Horseshoe Bay, B. C.

PART I

WAVE THEORY, MEASUREMENTS, AND ANALYSIS

Vancouver Harbor, B.C.

SOME COMMENTS ON COASTAL ENGINEERING

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The Canadian Organizing Committee, the Vancouver Executive Committee and the National Research Council of Canada have done a superb job in planning this conference and in carrying out the enormous amount of detail necessary for its realization. On behalf of the Coastal Engineering Research Council, the other participating organizations, and all of the attendees I thank most heartily all who participated in this work.

I am personally most grateful to those representatives of the Canadian Committee who made the final selection of papers. I should explain at this point that a small papers Committee is appointed for each of these conferences to review the summaries submitted by the authors - but this screening is intended only to appraise their appropriateness for a coastal engineering audience - and to eliminate those few papers which are promotional "blurbs". It has not been a technical review such as is made for "refereed" technical and scientific journals. The number of papers submitted for this Conference passing this simple review far exceeded the reasonable limits of the program - and for a brief period the Papers Committee faced the new and distasteful task of selection among papers acceptable under past standards.

However, the problem was handled by the Canadian Committee - applying a formula which seemed equitable and reasonable. I trust that those affected concur in this judgment.

There is a solid core of attendees who know about the origin of these conferences and about the Council which sponsors them - but there are also newcomers for whom a brief review is appropriate. About twenty-five years ago the late Professor Boris A. Bakhmeteff, while a visiting professor at Berkeley, learned about the research in coastal engineering in progress there and at a few other institutions in the United States and abroad. He became much interested in this new, small field of research and he suggested that a Research Council be proposed to the Engineering Foundation, of which he was a member of the Board. A proposal was presented and approved and the Council on Wave Research came into existence for the purpose of promoting research - but without a well-defined modus operandi. Other councils of the Foundation conducted research directly - in relatively narrow fields and with financial support from the Foundation. This pattern of operation did not fit the inter-disciplinary and international character of coastal engineering - and the new Council floundered about for a time - seeking an effective means of promoting research. To this end, a conference was held at Long Beach, California, to bring together both researchers and practitioners for a review of the status of the field - and thus to provide a stimulus and guide for future research. The success of this conference, as evidenced by the demand for the published proceedings, indicated that the Council should sponsor at least a few similar conferences at other locations in the United States. This first conference had been heavily weighted with Pacific Coast experience - and the papers were not representative of the conditions and problems met on the Atlantic, Gulf and Great Lakes shorelines. Accordingly, conferences were held at Houston, Cambridge, and Chicago. Professor Pierre Danel of the University of Grenoble, who had attended a number of these conferences, suggested that the Council sponsor a conference at Grenoble, France; the successful meeting there led to the international sequence of biennial meetings - alternately in the United States and abroad - and so here we are.

These conferences have, I believe, stimulated research and have contributed substantially to the advancement of coastal engineering and of the related applied sciences. An indication of this result is the high percentage of references to these proceedings to be found in the bibliography of almost any published papers in the field.

However, over the years there were comments - and some criticism - of the functioning of the Council; it was a maverick among the councils sponsored by the Engineering Foundation; it should collect funds and sponsor research directly; it should evolve into an international technical society, with elected officers, committees, and a periodical publication; it should operate more democratically; and so forth. These suggestions were considered many times and at length - but each round of discussion led to the same conclusion, namely, that the international conferences served a useful purpose, with a high return in benefits for the effort expended, and that the additional activities suggested would duplicate to some degree the work of other organizations and would require much additional personal effort with doubtful incremental benefits.

There was, however, a major defect in being attached to the Engineering Foundation - namely, the lack of an established mechanism for editing, publishing, distributing and publicizing the proceedings. A logical association - and one which solved the publication problems - was to transfer the Council from the Engineering Foundation to the American Society of Civil Engineers. This was done, and in the process, the title was changed, appropriately, to the "Coastal Engineering Research Council". Under this sponsorship, the Council retains the flexibility of membership and operation which it had under the Engineering Foundation.

So much for the antecedents of this Conference.

Turning now to coastal engineering itself, anyone active in the field has viewed with consternation - and possibly some jealousy - the heavy emphasis given for a time to the exploration of the deep-sea. Recently, however, there has been evidence of a growing recognition of the fact that the greatest needs and opportunities are to be found in the coastal zone rather than the deep-sea. On this point, a recent statement of Dr. William A. Nierenberg, Director of the Scripps Institution of Oceanography of the University of California, is particularly interesting and I quote him with some relish.

> "Want to make big money on oceanography? Then forget about mining nickel from the ocean floor or refining gold from seawater. Instead, build a harbor that won't silt up or beaches that won't wash away. Learn to clean up pollution."

After the Stratton Commission of 1965 made an unrealistic but glamorous forecast of the future of deep-sea exploration, a number of major companies plunged deeply into the field only to wind-up in "the most depressed business in the United States" - to quote one of the managers involved.

The volume of research and development in coastal engineering and in the applied sciences related to it has shown a steady increase for many years; the rate of increase seems to have turned sharply upward in the last few years - stimulated by petroleum exploration and production, by the Sea Grant and other programs of the U.S. government, and by the newly-aroused interest and support of many of the coastal states. Public and private universities have created departments, institutes or laboratories devoted partially or wholly to work in coastal engineering and related fields. With this level of activity in being and in prospect the practicing coastal engineer should benefit materially in basic data, analytical methods, and design techniques available to his practice.

There is a corresponding opportunity for engineers practicing in this field to influence the character and scope of research and development by pointing out important gaps in data or methods which practice has brought to light.

It was with this point in mind that I accepted the invitation to speak on this program.

There are many topics related to research which I should like to discuss with you, but I will limit myself to a few which I have mulled over for some time and which, I believe, are partinent to plans for future work in this field.

We have been unduly optimistic, I believe, about the degree to which the results of field studies made at one coastal location, and under one set of environmental conditions, could be generally applied. Differences in the wave climate, range of tide, bottom and shore materials, local winds, tidal and wind currents, shore configuration, and bottom slope tend to make each physiographic unit unique. No two such units are exactly alike in exposure to waves, wind, and tide, and in the resultant sequence of changes in the shoreline - but these differences may be so subtle as to produce evident effects only over long periods of time. These circumstances have led me to the conviction that comprehensive and continued field observations, backed by analysis and laboratory experiments, should be made along selected shorelines - and, to the extent feasible, at points of economic importance. Such studies may - and hopefully will - yield facts and principles applicable at other locations - but this objective should be secondary to the primary effort to measure and understand the complete regimen of an important segment of the coastline. The Pacific coast differs from the Atlantic and Gulf Coasts in many respects, and within these broad categories there are significant differences in the exposure and response of the shore. Clearly, one could identify so many different areas for study as to require an impossibly great effort - and for this reason it is suggested that major efforts of this type be devoted to areas of major economic importance - where the problems are usually urgent.

Regional studies continued over relatively long periods, will provide the factual basis needed for engineering design locally - and should, in the long run, provide data for appraising the validity of broad generalizations about coastal phenomena.

A comment related to the preceding discussion is that many field and laboratory investigations are what I term "half-experiments" - experiments in which only a portion of phenomena involved are observed or measured. A few examples of this are:

- observations of sediment motion without measuring the related waves and currents and, vice versa, extensive hydraulic measurements without observation of sediment movement.
- recording wave length and period without obtaining the deep water direction.
- verification of movable bed models without adequate information regarding the wave climate.
- and so on.

The circumstances which have caused this situation are understandable - inadequate budgets, personal interests, lack of effective instruments and techniques, limited time - but it is nevertheless true that these "half-experiments" are inconclusive - as much so as playing half a hole at golf. Furthermore, the results may be grossly misleading. Many coastal problems are such as to require the attention of an inter-disciplinary team - all working on the same problem with different approaches - and many of the gaps to which I have alluded would not have occurred had a broader view been applied in planning the programs.

A major deficiency in the data essential to the planning and design of coastal structures and systems - and one which accounts for many of the half-experiments mentioned - is the relatively primitive state of our knowledge of the wave climate.

Recording shore-based wave gage data, hindcasts from meteorologists' records, and observations from ships at sea are available, but these sources have not been compared extensively to test their reliability and they have not been presented in form for application to coastal problems. The ship reports include off-shore moving waves and probably do not include much of the swell; the shore-based wave records do not include direction; the hindcasts are in question at least by the degree of the differences between forecasting methods. To be useful for engineering purposes, these data should be evaluated and combined into a "best guess" of the climate at selected deep-water stations. Such an effort would highlight gaps and discrepancies and would provide guidance for future wave observation programs.

Data on the wave climate are needed for a wide range of applications and it will be feasible to publish only the most frequently used summaries. Special requirements can be met if the basic data are readily available for scanning by computer programs designed for the purpose.

Perhaps I exaggerate the importance of the wave climate, but from my own experience I rate it as the most frustrating gap in the kit of tools available to the coastal engineers.

There are few coastal problems which do not require a judgement regarding the direction and magnitude of the littoral transport. Laboratory and field data on the relationship between wave action and rate of transport show a scatter by a factor of about 10; most of the published field data pertain to a few locations and the laboratory data suffer in credibility for a number of reasons. Reliable measurements of littoral transport are difficult - and in fact may be possible only under very special circumstances - and the scarcity of good data is understandable - but the need is urgent for data on the gross and the net annual transport at important points on the coastline - and for an ad hoc relationship of these quantities to the local wave climate. Whether or not a general correlation, such as is now applied for lack of anything better, is generally valid will not be established firmly until there are comprehensive and extended measurements of the transport and the concurrent wave "weather" at a number of localities at which the range of material characteristics, offshore bottom slope, and other parameters span the range of field conditions.

A final comment deals with the need for more case histories of failures of coastal works. There are many types of failure - physical destruction due to inadequate design or construction, limited life because of corrosion, abrasion or fatigue, failure to perform the intended function and failure to achieve the predicted economic benefits. In addition to the human dislike of recording mistakes, there is the practical consideration that the engineers who design and build such works move on to other projects and are not in a position to observe such failures and to assess the causes. Studies of this type require a firm plan and sustained through low-key attention. They would be feasible for organizations engaged in studies of a particular coastal segment over a long period.

In brief, these few comments add up to the suggestion that plans for coastal investigations include regional studies having as their primary objective the measurement and analysis of the dynamical regimen of selected coastal segments. Such work will strongly support engineering practice in the areas studied - and will also provide a sound basis for appraising generalizations regarding coastal phenomena.

The initial program of the Beach Erosion Board included such field stations at two points on the coast of New Jersey - where measurements were made of waves, winds and currents and of the resultant response of the shore. A particular objective was to observe the effectiveness of the many groins, seawalls, and bulkheads then defacing this shore. These stations were manned for about two years. Looking back over the progress since that time, I feel that it was a mistake not to continue these observations - with improved instrumentation, backed-up by laboratory studies and analysis - and a mistake not to add stations on other coasts.

My comments may possibly be construed as advocating regression to an empirical approach but they are not so intended. What I have in mind is an addition to - and not a replacement of - the analytical, laboratory, and field work which has been so highly productive as the program of this Conference amply demonstrates.

ENVIRONMENTAL PROBLEMS AND MONITORING IN COASTAL WATERS

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INTRODUCTION - MAN'S CONCERN WITH THE COASTAL ENVIRONMENT

Man has been challenged by the sea from his early beginnings; he crossed the seas on rafts and boats driven by manpower and sails and adventurous cruises for booty and commerce developed into regular trade routes. With them in turn came the growth of anchorages and ports in the estuaries and inlets along the shorelines which offered the necessary protection against the storms with adequate channel depth for the constantly rising draft for larger vessels.

Probably older even than the exploits of seafaring are the manifold uses of coastal areas in man's quest for food. Fishing from the shore with nets and spears was followed with short, daily excursions into the coastal waters in small boats. As agriculture found the coastal shallows and wetlands suitable for raising crops and animals, these fertile areas were drained and diked in against the tides and storms. Today the delta regions team with life as in the Netherlands and in East Pakistan although still subject off and on to the ravages of waves and storm-tide flooding.

Exploitation of the coastal waters for commerce, fishing and agriculture is now joined in modern times of population growth by their use as sinks for all types of wastes and at the same time by the conflicting needs for food, sports, and recreation. In addition, the submerged sea bottoms have become accessible by modern technology for the extraction of minerals and oil. The apparent needs of society armed with the great potential of technology press for rapid development of the various coastal resources but also tend to endanger simultaneously these resources by conflicting goals.

Thus we stand today at the threshold of greatly accelerated growth in man's exploitation of the coastal domains, appalled by some of the apparent results of human interference. We are prone to extrapolate further unhindered activities to their surmised and fearful consequences but the basis of such predictions is often more emotionally founded than established by adequate knowledge.

Yet these serious concerns must be accepted as real and indeed helpful. We know that coastal developments of all types will be needed in man's survival. But survival has many facets, and proper balances between man's aspirations and nature's capacities for their attainment are still to be defined.

Man's happiness seems to him still best assured by interaction with nature as it is. Historically he has often good reason to distrust technological incroachments on the environment even though many of these were essential to his own well-being. Man can transform nature and even fundamentally change it over large areas, but adaptation processes in the past extended over many centuries for man and nature alike. These changes will undoubtedly go on. It is the rate of change which now gives such concern and at times causes violent reactions. These public reactions prescribe often a halt to further economic development without regard to environmental factors. Environment has acquired new values in the sense that a "high living standard" is no longer synonymous with a "high quality of life". Although the latter is not readily definable in economic terms, it nevertheless imposes restrictions on activities which in the past were conducted without hindrance. A reconciliation of economic aims with environmental conservation is now mandatory by public demand and by its legal responses.

This poses great new tasks and challenges to scientists and engineers alike in their roles as intermediaries between the public concern with the environment and the forward thrust of purely economic needs of the same public as represented by private and public enterprises and agencies. It is to be hoped that these roles can be adequately supported as they must be and that they can thus be carried to the point where rational judgement can be rendered to resolve the questions and doubts which the public may raise. It is towards these ends that meetings such as ours must be aimed. Let us examine in the following some of the problems involved in the coastal spheres and then look at what can be done towards rational definitions by scientists and engineers armed with past experience and modern instrumentation systems presently in sight to clarify what ought to be known.

PROBLEM AREAS IN THE COASTAL ZONE

THE PHYSICAL SYSTEMS

Past coastal engineering history has taught us through many bitter experiences a most important lesson: we cannot look towards convenient remedies for local problems in coastal areas without understanding the larger systems of which these local areas form a part and with which they interact in often very complex forms. We may build dams for flood control and power but we also shut off the supply of nutrients and of sediment to estuaries and beaches. We can create new communities by filling in the wetlands near the shore but we may deplete at the same time the catch of the fish which spawned there and which attracted many new inhabitants in the first place. We have in the past discharged our wastes into the shoreline waters and found beautiful beaches closed to the public served by these outfalls. There have been numerous examples of such unexpected short circuits but have we learned the lesson?

With these experiences of detrimental effects of human interference on shorelines public as well as professional awareness has grown of the chain reactions inherently engendered by many engineering measures in coastal and ecological processes. Reluctance of conservationists to condone the continuance of present practices or the institution of new measures cannot be waved off lightly but must be countered by rapid expansion of our knowledge on coastal processes and of the various factors governing life along the shorelines. Fortunately, governmental agencies on all levels have been given wide authority to assist and to sponsor such exploration in recent years. Our capacity to measure, to record and analyze data and to display the results in meaningful ways has been vastly expanded by modern computer facilities. We have on hand now most of the tools and we stand at the beginning of implementing the organization of useful information systems on the dynamics of coastal waters. This will surely be a multi-dimensional task and its ultimate scope can as yet hardly be estimated in view of the many feedback loops linking the physical environment to biological, economic and social systems. It seems however that the physical factors must form the building blocks for the others and that eventually their true understanding will lead to meaningful perspectives and judgements in these other spheres of human concern.

Offshore Circulation and Waves

The water masses of the oceans are in constant motion with few exceptions. We are all familiar with current systems such as the Gulf Stream or the Humboldt Current. Oceanographers have charted them and modelled them. But other forces are at work also, providing mixing and mass exchange through various mechanisms. Waves are breaking on the surface. Temperature and salinity variations produce layered systems and internal flows disturbed often by internal waves. Biological exchange takes place over the vertical and modifies water quality. Superimposed are the to and fro movements powered by tidal action. Over the long term therefore water masses are exchanged effectively at different rates depending on the topography of the shorelines. However, this rate of exchange is often over estimated in wishful thinking for convenient pollutant disposal.

Of great importance to the shoreline are the wave systems generated over the open ocean. These can be predicted now to a tolerable degree since wind conditions can be related to wave generation. But little success has been had so far in measuring waves at sea except by shipboard observation. Only as offshore structures are moved to larger depths of hundreds of feet have direct measurements of waves at these depths become possible. The waves reaching the shores are, however, transformed in many ways, by interference with other systems, by bottom friction and refraction, by partial reflection and predominant current systems. Waves provide another mechanism for internal exchange of water masses as onshore and offshore movements take place between surface and bottom.

Nearshore Interfaces

Waves arriving at the shoreline generate very powerful forces on shoreline structures erected by man and deform continuously the shoreline itself. Waves and breaker heights may be measurable here but reliable relationships between sediment transport rates and wave action still seem to escape more than very approximate estimates. Refraction and diffraction procedures have been developed for the varying bottom topography and the various boundary conditions at the shore. An important element in all calculations is wave direction, but very few attempts have been made to measure this crucial quantity and where such measurements have been attempted the complexity of the instrument systems involved defeats more general use. "Significant wave heights", no matter how expeditiously defined for engineering purposes from statistical wave records still leave us often to question the significance for specific applications to engineering structures.

The shorelines are vulnerable also to changes in water level caused by hurricanes and severe storms combined with severe wave action. Planning for such attacks is usually initiated after the damage has been done and is then confined to prevent a recurrence in areas of high investment. But such investments for structures near the shore are seldom deterred by dire warnings, the advantages derived seem to justify the risks even if these can be quantified to some extent by environmental predictions.

The tsunamis generated by earthquakes sometimes thousands of miles away add to environmental hazards near the shore in many regions of the Pacific. Warning systems have been set up to aid vulnerable shorelines in Japan, Chile, Hawaii, and California and numerous tsunami protection structures have been built to reduce the uprush of more than 20 feet and sometimes up to 100 feet in converging inlets and bays.

Under all these wave attacks the shorelines through the ages have been eroded, whether they consist of vulnerable bluffs or gentle beaches. Man has often heedlessly accelerated these processes, through ill-considered interference and only gradually have we come to appreciate the chain reactions we may set off by local exploitation. As an example we may mention here the destruction of natural or carefully nurtured dune vegetation by dune buggies.

Inlets, Estuaries and Harbors

Human activities are perhaps most intimately intertwined with the sea through the bodies of usually shallow water contained within the bays and estuaries of the land mass. These provide with the connected wetlands the spawning grounds for fish and also the shelter required for pleasure craft and commercial shipping. These waters are confined and communicate with the open sea through the tides entering and receding through often narrow passages. Human exploitation has polluted many of these bays and estuaries to the extreme limits based on the mistaken notion of tidal flushing. We know now that such flushing action is usually very slow and involves complex dispersion processes as yet subject only to very approximate analysis. Meeting public demand many of the barrier beaches have been pierced with new inlet channels to provide convenient access to the sea from interior waters. Beaches up drift and down drift of such inlets often "protected" by extensive jetties have suffered unforeseen damage and water quality in the interior waters has been affected usually to the detriment of the ecology. But advantages to the ecology have also accrued in some instances. Our experiences have made us generally more cautious in assessing cause and effect before launching on extensive engineering works which change the existing environment. But pressures for economic use of inlet and estuary shorelines remain very high, and therefore coastal engineers and marine scientists are concentrating more and more on research in embayments and estuaries to enhance our understanding of the dynamics of the circulations and the dispersive processes related to them. One of these studies on an interdisciplinary front is presently under way on Massachusetts Bay and has brought to the forth the wide range of interrelated factors governing even a purely physical description of the flow processes. Winds and tides, temperature and salinity variations, sediment transport, varying topography, water mass exchange along the boundaries, all assume a part in the seasonally varying patterns of the flow and dispersion dynamics of the Bay waters. They, in turn, relate intimately to chemical interactions and biological processes taking place in the various parts of the Bay. Understanding the integrated behavior of the combined systems is indeed an intellectual challenge and yet one that must be met if we are to fulfill society's needs in the future in harmony with the conservation of a viable coastal environment.

The Interactions: Sea - Shore - Estuaries

The coastal environment is the meeting ground for many natural forces acting seldom in readily described patterns. Each coastal area is subject to a broad spectrum of these forces in different combinations and the land responds to the attack in different ways depending on topography and geological materials in various stages of evolution. The sea provides for wave and current attack varying with the seasons; from the interior the rivers bring mineral and organic materials, which mix with those produced on the shores by erosion and biological activity; the fresh water meeting the saline waters in estuaries reaches the sea after complex mixing processes which have their reflection in varying biological life and sedimentation patterns; finally man has added his structures and pollutants which have disturbed the natural processes in embayments, estuaries and shore areas. While natural cyclic periods, both long-term and short-term, may be discerned and certain equilibrium conditions may exist these may be upset for long periods by catastrophic events such as hurricanes and earthquakes. Hence, it is clear that purely local observations may serve only a limited purpose in predicting the shoreline changes when local structures are planned since these may affect the environment of the coastline at considerable distances from the area of the local disturbance. To sort out all the resulting consequences becomes a very complex task of environmental monitoring as coastal waters are increasingly drawn into the service of man.

HUMAN USE OF COASTAL WATERS

The coastal environment is affected by man to an ever increasing extent. There are many conflicting interests as the limits to human use are recognized and systematic planning in harmony with nature has come to be accepted as an ideal to resolve these conflicts and to extract optimal benefits for the community rather than for private gain. It is difficult to enumerate the individual facets of human use of coastal waters without getting enmeshed immediately in their relationships to other human activities as will become apparent in the following.

Fishing and Aquaculture

Traditionally, fishing for food and pleasure is one of the most obvious associations with coastal waters in the public's mind. This is expressed best by the amount of fish caught by salt water sports fishermen which may be estimated in recent years, for the U.S. alone, as close to 800,000 tons for which equipment and services sold at retail exceeded 700 million dollars. Commercial fishing went beyond these numbers, producing over 2 million tons of fish with a retail value of one and one half billion dollars. The public therefore has a considerable stake in the preservation of appropriate environmental conditions for this important resource. However, other uses of coastal waters increasingly menace such environmental conditions particularly through various pollutants from human and industrial sources. While much of the public fervor raised on this point may be exaggerated, too little is still known on the biological processes of the food chain by which both shell fish and fin fish are sustained. Such knowledge must be developed if management of fishery resources is to be improved and if the supply of fish through aquaculture is to be enhanced. Great success has already been achieved in this area with certain variety such as salmon in the Pacific Northwest and with oysters and clams. Oyster production can be raised by a factor of over 30 when raft cultivation is employed as compared to bottom cultivation where the yield is only 600 pounds per acre per year. But successful aquaculture depends not only on better knowledge of the biological processes but also on relatively detailed information on the currents and on water quality for the waters in which the aminals are to be raised. Fish poisoning with its threat to public health is of increasing concern as pollutant levels have grown to dangerous degrees in local areas. It is not sufficient apparently to specify certain levels of pollution since fish and shellfish have the ability to concentrate certain pollutants such as mercury, DDT, or radioactive substances in their systems.

Navigation for Commerce and Pleasure

Modern shipping has produced many new problems for coastal areas and estuaries. Commercial ships have increased in size and hence draft and pleasure craft have reached tremendous numbers in our prosperous society. Much deeper channels are required and have been dredged to traditional harbor sites. Natural depths of 10-20 ft. are deepened up to 42 ft. in most of our estuaries and new harbors are in the design stage for 60 ft. depths with up to 100 ft. anticipated in the next two decades. These can only be obtained in a few coastal areas or with offshore harbor islands. Major shoreline changes must be anticipated, assessments of possible accidents with major spillage of cargo must be made, increased pollution from industrial and municipal wastes may result despite more stringent safeguards.

With the growth of pleasure craft we have already been faced with the need for suitable anchorages for home bases and for harbors of refuge at regular intervals along the shorelines. In many cases natural harbors for these purposes are not available and must be provided by new breakwaters and other structures. Inevitably natural shore processes are interrupted and dredge spoil disposal areas must be located. Detailed studies of waves and currents, of water quality and flushing characteristics, of marine biota from plankton to fish, of sediment transport and shoreline stability, seem incumbent in each case of such major interference in the marine environment.

Disposal of Wastes

Pollutants due to human activity reach the coastal waters in many ways and forms. Fertilizer components and insect sprays such as DDT come from natural run off on agricultural lands, find their way into lakes and streams where they are joined by human and industrial wastes and eventually reach the estuaries and the sea. Large population centers have evolved near the sea or interior shorelines with major industry and their liquid and solid wastes are dumped in near-shore waters with little or no treatment through pipe lines or barging. We have been alerted to the long-term consequences of such practices only in recent years and it is not apparent at this stage whether the public will be persuaded to shoulder the economic burden which a major clean up and reversal of these practices will impose.

Clear evidence also exists that many pollutants reach the sea by direct transport through atmospheric circulation and are absorbed into the water at the interface of water and air.

The ever increasing demand of society for electric power has created a new problem as the need for cooling water can no longer be met by interior sources. Considering overall use of electric power in relation to efficiency of production it is safe to assume that twice as much energy is consumed by heating the "cooling" water as finds its way to useful purposes in homes and industry. How to dispose these vast amounts of waste heat into the coastal waters without upsetting and permanently damaging ecological systems near the discharge points presents many engineering challenges. Various systems of effluent dispersal are applied but their relative merits can again be assessed only by major measuring programs extending over time and the coastal areas affected.

The proper assessment of a pollutant state for a given area is one of the most difficult tasks confronting scientists and engineers particularly when ambient environmental conditions are not known. Even with best intentions measuring programs pertaining only to major pollutants develop very quickly into projects with vast data production for which rational analysis faces considerable difficulties. What are the pollutants? Where did they come from? What are the dispersal processes? What are the chemical transfer processes? How do they affect the biological activity and interaction? Where are they finally deposited? All such questions should eventually be answerable before decisions can be made in good conscience. But it is almost evident by just asking such questions that many environmental decisions will have to be made in the near future without complete answers.

Recreation

Emotionally, recreation activities in coastal waters are most closely related to public concern. Beaches closed to swimming because of pollution, beaches eroded by structures misplaced or by natural processes, structures marring the esthetic enjoyment of a long sweep of a beach, dead fish washed up on the shores as well as other debris of human activity, clams and oysters made inedible by toxic pollutants, water fowl and other animals dying from oil pollution, all these examples have had a major impact on public thinking and have lead to steady pressure on government agencies to adopt means of redress.

Use of beaches for recreation has assumed tremendous proportions, as illustrated by an attendance of over 70 million at the major beaches on Long Island alone. Shore property values range from 15,000 to 50,000 dollars per acre on Long Island and annual land losses over the 120 miles of shoreline exceed one million dollars. Similar figures can surely be cited even in excess of these for shorelines in other parts of the U. S. and abroad.

Table 1 Shoreline Ownership and Use in the Continental U.S.

Ownership	Length in miles	Percent of total length
Federal Government	3,900	11%
State & Local Government	4,600	12%
Private	25,800	70%
Uncertain	2,600	7%

Use	Length in miles	Percent of total length
Public Recreation	3,400	9%
Private Recreation	5,800	16%
Non-Recreational Development	5,900	16%
Underdeveloped	21,800	59%

The National Shore Line Study of the U.S. Corps of Engineers directed by Congress in the River and Harbor Act of 1968 and recently completed in August 1971 provides one of the most comprehensive summaries of the problems of our national shorelines. Along the 37,000 miles of the ocean and Great Lakes shores in the continental U.S. approximately one half were found to be subject to significant erosion with 2,700 miles of these being classified as deserving economically remedial action by protective structures. First priority is to be given to a total of 190 miles where danger to life and public safety is expected within the next five years. This will cost 240 million dollars. The study further finds that 17,800 miles of these shores could be partly protected simply by improved management practices. The economic stakes in coming to grips with shore erosion and its environmental factors are thus clearly demonstrated for all shoreline uses of which recreational use is of the greatest value for residents in the 30 coastal states as well as for those from the interior of the country. Again expanded research to improve our understanding of the near shore environment with regard to prediction of governing physical and biological factors must form the basis for rational protective measures.

Effects of Land-based Engineering

Modifications in the shorelines and in the coastal waters have been brought about in many areas as the result of land use practices and related engineering structures in the interior of the country as well as in estuaries. Much of the sediment supplied to the streams terminating in the sea has been stopped in some areas such as California through flood control measures, mainly dams impounding the flood waters but with them also the sediment. In other areas, in the center of the country, agricultural practices of the past and still to some extent in the present have vastly increased the supply of sediment as the cultivated land eroded. Other engineering works such as road construction and mining added to this sediment supply. Eventually these effects are felt in the coastal areas. Beaches erode when the supply of sediment is stopped as in some cases in Southern California, while estuaries shoal and must be dredged when excessive supplies of sediment reach them.

In addition to natural sediments the use of waterways for liquid and solid waste disposal has also changed the natural conditions in coastal waters. Increased channel depths for navigation require extensive dredging in estuaries with consequent disposal of dredge spoil on adjacent lands or in the sea. Industrial chemicals, and minerals as well as human wastes make the silt and sludge deposits often a questionable addition to offshore waters with poorly understood environmental hazards.

Offshore Mining for Minerals and Oil

Finally, this brief summary of factors involved in changing the coastal environment through human use of the coastal waters may be concluded with the most modern encroachments by man through resource developments. The most explosive issue is probably concerned with the drilling for oil, which until recently was conducted with little regard for environmental damage until the blowouts in the Santa Barbara Channel aroused a public fury. There can be little question that oil wells will continue to be drilled but also that in the future every precaution available through advanced technological safe guards will be applied. With all safety devices however, the risks will be tremendously reduced but can never by reduced to zero. Assessment of possible mishaps must therefore precede new ventures of supertanker harbors or anchorages and future drilling of new oil fields in the offshore areas. This requires again a detailed description of the dynamics and of the biota of coastal waters and points to novel and comprehensive data systems for the decision making and regulating of activities.

What pertains to exploitation of the oceanic shelves for oil applies equally to the mining of minerals and the dredging for sand and gravel in coastal waters.

As landbased sources for sand and gravel for construction and sand for beach replenishment decreases, increasing dependence must be placed on offshore sources. Naturally, dredging in these areas should be conducted with proper regard to the existing ecology so that biologically productive grounds are avoided and operations in adjacent areas do not affect animal and plant life to the extent that restoration of the biota is permanently prevented. In contrast to sand and gravel resources the mining for other minerals will probably, with few exceptions, be concentrated in the deep portions of the oceans where Manganese nodules also rich in iron, copper, nickel, and cobalt are known to exist in large quantities. A new technology for such deep sea operations is yet to be developed as economic exploitation so far has not been feasible and has indeed been disappointing to venturesome enterprise barring a few notable exceptions.

THE NEED FOR REGULATION AND MANAGEMENT

As the actual and potential uses of coastal waters and their economic value to the many nations increased, concern for legal and regulatory authority has intensified. Numerous and frequently overlapping jurisdictions exist and are rapidly being extended. The old internationally-recognized 3 mile limit or "territorial sea", under the sovereignty of nations with shorelines, has been expanded by national edicts in many cases to 12 miles and a few nations claim jurisdiction over fishing activities up to 200 miles from shore. Peru and Ecuadore have been in conflict on this point with foreign nationals for some time and Iceland is presently fighting it out with Great Britain, as it tries to extend its sovereign rights over what have been regarded as traditional fishing grounds by the latter nation. New international agreements are obviously urgently needed to prevent such conflicts and to bring a unified approach to other pollution and resource management problems such as the dumping of hazardous and waste materials into the coastal waters. Pollution of the ocean waters has come to the fore as a threat to all nations with sources from ships as well as from natural and man-made outfalls. Offshore islands to be constructed for atomic power stations or as deep-draft harbors or transfer facilities for superships present further jurisdictional problems.

This is not the place to enumerate in detail the numerous laws and regulations enacted in recent years by federal and state legislative bodies and agencies. But a few of the principles may be recounted here in view of many misconceptions and much confusion which still exists with regard to the original meaning of the various acts. For example, the preamble of the National Environmental Policy Act of 1969 states as the Congressional purpose:

> "To declare a national policy which will encourage "productive and enjoyable harmony" between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; ...."

This is not a call for conservation only, but for responsible management of natural resources for the benefit of man in harmony with the environment. The Act emphasizes new environmentally-oriented decision-making practice and stimulates the elimination of those activities which threaten human health and ecology. In the subsequent years the Environmental Protection Agency (EPA) was established. EPA has incorporated the Water Pollution Control Program, formerly in the Department of the Interior, into its new Water Quality Office. EPA and State Officials work in concert with the U.S. Army Corps of Engineers, which has authority over numerous activities in the more broadly interpreted "navigable waters" to administer and enforce the standards for water quality in such waters. EPA and the Corps also jointly issue permits for industrial waste discharges, a function which has been derived from a little used provision in the Refuse Act of 1899 (33 U.S.C. 407), an Act revitalized for pollution control purposes by the judiciary courts. However, the implementation of the permit system for industrial waste discharge is still faced with the difficulty of the mass of permits to be investigated and to be passed. Since the recent Kalur case, new permits must be preceded by environmental impact statements, and include consideration of fish and wildlife effects, aesthetics, water quality and other factors.

EPA reviews and approves state water quality standards and criteria, and provides guidelines for specific problems such as the disposal of dredge spoil in ocean waters. In some cases, standards, criteria and guidelines have proven impossible to apply, since natural ambient conditions alone exceed the limits set for metal and organic contents, for example.

The administration of water pollution control programs raises a number of problems on which environmental science still lacks adequate knowledge and where further research is needed on dispersal patterns, on degrees of chemical analysis for metals and organic compounds, on maximum retention methods in certain areas in preference to dispersal and on the flow dynamics especially as related to internal velocities due to waves, storms and density variations.

However, the repeated refrain, "we don't know enough and the problem requires further study" should not be accepted as a call to stop all action on needed programs. In many cases, a reasoned judgment must be rendered on the basis of rational concern by private and public agencies, and of the evidence on hand. Risks will have to be taken but their number can be reduced in the future if we agree on needed research focused on specific local problems yet also of adequate scope to build an integrated framework of information for future decisions.

The time limits and pollution control measures for water quality consistent with the "protection and propagation of fish, shellfish, and wildlife and for recreation in and on the water" may become rather specific. If Congress passes one of several bills now before it, interim goals for water quality are to be achieved by 1981, and all discharges of pollutants into navigable waters are to be stopped by 1985. The primary responsibility for proper planning and management for these goals for coastal waters is placed on the many coastal states adjacent to the shores. Much stress is now laid on public involvement in developing the necessary enforcement of effluent limitations to be applied at the source. Such measures are spelled out in great detail in the "Act to amend the Federal Water Pollution Control Act" passed by the Senate in November, 1971 (S. 2770), and now awaiting further legislative action. Of foremost interest to our professionals in water quality control is the extensive mandate to the Administrator of this Act for the development of monitoring systems and for the support of research and training "relating to the causes, effects, extent, prevention, control and elimination of water pollution".

It is clear that the enactments of such goals for unpolluted waters are setting aside many privileges of private, industrial and municipal users, which had been assumed as rights rather than privileges through many years. This may cause hardships in some cases, and impose considerable financial burdens on many. These, the public, in it's own long-term interests, must assume. Reconciliation of private claims to exploitation of coastal waters now declared to be in the public domain will be subject to many difficult decisions spanning a wide and complex array of technical, ecological, economic and social interests, often seemingly oontradictory and as yet often based on vague judgments rather than objective knowledge.

A new bill recently (April 25, 1972) passed unanimously by the U.S. Senate and named the "Magnuson Coastal Zone Management Act of 1972" can contribute further to clarification of rights in the coastal zone if finally passed by the House of Representatives. This bill will provide federal aid up to 2/3 of the cost to coastal states to develop planning for coastal zones, to define permissible land and water uses ("so as to prevent such uses which have a direct significant or adverse impact upon the coastal waters"), to establish use priorities and a plan to administer the development guide lines. A further provision allows acquisition of valuable estuarine lands as sanctuaries and for baseline measurements. The bureaucracy, of course, will also be expanded through a National Coastal Resources Board under the Vice-President and with a Coastal Zone Management Advisory Committee to the Secretary of Commerce with 15 members. Most of the projected federal annual costs of 70 million dollars would go for planning and administrative grants to the states. Nevertheless, this bill would seem, if adopted, to lead to an orderly and systematic sorting out of the various private and public claims for the coastal zones and to their systematic conservation or development.

The aims of the various legislative measures either enacted already or still in an advanced state of final review in the U.S. are matched by similar efforts in other countries. International efforts are being promoted effectively by the United Nations through the Conference held in Stockholm, Sweden after detailed preparations extending over several years. The results of these deliberations unfortunately were not as yet available at the time this summary was written. However, it can safely be assumed that important principles for the preservation of the ocean environments will be agreed upon by most nations and that general guidelines for prevention of pollution, for international cooperation in monitoring and for national responsibilities in enforcement will be recommended.

MONITORING SYSTEMS

In view of the urgency bestowed on environmental quality in recent years by public pressure and it's political expression through the creation of new laws and standards the scientific and engineering community is confronted with monumental tasks. It must provide the extensive base for rational decision making through the development of reliable instrumentation systems to describe the physical, chemical and ecological interactions in the coastal waters. The necessary evaluation processes for the data collected with such instrumentation arrays must be built into effective systems for integrated analysis. Hopefully then, various mathematical models can be constructed to not only describe on a dynamic basis the integrated behavior but to provide predictive capabilities on the response of coastal water bodies to their possible use by man in harmony with a desirable but not necessarily an unchanged environment. This is the vision before us; the modern scientific and technological means to achieve it seem to be within our grasp with the electronic and computational tools of our age. But many intellectual challenges remain to merge these tools into effective monitoring and predictive systems. We will examine in the following some of the fundamental components which must be incorporated and which must be developed further for these purposes.

THE PHYSICAL SYSTEMS

In order to understand the physical dynamics of the coastal waters conventional as well as new observation techniques must be adapted for such systems studies, the goal being a computer compatible data acquisition array for all instruments.

Tides and Currents

Tidal observation stations exist all around the coastline of the U.S. and stage predictions for average tides varying with lunar and seasonal cycles have been practiced for a long time. However, tidal currents are known in detail to a much lesser extent and current charts have been updated only after long intervals of time. For environmental studies, it is usually necessary to know more detail in local embayments concerning tidal stages and phase lags as well as about currents. Stage recorders present little difficulty and are relatively cheap to install in adequate numbers for the shorter periods of such studies, although they seem quite essential to a complete investigation especially when wind stress may modify tidal stages.

Current measurements are desirable not only for the surface but must be made in considerable number over the depth with regard to current intensity and direction. Directional changes of velocities are especially important. Unfortunately current meters with computer compatible outputs are as yet not too reliable unless frequently serviced. For propeller and cup meters fouling is a frequent occurance and they are expensive when a number are to be installed in one location to test for variations over the depth. The old standby system consists in drogues drifting at several depths which require constant observations and are therefore, providing only temporary current information. Magnetic current meters have been used with some success and are subject to fewer limitations with regard to fouling as conventional current meters since no rotating parts are involved. Further and better ideas are still needed in this field.

In many studies, particularly of pollutant transport and dispersion, very weak time-averaged currents govern the transport processes. These are particularly marked in estuaries where salinity is a variable both longitudinally and over the depth. Velocities are highly variable also over lateral sections, and an accurate assessment of net currents averaged over time presents an almost insuperable expense in measurements. Bottom drifters may be employed to obtain long-period average trends in open coastal waters but are little suited to navigation channels in estuarine waters. Here accurate current meter surveys have proved quite successful when their expense was warranted for specific studies. In summary, new or at least improved techniques are highly desirable for current surveys in conjunction with other environmental studies to define the internal dynamics of coastal water masses. The slow exchange processes induced by wave or density generated currents here are important to our understanding of pollutant and sediment transport. Of further interest in this connection would be a suitable measuring system for turbulent fluctuations especially where salinity or temperature variations over the vertical exist.

Wave Climate and Prediction

Waves form another essential component of the processes governing the coastal environment. Generated by storms over the oceans or coastal areas they vary in amplitude and frequency over a wide range. Of importance in pollution and sedimentation studies are the mean currents produced by waves, such as the littoral currents along the shorelines, the onshore and offshore currents with variable mass transport over the depth, the turbulent mixing generated by breaking either offshore or on the beach. Wave forecasting and hindcasting have been practiced for a long time and improved as more reliable records became available from an increasing number of measuring stations around the U.S. coasts. Many of these measurements are taken however in relatively shallow water and deep water observations have only become available in very recent times as offshore structures are pushed out into deeper shelf-waters for oil exploration and production. Ship-board observations are numerous but less reliable because they depend essentially on visual observations.

When wave gauges can be mounted on fixed piers usually the capacitance wire type or a step resistance arrangement is employed. Where piers are not available, buoys have been anchored offshore but their expense is justified only in connection with other instrumentation packets for a variety of current and water quality measurements. Bottom wave sensors will record major wave action some distance from the shore and consist of electronic pressure transducers combined with local recorders or onshore recording terminals. Direct transmission of signals to a central data processing center would seem indicated however for modern requirements and for direct correlation with other environmental data.

Most systems have the shortcoming of determining wave height only and not direction. The latter property is subject to special difficulties of measuring and where this has been tried with multiple arrays of wave gauges, the data have only rarely yielded satisfactory outputs commensurate with the expense and the complexity of data analysis. Aerial photography has given some good results for directional properties under favorable weather conditions. Other systems are under development but so far it must be conceded that a routine measuring system for wave direction is still some distance off in time.

Nevertheless, for the prediction of littoral currents and of the littoral transport of beach sediments directional wave spectra will be needed in addition to prevailing wind data which are more readily available but furnish at best only an indirect approximation of the wave attack on our shores.

Sedimentation Problems

Sedimentation processes in the marine environment are intimately associated with the current and wave systems in a coastal area. Sediment reaches the sea from land sources through our estuaries as well as from wave attack on erodible shorelines. The most abundant and for recreation the most desirable constituent of sediment on beaches is sand. Aside from small proportions of other minerals it consisty of quartz particles ($Si\ O_2$) surprisingly uniform in size (0.10 to 0.50 mm dia). Sand has moved through rivers to the seas at a slow pace estimated to take a million years per 100 miles. Its supply on beaches is therefore something to be conserved as a precious natural resource which can be readily wasted by ill-advised structures and lost to deeper portions of offshore waters.

Silt and clay form other portions of the marine sediments augmented by abraded shells and organic material. For the most part our estuaries shoal with such material in flocculated form and must be dredged to maintain artificially large depths for navigation. The interaction of turbulence and shear flow through tidal currents with the resulting periodic suspension of this material produces transport processes of considerable complexity. Man in many places has contributed large amounts of sedimentary material from his own wastes in the form of all kinds of organic and inorganic matter. The sludge of sewage plants, as in our Boston Harbor, forms extensive deposits over the years and the garbage and refuse of most larger coastal cities finds its way via barging to offshore dumping grounds. No easy solutions are at hand, considering the overall aspects of environmental quality. Burning will cause air pollution, deposition on land is often impossible for reasons of suitable sites or associated ground water pollution, dumping in the coastal sea is fraught with danger to the local biological activities and with the uncertainties of where much of the finer material will drift with the turbid currents. Man-made refuse may carry many of the unwanted pollutants to the sea often to be found afterwards in concentrated doses in shell fish and round fish making them unfit for human consumption.

Surveillance of turbidity and of suspended sediments in coastal waters is an essential facet of environmental monitoring. It is especially important in connection with dredging activities for sand and gravel offshore and in the exploration of suitable dumping grounds for sludge and dredge spoil. These should be confined to biologically inactive bottom areas.

Rapid procedures of suspended sediment assessment in quantity and quality are not at hand for these purposes. Collection by pumpout processes has been proposed as one way to replace the ancient system of bottle sampling. It may be possible to determine sediment concentration over the depth by rapid filtering at sea and storing the residues in much smaller containers for later analysis on land. Measuring sediment concentrations by light absorption is subject to many objections even under optimum conditions in view of the large variation of particle sizes and of the presence of plankton and may be used only for approximate evaluation of particle concentrations. Again we are still in need of new ideas and devices if such may be to bring our measuring capabilities to a more economical and convenient state in sediment collection and analysis.

By contrast surveys of changes in bottom topography by sediment deposition or erosion in shoaling areas can be carried out rapidly and efficiently by means of fathometers, i.e., acoustic depth measurements combined with automatic navigation systems, of which several are on the market. Work is under way to utilize acoustic measurements not only to describe the surface of bottom deposits but to indicate by multiple reflections the layers of different composition and density. Navigation systems for effective and accurate location determinations at any instant of an environmental survey cruise are available but require as yet very skilled attendants and are quite costly in use.

Water Quality

Water quality in coastal waters is governed by natural conditions as well as by the direct and indirect input from human activities. Fine sediments reach the major streams from uplands to the extent of 1-2 billion tons annually of which one half comes from croplands. In addition to water-borne sediments, another 30 million tons are transported in the form of dusts through the atmosphere. Not all of this is detrimental to the environment. Dust in the atmosphere is needed to generate rain and water-borne sediments are needed in the coastal environment in many ways. The large streams discharging into the estuarine waters bring valuable nutrients as well as detrimental pollutants to embayments and wetlands. Their distinctive roles with the many chemical processes involved in their travel to the sea cannot always be clearly attributed to one or the other category. We simply do not know all the answers as yet.

With regard to dilution, retention and chemical transformation taking place in estuarine and coastal waters temperature and salinity distributions play an important part particularly by governing internal transport phenomena in these water bodies. The measurement of temperature and salinity distributions in coastal areas form therefore a fundamental part of all environmental monitoring and the methodology for it seems well in hand. Three instrument systems are in current use for this purpose: the bathythermograph (BT) for use in small boats and local observations, the towed thermistor array for temperature distributions over the depth and the conductivity-temperature-depth instrument (CTD). The outputs of all these instruments have been arranged to be computer compatible by tape recording and immediate or subsequent conversion to digital formats. Thus, extensive sections and areas of coastal waters can be quickly surveyed. Maps of temperature contours and, after conversion, of salinity and density distributions can be obtained. These developments have pushed extensive buoy systems for these measurements into a lesser role in environmental work. Buoy stations for continuous monitoring of water quality parameters in certain locations will be mainly used as important reference stations to which periodic overall surveys from cruises will be related.

In the newest version of the towed probe system a "hydroglider" has been designed which is buoyant and controlled from the boat. The tail surface deflections are manipulated to have the hydroglider dive up and down at approximately 45° at forward speeds up to 10 knots. The sensors on the glider will measure conductivity, temperature and depth and a water intake will allow water samples to be pumped on-board through a connecting hose which are identified by air bubbles released on the glider at different depths. Thus a complete water quality survey may be taken over a long section and repeated over a tidal cycle with simultaneous tape recording in FM signals of location, depth, time, temperature, salinity and of certain chemical constituents while the vessel is moving. Later, more detailed analyses may be made for additional chemical constituents in the water samples as well as for sediment concentrations.

A "Technicon" automatic chemical analyzer (auto analyzer) is used for laboratory determinations at present. It is planned to have this auto analyzer on-board for direct determination of at least phosphate concentration from the pumped samples and to store up to 160 samples for later use in a 20 meter long coil of tygon tubing separated by identifying air bubble codes.

The instrumentation and techniques reviewed here briefly have been developed and are still under development in connection with a major "Sea Grant" project at M.I.T. concerned with the "Sea Environment in Massachusetts Bay and Adjacent Waters". These systems, when fully operational, will furnish comprehensive surveys of all the basic parameters for water quality as well as for the characteristics responsible for internal currents and pollutant dispersal. These capabilities are urgently needed for assessment of input, dilution and transport of pollutants whether these originate from outfalls of sewage treatment plants processing human and industrial wastes, from dredging operations or from the condenser water discharges of atomic and fossil power stations. Many state standards must be met with regard to heat and chemical dispersal. To check conformance to these standards is a major task confronting at present environmental monitoring. To make the measuring systems reliable and comprehensive as well as fast in response and in evaluation of results is still a challenging field for engineers and scientists working in coastal waters. Many benefits will obviously accrue to our general basic knowledge of coastal dynamics and of coastal water ecology from the push received from public concern with pollution. New insights have already resulted from such studies on many aspects of water mass movement and of dispersal of properties when density variations are present.

In connection with these relatively new capabilities for massive data acquisition, another effective means of surveying coastal waters must be mentioned, the ability to distinguish surface temperature variations in coastal waters by infrared photography from the air. The entire pattern of a warm water plume originating from the condenser water of a power station may be made visible in one instant of time. Baseline data are needed in the area however for reference to evaluate the photographs quantitatively. Of course, such overflights have been used also in another facet of coastal surveys; by regular photography of the coastline to follow seasonal and long-term changes in the coastal alignments and in some cases of submarine features in shallow water as well.

THE DATA PROBLEM

With the large capacity for data acquisition through the various instrumentation systems discussed in the preceding sections and through similar systems developed elsewhere, the data processing must be automated and interfaced with available computer facilities. Large data records must be processed for extensive areas of the coastal waters covered by numerous sections for storage on magnetic tapes and possible graphic display rather than as tabulated data points for isolated measurements. The first requirement is therefore that all data acquisition be immediately designed with computer processing in mind as it has been done for the instruments discussed in the preceding sections. These give output in FM signals and record it on magnetic tape but also allow visual recording to observe proper functioning of the instruments and to plan for adjustment in cruise time and direction to cover particularly interesting features of the phenomena under investigation.

For example, in the case of the towed hydroglider the temperature sensing device furnishes output in FM format to the magnetic tape and to a pen recorder. The pen will record a dot for each desired isotherm as a function of depth and hence, as the chart moves with time and also with distance as the boat proceeds, a plot of isotherms with distance is available at once aboard for scrutiny. Other properties desired will be similarly recorded and stored for further processing.

Confronted with multi-faceted data for many current and water quality characteristics special attention must be given to systematic data filing. A multilevel hierarchy of storage is indicated. This hierarchy must be so designed that it will be useful to even untrained investigators interested in entering or recalling specific data in a conversational program. It is further desirable that the same system be used for possibly all environmental data collected by other investigators as well so as to bring together the environmental information of a large coastal area in one data storage system.

For the Massachusetts Bay study the first level of the hierarchy was chosen to contain only identification with regard to time, location and type of variables determined. On the second level more complete information is given; cruise number, purpose of stations occupied, other variables entered and related to the measurements, etc. Finally, the third level of the hierarchy will contain the actual data recorded on specific cruises for the various water quality items and other relevant oceanographic parameters.

The system has been adapted to the MIT MULTICS system which is connected to the ARPA computer network. The data files are therefore made accessible from remote computer consoles by telephone connection. Further development is needed on the software level to produce graphical or cathoderay displays of original data and of processed components such as total pollutant content in the water mass, change of water mass, or observations corrected for tidal components. It is believed that the amounts of information needed to adequately cover an environmental description for a large body of coastal waters such as Massachusetts Bay require the fullest application of modern computer facilities. It is also believed that any environmental assessment of the effects of a local interference in these waters by dredging, power stations, sewage treatment effluents, etc., can only be rendered in the context of fairly detailed knowledge of the larger system of waters with which these local projects must interact. We have no choice therefore but to make fullest use of instrumentation and computer capabilities to define such environmental systems in their physical dynamics, their chemical constituents and their biological activities for future planning. Environmental impact statements must be based on solid ground datawise to avoid the conflicts between utilization and conservation of coastal resources which presently are producing so much emotional stress.

PREDICTIVE MODELLING

The purpose of all data collection for environmental reasons as for all others is to serve as a foundation from which rational analysis can take off. Experience with large physical systems has taught us that the inherent governing laws may be combined into either a similar physical system of more manageable size or into a mathematical model in which the different variables appear in clearly defined relations superimposed to form the system comparable to the original. Neither the physical nor the mathematical model reproduces the complex original in all essential aspects and both are subject to assumptions and boundary conditions governed by empirical factors. Both are dependent on prototype data from which these factors must be determined and both must be refined to the point where some original processes will simulate the true state but do not reproduce it. The more complex the interactions of the governing physical factors are, the more these simulations become subject to critical questions with regard to extrapolations for predictive purposes. This applies, for example, especially to predictions of dispersal processes. Furthermore, simulation for chemical and biological processes in concert with physical processes seems as yet very far off. However, it is felt that with our modern capacity for data acquisition and analysis our understanding of the physical environment can be enhanced to the point where ultimately models of the physical and of the mathematical kind with different capabilities can be made more reliable.

It is further assumed that such models of the physical environment will form a sound basis for prediction of the effects of disturbances to the system and that valid conclusions may then be drawn with regard to consequent chemical and biological phenomena.

It is clear that the need for the physical and mathematical models discussed here must have as its goal the description and performance of the essential dynamic systems and subsystems for an environmental area. So far, only long-term time-averaged systems models for pollution are available based on spotty observations in time and space and incapable of predicting unusual phenomena due to local topographic features, wind conditions, water mass exchanges at the boundaries, etc.

As an example may be cited the floating off over large distances of extensive lenses of pollutant releases from the Deer Island sewage outfall at the Boston Harbor entrance, observed in Massachusetts Bay under our Sea Grant Project. These buoyant masses of lighter water are often not mixed readily with the ambient sea water because of insufficient shear and may retain their identity for very large distances in the prevailing transporting currents. They could be spotted only accidentally by buoy observations. This mode of inadequate dispersion is obviously applicable also to heated condenser water discharges from power stations along the shores or on artificial islands. These phenomena may govern, therefore, decisions concerning location, time of release in the tidal cycle, and type of discharge system to be employed for such power stations and pollutant outfalls.

It can be stated generally for both physical models and mathematical models that in order to provide meaningful predictive capabilities for environmental decisions more comprehensive field surveys are needed covering the governing parameters simultaneously in time and space. The development of instrumentation, software and computer adaptation for systematic and immediate processing, storage, recall and display in various forms is the most important task for engineers and scientists for the near future.

THE OUTLOOK

The preceding general review of the prevalent environmental problems in coastal waters was pointed essentially at the physical phenomena as the basis for connected chemical and biological processes. In view of these important connections man's activities cannot be assessed properly unless their implications to the larger natural systems in which they interfere become definable. Recognition of coastal water regions as systems subject to many natural inputs demands an integrated approach from all those interested and active in coastal monitoring of the various components. Hence, a new degree of cooperation and coordination by many professional disciplines must be established. Surveying and monitoring by many specialists provide ample research opportunities as well as useful and necessary data bases for the solution of practical problems in resource development. Scientists and engineers may proceed from different motivations but both groups now face comprehensive tasks in which their interests are merged towards a simple end: to make known what is needed for the conservation of the coastal environment in harmony with man's aspirations for its rational use.

Where do we stand at present? We do have a large reservoir of all kinds of sensor and measuring equipment to identify the environmental characteristics from moving platforms on the sea and in the air and from anchored stations, for remote and direct recording. We have capabilities for data transfer to computer based analysis, reduction, storage, retrieval, display and future manipulation. We have a variety of suitable dissemination procedures by which information can be made available to all potential users. We do not have adequate data bases at present for most environmental processes.

Where should we go? While much of the measuring equipment is developed there are considerable shortcomings with regard to precision, reliability, convenient calibration, ease of handling, speed of operation, computer compatibility, etc. In addition, to improving and possibly standardising monitoring devices, a great deal of work must be done to resolve difficulties at the various interfaces between instrumentation and computer, the computer and useful output and dissemination. Monitoring must be planned carefully and, in view of possible overfeed, data acquisition must be confined to that essential for system definition. This necessary management phase of data collection is probably the most important aspect as well as the most difficult one in environmental monitoring. Data collection must be justified by ultimate use. A proper balance must be developed between baseline information and system simulation by mathematical models. To all these ends more cooperation is needed in the scientific and engineering community to develop generally applicable systems for integrated environmental definition. For example, what is desired in a baseline study for environmental impact assessment of engineering projects is not only knowledge on tides and tidal currents, but also on salinity, temperature distributions, sediment transport, bottom conditions, wind stress and wave state, etc., not only for one period but also at least for various seasonal states.

Will we get there in time? An appropriate development of equipment capabilities and of data management procedures will take probably an order of magnitude more manpower, money and time than we have allocated at present for such purposes. The question as to whether we will be able to provide the answers to environmental questions in time to be useful for many urgent decisions depends very much on how long we are willing to face detrimental risks. There is every expectation that major resource developments will take place in coastal waters within the next decade. Disposal for all types of refuse, oil drilling, offshore islands and harbors, recreational facilities and boating, fishing and aquaculture, etc. will all expand. The national and international economic stake therein is so vast that it is hard to conceive that we will not extend our best efforts in environmental monitoring systems. To conserve as well as to use the coastal waters in a viable ecological state we must first comprehend them. This message has been accepted and is being heeded by the scientific community as evidenced by the explosion of reports and publications by their councils, new societies, workshops and committees. The public has applied pressure through its representative agencies and their regulations, standards, hearings and permit systems. Will concern with the problem however be matched by willingness to pay? A big push is still needed to assure the allocation of adequate funds for the desirable major systems developments. A good start has been made with computer compatible instrumentation in various coastal regions of the U.S., in the Pacific Northwest, the Gulf area and in Massachusetts Bay. The full potential of modern technology however has not as yet been tapped to the necessary degree because of inadequate funds. Hopefully, this situation can be changed in time to provide us with the means to accomplish the tasks necessary for environmental protection and proper resource development in our valuable coastal water areas.

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THE HISTORY AND PHILOSOPHY OF COASTAL PROTECTION

by

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Dedicated by the author to:
Andries Vierlingh
Dikemaster, Netherlands,
for his "Tractaet van Dijckagie" ("Treatise on Dikebuilding") 1576-1579.

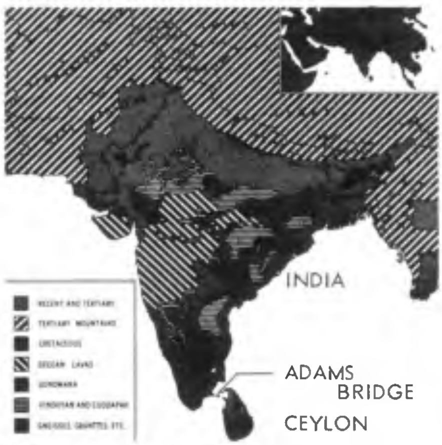
"Water shall not be compelled by any 'fortse', or it will return that fortse onto you".

Abstract - This paper gives a brief review of the history of coastal defence as it has developed since the year 1,000. It makes an attempt to outline what may be termed "the philosophy" and its relation to development.

The "State of the Art" is described by figures of characteristic designs including new developments. The paper establishes some general rules for future coastal protection and gives an outlook for the future.

HOW OLD IS THE ART OF COASTAL PROTECTION

We do not know; probably very old. Adam and Eve escaped from the gardens of Paradise located on the island of Ceylon following their blunder in an apple orchard. They crossed the waters on "Adams Bridge" which was not only a "bridge" (reef) but a coastal protection for a major part of the most southern SE coast of India.



Coastal protective works of major order probably first came into existence when man was forced to protect the land which he lived on to avoid the waters digging away the ground under his feet.

COASTAL PROTECTION IN THE LOW COUNTRIES IN EUROPE AND IN ENGLAND

NETHERLANDS

Although a great many training and irrigation walls, dams or dykes were built in the Far and Middle East coastal protection per se probably first developed in the low countries in Europe where rivers poured soft materials, mainly clay and silt, out in the ocean for settling. Consolidation was a slow process which made the land settle. In addition sea level was rising. To avoid loss of land by flooding and to protect themselves from drowning the Frisians and the Dutch first built earth mounds. Dyking started about the year 1,000. In the 13th century the Dutch had accomplished major coastal protection and reclamation works, particularly in the Dordrecht area.

Dr. van Veen in his book "The Art of a Nation" (1) writes: "The earliest written records about the Frisians (or Coastal Dutch) describe them as water-men and mud-workers. The Romans found in the North of the country the artificial hillocks upon which the inhabitants, already called 'Frisii', made a living. We shall follow their history, because written records are available about the early reclamation works they made. One and the same race, now called the Dutch, took, held and made the low country.

Pliny, who saw these mound-dwelling tribes in the year 47 A.D. described them as a poor people. He apparently exaggerated when he wrote that they had no cattle at all. Or did he see some much-exposed mounds near the outer shores where the sea had swallowed every bit of marshland? At stormtide, Pliny said, the Frisians resembled groups of miserable shipwrecked sailors, marooned on the top of their self-made mounds in the midst of a waste of water. It was impossible to say whether the country belonged to the land or to the sea. 'They try to warm their frozen bowels by burning mud, dug with their hands out of the earth and dried to some extent in the wind more than in the sun, which one hardly ever sees'.

No doubt the mud Pliny refers to was the peat which was found in the 'wolds', or swamps, some distance south of the clay marshes, where the artificial mounds had been made."

"In all they built 1260 of these mounds in the northeastern part of the Netherlands, an area of a mere 60 x 12 miles. Further East there are more of them in East Friesland. The areas of the mounds themselves vary from 5 to 40 acres; they rise sometimes to a height of 30 feet above normal sea level. The contents of a single mound may be up to a million cubic yards."

"They built their mounds on the shores of the creeks in which the tide ebbed and flowed. In their scows they went (in their language in which the roots of so many English words can be found): 'uth mitha ebbe, up mitha flood' - out with the ebb, up with the flood. The tide bore them towards the peat regions, or perhaps to the woods still farther inland and then brought them back. Or they went out with the ebb in the morning towards the sea, where they gathered their food, and returned in the evening with the incoming tide."

"The Coastal Dutch have now lived 24 centuries in their marshes and of these the first 20 or 21 were spent in peril. It was not until 1600 or 1700 that some reasonable security from flooding was achieved. During these long treacherous centuries the artificial mounds made their survival possible."

"It was a work which might be compared with the building of the pyramids. The pyramid of Cheops has a content of 3,500,000 cubic yards, that of Chephren 3,000,000 and that of Mycenium 400,000 cubic yards. The amount of clay carried into the mounds of the northeastern part of the Netherlands can be estimated at 100,000,000 cubic yards.

In Egypt it was a great and very powerful nation which built the pyramids throughout a series of dynasties. The aim was to glorify the Pharaohs. With us it was a struggling people, very small in number and often decimated, patiently lifting their race above the dangers of the sea, creating large monuments, not in stone, but in native clay."

"In this Lex Frisionum of 802 there is not yet any mention of seawalls, but the first attempts at dike building must have been made shortly afterwards. Frisian manuscripts still extant, dating from the early Middle Ages, deal chiefly with the following three points: First, the right of the people to freedom, all of them, 'the bern and the unbern'. Secondly, the 'wild Norsemen' whose invasions took place roughly from 800 to 1000, and thirdly: the Zeeburgh or Seawall.

This novel means of defence against the sea by means of a continuous clay wall was called a Burgh, or stronghold. The people were apparently very proud of this seaburgh, because they described it in poetical language as 'the Colden Hop', the Colden Hoop.

-'This is also the Right of the Land to make and maintain a Golden Hoop that lies all around our country where the salt sea swells both by day and by night'." (Plate 1, Fig. 1).

The spade, the hand barrow and the fork were the instruments used for diking, the fork presumably for the grass turfs which were used to heighten the dykes and make them stronger. Despite the tremendous efforts the sea was the strongest. "This was due partly to our insufficient technical skill and partly to lack of co-operation. For a single night, Dec. 14th 1287, the officials and priests estimated that 50,000 people had been drowned in the coastal district between Stavoren and the Ems. This is a large number considering that this was the area where so many dwelling mounds could be used as places of refuge."

The advances and successes have been tied to a few names. Says van Veen:
"We often wondered who was the master engineer who created the marvellous Great Holland Polder, south of Dordrecht, the work which had included the damming off of the tidal mouth of the river Maas, and the leading of that river into the Rhine. This proved to be William I. He had already finished that gigantic undertaking by 1213. The polder was destroyed in 1421 by the St. Elisabeth's flood, described in a former chapter. William was a man of great conceptions. He surrounded the entire area of Holland-Proper with strong dikes and made several canals intended to drain the vast moors. They also served as a splendid network of shipping canals. It is likely that he made the dikes around the Zeeland islands Walcheren and Schouwen too, and that he established the still-existing administrations for the upkeep of these islands. The other part of his clever and amazing reclamation and construction programme cannot be described here, but it is very clear that he knew the geography of his county by heart. No maps as yet existed!"

The earliest reference to the art of accelerating the natural rate of accretion is the manuscript "Tractaet van Dijckagie" (Treatise on Dikebuilding), written by the Dutch dykemaster ANDRIES VIERLINGH, between 1576 and 1579. VIERLINGH discusses the construction of "cross-dams" on mud-flats which are not yet dry at low water. In this connection he also advises that old ships should be sunk and earth dumped on the top of them so as to make artificial islands or flats which should hold back the silt and sand suspended in the water. These islands should subsequently be connected with low dams. Although this method has not been used commonly it is known that shipwrecks have been used at numerous places to close dyke breaches. These wrecks formed the basis for the fill material which was secured with mats or brushwood. VIERLINGH, however, was much against closing of dyke breaches with shipwrecks due to the non-homogenity they created in the dyke structure. Nevertheless, this method was widely used over a long period of time, not only in Holland but in the (at that time Danish) Schleswig-Holstein.

"Vierlingh was found to be a real master of the dikes and waters, a man of great ability and spirit - one of the greatest of his kind. Luckily the greater part of his manuscript has survived. Its ancient picturesque style is a joy to every hydraulic engineer. This remarkable book already shows the special vocabulary of the Dutch diking people in all its present-day richness. In some ways it is even richer.

His advice is simple and sound. The leading thought is:
Water will not be compelled by any 'fortse' (force), or it will return that fortse onto you.

This is the principle of streamlines. Sudden changes in curves or cross-sections must be avoided. It is the law of action and reaction. And truly, this fundamental law of hydraulics must be thoroughly absorbed by any one who wants to be a master of tidal rivers."

The work by the dykemasters and farmers to protect and to gain land has been remarkable. Plate 1, Figs. 2 and 3 (10) give an impression of how dykes were built up gradually by adding one layer of silt, or silt and sand, shell, willow mattresses etc. on the top of each other. Remains of old ships, brick walls and pile walls were used too. No less than two-thirds of the lower part of the Netherlands is manmade, while the other third is just "natural" sea marsh or moorish swamp. Since about the year 1200 the following areas have been gained according to van Veen:

On the sea shores	940,000 acres	
By pumping lakes dry	345,000 "	
By pumping the Zuiderzee dry	550,000 "	(partly future)
In all	1.835,000 acres	

With respect to the distribution of fill the 100,000,000 cubic yards of earth fill which the Dutch in the early centuries carried to their artificial hills were made only in a small area, covering roughly 8% of the country. Van Veen writes:
"The sea walls or dikes were our second work. In 1860, that is just before the advent of steam dredging, we had about 1750 miles of them, containing about 200,000,000 cubic yards of material. Moreover, there were many old deserted dikes, whose contents may be estimated at 50,000,000 cubic yards. Those 250,000,000 cubic yards were practically all transported by handbarrows, wheel-barrows and horse-drawn carts.

The third great work was the digging of the ditches and canals. In the lower half of the country about 800,000,000 cubic yards of earth have been removed, in order to drain the land and separate the fields. Of shipping canals there are about 4800 miles in Holland, for which a figure of 200,000,000 cubic yards would be a fair estimate.

The fourth and greatest task was the digging of peat. This digging served a double purpose: the provision of fuel and the creation of lakes which, when drained, gave more fertile land than the original moors themselves.

In total we have dug according to this rough estimate the enormous volume of some 10,000,000,000 cubic yards. This includes the making of lakes as well as the digging of moors in the higher eastern regions of the Netherlands.

Compare this figure with the dredging of the Suez Canal. We constructed about 100 Suez Canals of the size made by De Lesseps. All this was done by hand, whereas De Lesseps used 60 steam dredges."

But the work would never have been completed without the dykemasters, their foremen and "polderboys", who often were the farmers themselves. Figs. 4 and 5 (Plate 1) show them repairing dykes and building willow mattresses for bottom protection, an old but still active art.

A special kind of dykebuilding was the weed-dykes. Construction was limited to West-Friesland and the Zuiderzee-area, where sea-weed or sea-grass was found in ample quantities along the coast. The West-Frisian sea dyke were for a long time reinforced with seaweed, and so were some of the Wieringen dykes. It is not known with certainty how old the weed-dykes are, but weed dykes were constructed from the 8th century. A 16th-17th-century weed dyke was built at the northernmost point of the Island of Schokland, and another one in 1734 in the Northern part of Noord-Holland. Sea-grass for dyke building was collected offshore in the Zuiderzee and the Wadden area. Following drying, a broad, tough layer was placed on the sea side of the dike.

As ambition grew, dykes also grew. Moving them still closer to the dangers it became necessary to reinforce the dykes by hard surfaces like basalt blocks and/or other structures parallel as well as perpendicular to shore. These reinforcing or supporting structures developed as experience and exposure increased. The gradual reinforcement by structures like seawalls and groynes may have made a contribution to a not fully justified sense of security. It has been claimed that dykes were not raised rapidly enough in step with the sinking of the land and the rise of sea level, and that dykes were not subjected to thorough investigation of their structural soundness.

On February 3-4th, 1953, a spring tide whipped up by a raging gale overwhelmed the sea defences, and made tremendous breaches in the dykes (Plate 2, Fig. 6) and most of the islands in the south-west were inundated. 1850 people lost their lives. All the available material and manpower was mobilized and within a year all the gaps in the dykes had been closed and the flooded areas once more reclaimed, (Plate 2, Fig. 7). On November 5th, 1957, the "Delta Bill" was passed, containing plans for closing the tidal entrances in the south-west (Plate 2, Fig. 8). When this project has been completed the Dutch coast will have been shortened by 700 kilometers. The Delta project provides for the closure by means of massive dams of four broad, deep sea inlets, viz. the Haringvliet (1968), Veerse Gat (1961), the Brouwershavense Gat (1972) and the Eastern Scheldt (1978) and for the building of secondary dams in the Zandkreek, the

Grevelingen and the Volkerak. The Rotterdam Waterway and the Western Scheldt will be left open, since they provide access to the ports of Rotterdam and Antwerp respectively. This sequence was chosen after due consideration, since the transition from small to large sea arms enables experience gained to be profitably used in the larger projects. Another reason is the desire to achieve a higher degree of safety for the largest possible area in the shortest possible time. This - the world's largest coastal protection project - is thoroughly described in a number of publications and in the Dutch periodical "Deltawerken" published by the "Delta dienst". The status of this project at this time (July 1972) is that the Veerse Gat and the Haringvliet have been closed according to schedule: Two sections of the Brouwershavense Gat were closed in the spring of 1971, and the work will be completed by 1972. The southern gap was closed by telpher, (concrete blocks dumped from cable cars), the northern one by means of 14 caissons. The closing of the last gap meant that tidal currents involving the movement of 360 million cubic metres of water into and out of the inlet (each movement taking about 6 hours) ceased to flow. There remains the dam which will close off the Eastern Scheldt. This will be about 9 kilometres long and will stop tidal currents involving the movement of 1,100 million cubic metres of water into and out of the inlet every twelve hours. The construction of 3 artificial islands was needed to build the dam: the first was completed in 1969, the second in 1970 and the third in 1971. This dam, the last and largest to be constructed (it fills up channels as deep as 35 metres), is expected to be completed by 1978.

The construction of the large sluices presented enormous problems which were solved. Protection of the bottom was obtained by placement of large "Zinkstükken", upholding a 1,000 year old tradition. Although many tool and construction practices have changed, willow mattresses (Plate 2, Fig. 9) are still in use but they may in some cases have been replaced by mattresses of asphalt or synthetic sheets (Plate 2, Fig. 10). The cost of the Deltaproject by 1978 is estimated to be approximately 3,500 million guilders ($ 1,1 billion). It is an expensive project but it ensures greater safety for the entire South-west of the Netherlands, reduces the cost of dyke maintenance due to the coastline's shortening by nearly 700 km, opens up a whole series of islands, reduces silting, offers fast traffic links across the dams, and improves control of the supply of fresh water in almost the whole of Holland. In addition it provides new recreational possibilities for the vast population in the southwest urban areas and the provision of unique aquatic sports areas.

The development of Dutch groins. - A few remarks should be made specifically on the Dutch groins. The first groins were probably built at the beginning of the 16th century, but groin-like structures may have been built much earlier. We do not know exactly how they looked but the history of development during the latest 100 to 150 years is known (Plate 3, Fig. 11) and represents a continuous line of development of a streamlined structure exposing itself as little as possible to "the fortse" of currents and waves. Although groins have grown in size the principles are the same: Stone pitching on gravel on mattress in the middle and stones on mattresses on the sides with two or more pile walls as supports (12).

Today's length is usually approximately 200 meters and space between them is of the same order as described in more detail in a later section. Offshore elevations are about M.S.L. Occasionally groins are provided with piggy backs (Plate 3, Fig. 12) to break the longshore currents. Analyses by Bakker and Joustra (2) have demonstrated the ability of the Dutch groin protection which has not only decreased or stopped erosion in certain areas but has even caused accretion. The reason may be sought in the fact that (tidal) currents combined with swell action provided the shore with material from offshore so that the groins did not suffer starvation as often as is normally the case. While the situation at many other places where groins have been built is that erosion continues outside the extreme ends of the groins this, generally speaking, does not seem to be the case along the Dutch ocean shores. It may be said that nature itself made a demonstration of "artificial nourishment" in Holland. The groins, however, are not corner stone in the protection of Holland. This has always been the dykes. But foreigners who came and saw the results of the Dutch groins sometimes misinterpreted the situation very seriously. The massive Danish North Sea groins, Fig.43, which gradually increased in length to several hundred meters at the Thyborøn Barriers due to continued shore recession, is just one of these misinterpretations by which enormous quantities of materials were sacrified because of earlier insufficient understanding of the mechanism involved. One may ask: Could they have done anything else? The answer apparently is that it would have been difficult in the past but it is much easier today - for which reason it should be done. Misinterpretations also found their way to the New World, with the groins at Miami Beach (Plate 8, Fig. 45) being one of the most startling examples of how groins alone are inadequate as coastal protection. On the other hand it may be fair to say that the Long Island Atlantic shore groins are examples of efforts by groins to live up to the Dutch example. And there are several other examples where conditions were favorable (Plate 8, Figs.42,47).

"The Art of a Nation" became an export article. The Dutch also carried out many dyke and drainage projects in France. According to van Veen (1) the "Hollandries" were most abundant in Germany, Poland and Russia. Along the Molotschna there were 46 Dutch villages in 1836; the district Chortitza had at that time 20 such villages. In Poland there were about 2,000 villages inhabited by the descendants of the Dutch immigrants; in Posen there were 830 villages. The first great canal in the United States, the Erie Canal, was financed in 1772 by the Dutch and its locks were devised by Dutch engineers. Until 1798 the United States of America had no other creditor than Holland.

ENGLAND

In England coastal protection also has a long history because of the continuous erosion of strategic areas on the South Coast, in Lincolnshire, South Yorkshire and in many estuaries. There is already clear evidence of reclamation works by construction of "walls" (dykes) in the Dungeness area during the Roman occupation, the Rhee wall being the best known example. Historical evidence gives a consistent picture of the incursion of the sea along the Lincolnshire coast, by references to loss of land and damage to "sea banks", which had been a necessary defence since the 13th century. In 1335, according to records, the waves breached the sea banks at Mablethorpe and the land was flooded. By 1430 the sea-wall again needed repair. Erosion continued and the history of this area is one tough fight against the sea.

As in Holland, the first measures against erosion were "sea banks", the design being modified to serve as sea walls according to the local situation. Some were just earth dams, others were fascine or pilewalls (7). Later, vertical bulkheads were developed (Plate 3, Fig. 13). On the English shingle beaches abrasion presented a severe problem and called for the application of flint, basalt, or other suitable materials (backed by concrete) to resist abrasion (Plate 3, Figs. 14 a and b). The block walls at Pett Level (Dungeness) (Plate 6, Fig. 25) and Walland (Plate 6, Fig. 26), are mentioned later as examples of modern sloping walls providing flexibility rather than rigidity and low reflection of wave energy thereby being more considerate to the beach in front than vertical or slightly curved structures (11).

Groins were used as an additional protective measure. They were put into use in early times, probably as a result of observations of the effect of hard points protruding from the shore. This was likely to have been the case at Hornsea, South Yorkshire (9) where during an inquisition held in 1609 concerning heavy losses by erosion it was stated that "there was a peere at Hornsea Beach, during the continuance whereof the decay was very little". In 1864 six groins were built on the heavily eroding Spurn Head, South Yorkshire, at the entrance to the River Humber, where nature's forces were assisted by man's removal of shingle from the beach. The groins were of the King Pile type with horizontal boards which could be adjusted similar to the Withernsea Groynes erected in the 1870's (Plate 3, Fig. 15). They were strutted at the down-drift side to resist the pressure of the accumulating beach on the updrift side. Sheet pile groins were also tested, but the result was less satisfactory than the results with King Pile groins. The former were too rigid and lacked any means of adjustment.

Some enthusiasm seems to have resulted from the result of groin construction works of limited length along the shore but observations about ill effects in the form of downdrift erosion were also made. In a discussion of an article by Mr. J. Murray on "Sunderland Docks" printed in the Proc. of Inst.Civ.Engrs. 1849, Mr. Rennie and Mr. Walker refering to a report of 1832 admit "that groins were, under certain circumstances the best defence for a coast, for wherever the waves brought the sand and shingle in quantities, the seaward side filled up while on the lee side it was generally scooped out, but by a judicious distribution of these groins, such an accumulation of material might be produced, as would effectually protect a shore, or any sea works".

Inexpensive types were devised. Mr. Murray in Proc. of the Inst. of Civ.Engrs., 1847, discusses the design of groins and says "Groins might be formed with stones, timber, or fascines, either of the two first-named materials lasted well, but in cases where the deposit was rapid, and of such nature as to entirely fill up interstices, and prevent decay, the latter material would be sufficiently durable for all ordinary purposes".

The entire situation with respect to Sea Protection works was reviewed by a "Royal Commission on Coast Erosion etc." whose report was printed in 1911 by H.M. Stationary Office. One of the most significant references in this report is the statements that sea walls, unless properly constructed are "agents of their own destruction". In particular it refers to scour at the toe and the necessity of constructing a special toe, apron or groin protection in front of the sea wall to prevent undercutting.

With respect to groins advantages and disadvantages were fully realized. "The evidence laid before us goes to show that in many cases on the coast of the United Kingdom groins have been constructed of a greater height than was necessary to fulfil the required conditions, with the result that they have so unduly interfered with the travel of the shingle as to lead to impoverishment of the beach to leeward, causing in many districts serious injury to the coast".

The length of groins and the distance between them is discussed and 1 to 1 ratios are common but "satisfactory results were also obtained by 1 to 2 ratios". Alignment at right angles to the shore was best and provision for adjustment by adding or removing planks was preferable as low groins often proved to be more efficient than high ones being less adverse to downdrift beaches at the same time.

Reading this British document more than 60 years old, one regrets that the wisdom it contained was realized so late elsewhere and that designs as contradictory as possible to the century old British experience were advocated for a long period of time and to some extent still are being promoted. The difference between British and Dutch practice in groin design is related to the grain size of the material which the groins are composed expected to accumulate. In England a good many beaches are of shingle, and some of them experience a high rate of beach drift and significant fluctuations in beach profiles. A high (but adjustable) groin may therefore be practical. Energy loss along the stem is of less importance due to the coarseness of the material. Conversely in Holland all beaches consist of fine to medium sand which moves easily and fluctuations of beach profiles are of relatively small magnitude. Smooth streamlined cross sectional geometry causing little turbulence is therefore best for such conditions and groins should be low to conform with relatively gentle sand slopes. Groins having high vertical walls would result in scour and lowering of the beach on the either side of the groin.

DENMARK

In Denmark coastal protection started on the North Sea Coast in 1840 with a government project to increase the height of dunes on the Lime Fiord Barriers (3). In the 1870's experimental groins were built on the West Coast using a Dutch design which soon proved to be too weak to withstand the violent wave action on that shore. The design was reinforced and over the next 50-60 years almost 100 massive groins ranging in length from ab. 100 m to ab. 400 m were built in this general area of approximately 50 km length generally using a concrete block design (Plate 8, Fig. 43) of blocks ranging from 4 to 8 ts. now often provided with side slopes of 2 to 8ts granite. Blocks are placed with specially designed cranes. Erosion continued outside the extreme end of the groins and the outer parts were not kept up. The land ends were extended gradually as the dunes and dikes were withdrawn (3). Artificial nourishment from bay or offshore sources has - surprisingly enough - not been applied yet but is urgently needed particularly on the Lime Fiord Barriers.

COASTAL PROTECTION IN NORTH AMERICA

In the New World the professional history on how local problems were solved is becoming old too, but "public history" is new. It may be described briefly with a few notes (4,5).

Before 1930, Federal interest in shore problems was limited to the protection of Federal property and improvements for navigation. At that time, an advisory "Board on Sand Movement and Beach Erosion" appointed by the Chief of Engineers was the principal instrumentality of the Federal Government in this field. In 1930, the Congress assumed a broader role in shore protection by authorizing creation of the Beach Erosion Board. Four of the seven members of the Board were Corps of Engineers officers and the other three were from State agencies. It was empowered to make studies of beach erosion problems at the request of, and in co-operation with, cities, counties, or States. The Federal Government bore up to half of the cost of each study but did not bear any of the construction costs unless federally owned property was involved.

This important first step was followed by a series of improvements, in 1945, 1955, 1962, 1965 and 1968 demonstrating a still increasing interest and involvment in the matter by federal authorities (4, 5). Several states created their own beach erosion and shore development agencies which established co-operation with the local U.S. Army Corps of Engineers District and Division offices and with the Office of the Chief of Engineers. A great number of studies of actual beach erosion problems followed by reports to Congress by the Secretary of the Army authorizations and finally by federal contributions to actual improvements. These efforts were supported by research projects by the Beach Erosion Board and from 1963 by the Coastal Engineering Research Center (CERC). A number of special projects were handled by model tests at the Waterways Experiment Station of the USCE and CERC.

Structurally speaking the art of coastal protection suffered shortcomings compared to the low contries in Europe. Patented more or less useless coastal protection devices as e.g. permable groins, have had a bigger chance in U.S. business than elsewhere but the newest and most effective measure, artificial nourishment, although not born in the States, was raised there and has so far been most successful in the United States.

Being "philosophical" one may say that the difference between the European low country and the American coastal protection practice lies in "the scale" and in "the degree of involvement". The European is "high", but "short" and often "complex". The American is "long", relatively "low" (excluding hurricane protections) but "relatively simple".

The European practice is tough and silent, the American is flexible and it makes some noise because it is not only a measure but also a "nourishing machine".

WHAT WAS PAST EXPERIENCE? HOW SHALL IT BE UTILIZED?

The combined experience, gained through years of struggling, may be expressed briefly as

1) Whatever you do, avoid waves and currents turning their full fortse onto you (Vierlingh, 1570's).
2) Don't be nearsighted, think large if you possibly can. It is better to solve problems of some kilometers or miles than only of some meters or feet.
3) Look oceanward, landward and up and down the shore and evaluate carefully how your plans may be influenced by or influence the surrounding areas of land and water.
4) Coastal Protection does not necessarily need to be just coastal defence. Old Dutch experience and military tradition seems to favour defence by attack. In a war it is always best to keep the initiative and not leave it to the enemy.

An American version of this experience may be expressed as "the best protection for real estate is plenty of real estate in front of the real estate you want to protect", an approach which suits miles and kilometers and also matches economy as the general experience is that you (almost) always get a bargain when you order large quantities.

REASONS FOR BEACH EROSION

In order to define and discuss the problem it is necessary to go back to its roots. Erosion is caused by the forces of nature, sometimes assisted by man-made structures or by man's active erosion by removal of material from the shore.

Table 1 is a review of reasons for natural and man-made erosion. If no erosion is to take place from a particular shore there must be a balance between the quantity of material which arrives and the quantity of material which departs. Let us consider a shore which is not in balance but is losing material partly offshore by transversal drift and partly to the sides by imbalance in longshore drift or

$$|dE_{rosion}| = dT_{ransversal\ drift} + dL_{ongshore\ drift}$$

$dT_{ransversal}$ - With reference to long range development transversal drift is caused by sea level rise (disregarding sand drift by wind which in some cases may be of considerable importance).

Sea level rise (refs. 19 and 20) may sound innocent, but, realizing how narrow the beach is compared to the offshore area which is to be nourished by erosion of the beach in order to balance the rise of sea level with an equal amount of deposits of material on the bottom (Plate 4, Fig. 16 and ref. 15), it can be understood how an average rise of just 1/8 in per year may cause shoreline recessions ranging from 2 to 5 ft along the Eastern Seaboard of the United States. A general "rule of thumb" is that the shoreline recedes 1 ft for every millimeter which the sea level rises. There is, needless to say, a phase lag between rise and recession (15). An impression of the most recent sea level rises along the U.S. eastern seaboard may be obtained from the following figures by the U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration:

Ave. rise 1940-1970:

Eastport, Maine	1930-69	.338 cm/yr
Portsmouth, New Hampshire	1927-70	.165 "
Woods Hole, Massachusetts	1933-70	.268 "
Newport, Rhode Island	1931-70	.210 "
New London, Connecticut	1939-70	.229 "
New York, New York	1893-70	.287 "
Sandy Hook, New Jersey	1933-70	.457 "
Baltimore, Maryland	1903-70	.259 "
Washington, D.C.	1932-70	.244 "
Portsmouth, Virginia	1936-70	.341 "
Charleston, South Carolina	1922-70	.180 "
Fort Pulaski, Georgia	1936-70	.198 "
Mayport, Florida	1929-70	.155 "
Miami Beach, Florida	1932-70	.192 "
Pensacola, Florida	1924-70	.040 "
Eugene I., Lousiana	1940-70	.905 "
Galveton, Texas	1909-70	.430 "

It is obvious that the only way in which this erosion can be counteracted is by artificial nourishment replacing the material eroded by other material whether from land or from offshore sources, the latter becoming more and more popular due to shortage of land borrow areas. The integrated transversal transport of material including seasonal and long range movements is usually much larger than the longshore. Earlier planning tended to put the main emphasis on longshore transport and measures like groins, breakwaters and sea walls largely concentrated on a "different distribution" or "redistribution" of the material available - but on average there was always a net loss. Partly due to lack of recognition of that fact and partly due to lack of proper equipment to handle the "transcersal problem" effectively it was not until the last two decades that it was realized that ultimately the only way in which erosion may be fought is by artificial nourishment replacing the material eroded by other material. The only place where this general rule may be disregarded is where nature itself provides the nourishment. It was the "New World" which on purely coastal protective basis carried the initiative and it was there that efforts concentrated on the main and large problem of bringing material back to shore to replace the quantity which was lost by "submerging of the profile".

$dL_{ongshore}$ - It is generally accepted and justified by a great number of laboratory and field observations that the longshore transport of material (Q) has an almost linear relationship to the longshore input of wave energy (E) or:

$$\frac{dQ}{ds} = k\,\frac{dE}{ds}$$

when k is a factor which depends upon material and profile characteristics. Only wave induced currents are assumed to be present. This in turn means that the longshore transport depends upon the curvature of the shoreline. In nature this curvature is a function of natural geological and coastal morphological conditions like the existence of headlands, bedrock and river outlets (Table 1). This may upset the balance equation so that

$$\frac{dQ}{ds} \gtrless k \frac{dE}{ds}$$

in case of > accumulation will result
in case of < erosion will result

Nature demonstrates both cases e.g. by updrift accumulation and downdrift erosion at headland.

Table 1. Causes of Erosion by Nature and by Man

Nature	Man
Rise of Sea Level	Dams, dykes and other coastal structures causing rise and concentrations of tides
Protruding headlands, reefs and rocks causing downdrift erosion	Groins, breakwaters, jetties etc. causing downdrift erosion
Tidal entrances and rivers causing interruption of littoral drift	Man-made entrances causing interruption of littoral drift
Shoreline geometry causing rapid increase of drift quantity	Fills protruding in the ocean to such an extent that they change local shoreline geometry radically
Blocking of river outlets carrying sediments to the shore by flood stage barriers, change of location of outlets due to floods, erosion, tectonic movements etc.	Damming up of rivers without providing material sluices Irrigation projects decreasing flow of water and sediments to the shore Removal of material from beaches for construction and other purposes

What destruction effect nature in its abundance has demonstrated man unfortunately has imitated. Man-made erosion is a black spot on man's association with shores. It is a deplorable fact that all coastal protective measures apart from artificial nourishment (may) have an adverse affect on adjoining shores. An example is provided by a group of groins built in the 30'ies on the Danish North Sea Coast which caused severe lee-side erosion, up to 30 ft recession per year (situation corrected at a later date). Dams in California cut off river supply of sediments. Long harbor breakwaters and navigation channels often became almost complete littoral barriers causing severe erosion.

To evaluate the erosion quantitatively, records of erosion of profiles are needed. Such information may be available for areas of limited size but only a few countries have kept continuous records of areas of larger size through a long period of time. This includes the low countries in Europe e.g. parts of Denmark, England, France, Germany and Holland. Mostly only shoreline movements have been followed. A very illustrative example is given by Bakker and Joustra (2) whose paper does not only include data on shoreline movements on the open shore and at tidal entrances but also compares shoreline movements of groined and non-groined shores appraising the effectiveness of groin protection. Similar records are available in a few other places, e.g. in Denmark, Germany and some places in the U.S.A.

Several publications and books give considerable information on the development of erosion and on coastal morphological features (2, 3, 7, 9, 17, 21, 22, 24, 69). A great number deal with seasonal changes (13, 14, 18).

Space photography is now providing a tool for large scale checking of coastal movements (23 and re-references).

A very special type of erosion occurs in Norwegian fjords, demonstrating that disasters of tremendous dimensions can occur in subaqueous slopes in fine sand and coarse silt.

The explanation of why these slides frequently reach very large dimensions can be found in the two characteristic properties of these materials: The first property is the complete loss in strength after a shear failure which is characteristic for loose fine sand and coarse silt. As the result of this property the slide masses assume the character of a viscous liquid and, in the first place, flow downwards from the slide scar and possibly initiate new slides by erosion. In the second place, the disappearance of the slide debris means that the faces of the slide scar are left unsupported, involving the risk of an extension of the slide in an uphill direction by a retrogressive, slice by slice, development.

The second property of submarine deposits of fine sand and coarse silt responsible for the disasterous character of the slides is their exceptionally high erodability. The reason why these deposits are easily attacked by erosion is partly the lack of cohesion of fine sand and coarse silt particles and partly the lack of a protective cover of top soil and vegetation in submarine deposits. The consequence of the high erodability is that if a flow slide descends over this type of deposit, it will cut deep canyons into the slopes and undermine any obstruction which deflects it from its original path. The scars of such an erosion can lead to the development of a new series of retrogressive slides which can contribute both by extending the slide and by adding further liquid sand to the flowing masses. In the postglacial deltas and estuaries occupying the head of the fjords in middle Norway, the fine sand and silt slopes frequently stand steeply. In most cases the deposits are continuously growing as a result of accumulation of sandy and silty material being carried out into the fjords by the rivers. Under these conditions even small man-made fillings may initiate a slide of considerable size. A factor which may contribute to the instability of the submarine slopes in these fjords is artesian pore pressure conditions originating from high water pressures in the fissures of the bedrock beneath the deposits.

For further information on this "soil mechanics" erosion the reader is referred to a paper by Dr. L. Bjerrum, Proceedings of "The First International Conference on Port and Ocean Engineering", the Technical University of Norway, August 1971, pp. 24-38.

NATURE'S COASTAL PROTECTION. MAN'S COUNTERPARTS

By good luck nature has not only demonstrated how to erode but also how to protect. It may safely be said that there is no protection initiated by man which has not beforehand been invented by nature, and nature obtained all the good results as well as all the bad results before man did. Consequently we can learn from nature if we will only make the effort of opening our eyes and looking. It must be admitted that nature has been more imaginative and has had more success than man. Perhaps one reason for this may be sought in the fact that what we see is mainly the result of the successes. In the case of failures little or nothing was left! Coastal geographers and geologist, often unintentionally, describe natures coastal protection (e.g. 24 and 69).

Table 2. Nature's Coastal Protection. Man's Counterparts

Nature	Man
Shore rock	Sea wall
Rock reef	Submerged bulkhead or mound
Rock Island	Offshore breakwaters
Headland	Large breakwater perp. to or at an angle with the shoreline
Rock perp. to shore	Groins
Sea floor vegetation	Bottom Mattresses
Sea surface vegetation	Floating Breakwater
Dune	Dyke
Material transfer to shore by: Wind drift, Rivers, Shore erosion, Longshore Littoral Drift, Sea bottom transfer	Artificial nourishment from land sources
Natural by-passing of drift at tidal inlets	Artificial nourishment from offshore sources
	Mechanical by-passing of drift at tidal inlets

Table 2 gives examples of nature's protective measures and imitations of them by man. It is obvious that nature has immense resources and is able to play a "full orchestra" where man's instrumentation is somewhat limited by the lack of proper tools and adequate funding, one depending upon the other.

Plate 4 Fig. 17 shows updrift accumulation at a large rock headland, "Portland", on the Icelandic South coast. Plate 4 Fig. 19 demonstrates natural offshore breakwater protection causing tombolo formation in Dorset, England; Plate 4 Fig. 18 pocket beaches formed by outcroppings of coral rock and natural rock sea walls on the east coast of Puerto Rico (Palmas Del Mar) and Plate 4 Fig. 20 huge outpours of material by a glacial river in the Arctic. All glaciers have outbreaks of water reservoirs during the summer season. In Iceland subglacial vulcanoes, when erupting, occasionally cause discharges of the order of 1 billion cubic yards of material including bed load "particles" of 20 ts.

COASTAL PROTECTION A B C

The main cases of need for coastal protection are listed in Table 3, distinguishing between measures to be taken on large and on small scales.

Table 3. Main Cases of Needs for Coastal Protection

	Large Scale	Local (small) Scale
Reclamation of land and protection of the reclaimed land	x	
Protection of property and structures on the coast	x	x
Construction and protection of beaches	x	Pocket beaches

Table 4 is an attempt to establish a detailed classification of the types of coastal protection which are available today. Distinction is made between functional, operational and hydraulic or wave mechanics characteristics.

Table 5. Various Coastal Protection Measures Classified in Accordance with their Ability to Provide Protection of Extensive and Local Areas and their Influence on Adjoining Shores.

	Large Scale	Small Scale	Effect	Influence on neighbouring shores
Groins	(x)	x	May stop or decrease shoreline recession but not if offshore erosion continues	Adverse, often very severely
Sea Walls	x	x	Stop erosion where they are built but do not stop offshore erosion	May to some extent become adverse
Shore parallel breakwater	(x)	x	Will probably stop erosion and build up beach where they are erected	Adverse, often very severely
Artificial nourishment	x		Widens beaches Provides full protection if well maintained	Beneficial

(x) less attractive solution

TABLE 4

TABLE 4. DETAILED CLASSIFICATION OF TYPES OF COASTAL PROTECTION

Groins		Training walls, Shore parallel structures, Seawalls, Revetments.	
a) Classification:		a) Classification:	
i Beach groin	A coastal structure usually built perpendicular to shoreline to trap littoral drift and thereby retard erosion of shore. Narrow in width with its length varying from less than 100 ft. to several hundred feet. Stabilizes or restores or widens beach.	i Training wall	A structure placed parallel or nearly parallel to shoreline affording protection against waves and/or currents and retaining and preventing sliding of upland areas.
ii Current breaker groin	A groin with primary purpose to intercept currents which cause movement of material along beach. Light to heavy design with lengths up to 1,000 to 2,000 ft.	ii Sea Wall Bulkhead	A vertical or nearly vertical structure primarily designed to retain fill and stop erosion at a certain point or line
		iii Revetment	A sloping facing with primary purpose of providing protection against erosion of a dune scarp and beach in front. Sand accumulation in front is a secondary result from reduced wave energy.
b) Type:		b) Type:	
i Nonadjustable	A fixed groin high enough to block most of normal littoral drift but low enough to allow over-topping by storm waves carrying sand over groin.	i Vertical	A massive structure with variations in shape such as stepped and re-entrant curved face, vertical face, non re-entrant curved face, stepped face, inclined face, cellular sheet pile and rubble mound.
ii Adjustable	Groin with length and height adjustable.	ii Sloping (revetment)	A concrete or stone facing placed on seaward slope.
iii Impermeable	A solid or nearly solid structure preventing littoral drift passing through structure.	iii Impermeable	A solid or nearly solid structure. Seapage through structure through properly located drains only.
iv Permeable	A groin with openings, through structure of sufficient size to permit passage of littoral drift through openings will obstruct currents to some (variable) extent.	iv Permeable	A stone crib vertical wall or sloping rubble mound or rough stone revetment allowing movement of water inward and outward thereby dissipating energy.
Offshore Breakwaters		**Artificial Nourishment**	
a) Classification:		a) Classification:	
i Shore-parallel breakwater	A structure built parallel to and at a distance from the shore to absorb and/or dissipate wave energy and thus prevent or reduce wave action on the lee side.	i Direct nourishment of beaches	Operation of replenishing and nourishing an eroded beach directly by artificial means, that is, supply of dredged or other sediment material to eroded areas as a whole.
ii Shore-perpendicular breakwater	A structure connected to the shore in a perpendicular or nearly perpendicular direction mainly used to provide a protected area or harbor.	ii Bypassing at inlets and entrances	Operation by which normal littoral drift interrupted by inlets or entrances (littoral barriers) is restored on downdrift side by artificial means of sediment transfer across barrier.
iii Wave breakwater	An offshore structure built perpendicular or parallel to the shore to dissipate wave energy and thus prevent or reduce wave action on the lee side.		
iv Current breakwater	A structure supposed to break current.		
v Floating breakwater	A structure of hydraulic or pneumatic or barge fabricated type to serve as wave breakwater.		
b) Type:		b) Type:	
i Vertical	A vertical or nearly vertical structure of masonry concrete, concrete or steel caisson, sheet piling cells or timber crib. May be solid impermeable, permeable or of rock crib. Main purpose to protect against wave action.	i Offshore dumping method	Dredged material dumped in offshore zones of eroded areas.
		ii Stockpile method	A stockpile established on eroded area and nourished intermittently.
ii Sloping	Most common-rubble mound of natural rock or built-up precast concrete blocks. Used extensively as wave energy absorbers in the open sea as well as on shores.	iii Direct placement method	A method similar to stockpile method except entire fill spread out over entire area to be protected.
		iv Bypassing or continuous nourishment method	A mechanical method of intermittent sand bypassing from updrift (accretion) side of inlet or jetty entrance to downdrift (erosion) side without interference to navigation channel. Also continuous nourishment of eroded areas.

Table 5 lists different coastal protection measures and their relative ability in providing the protection, their influence on adjoining shores (beneficial or adverse).

Before we can evaluate which protection is preferable the situation with regard to erosion has to be appraised. This may by done by the introduction of the terminologies "undernourished", "sufficiently nourished" and "overnourished profiles" and by the terminologies "source" and "drain" of materials (38).

Beach Profiles Classified in Accordance with Nourishment - Considerations on the basis of the development of beach profiles built up of sand with grain size 0.2 to 0.3 mm seem to show that we can distinguish between profiles in another way: that is, between the "overnourished", the "sufficiently nourished", and the "undernourished profiles. These terminologies are especially valuable for an understanding of the problem of what kind of coastal protection should be preferred and how satisfactory such construction will be. The overnourished beach profiles are fed with more material than the waves can shape into real beach profiles. These, therefore, are irregular and often perform as irregular shoals. There are two different types of sufficiently-nourished profiles. At one of them the profiles are not fed with more material than the wave can shape into a profile having the same "equilibrium form". At the other, the loss of material equals the supply of material and the profile still has the same equilibrium form. The undernourished beach profiles are eroded: that is, the coastline retrogrades. The undernourished beach profiles will always keep an equilibrium form but the form may change from one locality to another, depending on the conditions in general. It seems, therefore, that progradation of a coast may take place with or without equilibrium profiles while retrogradation of a shoreline can take place only with equilibrium profiles having a maximum steepness corresponding to the quantity of littoral drift, the waves and the material. An actual equilibrium profile therefore should be defined as a stable profile with maximum steepness. Needless to say, we cannot expect that all undernourished profiles will always have the same shape, but we can expect that all undernourished and sufficiently-nourished profiles will have certain standard forms, which in turn means that where one of the standard erosion forms occurs, we know that the erosion is probably not temporary. This information is very important. If on the other hand no erosion takes place we can expect that only a slight change in the littoral drift balance may start erosion.

A source of materials is a coastal area which delivers materials to other beaches. A source might be an area where erosion takes place, a shoal in the sea, for instance; the shallow area in front of an inlet which has been closed; a river which transports sand material to the nearshore sea territory, or sand drift from dunes to the beach. Artificial nourishment of any kind is also a source.

A drain of materials is a coastal area where materials are deposited. A drain might be a marine foreland of any kind, a spit, recurved spit, a tombolo, angular foreland, etc. It might also be a bay, an inlet, or a shoal. Man-made constructions such as jetties, groins, or dredged sand traps, are also drains.

Both terminologies are used in the section dealing with coastal morphology in relation to problems of beach erosion and coastal protection. In practical coastal protection technology the following general rules are valid:

1) A coastal protection should be built in such a way that it functions as a drain. It should therefore have a source but not a drain on the updrift side. If there is a drain the coastal protection will not be very successful unless material is supplied artificially.

2) A harbor or an improved inlet on a littoral drift coast should not act as a drain. It should therefore have no source but if possible a drain on the updrift side. Meanwhile it is very difficult to find a place where ideal conditions exist, and many other factors play an important role. Most harbors are built in a sheltered area, an inlet, a bay or in a river mouth. In such areas depositions will almost always take place either from the littoral drift or as silting, which means that the harbor actually functions as a drain. This is the case with numerous harbors all over the world, notably on the East Coast of the United States. Protection against the littoral drift can be effected by the construction of jetties, making the "improved inlet". An improved inlet acts as a drain and protects the inlet, but at the same time it cuts off the supply of material to the beaches on the lee side which again means that these

TABLE 6

TABLE 6. COASTAL PROTECTION IN RELATION TO SOURCE OF MATERIALS AND CONDITION OF BEACH PROFILES
(Regarding beneficial versus adverse effects, see Table 5).

Coastal Situation: Actual Conditions of. Source of Material, and Beach Profiles			Groins (Adjustable, Impermeable & Nonadjustable)	Seawalls and Revetments	Offshore Breakwaters	Artificial Nourishment			
						Offshore dumping	Stockpile	Direct Placement	Bypassing Nourishment
A. Plenty of source material. Overnourished profiles.			Not Necessary	Might be necessary to avoid attack under extreme high-water and storm conditions. Should be built in such a way that they contribute to erosion of beach as little as possible. Vertical walls built too close to shoreline increase erosion. Energy absorbing walls. revetments or rubble mounds, are usually preferable.	Not necessary			Not Necessary	
B. Source material available. Sufficiently nourished profiles. Balance between material eroded and deposited.			Necessary if beach-widening is wanted in a particular location. Could be low or adjustable thereby permitting material to pass from updrift side to downdrift side as soon as they are filled with material.	Same as above. (A)	Able to build up a wider beach at a particular location.	If a beach is wanted in a particular location in short time, groins may be necessary to maintain the beach especially if the beach protrudes in proportion to the adjacent shoreline. Sand selected must have the same gradation as the beach sand if original beach slope is to be maintained. Sand may have to be obtained by offshore dredging.			Necessary if erosion is to be prevented on the downdrift side of an inlet. Groins may help retain material.
C. Only limited source of material or non at all. Undernourished beach profiles.	C.a Erosion only up to limited depth in the sea.	C.a.1 Source of material.	If extended beyond the depth up to which erosion takes place, they should be able to maintain beach. May be low or adjustable.	Can stop erosion provided they are stable at the depth at which erosion takes place. Even if groins are built. a seawall might also be necessary to avoid attack at foot of dune or cliff under extreme high water and storm conditions. It is very important that they be built in such a way that they contribute to erosion as little as possible. Sloping walls. revetments and rubble mounds work better than other types in avoiding frontal (beach) erosion.	Able to build up and maintain a local beach.	If a beach is wanted in a particular location in a short time. groins may be necessary for maintenance of beach. Selection of suitable sand for nourishment is important Sand may have to be obtained by offshore dredging.			Necessary if erosion is to be prevented on the downdrift side of the inlet or entrance. Extra supply of material probably necessary. Groins help retain material.
		C.a.2 No source of material.	Will not work even if extended beyond the depth up to which erosion takes place unless material is supplied artificially. May be low or adjustable.	Same as above. (C.a.1.)	Will provide local protection of shore but are unable to build up and maintain a beach.	Only continuous nourishment to balance erosion totally can maintain the beach or restore eroded areas. Groins may help retain fill. Selection of suitable sand for nourishment is important. Sand may have to be obtained from offshore areas.			
	C.b Erosion up to deep water in the sea.	C.b.1 Source of material.	Will retard retrogradation of shoreline temporarily after construction. Erosion will continue and continuous prolongation of land ends will be necessary if artificial nourishment is not made to balance erosion. Extension to deep water not important. May be low or adjustable.	Unless material is supplied artificially to balance erosion and groins are built, they will work only for a limited time before collapsing. It is very important that they be built in such a way that they contribute to erosion as little as possible. Sloping walls. revetments and rubble mounds contribute by themselves little frontal (beach) erosion compared to other types.	Able to build up and maintain a local beach but have to be reinforced as deep water erosion proceeds.	Periodic nourishment in quantities which balance total erosion can maintain beach. Groins may help maintain beach. Selection of suitable sand is important. Sand may have to be obtained from offshore areas.			Necessary to decrease downdrift erosion. Extra supply of material necessary. Groins help retain material.
		C.b.2 No source of material.	Will not work well unless continuously nourished to balance total erosion. Extension to deep water not important. May be low or adjustable.	Unless material is supplied artificially for total balance of erosion and groins are built, they will work only for a limited time before collapsing. It is very important that they be built in such a way that they contribute to erosion of beach as little as possible. Sloping walls, revetments and rubble mounds contribute to themselves little frontal (beach) erosion compared to other types.	Will provide local protection of shore but are unable to build up and maintain beach and have to be reinforced as deep water erosion proceeds.	Only continuous supply in the same quantity as total erosion can maintain beach or restore eroded areas. Groins may help retain fill. Selection of suitable sand is important. Sand may have to be obtained from offshore areas.			

TABLE 7. DETAILS OF THE PERFORMANCE OF SEA WALLS.

		Comments:
1. What is wanted:	Storm tide and/or extreme storm protection of shore and beach. Protection of specific valuable areas (industry, buildings, highways etc.)	Energy-absorbing wall or revetment on dyke or dune. Any type of substantial wall with as little adverse affects as possible.
2. Layout and geometry:	As streamlined as possible. It is best to leave and maintain a beach in front of the wall.	Erosion may be stopped at the wall but artificial nourishment may be needed to maintain beach in front of the wall.
	Influence on adjoining shores.	Leeside erosion may result if erosion continues leaving wall as protruding headland or if wall is built too far seaward and is not streamlined in horizontal geometry. Transfer of sand or other nourishment of downdrift shore may be needed.
3. Combination with other coastal protective measures:	Groins.	To break longshore current and possibly build up beach in front of wall.
	Artificial nourishment.	To maintain beach in front of wall and/or to check downdrift erosion.
4. Design:	Energy-absorbing (sloping and/or mound type).	Considerate to beach stability due to friction and low reflection.
	Non-energy-absorbing (vertical sheet pile or slab).	May create local erosion due to less friction against currents and more reflection.

TABLE 8. DETAILS OF THE PERFORMANCE OF GROINS.

		Comments:
1. Degree of efficiency wanted:	Just beach stabilization.	Short groins mainly covering the beach.
	Also widening of beach.	Longer groins, possibly extending beyond bar or breaker zone.
2. Layout and geometry:	Streamlined in horizontal geometry. No sharp turns or corners.	Reaction of shore protected: Stable or widening and then stable. Influence on adjoining shores: Usually beneficial or neutral updrift but adverse downdrift.
3. Combinations with other coastal protective measures:	Sea Walls.	To cope with extreme conditions incl. storm surges.
	Artificial Nourishment.	To fill groins and widen beach initially and maintain width.
		To eliminate adverse effects on downdrift beaches.
4. Design:		
Length in agreement with point 1. Height to match beach profile wanted to the practical extent possible.	Impermeable: Energy absorbing.	Less reflection, less loss of sand.
	Non energy absorbing.	More reflection, more loss of sand.
	Adjustable elevation.	May be operated to match fluctuations of beach
	Fixed elevation.	Can not be operated to match fluctuations of beach.
Length/space ratio from 1:1 to 1:4 depending upon quantity of drift and beach material. Most common ratio is 1:2.	Permeable: May be adjustable or fixed.	"To blow and have flour in your mouth at the same time". May provide beneficial results where currents are the main agents in the transport of materials, that means in rivers and estuaries.

TABLE 9. DETAILS OF THE PERFORMANCE OF OFFSHORE BREAKWATERS.

			Comments:
1.	What is wanted:	Protection, or protection and beach.	If breakwater is built on littoral drift shore both are usually obtained.
2.	Layout and geometry:	Parallel to shore or largely following depth contours.	Tombolo formation will result on shore to be protected. Severe downdrift erosion may result due to littoral barrier effect.
3.	Combination with other coastal protective measures:	Groins.	This combination is unlikely unless groins are used to check downdrift erosion, thereby transferring problem further downdrift.
		Sea Walls.	May be built to protect against extreme storms and tides or to check downdrift erosion.
		Artificial Nourishment.	May be used to create beach more rapidly if natural supply of material is limited or to check downdrift erosion.
4.	Design:	Energy absorbing structures preferable. See Table 7. Combination with natural reefs often advantageous.	

TABLE 10. DETAILS OF THE PERFORMANCE OF ARTIFICIAL NOURISHMENT.

1.	What is wanted:	Protection and beach.
2.	Layout and geometry:	Follow natural shoreline closely on straight or streamlined shores. Fill in pockets on headland shores and artificial pockets.
3.	Combinations with other coastal protective measures:	Groins: to create or maintain beach to eliminate leeside erosion Sea Walls: to protect wall and/or create or maintain beach in front of wall to eliminate leeside erosion Offshore Breakwaters: to create and maintain beach
4.	Design:	Nourishment from land or offshore sources. Offshore equipment under development. Various methods tested in actual operation. Sand shall be suitable for nourishment. Main requirement is that sand should be as coarse or coarser than the natural beach material and of no less specific gravity. By-passing - arrangements by fixed or movable plants incl. weirs and floating plants. Movable arrangements preferable.

beaches starve - having no source on the updrift side. It will be seen, therefore, that coastal protection problems are the reverse of harbor problems.

Table 6 is a general outline of the function of the type of coastal protection in relation to the actual situation of the beach and bottom profiles and to source and drain. When these factors are known, it is possible to evaluate the effects of various kinds of coastal protection and in that way determine the type which is most suitable.

Tables 7 to 10 give basic information on various types of coastal protection: putting the protection including sea walls, groins, offshore breakwaters and artificial nourishment in relation to "what is wanted" and giving some specific information on layout and geometry, combinations with other coastal protective measures and on designs. Plate 5 Figures 21-24, with accompanying note sheets following the plate sheets illustrates dyke protection and dune building. Plates 6-9 Figures 25-55 and the accompanying note sheets describe each particular measure: sea walls, groins, offshore breakwaters and artificial nourishment incl. by-passing of sand. Due to lack of space the number of figures had to bê limited to characteristic examples of "the State of the Art". Adequate information function is available in the list of references and bibliography which has been separated in sections referring to each particular measure. Space limitations had to be considered also on this matter. By-passing of material is mentioned specifically in the next section on future coastal protection.

HOW WILL COASTAL PROTECTION DEVELOP IN THE FUTURE

In future coastal protection one must think large. It will therefore develop as a function of the combined political, administrative and technical structure. There will be little or no use for "one-man shows". Large groups and large areas will have to be accomodated - by large scale measures. Needs will be concentrated on protective and recreational projects and all combinations thereof. Pressure will increase by the need for recreational beaches. Protection will be achieved simultaneously. The question of which protective measure will be most practical under such circumstances may be answered by just looking at Tables 5-10 which clearly demonstrate that artificial nourishment with suitable material offers the best large-scale protection. This, however, does not mean that it always suffices. It may need support from dikes and/or sea walls because of the possibility of storm surges or it may need groins to break scouring currents running close to shore. One main technical advantage associated with artificial nourishment is that it is "smooth" and "streamlined" and therefore not only has no adverse leeside effects, but, on the contrary, benefits adjoining shores by a gradual release of material. Other measures, particularly groins and offshore breakwaters, have definite adverse effects on neighbouring shores. The importance of streamlining is obvious from the following elementary reasoning: Most littoral drift formulas relate the quantity of longshore drift, Q, to the longshore component of wave energy as:

$$Q = (K\ we)\sin 2\alpha_b$$

If the breaker angle α_b increases, Q increases too, assuming that $_b$ changes only one degree up or down. The resulting relative increase (decrease) of material transport within various ranges of α_b is indicated in Table 11.

Table 11. Relative Increase or Decrease of Longshore Material Transport when α_b various ± 1 (one) degree

Range of α_b		Increase or decrease, approx. Percentage
10^o	5^o	20%
20^o	5^o	10%
30^o	5^o	5%

From these figures it is obvious that any (natural or) man-made discontinuity in shoreline geometry may have a considerable effect on adjoining shores. The beneficial effect is welcome but the adverse is not and it is often severe.

The "face" of the coastal protection will vary from place to place, depending upon local conditions. In Holland protection will have the main saying but recreation will become more and more important. In the United States more and more people are moving to the coastal zone. It is estimated (68, Herbich) that approximately 50% of the entire population will live in the coastal zone by the year 2,000. In Florida and in most places along the Eastern Seaboard of the United States coastal protection and recreational beaches will be combined. In California needs are mostly recreational. In Japan the need for recreational beaches is tremendous. In England sea walls and groins are needed for their steep shores but the demands for sandy beaches in lieu of shingle beaches will increase. In Denmark the massive expensive groin protection on the West Coast will be supported and partly replaced or in some cases abandoned by artificial nourishment from offshore and from bay shoals whenever possible. Accepting this inevitable trend of development it will be an increasing demand for just sand. In addition at some places measures will be needed and justified to hold on to the sand to decrease maintenance. In many areas all over the world reclamation will continue and this requires dykes and reinforcement of dykes by seawalls or recetments. From a technical as well as a coastal ethics point of view there can therefore hardly be any doubt that future coastal protection will comprise of the single or combined measures listed in Table 12.

Table 12. Future Coastal Protective Measures
AN = Artificial Beaches and Nourishment
GR = Groins
SW = Sea Walls and Offshore Breakwaters

Large Scale	Small Scale
AN possibly combined with artificial dunes or dykes providing storm tide protection	SW to protect a particular area sloping structures preferable
AN + SW SW to reinforce dyke or dune against extreme conditions of waves and tides	GR may be justified in local areas if well planned and kept filled by nature and/or by man
AN + GR when GR are justified economically to decrease maintenance costs	SW + GR to protect a particular area where groins are needed as current breakers
AN + SW + GR in unusual difficult cases	

The question which now arises is: how do we provide the optimal solution, technically, economically - and aesthetically? This question may be converted to: how do we get fill suitable for beach nourishment in ample quantities most economically? If it is necessary to build supporting structures as sea walls and/or groins, which design is then the most suitable? The problem which we are faced with concerns an optimalization of coastal protection considering all factors, the initial design as well as future maintenance.

As the need for sand increases the possibilities of securing the fill from land, bay or lagoon sources decreases which means that suitable fill to a still increasing extent must be secured from offshore sources. Such material must fulfill the following demands (54, 57, 61):

a) Grain size shall be as coarse or coarser than natural beach sand
b) Material shall be relatively well sorted with a distribution of particle size to cover all grain sizes present in the original environment

It shall include as little fine material ($<$ 0.15 mm) as possible and also little coarse material e.g. particles $>$ 2 mm to avoid separation and a steep and unstable - ever changing - beach.

c) It must be resistant against abrasion (quartz, feldspar and similar minerals)
d) Needless to say, it must also be clean without content of clay, silt and organic matters

e) But - very important - not all material needed to fill a beach has to be "first class". It is enough that all the exposed material is suitable. Below the lower level of fluctuation less adequate material may be placed - just to provide volume and support for the upper floor of "beach material".

Where do we find suitable material? - Every artificial nourishment project includes a hunt to locate proper material which can be secured in an economic bay. Such material may be found in borrow areas in nearby lagoons and bays where it is usually fairly easy to dredge it and dump it where it is wanted. Most artificial nourishment projects so far have been based on bay, lagoon and land sources. But it may also be secured from offshore sources. The "sand inventory program" carried out by the U.S. Army Corps of Engineers on the U.S. East Coast revealed the existence of such deposits - of varying origin almost everywhere - but not always within an economic pumping distance (61).

Is sand in ample quantities available offshore? - This depends upon the geological structure and the recent - that means the quarternary-geological development. All shores and shore areas have been subjected to changes in sea level. During submerges shores and beaches were drowned. We find old shores including shore material everywhere. Coastal geomorphologist have dealt extensively with ancient shores (69). During emerges materials returned to shore. Land areas which were subjected to glaciations - and deglaciations - and therefore to high fluctuations in pressure moved up and down with the ice load. At the same time oceans subjected to glaciations received tremendeous quantities of icecarried material incl. gravel, sand and clays and this was dropped in the ocean when the ice melted away. The North Sea and Baltic Sea offshore moraines and meltwater deposits are typical examples of that. The consequence is that many sea territories are able to deliver materials suitable for beach nourishment in ample quantities - but, this is not enough. The material also has to be available within a reasonable distance from shore and at depths which makes recovery practical and economical. To investigate the availability of material, core samples should be taken up to the depth of the planned borrow. It is selfexplanatory that the borrow pit must not be located so close to shore that it present a danger to beach stability. This question is dealt with in ref. 59. The 20 ft contour may be the boundary for milder conditions but 30 ft should probably be the minimum depth for conditions on the eastern seaboard of the United States.

How will we then bring this material back to shore? - As it cannot creep itself the only practical way of moving it is by hydraulic power, pumps and pipes. For this we need machinery and a device to carry the machinery. For the latter, three different possibilities seem to exist:

a) offshore mining from a surface vehicle (ship)
b) offshore mining from a vehicle operating on the bottom
c) offshore mining from a fixed or movable platform

re. a - Offshore mining from a surface vehicle - A test on mining of sand offshore was run by the U.S. Army Corps of Engineers in 1966 (67). The U.S. Hopper-Dredge "Goethals" was selected for the operation (Plate 9, Fig. 50). The mooring barge used for discharging from the hopper dredge was anchored in approximately 30 ft of water and its discharge pipe was connected to a 28-inch diameter, 2.000 ft long submerged pipeline running ashore. The line between the discharge piping on the barge and the submerged line, to form a connection from the plant to the ocean floor, needed both flexibility and ruggedness to withstand the lateral and vertical movement and the forces anticipated in this severe service. Much experience of operation and equipment was gained by this test by which fifty-two hopper loads, comprising more than 250,000 cubic yards of sand, were pumped ashore along a 7/10th-mile stretch of beach. The sand fill was piled on the beach to elevations about 5 feet higher than existed previously and the beach was extended seaward some 50 feet.

The Corps of Engineers beach nourishment experiment at Sea Girt, New Jersey, demonstrated that a suitably equipped seagoing hopper dredge could pump sand onto an ocean beach from an offshore mooring, thereby further enhancing the versatility and usefulness of this type of hydraulic dredging plant.

In 1971 a comprehensive nourishment from offshore sources was run at Pompano Beach,Fla.

by C.E.Bean, Inc., La. This work was performed between late April and October of 1970 by a cutterhead-suction dredge. During this period approximately 1,100,000 cubic yards of material was pumped on the beach. The material was located approximately 3-4,000 feet offshore in depths of 30-50 feet of water. The depth of sand available seldom exceeded 15 feet and never exceeded 20 feet. The dredge was 215 ft long, 45 ft wide, and 10 ft deep with a displacement of approximately 2,000 short tons. The pump engine was 3700 h.p. The pipeline used was 25" I.D. The floating line was conventional. The Pompano Beach project was described by the contractor as being "routine in every respect, with the exeption of sea conditions". The operation was limited by the inability of the floating pipeline to remain intact when the seas exceeded 4-5 ft in height. It is felt by the operators that the dredge could have operated in seas up to 5-6 ft provided the wave period was relatively short. Long-period waves tended to affect the dredge's capability while short-period waves had more effect on the floating pipeline. Subsurface pipes have now been developed for use in cases where a pipeline must be able to remain in position in bad weather.

The largest beach restoration or creation project is probably the 14 million cubic meters beach fill which was carried out in 1971 at Hook van Holland to create a 100-hectare (250 acres) beach north of the north breakwater of the Rotterdam Waterway. The material was dredged in the deep water channel serving Europort, Rotterdam's new gigantic seaport (62).

re. b - Offshore mining from a vehicle operating on the bottom - The underwater dredge is an old dream which appeared at intervals during the latest two decades. Underwater dredging for minerals has been known for long. Submergence of pipelines in the ocean bottom by jet pumps is of recent date. Similar large scale projects for placement of tunnel pipes across the Straits of Dover and elsewhere have been advocated during recent years. The underwater dredge (Plate 10 Fig. 52) which was put in operation on a test basis in 1970 at Ft. Pierce, Fla., was a result of many years of trial and error (66). A total of 63,000 cubic yards was discharged on the beach from the borrow area 1,200 ft offshore. Many improvements still seem to be needed to make such an operation successful technically and economically. 700,000 thousand cubic yards were pumped ashore by a convential dredge in continuation of this work.

re. c - Pumping from a platform - Another type of offshore dredge is a result of research undertaken by IHC, Holland, over a long period of years, which resulted in the development of the "platform-dredge" (56). Using this dredge a high rate of production can be achieved at considerable depth in currents and swells. Plan and side views of the platform are given in Plate 9, Fig. 51, which shows the dredge with the ladder lowered for dredging at the maximum depth of 25 meters. Supported on three legs, the platform can be moved by means of three twin-spud rotors, in any direction. Length of the L-sides is 30 m. The cutter ladder projects about 22 m when in the raised position. The legs are approximately 38 m in length. At a dredging depth of 25 m and a cutter penetration depth of 2 m, the platform can be jacked up to a height of 4 m above water. Table 13 is a list of data predicted by the IHC (56) comparing output capacities of conventional dredges to the cutter platform dredge.

Table 13. Output Capacity by Conventional and by Platform Dredge (56)

	Conventional cutter dredger with spuds	Conventional cutter dredger with swing wires	Cutter platform
Basic output in m^3/hr	1,000	1,000	1,000
Less factor for overrunning	-	0,5 m	-
Number of pump-hours attainable per year in calm water	3,100	3,100	3,100
Maximum wave height in even swell	0,30 m	0,75 m	2,0 m
Percentage of workable hours	15%	37%	80%
Actual pump-hours per year	465	1,145	2,480
Annual production in m^3	465,000	573,000	2,480,000

Maintenance - Any artificial nourished beach will suffer loss of material. This raises the question of how to decrease loss of artificially nourished material. This may be accomplished by structures. It is generally accepted that groins are able to slow down longshore drift but loss by transversal drift is probably far more severe, particularly on shores with steep offshore profiles. Addition of shoreparallel breakwaters at the extreme end making a "T-groin" or "mini pocket beach" is an improvement which has been used with success e.g. at Deerfield Beach, Fla. (Plate 8 Figs. 46 and 49) on Lido Key, Fla., on Hilton Head Island, S.C. etc. Another solution is the construction of an "offshore sill". Such sills have been used e.g. on some of the Chicago beaches and on Singer Island, Fla. It is in fact some kind of an offshore breakwater. The difference is that while offshore breakwaters are built in single sections sills are continous training walls providing an offset or step in the bottom profile.

Looking at the experience available in Florida, it may be said that many shores in Florida are already protected by some kind of offshore breakwater in the form of the limestone, coquina, and beach rock reefs, which are found along a good part of the S. E. coast as well as part of the lower Gulf coast. It is a known fact that deterioration of some of the offshore reefs had caused increased erosion (e.g. at Jupiter Island, Fla., Atlantic Coast and on Casey Key, Fla., lower Gulf Coast). Model experiments carried out at the University of Florida in 1965 demonstrated the ability of the sill (reef) to make a step in the bottom but also revealed the scour problem, particularely inside the wall. It is, however, quite evident that the offshore bulkhead or training wall has had a beneficial effect on the profile. The result, needless to say, is quantitative, but compared to field experience it indicates the trend correctly.

A very special type of "offshore training wall" has been built at Durban, South Africa. It consists (1972) of an almost 3 km (2 miles) long offshore deposit of 5 million m^3 of sand placed in 1966-1972 on 17-18 m depth, crown elevation at approximately 7,5 m below M.S.L., maximum waves ab. 6 meters (ref. 55 brought up to date by private comm. with Mr. J.A. Zwamborn). This "wall" or breakwater has so far been remarkably stable although it fluctuates slightly, the upper developing gentler slope during storms and steeper slopes during fair weather (swell) conditions. Losses have been small and the breakwater has caused considerable decrease of wave action during storms, benefiting the beaches.

Considering the coastal geomorphological side of the problem, nature has established large pocket beaches (Plate 4, Fig. 18). Improvments of natural conditions may be undertaken taking advantage of natural headlands and extending then by breakwater - additions. Such pocket beaches have been established at several places, e.g. on the Venezuelan shores at Los Caracos and at the Sheraton-Macuto Hotel. Pockets may also be established by stockpiling of sand on the beach at intervals. This will undoubtedly cause some (temporary) slow down of longshore drift creating a (temporary) leeside erosion problem. More material will probably be lost offshore however.

STRUCTURES

With respect to structures - whether groins, offshore breakwaters or seawalls including revetments - it may be expected that prefab. elements will take over to a still increasing extent. The shore-parallel structures will be in the lead because they fulfill requirements of consideration to adjoining property, recreational needs and aesthetics better than shore-perpendicular structures. Where the latter are built they are most likely needed for special "interlocking purposes" as "pocket" or "perched" beaches. Most structures will probably either be mass-produced in elements as large as practical or needed - or mass-produced in sheets of various materials easy to handle and place. This trend is already evident. A sloping sea wall e.g. may be split up in the following units: prefab. toe protection, prefab. mattress, prefab. armor, prefab. wave screen and prefab. overslash protection, totalling five "units". Groins may be made up of prefab. stem elements + possibly a T-head which could also be of prefab. elements.

Bypassing of material - Bypassing of littoral drift at tidal and other entrances cannot be considered "artificial nourishment". It is a re-establishment of natural processes which were disturbed due to man's adverse interference. This may be accomplished by "bypassing plants" or by "bypassing arrangements" (59, 60, 63, 65, 68).

Table 14. Sand By-passing Status in the United States

Location	By-passing arrangement	Status, 1970-1971
Bakers Haulover, Fla.	Bay shoal dredging	Permanent transfer from bay shoal trap suggested
Boca Raton, Fla.	Trap in entrance	Transfer from trap behind updrift jetty connected breakwater suggested
Canaveral Harbor, Fla.	Dredging of channel	Fixed plant to be constructed(?)
Channel Islands Harbor, Calif.	Trap behind breakwater	Operational
East Pass, Fla.	Depressed weir and trap	Weir jetty completed
Fire Island, L.I., N.Y.	Transfer from bay shoal	Has been studied/model study on trap arrangement
Ft. Pierce, Fla.	Transfer from bay shoals	Has been studied/suggested
Hillsboro, Fla.	Depressed weir and trap	In operation since 1952
Houston, Corpus Christi, Tex.	Bay and ocean shoal dredging	Sidecasting in operation
Jupiter, Fla.	Transfer from bay shoal	Depressed weir and trap/proposed
Masonboro, N.C.	Depressed weir and trap	Operation 3 years
Moriches Inlet, L.I.,N.Y.	Fixed plant proposed	By-pass of jetties to be extended authorized
New Pass, Fla.	Ocean shoal dredging	Occasional transfer from ocean shoals
Newport, Calif.	Undetermined or being studied	Recirculation by trap at lower end of ½-mile reach being studied
Ocean Beach, Calif.	Trap inside updrift jetty	By-pass from trap inside
Palm Beach, Fla.	Fixed plant	Revision planned
Perdido Pass, Ala.	Dredging of channel	Weir jetty completed
Ponce DeLeon, Fla.	Depressed weir and trap	Almost completed
Port Everglades, Fla.	Ocean shoal dredging	Transfer from shoals in ocean and entrance suggested (model)
Port Hueneme, Calif.	Trap behind updrift jetty	Transfer from trap behind updrift breakwater
St. Lucie, Fla.	Depressed weir and trap	Construction recommended
Santa Barbara, Calif.	Transfer from shoal inside updrift breakwater	Extension of west jetty, construction of east jetty and detached breakwater authorized
Sebastian, Fla.	Bay shoal dredging	Permanent transfer from bay shoal trap suggested
Shinnecock, L.I., N.Y.	Undetermined or being studied	By-pass of jetties to be extended authorized
S. Lake Worth, Fla.	Fixed plant	New jetties and pump in 1968
Twin Lakes Harbor, Santa Cruz, Calif.	Fixed plant	Operational 1972
Virginia Beach, Va. (Rudee Inlet)	Fixed plant	Revision planned; being studied

Table 14 shows the status of by-passing procedures in the United States 1970-1971. It may be observed that the flexible arrangements: dredging from traps behind depressed weirs or detached breakwaters or other traps now are in the lead compared to fixed or movable plants on jetties or trestles. Major movable plant installations are found in Durban, South Africa (stopped in 1953) and at Paradip, State of Orissa, Bay of Benegal, India. A small movable plant mounted on a trestle which may be closed or opened for passage of drift by "shutters" or "needles" is found at Nagapatam, State of Madras, India. The jetty is left open during the monsoon period.

Plate 10, Fig. 55, shows schematically various by-passing plants and arrangements. Hydraulic "lift procedures" (63) are being considered in a few places (U.S.A., India, Denmark).

DATA NEEDED FOR DESIGN

The data needed for design, needless to say, depends upon what one intends to design. If you are "scientific" you may make up a menu-card with 57 courses or so and start eating the appetizers without accomplishing any work of actual improvements. If you are "over-practical" and "over-experienced" you may wind up with a quick judgement with accompanying 50% change of failure. Table 15 summarizes what, in the opinion of the author, is necessary to secure information needed for a sound evaluation and design. With respect to artificial nourishment reference is made to the preceeding section.

Table 15. Basic Data Needed for Design of Coastal Protection

Structures	Beaches
Adequate tide data incl. data on storm tides (statistically and hindcasted).	
Adequate wave data incl. data on extreme storms (statistically and hindcasted).	
Current data to the extent needed for the particular location. Longshore and transversal currents are related to tides, winds, bottom topography, discharges from rivers, tidal inlets etc.	
Profile data incl. long range and short range (seasonal) movements of profiles and shorelines normally up to at least 30 ft depth. Knowledge about undulations of shoreline and changes in bar geometry.	Profile data incl. long range and short range (seasonal) movements of profiles and shorelines normally up to at least 30 ft depth. Knowledge about undulations of shoreline and changes in bar geometry.
Grain size analyses of sand from beach and nearshore offshore bottom.	Grain size analyses of beach and offshore bottom extending to min. depth of seasonal and/or long range fluctuations. Seasonal fluctuations of grain characteristics. Detailed investigations of borrow pit materials based on core sampling. Tracing preferably by fluorescent tracers advantageous for evaluation of stability and future maintenance.

Some may claim that the experienced designer needs less data than the in-experienced. Practice, however, often tends to demonstrate the opposite because the experienced person is more aware of the difficulties and he is therefore more careful with his planning. It is also experience that advocators of patented "super marked" devices, e.g. within the branch of permeable groins, usually need little or no data at all. The designer's "experience" is based on "faith" or on "just business". Consequently they can also be proud of having the absolute record of absolute failures.

PLANNING. ADMINISTRATIVE ASPECTS

With respect to planning of coastal protective measures even the best "philosophy" and professional (technical) approach will not work unless the administrative and political aspects are planned as well. In the United States national (federal), state, county or other public body if requested may grant specific favours in accordance with rules and laws but support by local groups is very essential and may be gained through confidence and detailed exposure of the program. The responsibility of developing plans that reconcile conflicting demands is the responsibility of all levels of government. Although planning criteria must be orientated towards the multiple-use concept based on local desires, it must also consider State and National needs. The State (province or county) should have - and some actually have - a single agency with the administrative and technical ability, financial resources, and enforcement authority to regulate coastal protective measures and provide cooperative support to help blend local interests with the State interests. It can also supply some expertise and files of basic data. And not least it should support with funds.

With respect to public administrative control with coastal protective structures it should always be an absolute requirement that what you do and ensure a positive result

for yourself should not be allowed to have any adverse effect upon property belonging to others. It is generally accepted that one should not deprive anyone of the water which flows to his property by which he upholds his living e.g. by farming or by industry. Neither should anyone cut roads or accesses over somebody else's property. Why should it then ever be permitted to rob your neighbour of his shore property by increasing nature's forces on his shore or by decreasing the flow of beach materials to his property? These are essential for maintaining it - just as important as water is for farming the land. Neither should anybody be permitted to expand the public access road constituted by the public ocean on the cost of any neighbour or shore property owner. It is peculiar that for a long period of time the most simple analogies in public administration were not recognized. The reason was probably twofold: first the mechanics of the matter were not understood and, next, public agencies were often responsible for the errors made either by direct sponsorship of the ill-advised structure or by permits granted to erect the structures. The consequence was that "face savings" and other "bureaucratic reasons" often became more important than recognition of facts. The peculiar situation therefore developed that it was the courts who were forced to look into such problems because a few individuals were hardheaded and wealthy enough not to bend their neck for certain shortcomings of public administration.
One of the major problems for progress in coastal protection, however, is that funds for planning have been difficult to obtain - or very late in coming. Most coastal states in the U.S.A. still have not provided adequate agencies and funding and the lack of coordination and planning of coastal protective measures has gradually become a national problem. The Federal Government has taken an active - but still incufficiently funded - interest. The most difficult task, however, seems to lie on the local government and group level because the democratic system does not advocate the kind of discipline which is a necessity in all warfare including the tough fight against the sea. Practices in Europe and in the United States differ to some extent due to differences in the political and administrative pattern. In Europe, particularly in the low countries and in the countries rimming the North Sea, problems are often fully national. Contributions by local governments or groups are minor or non existing but they may handle the problems partly or wholy on less exposed shores.

Ten demands in Coastal Protection are listed in Table 16. They are as strict and demanding as those listed in Deuteronomy. But if we do not obey them we may soon need a number of "Adams Bridges" for escape - because nothing can stop the forces by tides, waves and currents. King Canute of Denmark and England placed his royal throne on the beach but the waves washed over his feet. He withdrew. Flexible defence costs less and mostly it is the most successful and it does not prohibit stand-by positions when needed.

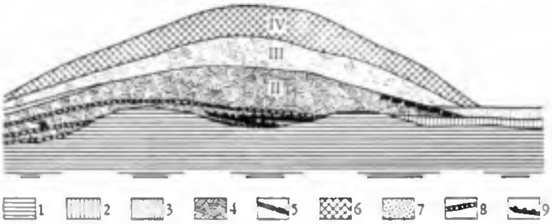
Table 16. The Ten Demands for Coastal Protection

1) Thou shalt love thy shore and beach
2) Thou shalt protect it gainst the evils of erosion
3) Thou shalt protect it wisely yea, verily and work with nature
4) Thou shalt avoid that nature turns its full fortse gainst ye
5) Thou shalt plan carefully in thy own interest and in the interest of thine neighbour
6) Thou shalt love thy neighbour's beach as thou lovest thy own beach
7) Thou shalt not steal thy neighbour's property, neither shalt thou cause damage to his property by thy own protection
8) Thou shalt do thy planning in cooperation with thy neighbour and he shalt do it in cooperation with his neighbour and thus forth and thus forth. So be it
9) Thou shalt maintain what thou has built up
10) Thou shalt show forgiveness for the sins of the past and cover them up in sand

Acknowledgement - The author wants to express his appreciation for the assistance offered him in preparation of the historic sections of this paper by colleagues in the Netherlands, Mr. J.F. Agema, Chief Engineer, Rijkswaterstaat, Mr. T. Edelman, Chief, Coastal Research Department, Rijkswaterstaat and Mr. J. Battjes, Research Engineer, Delft University of Technology and in England by Mr. D.L. Newman, Research Engineer, the Hydraulic Experiment Station in Wallingford.

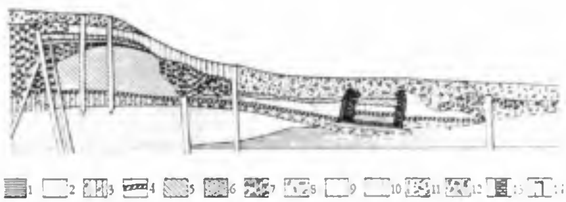
PLATE 1

Fig. 1. "Golden Hoop" in the Netherlands.
Currentbreaker of later date in front (van Veen, 1962)



1. PEAT PRESENT IN SUB SOIL
2. COVER OF CLAY ON PEAT
3. YOUNGER CLAY COVER
4. CLAY WITH CLODS
5. CLODS OF PEAT
6. CLAY (WHICH WAS " BROUGHT IN ")
7. MARINE SHELLS
8. MAT OF BRUSHWOOD
9. PARTS OF SHIPS HULL

Fig. 2. Cross section of ancient dike, Netherlands.
("Antiquity and Survival", 1959)



1. PEAT PRESENT IN SUB SOIL
2. CLAY
3. CLAY WITH SAND AND SHELLS
4. REED
5. SEA - GRASS (WEED)
6. PEAT
7. CLAY WITH RUBBLE
8. SAND WITH SHELLS
9. CLAY
10. CLAY WIYH SAND
11. CLAY WITH SHELLS
12. RUBBLE WITH SHELLS
13. MASONRY
14. PILE

Fig. 3. Cross section of ancient dike with pile support.
("Antiquity and Survival", 1959)

Fig. 4. Polder boys repairing dike with willow,
Netherlands (van Veen, 1962)

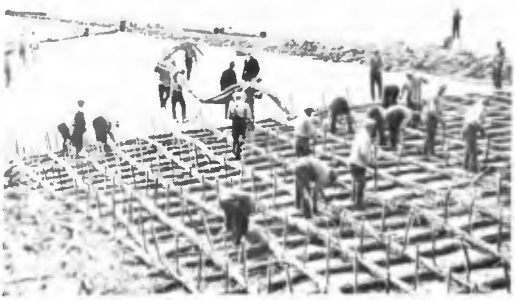


Fig. 5. Willow mattress, Netherlands (van Veen, 1962)

PLATE 2

Fig. 6. Breakthrough at Vosmer, Netherlands, Febr., 1953 (van Veen, 1962)

Fig. 8. The Delta Plan. (Rijkswaterstaat, 1971)

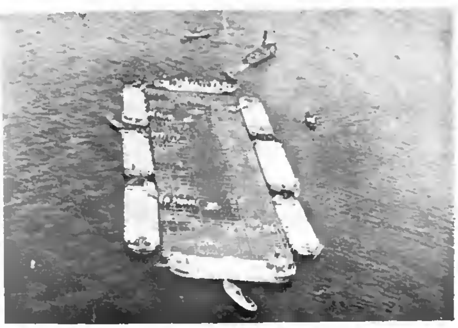


Fig. 9. Towing of willow mattress for bottom protection (van Veen, 1962)

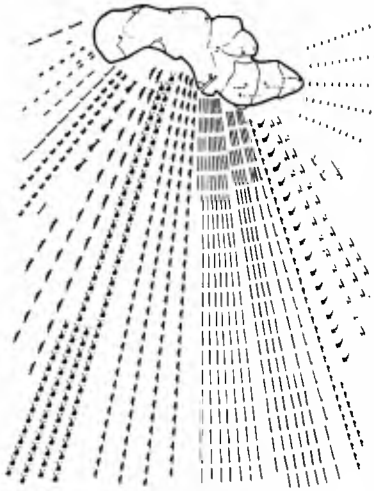


Fig. 7. Equipment parade at closing of breaches in the dikes of Schouwen - Duiveland (van Veen, 1962)

Fig. 10. Placement of zinkstuk of synthetic materials. (Deltawerken No. 58, 1971)

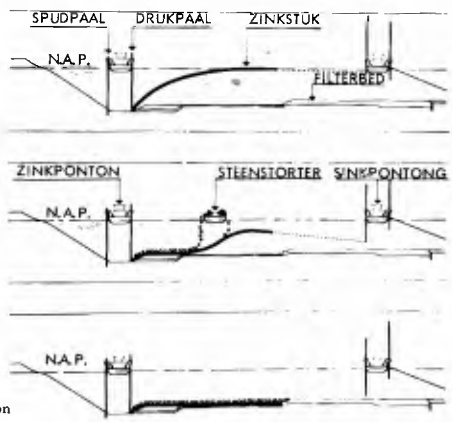


PLATE 3

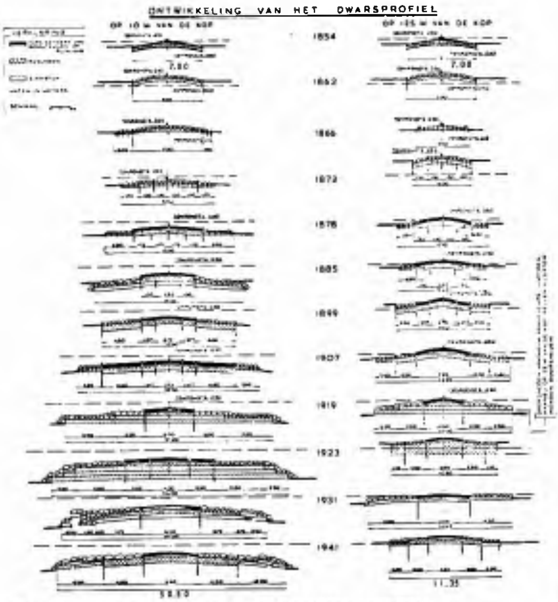


Fig. 11. Development of groins in Holland 1854-1941. (Visser, 1953)

Fig. 12. Dutch groin with piggy back

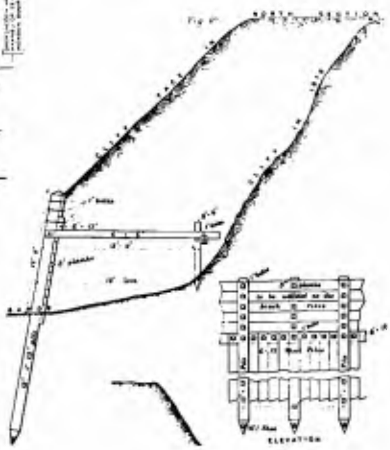


Fig. 13. Hornsea sea wall. (Journ. Inst. Civ. Engrs., 1877-78)

Fig. 14 b. Beaconsfield Sea Wall, Bridlington, under wave action

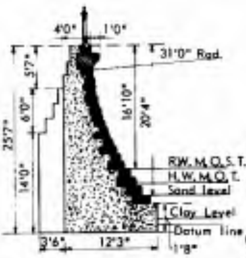


Fig. 14 a. Beaconsfield Sea Wall, Bridlington (Mattews, 1934)

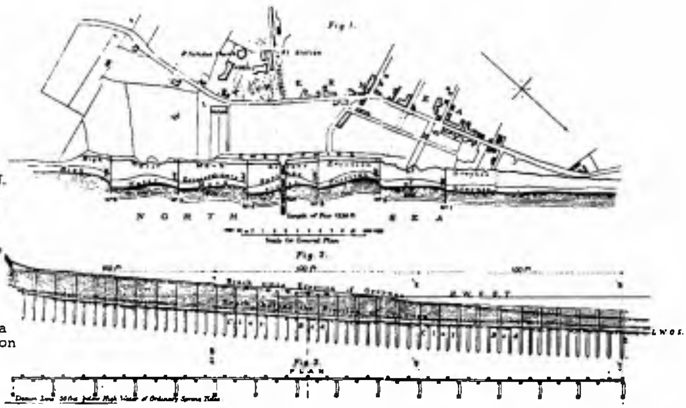


Fig. 15. Whithernsea Groins (Journ. Inst. Civ. Engrs. 1877-78)

PLATE 4

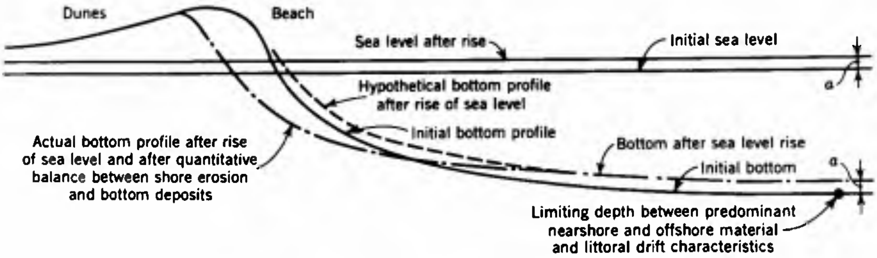


Fig. 16. The influence of sea level rise on erosion (Bruun, 1962)

Fig. 17. Dyrholaey, headland and natural break-water on the Icelandic South Coast

Fig. 18. Rock outcroppings make natural sea walls and form pocket beach in Puerto Rico

Fig. 19. Man o'War Rocks, Dorset, makes off-shore breakwater (Steers, 1947)

Fig. 20. River pouring material into the sea nourishing beach and off-shore profiles on the Icelandic south coast

PLATE 5

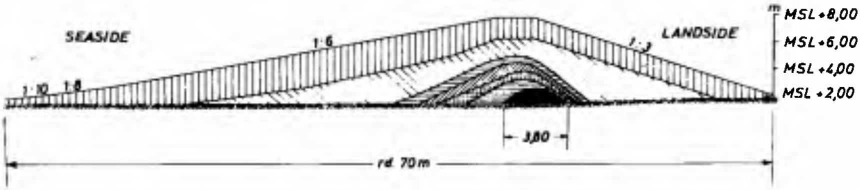


Fig. 21. Comparison of elder with modern dike profiles (Kramer, 1971)

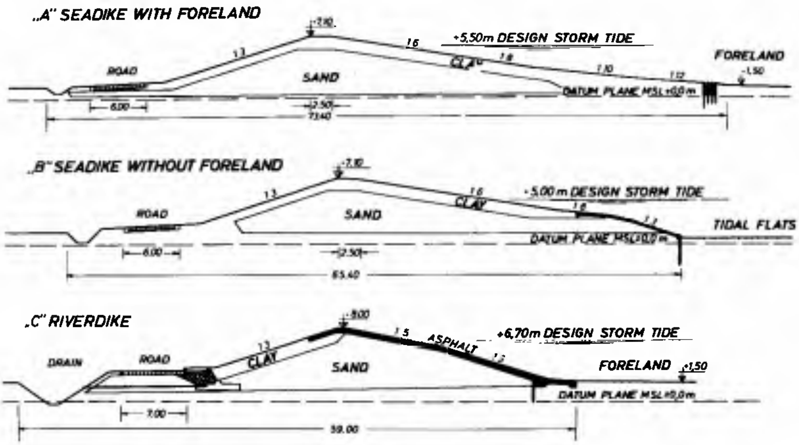


Fig. 22. Cross sections of dikes with sand core and clay or asphalt cover (Kramer, 1971)

Fig. 24. Dune building by sand fences (NPS, USA)

PLATE 6

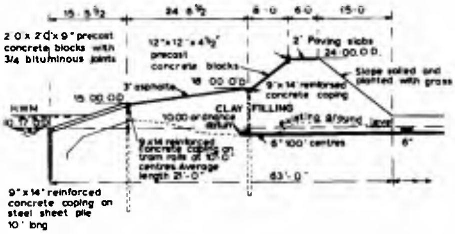


Fig. 25. Pett Level Sea wall (Thorn, 1960)

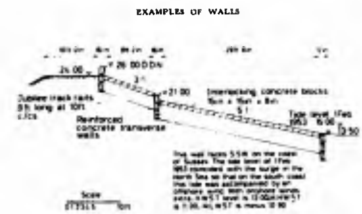


Fig. 26. Walland Sea wall (Thorn, 1960)

Fig. 27. Stone pitching revetment and stone pitching piggy back groin (Rijkswaterstaat)

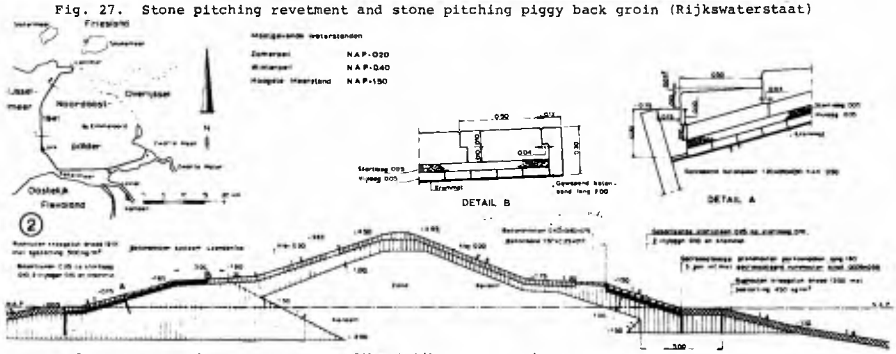


Fig. 28. Noordostpolder revetment on dike (Rijkswaterstaat)
Legend: Basaltzuilen (basalt prisms), stortlaag (gravel layer), vlijlagen (láver of brick), krammat (straw mat), kraagstuk (willow mattress), bestorting (rock), beton (concrete), klei (clay dug from canals and marshes)

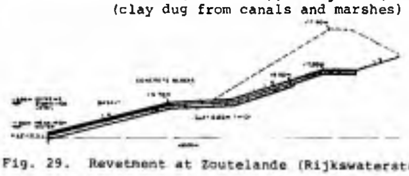


Fig. 29. Revetment at Zoutelande (Rijkswaterstaat)

Fig. 30. Sea Carpet at Europeport, Netherlands (Hydrospace, Oct. 71)

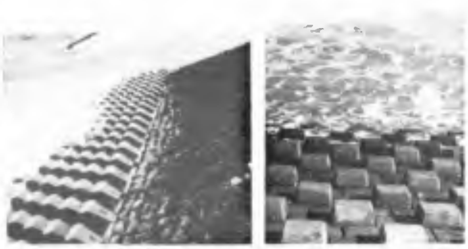


Fig. 31 a and b. Concrete blocks with friction arrangements (Rijkswaterstaat)

PLATE 7

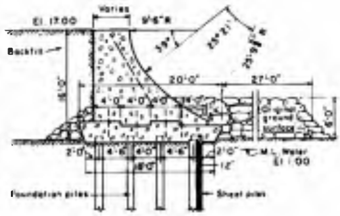


Fig. 32. The Galveston Wall, Texas (USCE = U.S. Army Corps of Engineers)

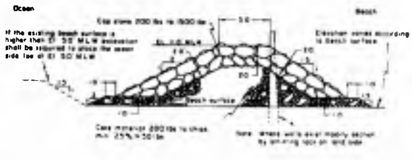


Fig. 33. The Fernandina Wall, Florida (USCE)

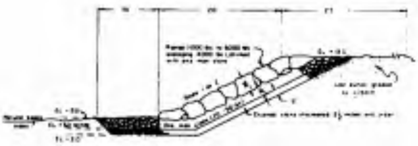


Fig. 34. The Ft. Story Wall, Va. (USCE)

Fig. 35. Indian Sea Wall (Kerala State)

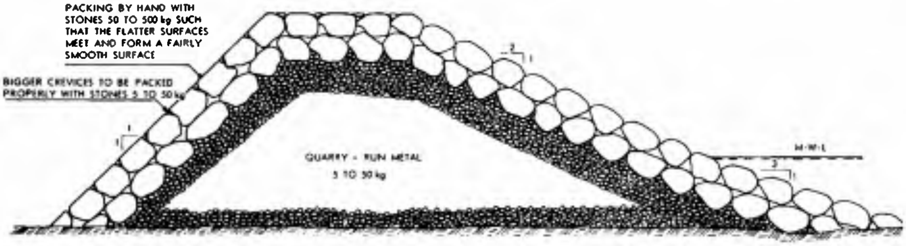


Fig. 36. Vertical wall on Jupiter Island under heavy wave attack, 1962 (Bruun and Manohar, 1963)

Fig. 37. Interlocking block revetment on Jupiter Island under heavy wave attack (Bruun and Manohar, 1963)

PLATE 8

Fig. 38.
Dutch basalt pitching groin at Petten

Fig. 39. Dutch group of groins, Walcheren (Rijkswaterstaat)

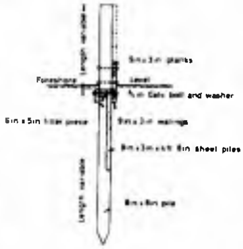


Fig. 40 a and b. British adjustable king pile groin (Thorn)

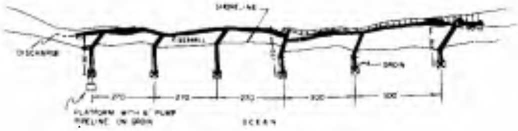


Fig. 42. Group of groins with slanting land ends at the Old Skaw, Denmark (Bruun and Manohar, 1963)

Fig. 43. Groin built of 4-8 ts concrete blocks in the crown and 2-8 ts granite in the slopes. The Lime fiord barriers, Danish North Sea Coast (Hofdahl)

Fig. 41. Adjustable groin at South Palm Beach (Greiser)

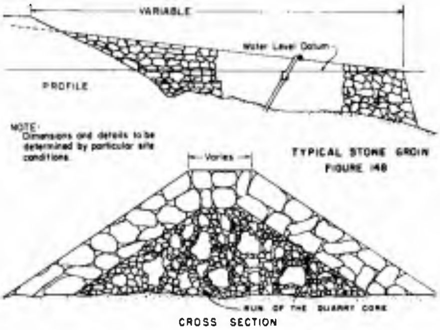


Fig. 44. American rock groin (USCE)

Fig. 45. Groins, mostly steel sheet piling, at Miami Beach, Florida

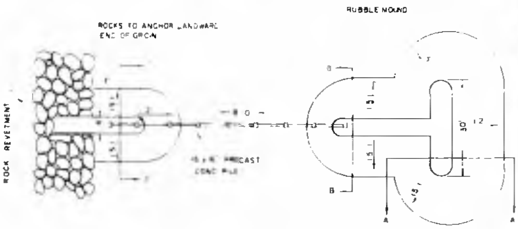


Fig. 46. T-groin design for Deerfield Beach, Fla. Adjustable king pile stem, rock T-head (Bruun and Manohar, 1963)

Fig. 47. T-groins at Deerfield Beach, Fla. (Bruun and Manohar, 1963)

PLATE 9

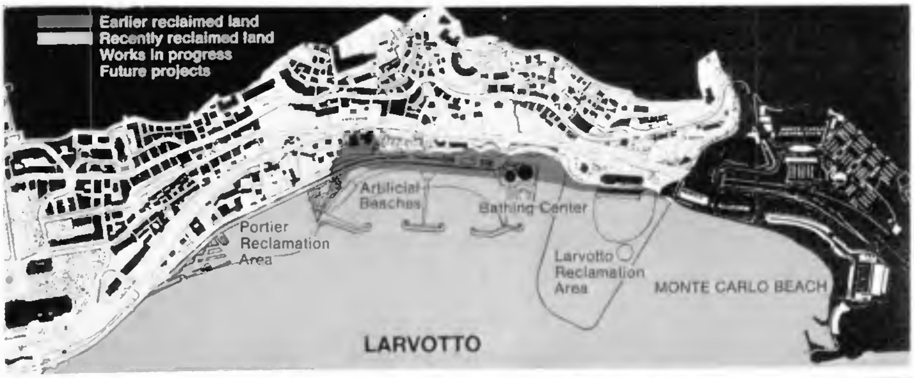


Fig. 48. Offshore breakwaters form pocket beaches, at Monte Carlo (Terra, Holland, No. 1, 1972)

Fig. 49 a and b. Artificial nourishment from land sources, 1,6 mill cuyds on 16,000 ft of shore, Hilton Head Island, S.C.

a

b

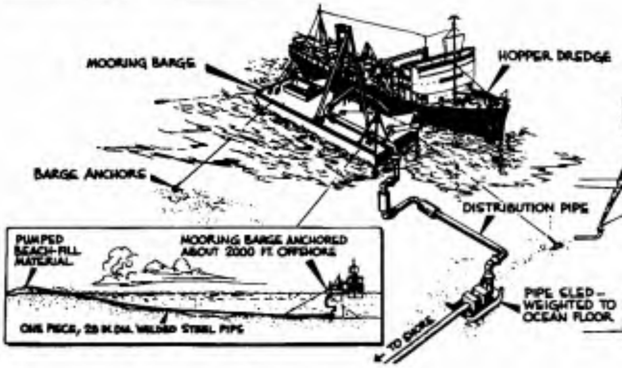


Fig. 50. Artificial nourishment from offshore by hopper dredge. See Girt, N.J. (Mauriello, 1966)

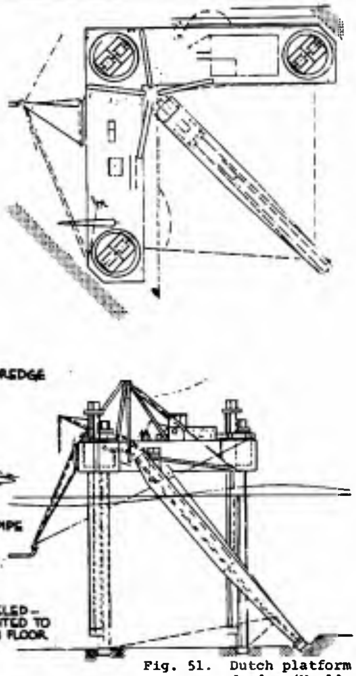


Fig. 51. Dutch platform dredge (World Dredging and Construction, Jan. 1972)

PLATE 10

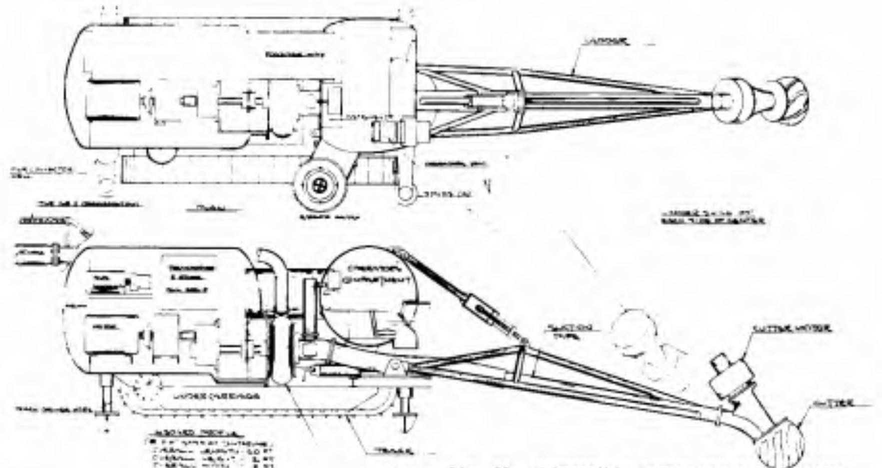


Fig. 52. Submersible Dredge (Mardesich, 1971)

Fig. 53. Artificial nourishment by dragscraper on Jupiter Island, Fla. (Bruun, 1967)

Fig. 54. Bulldozer operation at Deerfield Beach, Fla., following the March 1962 storm (Bruun and Purpura, 1963)

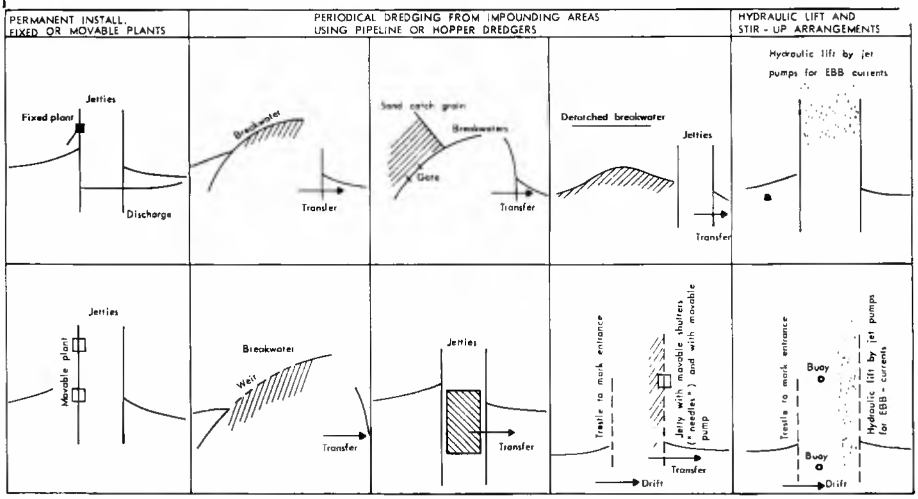


Fig. 55. Various bypassing arrangements (schematics)

NOTES ON DUNES AND DIKES

1 The dune is a natural dike which was created by wind-blown sand and was possibly vegetated by nature. Man's counterpart to the natural dune is the artificial dune or dike. The difference between dune and dike lies solely in the fact that the dune usually has land higher than sea level behind it, while the dike may protect low lying land which would otherwise be flooded.

Dunes are always built of sand, using mechanical equipment like draglines, scrapers, hydraulic pumps etc. The experience on the North Sea Coast is that an outer slope of 1 in 7 and an inner slope of 1 in 3 is practical (25). The width and elevation of the crown depends upon the actual exposure and upon the expected combined tide and wave elevations. Dunes, however, may also be erected with the assistance of wind and sand fences (28, 30). See Plate 5, Fig. 24.

They may be protected by dune vegetaion of various kinds (26, 27, 31, 32, 33). Most common are species of Ammophila - (arenaria or brevigulata, the latter called American Beach Grass in the U.S.A.). Planting machines have been developed. See Plate 5, Fig. 23 (29) and considerable research has been undertaken on fertilization etc. (32).

2 The dike is by its nature a more solid design because its tasks and obligations are more severe. The modern dike is a result of almost 1.000 years development. Plate 5, Fig. 21 (42) is a comparison of older and modern dike profiles on the German part of Nord Friesland. The oldest dike built about 1.000 A.D. had a width of 3.80 m and steep slopes. The 1962 dike was higher, had gentler slopes and a width of about 70 m. In some vulnerable areas "sea dykes" and "withdrawn dykes" have been built parallel to each other to provide satety against breakthroughs of the sea dike (25).

Dike design and construction has developed in various directions in accordance with actual needs. Plate 5, Fig. 22 shows various cross sections all fulfilling specific requirements. Plate 6 shows examples of hard pavements described in a great number of publications (11, 34, 38, 40, 42).

3 A new type of dike protection consists of various kinds of synthetic materials incl. polypropylene and nylon fabrics used as replacement for willow and other types of mattresses which are much heavier and difficult to handle. One of the best known is the Dutch-German "Sea Carpet". Plate 6, Fig. 30 demonstrates an application in reclamation work at Europeport, Netherlands. This carpet is a combination of natural reed and woven polypropylene fabric which has a tensile strength of 2 to 10 metric tons per meter. It is claimed that it is unaffected by wet conditions and is very durable, remaining stable against chemical and bacteriological influences. An additive incorporated into the polypropylene gives it high resistance to ultra-violet rays. Its specific gravity of 0.9 enables it to float, while its lasting filtering properties permit the water, but not the sand, to pass through. The reeds assist in the filtering action of the fabric and increase bouyancy enabling it to be towed to the site and protect the fabric against damage from stone used to sink the carpet and keep it in position when it is used as a mattress. Not all synthetic fabrics or impermeable sheets offer adequate protection against ultra-violet light and generally speaking experiences are best when the sheets are not subjected to light but covered with other materials.

For further information on various commercially available brands in the United States and in Europe the reader is referred to articles in Proc. of the recent Coastal Engineering Conferences (Japan, 1966, London, 1968, Washington, 1970) and to commercially available catalogues.

NOTES ON SEA WALLS

1 Wave run-up - An important design parameter for sea walls and revetment is the wave run-up which depends upon spectral characteristics. According to Battjes(35) explicit expressions for the run-up on a smooth slope are obtained for waves of which the heights and periods squared have a bivariate Raleigh distribution. For further information the reader is referred to refs. (11, 35 and 44) and to several papers on this topic in the Proc. from the 11th Conf. on Coastal Engineering, London, 1968, part 2. Furthermore the Proc. from the 10th, 11th and the 12th Conf. on Coastal Engineering include a great number of papers on wave forces on all kinds of coastal structures, fixed as well as floating.

2 The scour problem in front of sea walls is important and has to be considered. Wave height is the most significant variable to the depth of scour (39 and 41). Other important parameters are the position of the wall in the profile, the beach slope, the wave length, characteristics of beach material (41) and longshore current velocities. As the beach slope flattens, scour decreases. Scour decreases as the angle of inclination of the wall decreases, which indicates that scour decreases with decrease of reflection. Each case has to be considered separately. Model studies will be able to give qualitative information on the relative magnitude of scour. A 10 to 20 ft scour (toe)protection is usually necessary.

3 Plate 6 and 7 - Ordinary design criteria for a revetment call for sufficient weight of blocks including interlocking effect to withstand the combined effect of hydrodynamic uplift pressures due to wave breaking, down-rush and hydrostatic pressure which both cause uplift. Normally a filter layer is placed partly to make an even slope and partly to drain water, which will inevitably penetrate through the joints between the blocks. This needless to say, requires a proper "filter ratio" between block layer and filter material. If the filter material is too small it may disappear out through the joints of the blocks and if it is too large this may increase hydrodynamic and hydrostatic pressures with adverse affects on stability. Drain holes may then replace the space between blocks.

Slope should not be steeper than the core material has a stable slope in fully saturated condition apart perhaps from the uppermost less exposed section of the revetment when - as proved by experiments - the weight of blocks is useful for squeezing blocks in the lower part of the slope together. Fill material must be well compacted to minimize settlings. Examples of failures e.g. in Holland and Florida can often be traced back to inadequate compaction e.g. caused by negligence during construction. Revetments of blocks are not used in Holland where wave action exceeds 10 ft. In Florida the limit may be set a little lower due to the predominance of sand fill and less experience in building such walls, which require good workmanship and in addition on exposed shores a protective apron and/or beach in front (38, 40).

Research on revetments for reservoirs carried out in the U.S.S.R. (43), has proven that the stability of a revetment may be improved by reducing thickness of or eliminating the filter layer entirely. The flexibility of the armor layer and the porosity of the underlying soil are important parameters.

Regarding design principles for rubble mound revetments, reference is made to a paper by Johannesson and Bruun (51).

4 Plate 7, Fig. 35 - The "developing countries" have sometimes been wiser than the "developed countries". As an example the Indian standard stone-pitched rock mound used extensively for sea walls particularly at many places along the SW coast (State of Kerala) is an excellent example of long time experience adopted to "what we have and what we can do with available tools". It is startling to see the similarity in several respects between old Dutch and old Indian experience.

5 Plate 5 and 6: Asphalt and bitumous products have been used considerably for breakwaters and revetments under small to moderate wave action (34). In several cases maintenance has presented some problems and in some respects the application of asphalt is still in an experimental stage.

NOTES ON GROINS

1 Layout and geometry - The general experience is that groins should be built perpendicular to shore although some laboratory experiments may have revealed that efficiency increases a little by turning them downdrift e.g. to 70 degrees in case waves approach the beach under 70 degrees. Length/spece ratio may vary according to littoral drift capacity and exposure from 1:1 to 1:4. Streamlining downdrift is often advantageous (6 to 10 degrees tapering off).

2 The design of a groin protection also depends upon the beach material as well as the material available for construction. Unless beach material is coarse (pebble up to shingle) a streamlined design is preferable and the optimal design undoubtedly is the one which is streamlined and energy-absorbing at the same time. The Dutch groins (Plate 3 and 8) with their wide stone pitching fulfil such requirements. The vertical face sheet pile or king pile groins do not, but their function may be greatly improved

by adding roughness on their sides, e.g. in the form of rubble mounds.

One rule should always be obeyed: If groins are nonadjustable they should be low or the beach will be nourished continuously. If groins are high they should be of the adjustable type and be kept adjusted to the actual beach profile, that means they largely should follow its movement. Their function is to decrease beach fluctuations, not to hinder them.

3 The efficiency of and distance between groins may be increased by adding a shore-parallel breakwater at the extreme making a T or L-shaped geometry (Plate 8, Figs. 46 and 47). This appears to be a definite advantage on steep shores but costs increase. Scour may develop at the breakwater ends if groins extend to depth when wave action is more violent.

4 Sand filled tubes of synthetic materials have been tested in Denmark, Holland and Germany. Diameter may be from 2' to 6'. Generally speaking, experience has been rather satisfactory but the tubes are exposed to sabotage and have to be protected against ultra-violet light by special treatment.

5 Please do not use groins unless they are naturally or artificially supplied with adequate quantities of sand fill.

NOTES ON OFFSHORE BREAKWATERS

1 Some offshore breakwaters are shore-connected and some are not. Plate 9, Fig. 48 from Monaco is an example of the former. Many Southern European (Italian and Spanish) offshore breakwaters are not shore-connected. Refs. 49, 50, 53 and 54 advise on design principles and practical design and construction. Ref. 51 is a review of the ressons for failures of rubble mound breakwaters.

2 Submerged breakwaters - submerged sills and training walls are mentioned in the main paper. Ref. 52 is a comprehensive paper on wave mechanic aspects of the function of submerged breakwaters. Some patented devices are also on hand. They all have in common the fact that they suffer from scour problems, and they should never be placed in the breaking zone or where longshore currents are strong.

3 The submerged sand breakwater built at Durban, South Africa, mentioned in the main paper, is an interesting invention which so far has been successful. One of its main advantages is that should it fail as a breakwater its material will function as artificial nourishment. This experiment therefore advocates offshore dumping of sand material in certain cases.

4 Various laboratory and field tests have been run with a special type of shoreparallel protection, namely, artificial seaweed; but the results are inconclusive, although it appears that it may have an application mainly in uni-directional flow (C.F. Wicker, Shore and Beach, Oct. 1966).

NOTES ON ARTIFICIAL NOURISHMENT

1 Suitable sand - It should always be remembered that not all material for artificial nourishment needs to be suitable as beach material. In cases when heavy erosion has taken place, requiring large quantities for replacement, the lower layers may be "fill which may be separated from the upper layer by a sheet of synthetic material.

2 Heavy sand - Tests have been run with heavy sand. Laboratory tests confirm the suitability but the quantities needed makes practical application highly questionable apar from enclosed areas of limited size.

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CHAPTER 1

COASTAL ENGINEERING MEASUREMENTS

by
J.A. Zwamborn* K.S. Russell** J. Nicholson**

ABSTRACT

Research during the past ten years into coastal problems around the coasts of South Africa has resulted in the development of measuring instruments and techniques which, although specifically designed for conditions around these coasts, could possibly be used equally well in other areas.

This paper deals specifically with measuring instruments and techniques used for collecting data on offshore and nearshore currents, wave conditions and beach profiles extending through the surf zone. Also included are examples of the data collected and some discussion on the accuracy of these data.

INTRODUCTION

Proper design of coastal structures, commercial harbours, marinas, single buoy mooring systems, offshore ore loading facilities, coastal development works, reclamation schemes, coastal protection works, submarine outfalls for effluent disposal and anti-shark protection works should be based on reliable coastal engineering data. These data should be collected over a period of time of sufficient length to include all the significant changes taking place in the coastal environment concerned. For example (see Figure 1) an intensive programme of field measurements

Fig. 1 Richards Bay field measurements

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lasting more than three years was carried out prior to the development of Richards Bay, which is situated 160 km north of Durban on South Africa's east coast, as a major port for bulk export of coking coal.

This programme included the following measurements

(a) On a continuous or regular basis

- Recording of wave heights, periods and directions
- Deep sea and nearshore current measurements
- Wind recordings
- Tidal recordings in the sea and in the estuary
- Sand tracer tests in the littoral zone and in deeper water (up to 18 m)
- Water temperature and salinity measurements in the sea and in the Bay
- Flood and suspended solid records in the Umhlatuzi river which discharges into the Bay

(b) Every three months (at the end of each season)

- Beach survey extending through the breaker zone
- Offshore depth soundings
- Depth soundings of the estuary area
- Aerial photographs of the estuary mouth
- Beach sediment survey

(c) Once per year

- Sedimentological survey of the sea bottom
- Sub-bottom survey of the nearshore area
- Depth survey of the Bay

Similar field programmes were executed or are still in progress for several other harbour and beach improvement schemes on the coast of Southern Africa.

Measurements of sea and sea-bottom conditions, particularly in the breaker zone, are extremely difficult and in several instances new techniques had to be developed in order to complete the planned data collection programmes.

A brief description is given of the measuring techniques used for the collection of coastal engineering data with particular reference to the techniques developed in South Africa. Typical results of the collected data and discussions on the reliability of the data are also included.

MEASUREMENT OF CURRENT VELOCITIES AND DIRECTIONS

Reliable data on currents are required for various applications such as sediment transport calculations, effluent dispersion studies, determination of current effects on ship movements and model investigations into the effect of structures on current patterns. Various techniques for the determination of nearshore and offshore surface and bottom currents have been used with varying degrees of success. Some of these techniques were developed in the Hydraulics Research Unit of the South African Council for Scientific and Industrial Research to meet particular circumstances.

Dye techniques for current measurements

Breaker zone current directions and velocities can be determined by timing the longshore movement of small fluorescent dye floats (such as a tennis ball filled with dye). The tests, when undertaken daily over an extended period, give a good indication of the predominant current direction and the range of velocities.

Fluorescent dye is also very effective for *nearshore circulation* studies including rip currents. The movement of a dye patch resulting from ½ kg fluorescent dye is plainly visible and can be recorded photographically from aircraft or from a high vantage point on the shore. The nearshore circulation patterns can also be observed by aerial photography of estuarine silt discharges.

To improve the accuracy of dye tracking especially in the *offshore zone*, a so-called dye bomb technique was developed[1]. A dye 'bomb' consists of a weighted canister preferably with fins to ensure vertical entry into the water. A bag containing a float and fluorescene dye is packed into the bottom of the canister and attached to the canister by a thin nylon cord while the upper section of the canister contains a bag of Rhodamine dye also attached to a small float to which a collapsible (cloth) drogue is connected by a thin cable (see Figure 2).

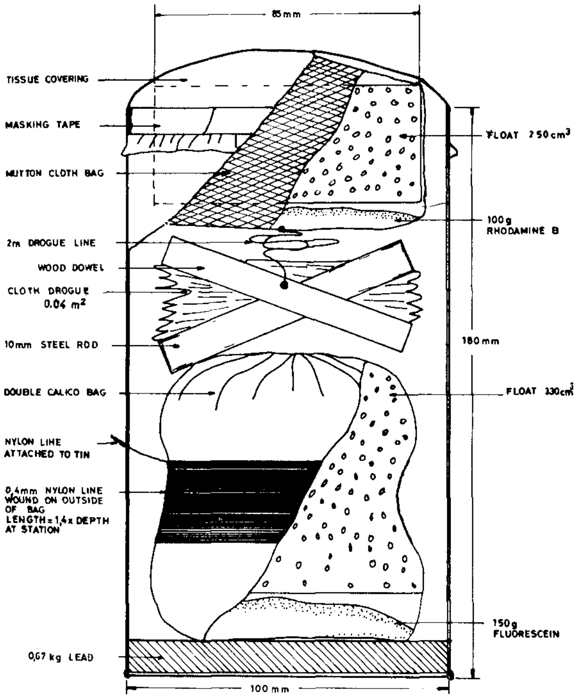

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Fig. 2. Dye 'bomb'

The length of this cable depends on the depth at which the current is to be measured. On entering the water, the canister sinks to the bottom, but the bag of Rhodamine dye comes to the surface immediately and with the attached drogue begins to drift under the influence of the current. The deposition point is marked by the fluorescene dye leaking from the bag attached to the canister. In practice a series of 'bombs' and their movement are photographically recorded from an aircraft. Current direction and speed can be estimated from the relative positions of the two dye patches, provided the aircraft course and altitude are recorded (see Figure 3).

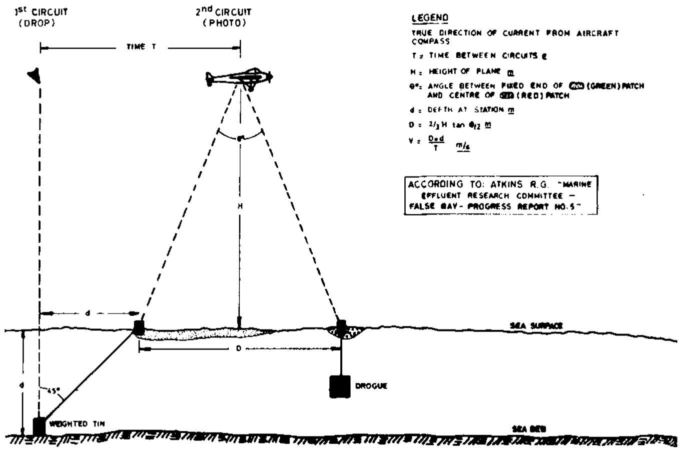


Fig. 3. Dye 'bomb' drop principle

Floats and current meters

To obtain information on the general pattern of *sea currents*, drogue floats consisting of a brightly coloured float to which a cloth drogue is attached at the required depth are used (see Figure 4)[2].

Again a series of drogue floats are released at various points from a boat or from the air and their movements are tracked either photographically from the air or by shore instruments.

In most cases sea current data are required on a regular basis. For measuring current directions and velocities near the sea bottom (e.g. 2 m above the sea bottom) extensive use is made of self-contained Kiel Hassee propeller current meters which are anchored in a fixed position. These current meters, which are not described in detail in this paper, photographically record current directions and velocities.

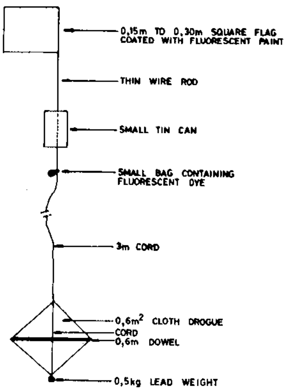


Fig. 4. Drogue float

Current measurements using a system of moored buoys

A simple method was developed to obtain near surface current directions and velocities from observations of the movements of a system of three moored buoys using binoculars specially adapted for the purpose. As can be seen from Figure 5 the system consists of an anchored buoy A connected by means of a nylon rope to a second buoy B, the so-called directional buoy. Buoy B is in turn connected to a third buoy C, the so-called velocity buoy, by means of a chain to which a weight is attached halfway along its length. A drogue is suspended below buoy C at the depth where the current is to be measured.

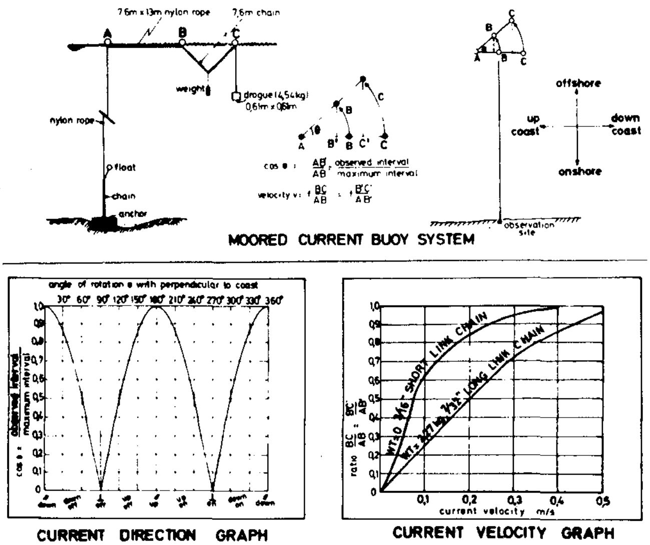


Fig. 5. Moored current buoy system and current direction and velocity graphs.

The *direction* of the current at the buoy system is determined from the distance between the anchored buoy A and the "directional" buoy B. The binoculars used in the readings are fitted with a graticule on which are inscribed a series of equally spaced vertical lines and the distance between buoys A and B is expressed in terms of the number of graticule divisions observed between the buoys. When the line of the buoys is at right angles to the sighting line the greatest number of graticule divisions will obviously be observed between buoys A and B. This maximum reading depends on the distance between the observer and the buoys and the magnification of the binoculars. When the buoys swing through an angle θ, say, as shown in Figure 5 and line themselves up parallel to the direction of the current, the apparent distance between the buoys becomes AB' and θ is given by

$$\text{Cos } \theta = \frac{AB'}{AB}$$

Curves are plotted of cos θ versus θ as shown in Figure 5. As the observer must also indicate whether the current direction is upcoast or downcoast and onshore or offshore the current direction can easily be determined if the bearing of the line of sight is known.

The current *velocity* at the buoy system is determined from the ratio of the distances between adjacent buoys. As the drag force on the drogue attached to the "velocity" buoy C depends on the velocity of the current, the greater the current velocity, the greater the distance between buoys B and C. The current velocity, V, is therefore given by the relationship:

$$V = f\left(\frac{\text{distance BC}}{\text{distance AB}}\right) = f\left(\frac{\text{observed distance B'C'}}{\text{observed distance AB'}}\right) \quad \text{(see Figure 5)}$$

where f indicates "function of".

Various systems were calibrated, both in the field and in the laboratory, from which curves giving the relationship between the ratio B'C'/AB' and current velocity are obtained. Typical calibration curves are included in Figure 5 from which actual sea current velocities can be determined from the binocular readings.

Since moored current buoy systems are inexpensive, easy to place in the sea (by ski-boat) and to maintain, extensive use is made of this system for measuring near surface (usually at 3 m from the surface) sea currents along the coast of South Africa. Once an observer is available, who can make measurements at regular intervals (usually three times daily) it is often worthwhile to place a number of current buoy systems at different distances offshore.

The *readings* of the moored current buoys are summarised both on a seasonal and a yearly basis and are presented in the form of current roses. A typical example for Richards Bay is given in Figure 6.

To illustrate the resolution and *accuracy* which can be achieved when using a moored buoy system, the layout at Richards Bay is again taken as an example. At this location three buoy systems were placed 600 m, 1200 m and 2400 m offshore, the corresponding maximum distances between buoys A and B, i.e. AB, as measured by the graticule of the binoculars, being 2,0, 1,0 and 0,5 divisions respectively. The accuracy of reading is 0,1 graticule divisions.

For the purpose of investigating the accuracy of the *current direction* measurements derived from the buoy systems consider the system moored a distance 600 m offshore. Assume that

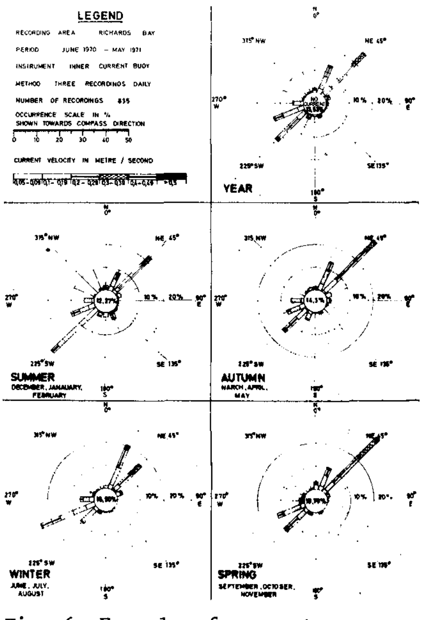


Fig. 6. Example of current roses

the current is such that the buoys are aligned in a downcoast, offshore, direction (see Figure 5) and AB' is say 0,35 thus AB'/AB = 0,175. The value of θ can then be read off from the current direction graph in Figure 5 as about 80°. As can be discerned from this graph an error of $\pm 1,5^{\circ}$ would have been made if the reading had been taken as 0,3 (AB'/AB = 0,15, $\theta = 81,5^{\circ}$) or 0,4 (AB'/AB = 0,20, $\theta = 78,5^{\circ}$) instead of 0,35 (AB'/AB = 0,175, $\theta = 80^{\circ}$). However, if readings of 1,9 (AB'/AB = 0,95, $\theta = 18^{\circ}$) or 2,0 (AB'/AB = 1,0, $\theta = 0^{\circ}$) had been observed instead of 1,95 (AB'/AB = 0,975, $\theta = 13^{\circ}$), when the buoy system is virtually perpendicular to the line of sight, larger errors would have been incurred, viz. $+5^{\circ}$ or -13° respectively.

For the buoy systems 1 200 m and 2400 m offshore, the possible errors are much greater. This is because the graticule readings can still only be made to the nearest 0,1 division and hence the possible errors for the 1200 m offshore system are twice and those for the 2400 m offshore system four times the above values.

From the above it is clear that the greatest accuracy as regards current direction measurements is achieved when (i) the distance between the mooring point and observation sight is not excessive and (ii) when cos θ is less than approximately 0,9 or, in other words, when θ is greater than about 25°.

As regards the *current velocity* measurements derived from the moored buoy systems the readings are most accurate when the buoy intervals AB' and B'C' (see Figure 5) are both large. Thus the buoy system generally becomes more accurate when moored comparatively close to the shore and cos θ exceeds 0,10, say, which corresponds to a value of θ less than 85°. Under these conditions the accuracy of the current velocity readings is estimated to be about 25%.

It can, therefore, be stated that the moored current buoy system provides an inexpensive, simple and effective method of determining current directions and velocities provided the above limitations of the system are taken into account. The accuracy of reading generally reduces proportionally to the distance offshore, and direction errors are minimal when the angle between the line of buoys and the perpendicular to the line of sight, θ, is greater than 25° and the velocity errors are minimal when θ is less than 85°.

Other factors which influence the accuracy and reliability of this method of measuring current directions and velocities are:

(a) the difficulty of distinguishing whether the current is onshore or offshore - particularly with increasing distance between the buoys and the observation point;

(b) the possibility of the anchor dragging makes it necessary to make constant checks on the bearing of the buoy system;

(c) the effect of wind was investigated and although its influence was found to be complex the resulting errors were found to be within the limits of accuracy accredited to the system;

(d) tangling of the chain connecting the "direction" and "velocity" buoys can occur, but experienced observers soon become aware of such an eventuality having arisen.

The accuracy of the current buoy systems as used at present could be further improved by increasing the distance between the buoys and by using binoculars with a higher magnification. These improvements should be considered if the distance between the buoys and the observer considerably exceeds 1 km.

RECORDING OF WAVE CONDITIONS

In most cases, reliable data on wave conditions are even more important than those on currents. Wave conditions have been recorded along the coastline of Southern Africa for many years, in particular since 1967, when the Ocean Wave Research Programme was launched and recording stations were established along the entire coast[3]. Various instruments are used for the wave recording programme including:

(i) Wave clinometers (visual measurement),
(ii) INES (Inverted Echo Sounder) wave recorders,
(iii) Ospos wave recorders (pressure type),
(iv) Wave riders (accelerometer) and
(v) NIO shipborne recorders.

The Wave clinometer and the INES wave recorder were developed in the Hydraulics Research Unit and are discussed in some detail in the following paragraphs.

Wave Clinometer

The wave clinometer was developed as a simple instrument which could be operated by non-technical personnel in remote and undeveloped coastal areas for recording wave conditions. Basically it is an instrument for measuring wave directions although it can also be used to give approximate wave height and period values. It is being used extensively in the wave climate studies along the South African coastline.

The instrument consists of a specially adapted hunting telescope mounted on a stand in such a way that its axis can be depressed relative to the horizontal at one of three fixed angles, namely 3°, 5° or $7\frac{1}{2}^{\circ}$ (see Figure 7). It is installed on an elevated position onshore at a

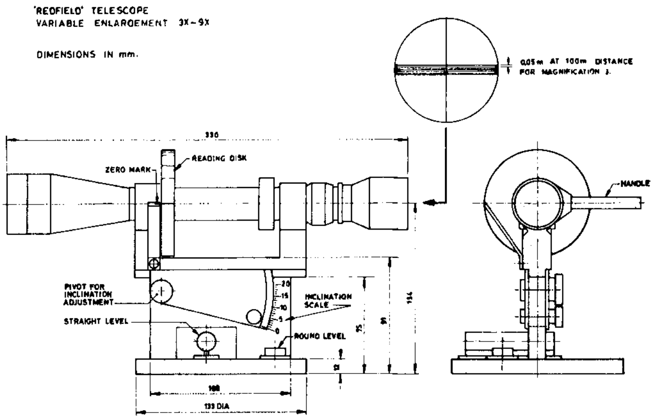


Fig. 7. Wave clinometer assembly

fixed compass direction and the angle of depression of the telescope fixed at one of these angles so that it can be focussed on the observation point at sea where a buoy (0,5 m dia. polyform buoy) is anchored. The general arrangement is shown in Figure 8.

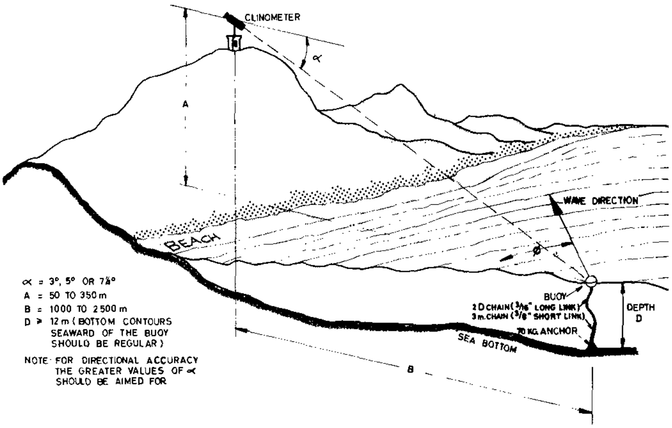


Fig. 8. Typical clinometer and clinometer buoy layout

For *wave direction* measurements the clinometer telescope is equipped with a graticule consisting of a metal ring which supports a series of equally spaced lateral cross hairs. The wave direction is measured by rotating the telescope about its optical axis until the cross hairs are aligned with the wave crests, the angle of rotation from the horizontal position, θ, being read off on a graduated disc mounted on the telescope. The angle ϕ between the direction of wave approach and the fixed bearing of the instrument is related to the angle of rotation θ by the following formula:

$$\tan \theta = \sin \alpha . \tan \phi$$

where α is the angle of depression of the clinometer. The graduated disc fitted to the barrel of the telescope can thus be scribed to indicate directly the angle of wave approach for any angle of depression.

The *wave height* is measured by observing the movements of the buoy relative to the graduations on the clinometer telescope graticule, the buoy movements being observed over a period of about five minutes in order to obtain an average reading. The graticule graduations in the instruments at present in use are so spaced that one division is equivalent to 0,05 m of wave height for every 100 m of distance between the instrument and the buoy, the telescope having a magnification of x3. The standard graticule contains seven graduations. It is not possible to increase the number of graduations without obscuring the field of view and thereby adversely affecting the wave direction observations. If no direct correlation with instrument recorded wave heights is available, the wave heights recorded with the wave clinometer may be assumed to be equal to the significant wave height, H_s.

The *wave periods* are also determined with the aid of the graticule graduations by noting the time taken for twenty wave crests to pass the buoy, the dominant wave period being the value recorded.

Wave clinometer *recordings* are normally made three times daily - early morning, mid-day and early evening. The records are combined to give seasonal and yearly distributions and typical examples of direction/ height and direction/period roses for Richards Bay are illustrated in Figures 9 and 10. Wave clinometer records are usually made in relatively shallow water. Using well-known refraction theory these records can, however, be converted to deep sea wave conditions which are applicable to a much larger area of the coast.

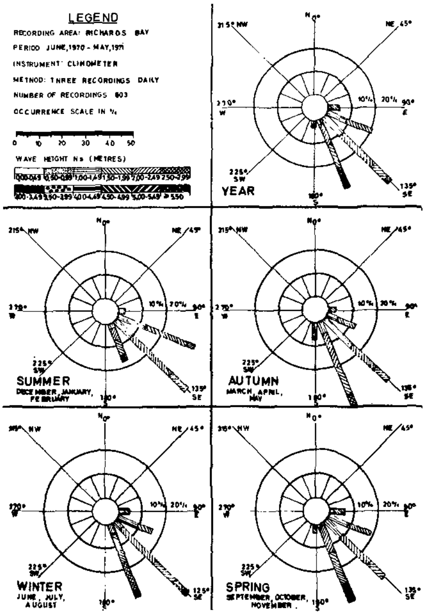


Fig. 9. Typical clinometer wave height roses

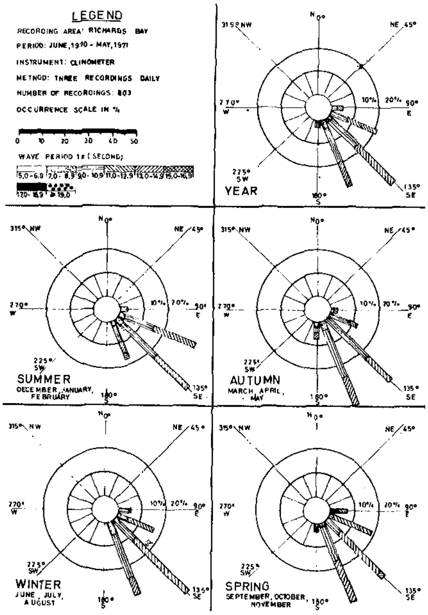


Fig. 10. Typical clinometer wave period roses

The *directional accuracy* of the wave clinometer is primarily dependent on the angle of depression of the instrument. As the angle of depression, α, increases the corresponding values for the angle of rotation of the telescope, θ, for given directions of wave approach, Ø, become more evenly distributed around the perimeter of the measuring disc. This can be seen from Table I below which is based on the relationship $\tan \theta = \sin \alpha . \tan \phi$.

Table I : Angular rotation of the clinometer telescope as a function of direction of wave approach

ϕ	Values of θ		
	$\alpha = 3^o$	$\alpha = 5^o$	$\alpha = 7\frac{1}{2}^o$
10^o	00^o 32'	00^o 53'	01^o 19'
20^o	01 06	01 49	02 43
30^o	01 44	02 53	04 19
40^o	02 30	04 11	06 15
50^o	03 34	05 56	08 50
60^o	05 11	08 35	12 44
70^o	08 11	13 29	19 43
80^o	16 32	26 19	36 30
90^o	90 00	90 00	90 00

The instrument is normally positioned so that its line of sight makes an angle of about 45^o to the dominant wave direction in order to ensure that the majority of the readings occur in that area of the measuring disc where the graduations are spaced relatively far apart. However, it is usually desirable to record the wave direction in comparatively deep water, a requirement that leads to an instrument bearing which is often nearly parallel to the dominant wave direction. In addition the angle of depression of the telescope tends to be small under these circumstances. The values ultimately chosen for these two variables are therefore a compromise between accuracy and the need to obtain wave data in comparatively deep water.

The *accuracy of wave height* measurements depends mainly on the distance between the instrument and the reference buoy, the magnification of the telescope and the size of the graticule divisions. For a telescope with a magnification of x3, a graticule division calibration factor of 0,05 m per 100 m and with the distance from the reference buoy being 1500 m, each graticule division represents a wave height of 0,75 m. Thus by estimating to the nearest half division the wave height can be read off to the nearest 0,4 m approximately. The ability to estimate to the nearest half division is influenced by the size of the buoy which, if large relative to the size of the graticule divisions, makes observations more difficult. In general it has been found that the most satisfactory arrangement is for the buoy and graticule divisions to be of the same size.

Due to the fact that the instrument is clamped in a fixed position, under certain tidal conditions the buoy may not be in the centre of the field of view. Thus for very large waves the image of the buoy may move beyond the extreme graticule divisions and the wave height reading has to be estimated. The accuracy of the instrument is therefore reduced under these conditions.

It is not possible to arrive at quantitative conclusions regarding the *accuracy of the wave periods* measured with the clinometer. Under regular swell conditions there is no reason to doubt the reliability of the results. Under choppy local "sea" conditions, however, the measured periods may tend to be too high because the shortest waves in the spectrum create small movements of the buoy which may not be noticed by the observer.

It can therefore be *concluded* that individual wave height and period data derived from a clinometer have a limited degree of accuracy. For this reason it is of little use when isolated wave measurements are required but its value has already been proved in the field when information is required on a regular basis extending over a recording period of a year or more.

Suggested *improvements* to the wave clinometer envisage the addition of a second and separate telescope which would be used to measure the wave heights and periods while the existing instrument would be used to measure the wave directions. The advantage of this arrangement is that the latter could then be fitted with a graticule containing one horizontal cross hair only thus leaving a large unobstructed field of view for the observations. A further possible improvement is to increase the diameter of the circular measuring disc mounted on the barrel of the telescope. This modification would increase the space between the graduations and enable the wave direction to be estimated more precisely. The second telescope, on the other hand, would have a magnification of x6 or x9. One graticule division would then correspond to wave heights of 0,025 m and 0,017 m per 100 m respectively. Thus if the distance between the instrument and the buoy is 1500 m and the observer can gauge the wave heights to the nearest half division wave heights could be estimated to the nearest 0,2 m and 0,1 m respectively as against 0,4 for the present instrument. In addition the number of graticule divisions could be increased from seven to about twenty making it unlikely that the image of the buoy would move off the scale under extreme tide and wave conditions.

INES wave recorder

The INverted Echo Sounder or INES* wave recorder is an acoustic type recorder developed by the Hydraulics Research Unit. A photograph of an INES wave recorder is given in Figure 11. It is a self-contained instrument consisting of a conventional echo sounder which is converted to carry a large supply of recording paper. It has a rechargeable battery with an operational life of four weeks and a control mechanism with a clock which can be set to operate the instrument at

Fig. 11. INES wave recorder

*INES recorders are now commercially available any pre-set time interval. The instrument is enclosed in a fibre-glass canister which is light, strong and resistant to corrosion. The canister is placed on the sea bed in a metal tripod to which a marker buoy is attached. A transducer is fitted on the lid of the canister and the acoustic waves are reflected from the air-water interface giving a continuous record of the sea surface. For wave recording, the instrument is generally set to operate for 15 minuts every 6 hours. The INES recorder can be used in water up to 30 m deep.

The INES wave recorder including its tripod can be lowered onto and raised from the seabed if a sufficiently large boat with lifting tackle is available (e.g. a fishing boat). Alternatively the recorder can be removed from the tripod and a replacement fitted by skindivers operating from a small ski-boat. In theory the instrument need only be serviced every twenty eight days, but in practice it has been found to give a much higher percentage coverage if serviced at fourteen day intervals. To ensure recovery the master buoy must be anchored in such a way that the chance of losing this buoy is minimal. The anchoring system shown in Figure 12 has proved to be the best for prevailing South African sea conditions.

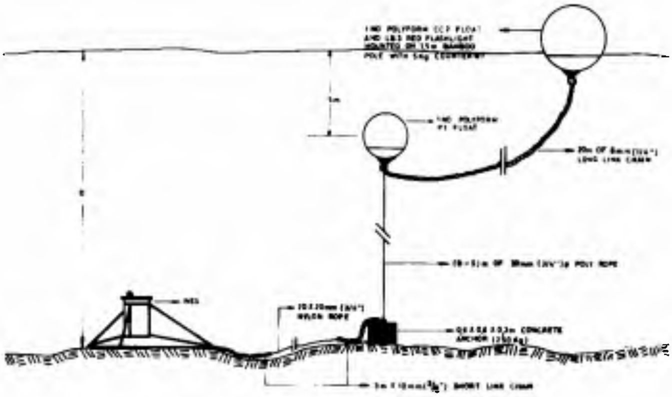
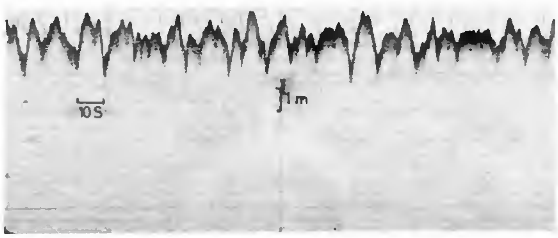


Fig. 12. INES anchoring system

A short length of a typical *wave record* obtained with an INES recorder is given in Figure 13.



INSTRUMENT NO. W.2.
LOCATION RICHARDS BAY
PERIOD 18 00 hrs. 15th APRIL 1970

Fig. 13. Typical INES wave record

The records are analysed by the standard Draper method[4] and the results are plotted in the form of wave height and period occurrence tables and combined into exceedance curves for significant wave heights and zero crossing periods. An example of a wave height exceedance curve is given in Figure 14.

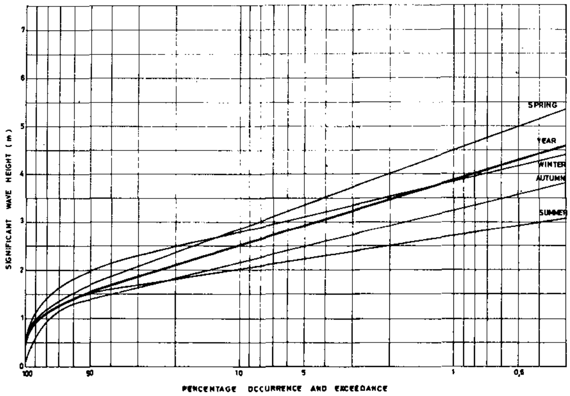


Fig. 14. Typical INES wave height exceedance curve

The *accuracy* of the INES recorder is affected by changes in the temperature and salinity of the sea water, the precision of the timing clock and the divergence of the acoustic beam.

The extreme water temperature and salinity conditions experienced at one fixed recording station may produce inaccuracies exceeding 5 per cent. It is therefore advisable to check the calibration of the instrument every three months if it is used at one fixed location, or every time it is moved to a new position where the salinity or temperature conditions are considerably different.

Inaccuracies in the timing clock are extremely unlikely to be so large as to affect an individual 15 minute wave record. However, during a monitoring period of fourteen or twenty eight days the accumulated error of a slow or fast running clock may result in the waves being recorded at the wrong time of the day.

The accuracy of the INES is also affected by the divergence of the acoustic beam, the beam divergence of a standard instrument being 20°. The fact that a circular area of the sea surface is surveyed instead of a point causes distortion of the ascending and descending slopes of the waves as well as a flattening effect on their crests. The resulting error has yet to be quantified but it is most pronounced when the waves are steep. Fortunately the majority of the wave records are unlikely to be seriously affected because the ratio of the beam width at the water surface to the wave length is small. For example the beam width is only 7 per cent of the wave length for an INES placed in 20 m of water recording waves with a period of 8 s.

Bearing in mind the above limitations it is *concluded* that the INES recorder can be used effectively for measuring coastal wave conditions. A further improvement to this instrument would be to record the output on magnetic tape instead of in the form of a graph. Consideration is at present being given to this possibility.

Correlation of wave recordings of various instruments

In an attempt to check on the overall accuracy of the various wave recording instruments a comparison has been made of their outputs. Comparisons of wave height and period values as well as energy spectra obtained from simultaneous records of five different instruments were included in an earlier paper[3]. The results were found to be in general agreement although significant differences in individual values of certain parameters were found to occur.

In a further comparison between different recording instruments, an INES *recorder* and a *waverider buoy* operated simultaneously for three months in virtually the same position (100 m apart), 1,6 km offshore in a water depth of 17,5 m at Richards Bay (see Figure 15).

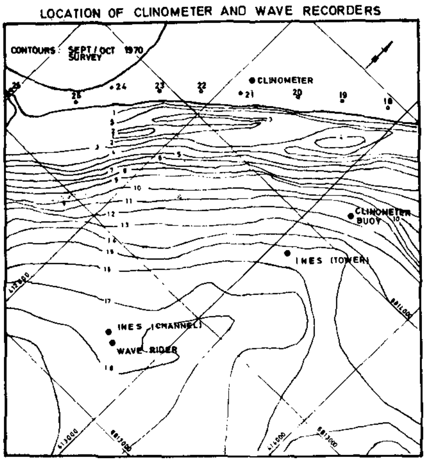


Fig. 15. Instrument positions

In Figure 16 the results of the two instruments are compared by correlating their respective significant wave heights and zero crossing periods, as given by the standard Draper method of analysis[4]. Although a good correlation is evident there are values which exhibit a poor measure of agreement. For small wave heights (up to 1 m) the waverider gives slightly smaller values than the INES, whereas for wave heights in excess of 1 m the waverider values are somewhat greater than those of the INES. The wave period correlation shows much greater differences for the two instruments. Again the waverider periods are shorter in the lower ranges (below 7s) and larger in the higher ranges (above 7s). However, it is clear from these correlations that the INES and waverider outputs on average compare well although in individual cases they can differ by more than 50 per cent.

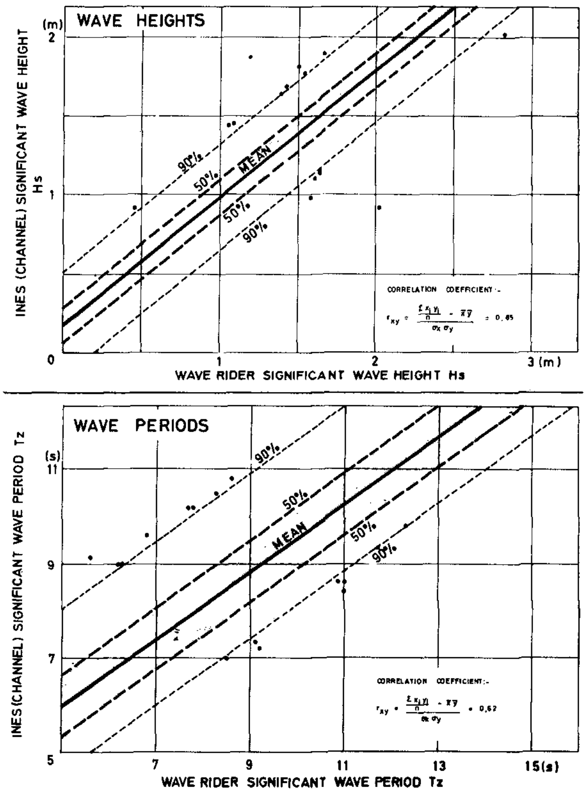


Fig. 16. Correlation of INES and waverider wave heights and periods

A detailed comparison was also made between data obtained at Richards Bay using a *wave clinometer* and those from an INES *recorder* installed approximately 350 m from the clinometer buoy. The disposition of the instruments is shown in Figure 15, the INES recorder referred to being marked INES (Tower) in the figure.

The results given in Figure 17 clearly show, that, although the distance between the two recording points is much greater than in the above case and the recordings were not simultaneous (1 to 2 hours difference between INES and clinometer recordings), there was a reasonably good correlation between the respective wave height values. For wave heights above 1 m the wave clinometer generally gives higher values than the INES recorder.

Since the same applied to the wave rider heights, in the case of Richards Bay the wave clinometer heights should compare even better with the waverider data. It must, however, be realised that wave clinometer readings depend on the particular installation (i.e. distance of buoy to instrument) and to some extent on the observer. The correlation found for the Richards Bay case, therefore, does not necessarily hold for other measuring stations. As regards the periods, the wave clinometer values at Richards Bay are on average 2 to 4 s greater than the INES values. This has been found in all other cases and can be explained by the tendency of the observer to record the period of the main swell, neglecting the small, short period waves, whereas for the determination of the zero crossing period of the INES records all the waves are taken in to account.

Although the wave clinometer was primarily developed as a wave direction measuring instrument, reasonably reliable wave height and wave period data can still be obtained with this instrument which is extremely cheap, easy to operate and very reliable. Correlation of the wave clinometer data for each particular installation with a wave recording instrument over a short period will further improve the reliability of its output.

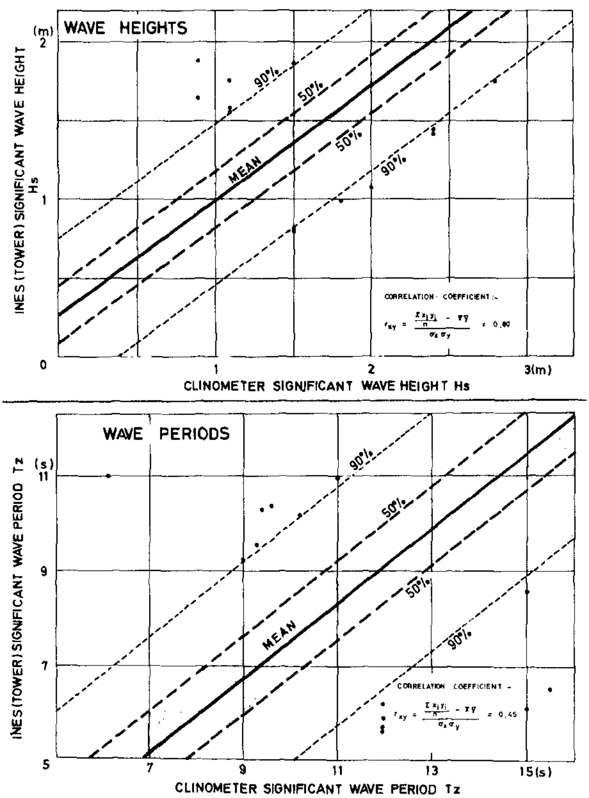


Fig. 17. Correlation of INES and Clinometer wave heights and periods

BEACH PROFILES EXTENDING THROUGH THE SURF ZONE

Until fairly recently it was not possible, on the unprotected coasts of Southern Africa, and presumably on other coasts with similar heavy swell and surf conditions, to measure beach profiles extending through the breaker zone on a regular basis. Various methods were tried with little success including the use of a pressure gauge which was attached to a line, fired across the breaker zone by rocket and then pulled back to shore while recording the water depth. The main disadvantage of this method was the large friction force caused by the line "cutting into" the offshore sand bar through which it had to be dragged.

About three years ago, a technique for measuring profiles through the breaker zone was developed by the Hydraulics Research Unit using light and highly manoeuvrable ski-boats (see Figure 18) equipped with echo-sounding equipment and operated by skilled personnel. This technique has been used successfully since its adoption.

Fig. 18. Ski-boat in the surf returning to sea

The ski-boat is kept *on course* using two theodolites and radio communication. One theodolite sights along the profile line and keeps the boat heading in the right direction while the second theodolite intersects the boat position from a point further along the beach. At each intersecting fix the echo-sounding trace is simultaneously "marked". Ski-boat surveys are normally undertaken during high spring tide conditions and extended into a water depth of as little as 0,5 m. The "dry" beach profiles are surveyed during low tide and extended as far as possible into the water. In this way it is possible to obtain an overlap of "dry" and "wet" profiles, thus providing an excellent check on the profiles measured by ski-boat. For obvious safety reasons and to keep the reference level of the echo-sounder as constant as possible the ski-boat travels at the same speed as the waves, remaining during the entire run in the same wave trough.

A complete profile through the surf zone can be measured in a few minutes and the operation must, of necessity, be extremely well organised and requires considerable skill from the ski-boat operator. Under favourable conditions a 5 km length of coast, with sections at 200 to 300 m intervals, can be profiled in less than a day using this technique.

Originally Inshore Ferrograph echo-sounders, which are very simple instruments, were used for this work, but they were later replaced by high resolution Atlas Deso 10 and Elac echo-sounders which give much more accurate results. A typical echo-sounding profile using an Atlas Deso 10 echo-sounder is given in Figure 19.

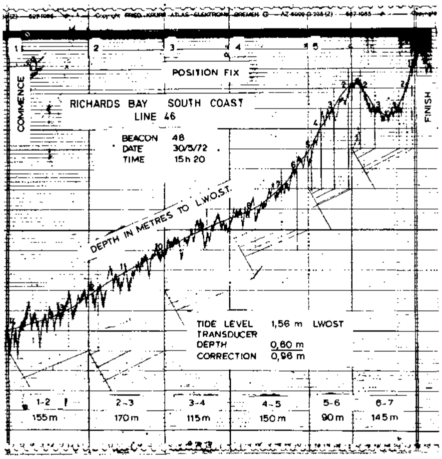


Fig. 19. Beach profile as recorded by an Atlas Deso 10 echo-sounder.

The *accuracy* of profiling by ski-boat has been checked by repetitive runs along a particular section combined with depth measurements taken by lead line at regular intervals. From the results of these checks, it was established that water depths which include tidal reductions, elimination of wave action and temperature effects, could be determined to within 0,5 m. When comparing successive hydrographic surveys differences of less than 1 m should therefore be considered as insignificant.

A valuable *application* of this technique is the study in detail of the formation and movement of sand bars along the coastline by comparison of successive surveys. When the measurements are made at regular intervals, the changes in the profiles and the general bottom topography can be related to the sea conditions which occurred in the period between the two surveys.

A very good example of nearshore bottom changes at Richards Bay in the spring of 1969 established by the above type of survey is shown in Figure 20.

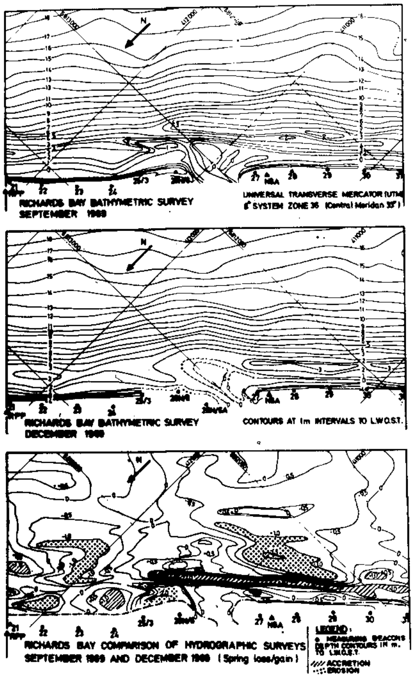


Fig. 20. Comparison of hydrographic surveys

CONCLUSIONS

Accurate data on sea conditions and the related coastal morphology are essential for the proper design of all coastal works. Coastal measurements, however, are inherently difficult and normally expensive which often results in a curtailing of the data collection programme. It is believed that a number of simple and economic measuring techniques developed in South Africa over the past ten years may be of use in the systematic collection of coastal data on a limited budget.

ACKNOWLEDGEMENTS

The assistance given in the preparation of this paper by Messrs. J.W. Kluger, C. van Schaik, A. Harper and A. Duncan is gratefully acknowledged. The photograph used in Figure 1 was supplied by Mr. D. Greaves, A.I.P.

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