem encountered in service.

CORROSION - POTENTIALS IN FLOWING SEA WATER
(8 TO 13 FT./SEC.) TEMP RANGE 50° - 80°F

VOLTS: SATURATED CALOMEL HALF-CELL REFERENCE ELECTRODE



Alloys are listed in the order of the potential they exhibit in flowing sea water. Certain alloys indicated **by** the symbol: ⊏⊐ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near −0.5 volts.

Figure 1

From Nickel Topics Vol. 23, No. 3

Crevice Corrosion

Crevice corrosion occurs in areas that are partially protected from the corrosive environment. Crevice corrosion is the result of stagnant solutions which are found under bolts, rivets, in cables, etc. Protection of two dissimilar metals by insulating washers often results in crevice corrosion under the washer. It is hidden from casual inspection and can lead to unexpected failure of the part. Many of your metals that are resistant to general attack have crevice corrosion problems. Stainless steels are quite susceptible to crevice corrosion in stagnant chloride ion solutions (stagnant sea water).

Pitting Corrosion

Pitting corrosion is the very rapid, local attack that creates pits or small holes in a metal. The remaining surface area may not exhibit much corrosive attack. The exact cause is not known; however, two phase alloys (dissimilar metals) often show pitting. In many metals months may pass without any sign of pits, then, in a period of a week, holes will be found. Again, pitting corrosion is found in stainless steels.

Intergranular Corrosion

Intergranular corrosion is the rapid attack of a metal between metal grains or crystals; or, in the region adjacent to the grain boundary. The attack is due to the presence of an active metal in the region. Often stainless steels are somewhat blindly used to solve all corrosion problems. Stainless steels are susceptible to intergranular corrosion if handled improperly. Stainless steels are corrosion resistant primarily because of a chromium oxide layer on the surface. A minimum of about 12% Cr is required to form the oxide. Welding can often result in the formation of chromium carbide which does not allow the chromium to form the protective oxide layer. The stainless steel is said to be sensitized (weld decay). The corrosion resistance can be restored, or, can be minimized by using extra low carbon stainless steels or adding titanium to collect the carbides as TiC. Restoration is simple, but care must be used. The austenitic stainless steels (200 or 300 series) require a rapid cooling after heating to about 2000°F; the ferritic stainless steels (400 series) require a slow cool after reheating to about 1400°F for a short period of time. Reversing the treatment can result in a sensitized stainless steel.

Selective Leaching

Selective leaching is the selective removal of one element or compound from an alloy. This results in a weaker material. Dezincification of brass (Cu-Zn alloys) is an example of selective leaching. The zinc rapidly disappears leaving a spongy copper material behind.

Erosion Corrosion

Erosion corrosion is an acceleration of the corrosion process on a metal by a mechanical attack. Turbulant flow and particles in water greatly accelerate the erosion problem. Erosion corrosion and cavitation corrosion are closely related. The latter is the result of the collapse of bubbles on the metal surface which causes rapid local attack. Many bronze alloys have problems with this form of corrosion. The reversal of propellers on a ship often leads to great local turbulance and rapid cavitation or erosion corrosion.

Stress Corrosion

Stress corrosion results in cracking of a metal by the combination of a stress, either applied or residual, and a corrosive environment. Normally, the stress along or the corrosive media alone would not cause the part to fail. The actual fracture occurs quite rapidly with little warning. "Season-cracking" of brass or "caustic embrittlement" of steel are examples of stress corrosion. There is normally a threshold value or a stress below which there is little problem. Normally, the residual stresses can be removed by a simple stress relief anneal. Incidently, stainless steels are susceptible to stress corrosion.

PREVENTION OF CORROSION

The prevention or the minimization of corrosion requires a careful study of each individual problem. The solution of one form of corrosion often leads to another form. According to Fontana, virtually all corrosion failures result from carelessness on the part of the user or poor choice of materials or configuration by the designer (4).

Each form of corrosion has a variety of rather specific solutions. Time does not permit a look at each form. A more general approach will present ideas that may be carefully studied and used for each corrosion problem. These general approaches are discussed below:

A. Use the correct material coupled with the correct handling of the material.

Correct metal selection is very important in designing an apparatus for use in the sea; this may involve replacing steel with stainless steel, etc. Often, however, the solution may be to use a thicker section of material and let it corrode. Replacement of parts or sections is often the most economical. This is not always the answer, but it is often overlooked. Many of your more corrosion resistant metals have to be handled with care. Many can cause problems, the more complicated the alloy, the more care that must be used in welding, designing, etc., of the part. Many of your most corrosion resistant metals will be found with the so-called exotic metals; tantulum, zirconium, titanium, etc. Titanium is now about

$2.00/lb, or on a volume basis, about twice as expensive as stainless steel. However, titanium should be carefully studied and not just "used" in service. Some problems of stress corrosion have been found and other problems may be found in titanium but it does look promising.

Plastics have a great future in the sea. The main problems with plastics are their low elastic moduli, relatively low strengths and low tear or cutting resistance; a strong temperature dependence on properties and in many cases, cost. A greater understanding of plastics by engineers will create many new uses for plastics. The plastic industry must standardize properties, such as the metals industry has, before engineers can truly make engineering designs with plastics. This will, hopefully, come in the future.

Inorganic materials, such as oxides, glasses, concretes are being used. In general, they are quite corrosion resistant; however, they are very brittle and often limited to stationary structures.

B. Cathodic protection

Cathodic protection or the use of sacrificial anodes is a very important corrosion protection device. Basically, it allows the use of a cheap metal (steel) which is protected by making the structure cathodic. This can be done by the use of a D.C. source or a more active metal connected electrically to the structure. Typical current densities are of the order of 1-10 milliamps/sq. foot. Typical sacrificial anodes are zinc, magnesium, and now, an aluminum-tin alloy.

Cathodic protection is not always the solution; the crevice corrosion problem is not solved, the rapid attack in the splash zone is not affected. Cathodic protection can also lead to other problems. Many metals, such as steels, can be harmed by "overprotection". The overprotection in steels allows hydrogen atoms to diffuse into the steel making the steel brittle. If aluminum is "overprotected", the oxide film breaks down and the aluminum is rapidly attacked. Care must be used in applying cathodic protection.

C. Coatings

Coatings can be metallic, organic, or inorganic. The most common coatings are metallic. Zinc (galvanizing) coatings on steel exclude the environment when continuous over the surface, if a crack forms where the steel is exposed, the zinc acts as a sacrificial anode to protect the steel. Copper or tin coatings on steel must be complete. A small exposure of the steel tends to cause the steel to protect the more noble metal coatings.

Many possible corrosion resistant organic coatings such as plastics have possible uses as coatings for stronger metals. However, many plastics allow moisture to penetrate and can cause crevice corrosion or other problems. These should be used with care.

Many of the inorganic coatings are very corrosion resistant, such as glass. They also tend to be brittle and break, exposing the metal to rapid attack. Some intermetallic compounds are corrosion resistant and show some ductility. These may find a great use in the future, relatively little is known about them at the present time.

D. Change the environment

Changing the environment to a less corrosive media is important and may be more important in the future. This may be nothing more than lowering the humidity, or using primers before painting a metal surface. The use of various types of inhibitors may be an answer. Primarily, this method is limited to a closed system of some type.

E. Design

Correct design is basically paying attention to details. The elimination of crevices, use welds rather than bolts where feasible, the complete drainage of storage tanks, etc., are all marks of good design.

The correct design and the correct use of materials can lead to the solution of many corrosion problems. An example is the use of high quality aluminum alloys (reactive metals) in boats. Aluminum boats have been used for several decades on the seas with little trouble.

SUMMARY

This paper has, hopefully, given an insight to some of the corrosion problems encountered in a marine environment and some of the possible solutions. It is not a complete paper, but it is hoped that it will make you conscious of the problem and you will obtain professional help in solving corrosion problems. It may possibly stimulate an interest in corrosion which will lead to further study of the subject.

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