A buoy system and two surf prediction models are being developed, tested, and evaluated for obtaining wave breaker statistics and longshore currents. Input data is based upon measurements from an offshore location outside the surf zone.

Data from pressure-transducer wave and tide gage, a two-axes electromagnetic current meter, and temperature sensors are digitized and sent in a serial–digital format to an off-line processor.

Both models used to describe the nearshore waves and longshore current velocity are based upon linear theory. Results of measurements indicate that prediction of breaker heights within an accuracy of 10 to 15 percent is feasible using offshore measurements.

INTRODUCTION

The coastal environment plays a key role in many of the Navy's vital operations. Of specific interest to the Navy are such parameters as nearshore waves, tides, currents, and surf conditions. Actual measurements of these parameters within the active surf zone is a difficult task, particularly if it is to be done in a tactical situation. The surf zone is a very hostile environment on most occasions. And, it is where the surf is hostile that information concerning its statistics are most needed. Measurements outside the surf zone have been done more extensively and with considerably more success. Also, data processing techniques have been developed for offshore conditions as have environmental instrumentation. Therefore, the use of these developed processes and hardware coupled together with an effective reliable prediction, can provide valuable information to the coastal investigator.

This paper will report on the efforts of the Naval Coastal Systems Center (NCSC) to develop an offshore buoy system for measuring wave and current parameters and related prediction models that take these parameters and generate surf zone statistics.

The specific details of the buoy system, its application, the software algorithms, the data processing, and test results are given by Pidgeon.¹

DATA BUOY SYSTEM

The design of the data buoy system involved considerations of many factors. One of the major objectives of the design was to develop a measurement system that would operate in shallow water outside of the surf region and would be able to measure the hydrodynamic parameters needed as offshore inputs into the prediction model for determining the statistics of wave breakers and the longshore currents induced by these breakers. A secondary consideration was the development of a system that might either lead to or provide significant information for the design of an operational buoy system that could be used in Fleet operations and provide outputs detailing the near-surf and surf regions of an area under consideration. Although it was realized that this would be a multi-phase program, ultimate end products were considered along the various development stages of the present system. While considerable program development was done using the Hewlett Packard HP-9825 programmable calculator, additional processing was done using microcomputers in preparation for adapting the buoy system to perform on-board data processing utilizing state-of-the-art microprocessing components within the buoy.

The buoy system measures waves, tides, two orthogonal components (horizontal) of current, water temperature, internal temperature, and system calibration. Waves and tides are simultaneously measured by a Statham, Model UC-3, pressure cell. A Marsh-McBirney, Model 711, two-axis electromagnetic induction current meter measures water motion in the horizontal plane. Water temperature is measured both inside and outside the unit by using two Analog Devices, Model AD590, two-terminal integrated circuit temperature transducers. In addition, a leak detector circuit was added to the buoy to detect the presence of water in the bottom of the unit. All signal outputs from the system sensors are analog voltages and are tied into a 16-channel analog to digital multiplexer having 12-bit accuracy prior to transmission to shore. The sensors and all associated electronics are contained in a cylindrical pressure housing capable of withstanding pressures equivalent to 30 meters of water depth. Weighing less than 25 kilograms in air, the buoy is easily deployed by divers and is normally attached to a stand that has been previously jetted into the bottom for support.

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¹ Pidgeon.
A major consideration in the design of the buoy system was the method of getting the analog signals from the sensors to the processing equipment. Desirably, the data would be sent in digital form in order to obtain the most immunity from noise and other degrading factors. Also, in order to avoid having many signal lines between the buoy and the receiving station, a serial not a parallel system was needed. A very important consideration in the design of this interfacing system was the formatting and makeup of the data. With future on-board processing in mind, a format that would be directly compatible with microcomputers and other similar processors is what is needed. Each of these considerations fit very well into an interfacing system that has been developed by Dynex for another NCSC task. This system, called Information Transmission System (ITS), takes multiple analog data channels (up to 128), multiplexes them into a 12-bit digitizer (giving one millivolt resolution out of four volts), converts the parallel output data into two eight-bit bytes, which are sequentially applied to a standard UART (Universal Asynchronous Receiver Transmitter), from which the data are sent in a bit-serial, digital format. The serial format is completely compatible with computer standards for serial data transfer, i.e., meets RS-232C standards. Therefore, any computer processor with a standard RS-232 serial interface can accept the data from this buoy system without any further modification.

An important consideration in the transfer of data from the measuring source to the processing system is the preservation of the data as nearly as measured as practical. Secondly, the ability to input directly into the processor with minimal reformatting means more efficiency, fewer errors, and less processing costs. For on-board processing, both of these considerations are almost mandatory. These factors are the prime ones considered in the development of the ITS system, and they also made it a prime candidate for the data buoy system. The addition of ITS to the buoy system allowed considerable flexibility in how the data could be handled, once it was obtained in the buoy. The data could be transmitted via standard telemetry links with relatively low bandwidths. Or the data could be directly connected to a beach site via cable. This latter version was selected for these preliminary tests since both data signals and buoy power could be cabled between the beach site and the buoy with a modest cable having as few as four conductors—two for power and two for signals.

Since it was desirable to record data at selected intervals, it was decided to input the data signals directly from the buoy cable into a standard Bell 103 telephone modem, having an auto-answer capability. The RS-232 data format at a 300 baud rate is completely compatible with this type modem. Thus, when it was desired to take data or to check the buoy operation, all that one had to do was to call up the buoy from NCSC or the Dynex office with either an acoustic coupler (which was used by NCSC) or a modem (which was used by Dynex). When the modem at the beach tower auto-answered, the handset was completed at the originating end. At this point, data began to stream in and continued until the originating source turned off its lock-up tone or the calling phone was hung-up. The data that was received could then be used in several ways. It could be checked to ascertain proper buoy operation, it could be used to determine the real-time conditions of the Gulf of Mexico at that time, or it could be directly recorded or input into the processor for data processing.

In order to be able to sample the wave data rapidly enough to detail with accuracy the wave profile, the wave data were sampled most often of the data. This was done by putting the wave data on every other channel. Interdispersed between the wave data were the other signals. With the ITS system running at 300 baud wave data were sampled almost five times per second. This was sufficiently fast enough to adequately determine wave shape. (It is necessary in the data processing to determine the peak and trough of each individual wave as well as its period. Therefore, an accurate reproduction of the wave profile is necessary.)

**PREDICTIVE MODELS**

Using the wave buoy to provide a time history of hydrodynamic pressure and the two horizontal components of water motion at a point seaward of the surf zone, a scheme was developed to compute the following parameters:

- a) Average breaker height \( H \) and maximum breaker height \( H_m \)
- b) Average breaker position \( \bar{X} \) and maximum breaker position \( X_m \)
- c) Breaker type (i.e., plunging, spilling or surging)
- d) Average longshore current \( V_1 \) and maximum longshore current \( V_{1m} \)

Wave theory used for this study is linear wave theory. This theory is able to treat waves in intermediate and shallow water and is easily programmable onto a microcomputer. It is, of course, limited to waves of small height to wave length ratios (low steepness), and small wave height to water depth ratios. In addition to wave and current parameters, bottom slope \( \beta \), elevation of buoy off the bottom \( d \), and orientation of current meter \( y \)-axis, parallel to shoreline and \( x \)-axis, normal to shoreline are also required input parameters (see figure 1). Data is sampled at a constant time interval, \( \Delta t \), over an interval of time, \( t \), to produce \( N \) data samples, where \( N \) equals \( t/\Delta t \). Usually \( t \) will be in the range of five to 20 minutes and \( \Delta t \) will be 0.25 to one second.
The preliminary computations include determining the mean pressure ($\bar{P}$), the pressure change between wave crest and wave through for each wave ($\Delta P_i, j=1 \cdots M$), the wave period for each wave ($T_j$), the mean velocity components ($V_j$ and $U_j$) and the wave crest current components ($U_{cj}$ and $V_{cj}$).

The wave parameters computed for the location of the instrument are:

- water depth $h = \frac{\bar{P}}{\rho g} + d_i$
- for each wave:
  - wave height $H_j = \frac{\Delta P_j}{\rho g} \cosh \left( \frac{2\pi h}{L_j} \right)$
  - wave length $L_j = \frac{2\pi}{T_j}$
  - wave angle $\theta_j = \tan^{-1} \left( \frac{V_{cj}}{U_{cj}} \right)$

**SIMPLIFIED MODEL—PREDICTION EQUATIONS**

For the prediction of breaker heights, the simplified model utilizes pressure measurements (uncorrected for the depth) from the bottom mounted pressure transducer and computes a breaker height from the following equation:

$$H_b = \left[ .89 \frac{\bar{P}}{\rho g} + h_1 \left( \frac{\Delta P_1}{\rho g} \right)^4 \right]^{1/5}$$

This computation is made for each individually measured wave recorded at the data buoy.

The predictive model also gives a prediction of the maximum longshore current from the measured average longshore current at the buoy and the predicted breaker depth obtained from the mean breaker height as given by:

$$V_{lm} = 1.77 \sqrt{\frac{H_b}{h_b}}$$

**DETAILED MODEL—PREDICTION EQUATIONS**

The prediction of the surf zone parameters involves a set of equations which must be applied simultaneously. The equations use the instrument site wave parameters $H_j, T_j, L_j,$ and $\theta_j$ to predict the same parameters at the break point $H_{bj}, T_{bj}, L_{bj},$ and $\theta_{bj}$.

It is assumed that the period of each wave remains constant so that $T_j = T_{bj}$. The equations are as follows (3):

1. **Breaker Depth**
   $$h_{bj} = H_{bj} \left(1 - 4.78 + 128 \frac{h}{L_j} \right), \ s = .15$$

2. **Breaker Angle**
   $$\sin \theta_{bj} = \frac{C_{bj}}{C_j} \sin \theta_j$$
   $$C_j = \frac{L_j}{T_j}, \ C_{bj} = \left[ g(H_{bj} + h_{bj}) \right]^{1/2}$$

3. **Breaker Wavelength**
   $$L_{bj} = C_{bj} \cdot T_j$$

4. **Breaker Height**
   $$H_{bj} = H_j \cdot K_{rj} \cdot K_{sj} \cdot K_{fj}$$
   where
   $$K_{fj} = .98, \ K_{rj} = \left[ \frac{\cos \theta_j}{\cos \theta_{bj}} \right]^{1/2} \left( \frac{4\pi/h_{bj}}{\sinh(4\pi/h_{bj})} \right)^{1/2}$$
   $$K_{sj} = \left[ \tanh \left( \frac{2\pi h_{bj}}{L_{bj}} \right) \right]^{1/2} \left( \frac{4\pi/h_{bj}}{\sinh(4\pi/h_{bj})} \right)^{1/2}$$

The set of breaker values are computed for $j = 1 \cdots M$. For this the maximum breaker height $H_m$ can be identified, furthermore

$$\bar{H}_b = \frac{1}{M} \sum_{j=1}^{M} H_{bj}, \ \bar{h}_b = \frac{1}{M} \sum_{j=1}^{M} h_{bj}$$

$$\bar{\theta}_b = \frac{1}{M} \sum_{j=1}^{M} \theta_{bj}$$

The positions of $\bar{h}_b$ and $h_{max}$ can be located on the nearshore chart.

**PREDICTION PROCEDURE—DETAILED MODEL**

The simultaneous solution of the set of equations needed to make a prediction is too complex for a practical scheme. Rather, the solution can be approximated by an iteration scheme in which initial values for selected parameters are computed from an input data. The formula for the initial value of the wave height is

$$H_{bj} = .95 \left( \frac{h_{bj}^{1/5}}{H_j} \right)^{4/5}$$
With this initial value, the set of equations in the surf prediction model can be computed explicitly in order, that is, finding \( h_{bj} \), use this to find \( \theta_{bj} \) and finally \( H_{bj} \). The difference between \( H_{bj} \) and \( H^*_{bj} \) should be small (a few percent) and, if not, \( H_{bj} \) can be used in place of \( H^*_{bj} \) in a second iteration.

**BREAKER TYPE**

The prediction of breaker type is based upon breaker wave characteristics and the beach slope. The empirical formula suggested is:

\[
\frac{H_{bj}}{L_{bj}^{\theta_{bj}}} > 1.2 \text{ SPILLING BREAKER}
\]

\[
0.5 \leq \frac{H_{bj}}{L_{bj}^{\theta_{bj}}} \leq 1.2 \text{ PLUNGING BREAKER}
\]

\[
\frac{H_{bj}}{L_{bj}^{\theta_{bj}}} < 0.5 \text{ SURGING BREAKER}
\]

**LONGSHORE CURRENT MODEL**

The prediction of longshore currents is based upon the theory of linear waves on a plane sloping beach. The formula for the maximum longshore current \( V_m \) and the longshore current at the average point \( V_b \) are given by (4):

\[ V_m = 20.7 \cdot \beta (gH_b)^{\frac{1}{2}} \sin \theta_b \]

and

\[ V_b = 0.60 V_m \]

**FIELD TESTS AND RESULTS**

To date the buoy has been deployed on five different occasions to acquire data for various sea state conditions. Prior to each deployment and upon return to NCSC, the entire system undergoes a check procedure to verify operability and calibration. Problems encountered with the use of a cable between buoy site and shore station have been the most prevalent. Strong longshore currents associated with the passage of storm fronts have caused the cable to break or to pull away from the buoy on several different occasions.

To properly evaluate the predictive models, it was desired to compare actual measurements of breaker heights on an individual basis with corresponding predicted heights. This necessitates time correlation of recorded buoy measurements with observed/measured breaker measurements. Due to the dispersive nature of waves approaching the breaking zone, the sequence of waves arriving at the buoy will not necessarily be the same sequence that arrive at the breaker zone. However, in general, the measurements of a group of waves can be compared with that for time-delayed measurements to the breaker region for a similar group of breakers.

Two different approaches to the verification of the predicted heights were utilized. The first approach developed was a technique using a transit with vertical graduations. This vertical scale was calibrated for known locations (anchored floats) within the breaking zone. Vertical displacement of the float was measured, giving a reasonably accurate measurement of waves immediately prior to breaking. A comparison of measured versus predicted breaker heights for the predictive models is presented in Table 1. Although it was not possible to make a one-for-one comparison between the predicted breaker heights and the measured breaker heights, their respective statistics provided adequate data for comparison.

It can be observed that the detailed model over-predicts the heights in all cases, whereas the simplified model comes closer to the measured conditions, in some cases under-predicting, but in others over-predicting. However, on the average, the simplified model is very close except for the largest of the heights. For this test date the average wave periods are running close to six seconds. It should be noted that periods of less than three seconds are not included due to frequency cut-off of pressure transducer.

A brief examination of the effect of beach slope on the results given for the detailed model was done. A slope of 1:20 was used for the data processing. At this point, this value is felt to be too large. 1:30 to 1:50 probably fits the conditions more closely. Using the more gradual slope in the detailed model, the prediction results for the cases tested was less, but not by as much as the results for this test date indicate. The slope, as well as other factors, need to be further investigated for model refinement.

It should be noted at this point, that the results of the comparisons of the models with observations are very encouraging. The results indicate that for breaker heights up to two meters, the detailed model predicts breaker heights to an accuracy of the order of ten percent. For the higher energy waves, the simplified model does almost as well, but does less well for the shorter wave periods with lower amplitudes.

The second approach to model verification involves the use of wave data collected from the U. S. Army Coastal Engineering Research Center Field Research Facility at Duck, North Carolina. Breaking wave data recorded from a series of wave gages positioned throughout the active surf zone will be compared with predicted breaker heights whose input data have been simultaneously recorded from gages positioned just outside the surf zone. These detailed time correlated measurements will provide valuable calibration data for both predictive models. Results of this experiment will be published at a later date.
CONCLUSIONS

Regarding the over-all buoy system and its operation, the results of this study have demonstrated that this system is a very reliable one, has the ability to measure very accurately the required wave, tide, and current inputs for data processing, is easily deployable by divers from a small boat with minimum equipment required, and is readily adaptable to a variety of Fleet operations and applications. It has demonstrated that it can withstand the hostile environment of the near-surf zone within the limits tested and has the ability to transmit its data via a wide variety of methods to the end user, thus making this buoy system a prime candidate for Fleet operations.

The models presented in this study provide a means for making predictions of the desired surf parameters. Each model is limited in application because of the assumptions contained in the underlying wave theory. The models do not account for wave induced pressures near the break point, resulting from wave crest accelerations. Furthermore, the bottom topography is assumed to be planar and therefore real beach profiles and longshore bars cannot be treated. Finally, the longshore current predictions neglect temporal variations in current speed and spatial variations associated with nearshore topography.

It is concluded that the software developed for the support operations of the buoy system is efficient in terms of processing capabilities of speed, size, and complexity, can be adapted to on-board buoy processing without considerable modification, is flexible and readily adaptable to a wide range of user applications, and the study results further show the software to be reliable and accurate.

It is further concluded that both of the prediction models used in this study give very good results, often with prediction errors of only a few percent, that the detailed model allows for a greater flexibility and range of environmental inputs but does require more complexity in processing, and that the simplified model, although limited, gave accuracies that are well within the requirements of many user applications.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. R. A. Brown, NCSC Electronics Technician, who did most of the fabrication of the buoy system and who put up with all of the seemingly endless testing and checking-out and development of the buoy system.

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TABLE 1. COMPARISON OF MEASURED VERSUS PREDICTED BREAKER HEIGHTS FOR SIMPLIFIED AND DETAILED MODELS

<table>
<thead>
<tr>
<th>TIME</th>
<th>AVERAGE BREAKER HEIGHT (M)</th>
<th>SIMPL. Model</th>
<th>DETAIL Model</th>
<th>MEAS'D</th>
</tr>
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<tbody>
<tr>
<td>11:15-11:18</td>
<td>.69</td>
<td>.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:18-11:22</td>
<td>.70</td>
<td>.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:22-11:26</td>
<td>.76</td>
<td>.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVERAGE</td>
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<td>.82</td>
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AVERAGE TIMES

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<th>TIME</th>
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<th>DETAIL Model</th>
<th>MEAS'D</th>
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<td>.83</td>
<td>.75</td>
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### TIME AVERAGE HIGHEST 1/10 (M) REFERENCES

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<th>Detail Model</th>
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<td>11:18-11:22</td>
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<td>AVERAGE ALL TIMES</td>
<td>1.20</td>
<td>1.25</td>
<td>1.10</td>
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**FIGURE 1.** Schematic Diagram of Beach and Definition of Variables.