SUMMARY

The Corps of Engineers, CE, has a long and varied history of research and development (R&D) in military/civil ocean engineering. Model tests were performed of floating breakwaters used during the Normandy invasion, investigations have been made of military harbors, and designs have been prepared for breakwaters and jetties. The CE has had a key role in numerous joint studies with the Navy of underwater explosive cratering, investigations of explosion generated water waves, shock propagation and bottom reflection in shallow water, underwater POL storage, logistic support over the shore in theater operations, and port development. Ongoing efforts related to military ocean engineering include studies to minimize navigation channel shoaling; investigations of dredging requirements in coastal channels; hurricane, tsunami and storm surge flooding; and numerical directional spectral wave climatologies. Emerging technologies include development of reliable and quantitative theoretical descriptions of wave-wave interactions that result in a much improved estimation of the directional spectral wave climate. With this emerging technology, when coupled with the National Weather Service's forecast capability, it is conceptually possible to forecast wave, current, and water level conditions and the response of ships to these conditions. Although the basic technology is available; a concentrated multiyear development effort is required for such forecasts to become an operational reality. Experimental technology to accurately investigate directional spectral waves in the laboratory and to perform more advanced studies of breakwaters and harbors and their response to directional spectral waves is rapidly developing. Evolving instrumentation technology for measuring the directional spectrum, currents in the surf zone, sediment concentrations and bathymetric modifications will soon provide us a new set of prototype data from which we will gain a vastly improved comprehension of dynamic nearshore coastal processes. The last and perhaps most important emerging technology is remote sensing. Considerable research and development is required to realize the full potential of remote sensing to specific coastal/ocean engineering projects, but its potential is far-reaching. Remote sensing is the only viable method for obtaining synoptic ocean measurements worldwide. The CE program related to military ocean engineering is almost totally funded from civil works research and development programs which have no military related objectives. Recent concentrated efforts by the CE in actively promoting and successfully culminating inter-agency and international cooperative research and development projects is enabling us to obtain an improved quality and increased quantity of research products for a smaller investment. The emerging technological spin-offs from our civil works research and development program are an outstanding example of the synergistic benefit gained by military ocean engineering for no direct investment of funds. Conversely, the civil works ocean engineering program benefits directly from output of the Navy's military ocean engineering R&D.

INTRODUCTION

The Corps of Engineers (CE) has a long and rich history of research and development in military ocean engineering related programs. This paper will only be concerned with the last fifty years of this research. World War II was the catalyst for the blossoming CE efforts in this area. Past achievements are discussed in the following section and they begin with several investigations concerned with World War II. Current thrusts are discussed next where the emphasis has shifted to direct mission-oriented applied research and development. Finally the paper concludes with a discussion of emerging technologies and some predictions of things to come.

PAST ACHIEVEMENTS

A discussion of the CE role in military ocean engineering would be remiss without mention of their great contribution to the successful invasion of Europe by allied powers. Model tests were conducted at Waterways Experiment Station to aid in final design of floating breakwaters to be used to develop artificial harbors off the coast of Normandy to support material and troop transfer from ship to shore. These floating breakwaters were the key ingredient to logistical support for early stages of the invasion. They were built in secrecy after completion of model tests and were towed across the English Channel behind assault forces for installation just seaward of the Normandy beaches. The breakwaters were referred to by the code name Mulberries. They were used to furnish supplies to the invasion armies and, according to a statement from Supreme Allied Headquarters, "Made possible the liberation of Western Europe."

Another high priority effort during World War II involved analyses and model tests to design a satisfactory solution to ship surging in the Navy harbor at Terminal Island within Los Angeles and Long Beach Harbors. Navy ships were experiencing intolerable levels of surging while moored. The surging was causing delays in the normal flow of personnel and material to and from the harbor. Measurements were made in the harbor, a model was constructed and tests resulted in a satisfactory solution being developed to alleviate the surging problem. The solution was an extension of the Navy mole to produce a more enclosed and more protective harbor area. To date, over 30 years after completion of the project, there have been no reported problems by the Navy regarding their ability to moor and operate satisfactorily from the modified harbor. Additional studies conducted by the CE during and shortly after World War II included investigations of a breakwater location for the U.S. Naval Air Station, Alameda, California, studies of wave and surge action in Anaheim Bay, California, and an investigation of wave and surge action at the Naval Supply Depot, San Pedro, California. Research and development concerning problems related to military ports and harbors has continued steadily since this time. Several studies were performed during the Korean War and the Vietnam War to aid in developing ports and harbors to serve as logistical support areas or evacuation areas. The most recent completed study involved model testing to develop the optimal plan for a new naval harbor at Jubail, Saudi Arabia. The Royal Saudi Navy requested the U. S. to construct this harbor for their Navy. The study was completed in 1976 and the harbor was completed in 1978.
CE has a long history of research and development in underwater explosion effects; in particular, prediction and estimation of bottom craters, prediction of surface waves and bottom reflection and shock propagation. A comprehensive high explosive test series, the Waterways Experiment Station developed an empirically based technology to predict the underwater crater produced by explosions, to predict the surface waves generated by underwater explosions, and to estimate the shock propagation underwater and shock reflection characteristics of the ocean bottom. This research was performed during the 1950's and 1960's. There has been little interest in this subject during the past decade. Expedient construction techniques using conventional and/or nuclear explosives was investigated and resulted in a demonstration project in Hawaii where a channel through coral was excavated with explosives. This study was designated Project TUGBOAT and was quite successful in demonstrating the viability of explosive excavation for such operations. All these underwater explosion related tests were performed in cooperation with the U. S. Navy and many were sponsored by various elements of the U. S. Navy (Bureau of Yards and Docks, Office of Naval Research, etc.).

CURRENT THRUSTS

Current thrusts of the CE research and development program include estimating the directional spectral wave climate; measuring and quantifying the directional spectral wave climate; understanding wave transformations; improving laboratory technology; quantifying stresses in concrete armor units; measuring hurricane induced water levels, waves and currents; quantifying shoaling rates in unprotected deep-draft channels; and understanding the complex wave current interactions occurring at tidal inlets. Each of these major thrusts are discussed briefly in the following paragraphs.

Wave Climatology

The CE is producing a directional spectral wave climate for all U. S. coastlines to be used by Corps field offices for the design of coastal engineering related projects. A twenty year hindcast is being used (1955 through 1974) as the basis for the daily climatology. Greater reliability is obtained for extremal estimates by supplementing the 20 year hindcast with an analysis of the 12 most severe events occurring since 1900 on each coast (i.e., east coast, west coast, and gulf coast). The joint probability distribution of waves and water levels is available from this data base. Computations have been completed for the east coast of the U. S. including extratropical storms. Waves and water levels from tropical storms are currently being evaluated and computed and will be merged in with the east coast data base during the next two years. Data for the east coast wave climatology can be accessed by CE users through our Sea-State Engineering Analysis System (SEAS) which is a user friendly data base and computational system. The user can access the wave climate data, manipulate it and use it in almost any manner desired. Other users can obtain the wave climatology data base from NOAA's National Climatic Center in Asheville, North Carolina where the data are being permanently archived. Computations for the west coast were just completed for the basic twenty year hindcast period. Southern hemisphere swell estimates are being made and the joint probability distribution of waves and water levels should be available for the west coast (including Hawaii) by the end of 1984. Computations for the Gulf Coast and the Great Lakes will follow.

The rationale for performing these wave climatology studies was to obtain a more reliable and consistent set of deep water and nearshore wave statistics for use by CE field offices in the planning, design, operation and maintenance of coastal engineering projects. The design of every coastal project is dependent of the waves and water levels to which the project is exposed. Consequently, the reliability of any coastal design is a direct function of the reliability of the wave climate. Before this study was undertaken, wave statistics used for designs were suspect in their reliability, especially any estimate of the directional distribution of wave energy. Before initiating this investigation, an assessment of wave generation technology revealed that, although extremely complex, the basic technology was available to numerically compute a substantially better directional spectral wave climate than was available from any other source.

Measuring the Directional Spectrum

Commensurate with the ability to numerically estimate the directional spectral wave climate and to produce a directional spectrum in the laboratory (to be discussed in a later section), one must be able to measure the actual directional spectrum in the real world. These measurements are required to quantify the real directional spectrum, to understand how the directional spectrum is transformed from deep to shallow water including refraction/diffraction around islands and over shoals. Current efforts are underway to directly compare several different approaches to quantifying the directional spectrum and to define the advantages and limitations of each method. These methods include a linear array; two directional wave buoys; a PUV measurement, a differential pressure gage array, a $S_{xy}$ gage, and a surface contouring radar. This is, of course, a difficult undertaking and questions of spatial homogeneity must be addressed.

Wave Transformations

Research into wave transformations from deep to shallow water has paralleled the wave climatology investigations in order to improve the available technology to reliably estimate wave transformations. Considerable progress has been and is being made in our understanding of the proper roles of wave-wave interactions and bottom friction in transforming the wave spectrum.

Laboratory Technology

Recent advances in understanding and estimating the directional spectrum have made it imperative to upgrade laboratory capabilities to produce a directional spectrum for experimental studies and model investigations. This is a very complex task, however the basic technology is available to make such an advance. Ongoing research in the CE related to laboratory technology has two principle thrusts. The first is directed toward producing and measuring the most reliable laboratory directional spectrum possible consistent with the CE mission and objectives (i.e., intermediate and shallow water applications). A modular directional spectral wave generator will be operational this calendar year in our new movable-bed test facility. This generator has 90 sections which are driven at the joints (each section in approximate 0.4 m). Each joint can be driven by an arbitrary spectral signal and the system is controlled by a VAX computer. The other current thrust in laboratory technology is to better determine the optimum method of producing a laboratory spectrum in a wave flume. Specifically, an experimental investigation into generation of the laboratory spectrum using a dual actuator spectral generator is underway. A comparison
of spectra produced using only piston motion, only flap motion, and a combination of both to produce the best possible representation the wave velocity field is being evaluated as a function of water depth relative to the spectrum. This study should determine the need for using dual actuator spectral generators and should quantify the consequences of either using a piston or flap generator as a function of water depth.

Stresses in Concrete Armor Units

One of the most discussed current problems in the coastal engineering profession is the breakage of concrete armor units (particularly the dolos unit) and the requirement for reinforcing steel in concrete armor units. The literature is rampant with many times, passionate views on the subject; and all too often, there is not necessarily sufficient engineering and scientific rationale to support these views. To put the problem in perspective, there have been a number of highly publicized failures (the most famous being Sines, Portugal) of concrete armor units; particularly when the size is over twenty tons. The CE has seven dolos armored breakwaters and none that have been model tested (Humboldt jetties, Wainiha breakwater, Nawiliwili breakwater, and Jubail breakwater) have exhibited any problems that were not indicated during the model tests. The Shore Protection Manual states that all dolos armored breakwaters should be model tested because of the complexities of the armor unit and its history of problems. It is this author's view that we merely need to quantify the stresses and impacts to which armor units are subjected and, although difficult, the technology is available to design for whatever level of stress is necessary to assure the integrity of the structure. The CE is addressing this area of research through laboratory tests and full scale measurements in the prototype.

Hurricane Waves and Water Levels

A study is ongoing to perform reliable measurements of hurricane waves and water levels in order to obtain quantitative estimates of coastal flooding from hurricanes. An assessment of the reliability of various numerical models used to estimate hurricane surges revealed that, although the models had substantial differences and produced results which were relatively different, the prototype data available for verifying the models was not of sufficient quality or quantity to make a determination of the veracity of the various models. Consequentially, a study was initiated and is underway and operational to obtain several reliable sets of data on wave levels, waves and nearshore currents produced by Gulf of Mexico hurricanes. Fifteen sites from Brownsville, Texas to Jacksonville, Florida are instrumented with hardened surge gages to measure water levels in depths ranging from 5 to 20 meters MLW. One of these gages sustained a direct hit from Hurricane Allen and survived while making a valid measurement. An additional 280 sites have been preselected for installation of 25 surge gages (on land at elevations less than 3 meters) about 2-3 days prior to landfall. An air-droppable gage also has been developed for deployment on the continental shelf about 24-36 hours prior to landfall. Coordination of these efforts with the National Hurricane Center should result in the best data set available on both winds and waves from the next Gulf of Mexico hurricane.

Shoaling in Deep-Draft Channels

Numerical and laboratory investigations are underway to better quantify our ability to predict shoaling of deep-draft navigation channels on the continental shelf. Maintenance of navigation channels is one of the major expenses of the CE and concentrated research is underway to produce a more comprehensive understanding of the complex hydrodynamic/sediment interactions involved in shoaling of these deep draft channels. The potential payoffs for this research is quite large should it result in a decrease in our future dredging requirements.

Wave-Current Interactions

Fundamental research into wave-current interactions is underway to produce a more accurate estimate of the combined wave and current fields at tidal inlets and navigation entrances where both commercial vessels and recreational craft are most vulnerable and have the highest accident rate. The objective is to better understand wave/current interactions so more reliable estimates of ship and recreational craft responses to these forces can be made. This information can be used to provide better quantified design guidance for channel dimensions and alignments as a function of waves, currents and type of vessel.

Emerging Technologies

Several emerging technologies in military/civil ocean engineering are existing and will result in great changes in our future capabilities. The blend of vastly increased relatively low cost computer capability, highly sophisticated and reliable sensors and measurement systems, and a more comprehensive understanding of the complex air-sea boundary layer and the nearshore hydrodynamic/sediment/structure interactions portends monumental advances in our capabilities. Some of these potential advances are discussed below.

Real-Time Forecasting

Recent research concerning with wave transformations and the directional spectral wave climatology portends an explosive future in our ability to provide reliable real-time estimates of nearshore wave climates anywhere worldwide. While the Navy has provided an operational forecast for the fleet for many years, it is one or two orders of magnitude more difficult to provide this information reliably in real-time in nearshore areas sheltered by islands and perhaps influenced by tidal currents. While this task is enormously difficult, emerging technologies are here which make it a feasible undertaking. Such real-time forecasting can be used to optimize productivity of the dredge fleet used to maintain our coastal navigation channels. A tremendous potential payoffs exists for this application since transit time for dredges is unproductive in dredging sediments.

Interactive Computer-Aided Design of Coastal Projects

Development of the wave climatology and the SEAS system to manage and operate on the data has made it abundantly clear that we are on the threshold of being able to perform computer-aided design of coastal engineering projects. It appears a virtual certainty that SEAS will form the nucleus of such a system. Existence of the directional spectral data base is the essential ingredient for such a system. The day will come when an engineer can sit at his interactive computer terminal and evaluate alternative plans for a harbor in a day or two. Final comprehensive design of the harbor may still require data collection, use of a physical model, or application of some highly complex numerical modeling system.

Remote Sensing

Remote sensing techniques are emerging as a future trend in military/civil ocean engineering. The CODAR (Coastal Ocean Dynamics Radar) shows great promise in measuring the wave energy and surface current.
field on a 1 km square area of ocean from a shore-

based facility. If this technique indeed functions as
expected, we may be able to substantially increase our
reliability of making measurements as well as the cost
of doing so. LANDSAT imagery is currently having many
nearshore ocean/engineering applications. As the accu-
curability and reliability of satellite observations con-
tinue to increase, the potential applications to the
profession grow exponentially. Routine bathymetric
surveys from satellite imagery should be a reality in
years to come. Remote sensing offers the only viable
means of making synoptic worldwide observations. The
meteorological and oceanographic applications of
synoptic observations are endless.

ACKNOWLEDGEMENTS

The research and development efforts described in
this paper are contained in the Coastal Engineering
Functional Area of the Civil Works Research and Devel-

gment Program of the Corps of Engineers. Technical
monitors for the coastal engineering functional area
are Mr. John H. Lockhart, Jr., Hydraulics and Hydrology
Division and Mr. John Housley, Planning Division of
the Civil Works Directorate, Office, Chief of Engineers.
Dr. W. E. Roper and Mr. J. A. Pfeiffer, Jr. of the Re-

search and Development Directorate, Office, Chief of
Engineers were responsible for the MACOM level man-
agement of this research. The Chief of Engineers is
gratefully acknowledged for approving publication of
this paper.

REFERENCES

1. "Model Study of Wave and Surge Action, Naval Op-

erating Base, Terminal Island, San Pedro, California,"  
Waterways Experiment Station, Vicksburg, MS, Technical
Memorandum No. 2-237, Sept 1947.
2. "Wave and Surge Action, Point Fermin Naval Supply
Depot, San Pedro, California," Waterways Experiment
Station, Vicksburg, MS, Technical Memorandum No. 2-
238, Nov. 1947.
3. "Breakwater Location, U. S. Naval Air Station,
Alameda, California," Waterways Experiment Station,
Vicksburg, MS, Technical Memorandum 2-242, December
1947.
4. "Wave and Surge Action, Anaheim Bay, California,"  
Waterways Experiment Station, Vicksburg, MS, Technical
Memorandum No. 2-255, May 1948.
5. "Design of Jubail Harbor, Saudi Arabia, Royal
Saudi Naval Expansion Program," H. L. Giles and C. E.
Chatham, Waterways Experiment Station, Vicksburg, MS,
6. "Effects of Explosions in Shallow Water: Re-
port 1, Cratering Effects in Loess Soil and Surface
Waves for a Scaled Water Depth of 200 Ft (AFSWP-131),"
Dec 1951.
and Surface Waves for a Scaled Water Depth of 30 Ft
(AFSWP-343)," Mar 1952.
Surface Waves for a Scaled Water Depth of 200 Ft
for Scaled Water Depths of 200 and 30 Ft (Addenda to
Reports Nos. 1 and 2) (AFSWP-133)," Aug 1952.
Surface Waves, and Air-Blast Measurements for a Scaled
Water Depth of 30 Ft (AFSWP-134)," Jan 1953.
Surface Waves, and Air-Blast Measurements for a Scaled
Water Depth of 200 Ft (AFSWP-135)," Apr 1953.
Loess Soil, Surface Waves and Air-Blast Measurements
for Scaled Water Depths of 60 and 100 Ft (AFSWP-136),"
Jul 1953.
for Scaled Water Depths of 30, 60, 100, and 200 Ft
(AFSWP-137)," Sep 1953.
Sep 1953.
15. "Effects of Explosions in Shallow Water: Final
Report (AFSWP-452)," Waterways Experiment Station,
Vicksburg, MS., Technical Report No. 2-406, April
1955.
Report (AFSWP-960)," Waterways Experiment Station,
17. "Nuclear Construction Engineering Technology,
B. C. Hughes, R. S. Holmes, B. B. Redpath, et al,
Explosive Excavation Research Center, Livermore, CA,
18. "Nuclear Excavation Design of a Transisthmian
Sea-Level Canal," B. C. Hughes, Explosive Excavation
Research Center, Livermore, CA, Technical Report
No. 6, Oct 1968.
19. "The Corps of Engineers Nuclear Explosives
Studies for Civil Construction," B. C. Hughes, Ex-

plosive Excavation Research Center, Livermore, CA,
Screen," Waterways Experiment Station, Vicksburg, MS,
21. "Surface Waves Resulting from Explosions in Deep
Water: Report 1, Summary of Experimental Procedures
and Results of Tests at WES Underwater Explosion Test
Site," Waterways Experiment Station, Vicksburg, MS,
22. "Ibid, Report 2: Summary of Experimental Pro-
cedures and Results of Tests at Lake Ouachita, Arkan-
sas," J. M. Pinkston, Waterways Experiment Station,
C. E. Pace, R. W. Whalin, and J. N. Strange, Water-
ways Experiment Station, Vicksburg, MS, Technical Re-
port No. 1-647, Apr 1968.
24. "Ibid, Report 4, Effect of Charge Depth of Sub-
mergence on Wave Height and Energy Coupling," C. E.
Pace, R. W. Whalin, A. Sekurai, and J. N. Strange,
Waterways Experiment Station, Vicksburg, MS, Tech-

25. "Ibid, Report 5, Summary of Results, Comparison
with Theory, and Development of a Prediction Method,"  
C. E. Pace, R. W. Whalin, and J. N. Strange, Water-
ways Experiment Station, Vicksburg, MS, Technical
26. "Water-Shock Wave Reflection Properties of
Various Bottom Materials: Report 1, Reflection of a
Clayey-Silt Bottom," Louis Miller, Waterways Ex-
periment Station, Vicksburg, MS, Technical Report
638


59. "Methodology for the Calculation of a Shallow Water Wave Climate," R. E. Jensen, Waterways Experiment Station, Vicksburg, MS, WIS Report 8, (to be published).


