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A Capacitance Wavestaff and Measurements of Wave Height Decay in the Surf Zone

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A CAPACITANCE WAVESTAFF AND

MEASUREMENTS OF WAVE HEIGHT DECAY IN THE SURF ZONE

by

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Approved by:

John C. Ludwick (Director)

ABSTRACT

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MEASUREMENTS OF WAVE HEIGHT DECAY IN THE SURF ZONE

David L. Timpy
Old Dominion University, 1982
Director: Dr. John C. Ludwick

A wavestaff system utilizing capacitance was developed to measure wave heights in the surf zone. Data were used to test the assumption that wave height decays linearly across the surf zone. The instrument system consisted of two wavestaffs and housing which contained the needed electronic circuits and a data recorder. Acceptable frequency response for waves of period greater than two seconds could not be obtained if sensor wires were greater than 0.35 mm in diameter. The size used was 0.35 mm.

Simultaneous wave height measurements at points distributed across the surf zone were obtained during four field experiments at Virginia Beach, Virginia. Wavestaffs were repositioned along a line perpendicular to the shoreline. Wave height decay across the surf zone was found to be nonlinear and appears to be categorizable into three divisions: (1) rapid decay due to turbulence induced by the breaking process; (2) nearly constant decay due to a balance between turbulence and wave shoaling affects; (3) rapid decay (of remaining wave energy) as a wave propagates up the beach slope against the force of gravity. Energy is

dissipated less rapidly by spilling breakers than plunging breakers. Spilling breakers result in greater runup at the shoreline.

ACKNOWLEDGEMENTS

I am especially grateful to the director of my advisory committee, Dr. John C. Ludwick. His patience and understanding were critical to the completion of this project. The capacitive wavestaff would not have been successful without his time and effort. Working with him has been a memorable experience. It has molded me into a better scientist.

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The capacitive wavestaff could not have been built without the School of Sciences Shop. I owe a lot of thanks to Thurman Gardner for all his advice and allowing me free use of his shop. He also did an excellent job on the machining and welding of the instrument housing. I thank God for creating Bobby Powell and his talent for electronics. Bobby taught me electronics and helped me build the wavestaff circuits. The work of Ray Stewart on the hand crank and clacker is appreciated. I would also like to thank the rest of the shop personnel and friends for their advice and assistance. These include John Hill, Charlie Dunham, Ed Carpenter, Mike O'Brien, Ken Porter and Greg Robertson.

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I am appreciative for the volunteer help from fellow graduate students and friends in collecting the field data. Special thanks goes to Mike Jugan for his help with the calibration of the wavestaffs and his transit work during the field experiments. Jim Perry, Dave Driver, Tony Mauser, Paul Bowen, John Koster, Kim Zauderer, Dave Velinsky, Joe Fitzgerald, and Ray Sawyer helped me deploy the wavestaffs in the surf zone. Greg Kopanski, Joe Lewandowski, Malcolm Kay, Al Moore, Dennis Lundberg, Ian Anderson, and Mike Matylevich assisted with the work on the beach. Tom Lutton, Andre Rivamonte, Mike Weston, and Harry Winnik also assisted in various ways.

A large measure of thanks must go to my friends and brothers for their help in collecting field data during a bitter cold day in New Jersey. The air and water temperatures during the field experiment were 10°F and 33°F, respectively. Ernie Timpy, my younger brother, allowed me to con him into helping me in the surf zone. Kevin Timpy, my older brother, allowed my coffee to freeze. Jim Cousins and Phil Heinle helped out on the beach. Peter Dedham was outstanding with his transit work. I also would like to thank my

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Much appreciated assistance with the computer software was given by Dick Phillips, Dr. Gerardo Perillo and his wife, Dr. Cintia Piccolo, and Dr. Im Sang Oh. The staff of the computer center, particularly Tim Hendrickson, were also of great assistance.

The O.D.U. Weather Center and meteorology graduate students forecasted the weather correctly throughout the project. Colonel Jim Smith acquired the weather data at Cape Henry for this study.

Dr. D.J. Shirley, University of Texas, supplied the basic schematic for the wavestaff electronics.

Dick Ribe of the National Oceanographic Instrument Center (NOIC) supplied valuable information on oscillators and wave-measuring instruments.

Mr. R.K. Keplar, Civil Engineering Technology, was kind in helping me calibrate the transit.

This project would never have begun without Dr. Ron Johnson. He admitted me into the oceanography program and miraculously found funds to support me while I slowly completed my master's degree requirements.

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Equipment support was provided by the Department of Oceanography, Old Dominion University.

Above all, I am indebted to my wife, Cathy. She helped me with every aspect of this study. This includes working to pay the bills, doing the household chores, and taking care of our infant daughter, Sarah. Her help with my project was invaluable. She assisted with the wavestaff calibration experiments as well as the field experiments. In addition, she proofread and typed this report.

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I. INTRODUCTION

Waves on beaches are a source of energy which drives the nearshore circulation and the resulting sediment transport along the shore and in the cross-shore direction. Incident waves breaking in shallow water dissipate most of their energy as broken waves or surf bores which propagate across the surf zone.

Previously, wave height decay across the surf zone has been assumed to depend on local water depth. The primary objective of the present study was to test the validity of this assumption. Stated another way, the objective was to determine whether the wave height decay in the surf zone can be described with a linear or nonlinear function. A secondary objective which evolved during the early part of the study was the development of a capacitance wavestaff system that could measure wave height accurately and be deployable in the surf zone. The resulting system consisted of two capacitance wavestaffs and an instrument housing which contained all the electronics and data recorder.

The number of studies in the literature on wave height decay in the surf zone is small. Laboratory studies far outnumber field studies. The obtaining of field measurements of wave height in the surf zone is a difficult and at times an impossible task.

Working on the coast of Lake Michigan, Wood (1970) obtained wave height measurements and horizontal particle velocities beneath breaking waves. His data show a decrease in wave celerity shoreward of the breaker point, probably due to the breaking process. In a later study, Wood (1972) measured waves in the surf zone with capacitance wavestaffs and concluded that wave height decay across the surf zone was nonlinear. The probes used on the wavestaffs during the field experiments had diameters of 1 cm.

Suhayda and Pettigrew (1977) measured the average wave height and celerity of ten individual waves during movement across the surf zone by photographing closely spaced graduated poles. Breakers were visually observed to be plunging. It was shown that wave height decays rapidly after breaking, followed by a slower decrease with further progress toward the shoreline. They also conclude that wave height decay across the surf zone was nonlinear. Wave celerity values for the same data show a rapid decrease after breaking with values slowly decreasing as the shoreline is approached.

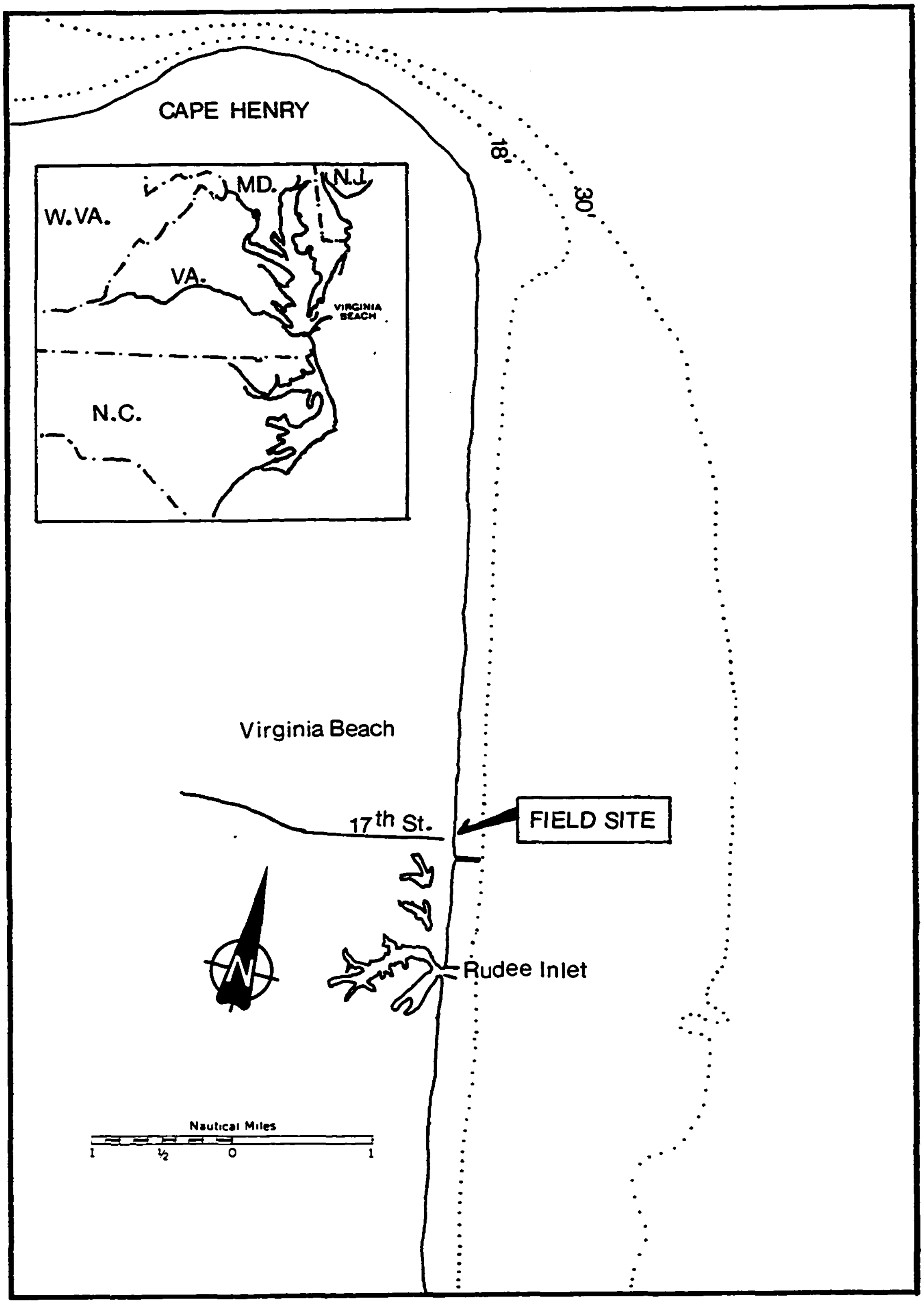
Guza and Thornton (in press) state that wave measurements collected at Torrey Pines indicate that wave height decay across the surf zone is linear. In this study, field measurements of wave height were obtained with current meters, pressure sensors, and dual resistance

wavestaffs. The sensor wire diameter of the wavestaffs used during the study was 0.6 mm. L.D. Wright (personal communication) has also obtained similar results to those of Guza and Thornton (in press) from pressure sensor measurements of waves off the coast of Australia.

Most laboratory studies of wave transformation across the surf zone indicate that bore height decay is nonlinear and that wave heights in the surf zone cannot be assumed to be a constant fraction of the local water depth. Studies of this kind include those by Horikawa and Kuo (1966), Sawaragi and Iwata (1974), Goda (1975) and Walker (1974). This finding is in direct contrast with laboratory measurements obtained by Bowen et al. (1968), who indicated that wave heights in the surf zone can be assumed to be a linear function of the local water depth.

In the present study, wave height measurements at points distributed across the surf zone were obtained during four field experiments at one site located in Virginia Beach, Virginia (figure 1). Each field experiment was comprised of five to seven data sets, with the sampling time of each data set about ten minutes. In each data set, two capacitance wavestaffs were positioned in the surf zone along a line perpendicular to the beach. Wave measurements from the wavestaffs were recorded simultaneously on magnetic cassette tape. After each data set was taken, the wavestaffs were repositioned to new locations on the same

Figure 1. Field Experiment Site


CAPE HENRY
18'
30'
W.VA.
MD.
N.J.
VA.
VIRGINIA BEACH
N.C.
Virginia Beach
17th St.
FIELD SITE
Rudee Inlet
N
Nautical Miles
1
½
0
1

line within the surf zone. Measurements of breaker position, water depth and swash were taken during the acquisition of each data set. Subaqueous beach profiles at the study site were obtained before each field experiment. Generally, results obtained from the present study indicate that wave height decay across the surf zone is nonlinear, but can be approximately linear under certain circumstances.

II. METHODOLOGY

Capacitance Wavestaff System

Many different devices have been used to measure the elevation of surface water waves as a function of time. These vary from the most economical, using the human eye, to the extremely costly, using laser beams. The choice of device usually depends on the intended use and available resources.

Adequate descriptions of the different wave-measuring instruments have been given by Ribe (1974), Grace (1970) and Draper (1966). Grace (1970) classified wave instruments into four general categories. They are: (1) measure above the water surface; (2) measure below the water surface (3) measure on the water surface; (4) measure through the air-sea interface. Generally, a wave-measuring instrument which uses a sensor element that passes through the air-water interface is termed a wavestaff. The most common types of wavestaffs are resistance and capacitance. Types and characteristics of wave-measuring instruments are numerous (Table 1).

For this study, a wave-measuring instrument was needed that was simple, easy to build, economical, accurate and capable of being deployed in the surf zone. A pressure sensor was not chosen mainly because it was expensive

Table 1. Types and Characteristics of Wave-Measuring Instruments

Sensor type	Principle of operation	Cost range
Capacitance	Water level variations cause a change in capacitance which produces proportional output voltage.	$ 57[1]
Resistance wire	Water level variations change sensor resistance which produces a proportional output voltage.	1,150-5,000[2] 1,400-2,200[3]
Step resistance	Same as above except the sensor is constructed of equal resistors placed in series along the staff.	20,000[2]
Reed switch	A magnetic float switches on and off. A series of reed switches along a staff to connect resistance into a circuit.	Described by Ribe (1974)
Rapid frequency transmission lines	A transducer element electrically senses length of parallel wires above the water and yields a voltage output proportional to water level variations.	4,200[2]
Pressure	Measured changes in pressure at a fixed depth below the water surface are used to calculate actual surface elevation.	3,200-18,800[2] 2,600- 4,000[3]

[1]Timpy (1982), see Appendix I.

[2]Ribe (1978)

[3]Grace (1970)

Table 1 (continued)

Sensor type	Principle of operation	Cost range
Upward directed sonar	Time between sound pulses directed toward and reflected back from the water surface are used to calculate the surface water elevation.	\$10,000-37,750[2] 7,500-19,000[3]
Downward directed sonar	Surface elevation determined by measuring transmitted time interval of sound from transducer down to water surface.	prototype[2]
Buoys	Vertical buoy displacement measured with some type of device such as accelerometers, pressure transducers, wavestaffs and graduated rods.	5,000-100,000[2]
Lasers	Travel time interval of low power laser beam down to water surface determines surface elevation.	30,000-80,000[2]
Shipborne recorder	Combines accelerometers and subsurface pressure sensors to cancel out ship motion yielding surface wave measurements.	See Tucker (1956) and van Aken, H.M. and E. Bouws (1974)
Wave orbital velocity	Measured wave-induced velocities are used to calculate surface elevation using Airy wave theory.	1,800[2]

and would not provide direct measurements of surface elevation. A resistance wavestaff was not chosen because of major problems of stability and accuracy associated with changes in water conductivity due to water temperature and salinity variations. The accuracy of the resistance staff is also affected by corrosion of the sensing probe during operation. Resistance wavestaffs are generally not as popular as pressure sensing devices, and the literature on resistance wavestaffs is not as abundant. The reader is again referred to Ribe (1974) and Grace (1970) for general information. Further information on resistance staffs can be found in Wiegel (1966), Bigelow (1968) and Flick et al. (1979).

All of the wave-measuring instruments listed in Table 1, with the exception of capacitance wavestaffs, are commercially available, and probably at higher costs than listed in the table. Caution should be exercised in purchasing one of these devices. An evaluation of commercially available wave-measuring instruments has been completed by Ribe (1978). In addition, Althouse (1968) reports sources and costs of wave-measuring instruments. It should also be mentioned that the National Oceanographic Instrumentation Center (NOIC), Washington, D.C. has published, up to 1976, instrument performance data on most types of ocean instruments. This information exists in the form of Instrument Fact Sheets, Technical Bulletins

and Technical Memorandums. Since 1976, results of NOAA-conducted tests have been published in the form of NOAA Technical Memorandums. They are available for sale from Superintendent of Documents, Government Printing Office and through the National Technical Information Service (NTIS), Springfield, Virginia, 22161.

The type of wave-measuring instrument finally selected for this study was a capacitance wavestaff. This type is simple, economical, easy to build, and extremely accurate when fitted with the proper sensor wire. The cost breakdown for the development and construction of the wavestaff system is given in Appendix I.

Capacitance wavestaffs consist of three essential components: a sensing element, detector circuit, and a data storage device. The sensing element is usually an insulated wire which is passed vertically through the air-sea interface. The insulator is the dielectric of a variable capacitor with the center conductor and the sea-water acting as the plates of the capacitor. Variations in the elevation of the water surface are detected as changes in capacitance by a detector circuit. This same circuit transforms the varying capacitance into a proportional voltage signal, which is then transmitted to the data storage device. It is to be noted that the sensing element of the capacitance wavestaff is not subjected to corrosion.

There are many variations of capacitance wave-measuring circuits (see Table 2). The circuit design published by Anderson, Shirley, and Wilkins (1972) was chosen for this study because it was found to be cheaper, simpler, and easier to adjust than all other reported designs. The design also incorporates low power integrated circuits which made modifications to suit the needs of this study a relatively simple task.

The electronics of the wavestaff measuring circuit is composed of five major elements as shown in the upper portion of figure 2. A schematic is shown in figure 3 to facilitate the following description: The sine wave oscillator is a Wein Bridge circuit and is the heart of the detector circuit. When properly balanced this part of the circuit has constant voltage output under variations in load and has good frequency stability. Ways to achieve this balance are discussed in detail by Jung (1980) and Irvine (1981). Only a brief discussion will be given here: The frequency of oscillator, f_o, can be approximately adjusted using the following relationship,

$$f_o = \frac{1}{2\pi R_1 C_1} \tag{1}$$

where R_1 is resistance in ohms and C_1 is capacitance in farads (see figure 3). It is required that $R_1=R_2$ and $C_1=C_2$. The Wien network, composed of R_1-C_1 and R_2-C_2, provides a

Table 2. Summary of the Various Capacitance Wavestaff Designs

Reference	Use Designed For	Gain Constant	Sensor Diameter (mm)
This paper	field	33 mv/cm	0.35
Anderson et al. (1977)	field	59 mv/cm	1.60
[1]Gardner (1970)	field	--	9.50
[1]Davidson (1970)	laboratory	--	6.40
Brown et al. (1966)	field	5.2×10^{-5} sec/cm	0.25
Kinsman (1960)	field	8 mv/cm	13.00
Killen (1955)	laboratory	33 pf/cm	0.35
Tucker & Charnock (1954)	laboratory	28 ma/cm	0.62
Krizek (1974)	laboratory	0.7 mv/cm	1.00
Lion (1964)	laboratory	394 mv/cm	0.025
McGoldrick (1969)	laboratory	50 mv/cm	6.40
[2]Wood (1973)	field	--	6.20
Blair (1976)	laboratory	--	16 awg

Table 2 (continued)

Reference	Use Designed For	Gain Constant	Sensor Diameter (mm)
[2]Bub (1974)	field	20 mv/cm	6.20
[2]Galvin (1975)	field	15 mv/cm	6.20

[1]Cited by Anderson et al. (1977)

[2]Followed McGoldrick's design

positive feedback loop while R_3 and L_1 provide a "regulated" negative loop. The attenuation of the Wien network is three (3.0) and must be maintained using the relation,

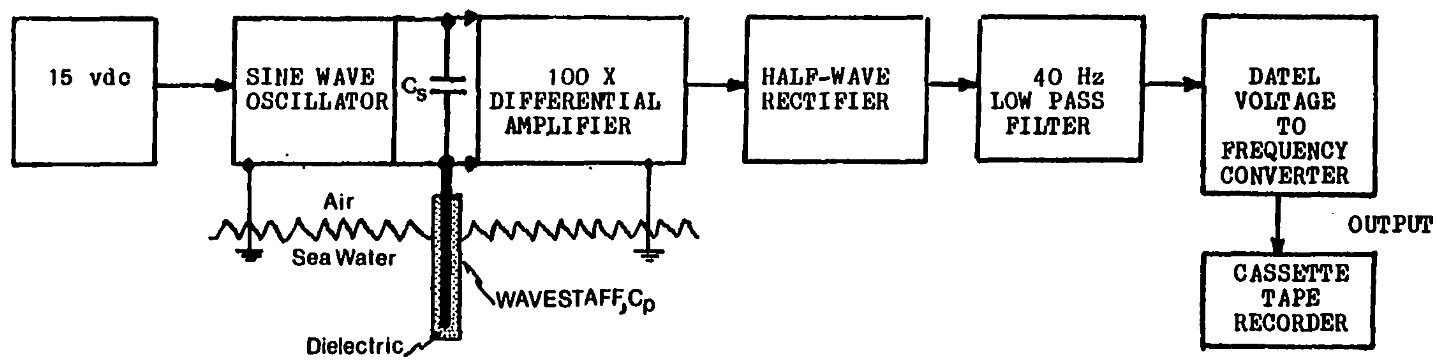
$$\frac{R_4 + R_3}{R_3} = 3 \qquad (2)$$

where R_3 and R_4 are resistors as shown in figure 3. Maintaining the attenuation at this level will automatically balance the positive and negative feedback so that the amplitude of oscillations will be regulated. In this state, the sine wave voltage output will be at a maximum, as will the frequency stability. The nonlinear resistance of the lamp (L28/40) is used to regulate the amount of negative feedback (figure 3). The lamp responds to the output level

Figure 2. Capacitance Wavestaff System. Part I Represents Field Portion and Part II Represents the Laboratory Portion.

SYSTEMS BLOCK DIAGRAM

PART I.



PART II.

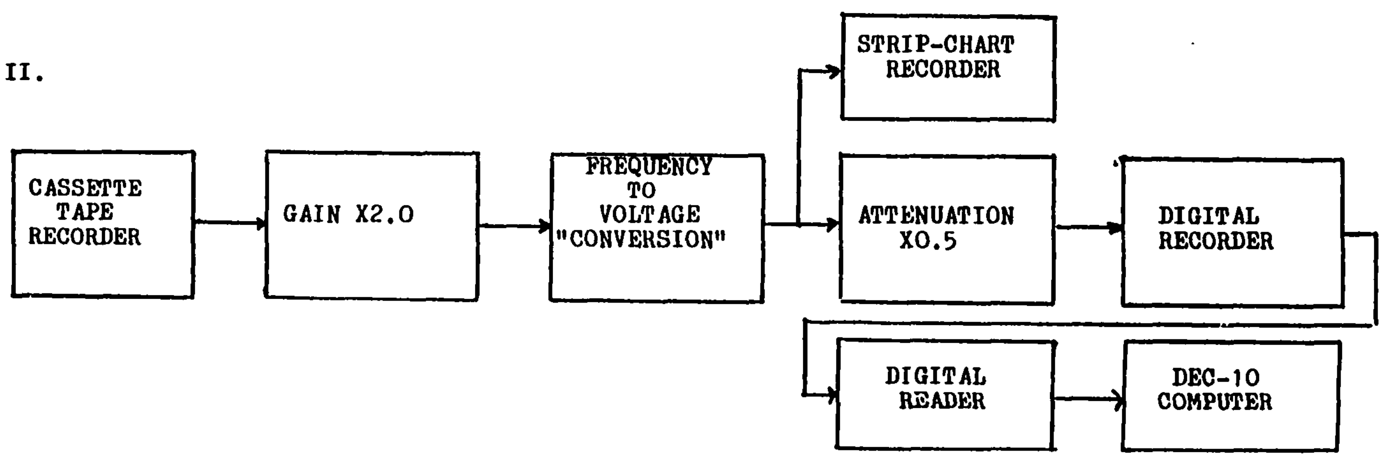
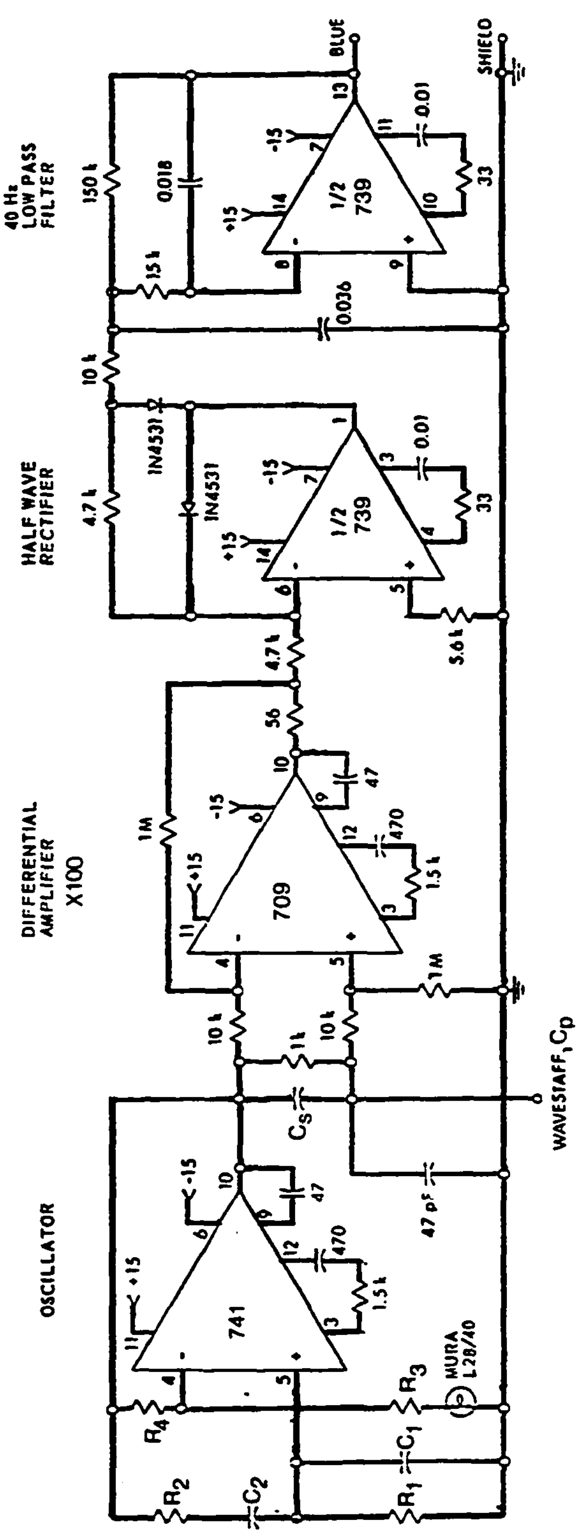


Figure 3. Circuit Schematic for Linear Capacitance Wavestaff


OSCILLATOR
DIFFERENTIAL AMPLIFIER
X100
HALF WAVE RECTIFIER
40 Hz LOW PASS FILTER
741
709
1/2 739
BLUE
SHIELD
WAVESTAFF, C_p

of the oscillator, adjusting its resistance in inverse proportion. If the output level of the amplifier rises, the resistance of the lamp increases, counteracting the rise. Similarly, a reduction in output level results in a decrease of lamp resistance, thus stabilizing the oscillation level.

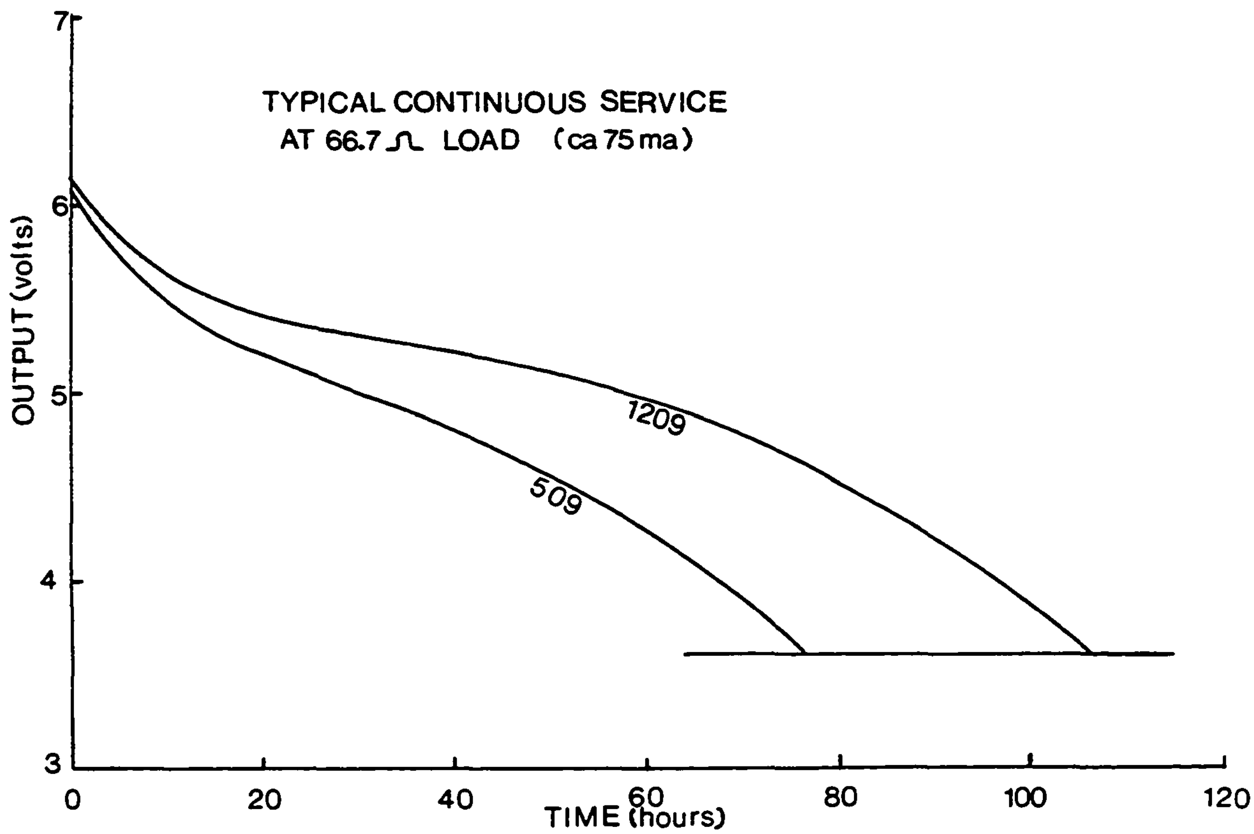
The constant voltage of the sine wave oscillator is applied to the measuring circuit of the wavestaff, which consists of two capacitors in series. One is a discrete component in the circuit, the other is formed by the sensor wire. These capacitors are labeled C_s and C_p respectively in figure 3. If C_s is made much larger than C_p, then the voltage across C_s is directly proportional to the capacitance of C_p which varies with the surface elevation of the water surface.

The voltage across C_s will be an amplitude modulated sine wave. This signal is amplified 40 db by a differential operational amplifier. This is followed by a precision half wave rectifier to detect the amplitude modulated signal. This rectifier consists of an operational amplifier with diodes in the feedback circuit such that on negative excursions of the sine wave, the gain is much less than one. This circuit has much less nonlinearity than a simple diode rectifier and so reduces errors at low water levels. The rectifier is followed by a 40 Hz low pass filter to eliminate the carrier frequency.

The output at this point is an amplitude modulated voltage signal proportional to the capacitance of the sensor wire. This voltage is then converted into a proportional frequency with a VFV-10K voltage-to-frequency converter, manufactured by Datel Systems, Inc. The VFV-10K converter can be thought of as an analog-to-digital converter with serial output pulses which must be counted. The output pulses are constant width pulses of 70 μsec and a 200 nsec rise time.

The power requirements for a single wavestaff system are ± 15 volts at 45 milliamps. The power requirements for just the frequency-to-voltage converter are ± 15 volts at 25 milliamps. The wavestaff system, without the frequency-to-voltage converter draws 18 milliamps. The power supplied to the wavestaff system was regulated using two ± 15 volt linear voltage regulators. The plus and minus supply voltages for the two wavestaff circuits were supplied by two sets of four six-volt Eveready Heavy Duty lantern batteries (model no. 1209). Each set of four were connected in series to supply ± 24 volts to the linear voltage regulators. The voltage regulators have a maximum rating of 35 volts and a cutoff voltage of about 17 volts (4.25 volts per battery). Figure 4 shows that with a current drain of 75 milliamps, the service life of the lantern batteries is about 89 continuous hours.

Figure 4. Voltage Versus Time for Eveready Models 1209 and 509 Six Volt Lantern Batteries


TYPICAL CONTINUOUS SERVICE
AT 66.7 Ω LOAD (ca 75 ma)
1209
509
OUTPUT (volts)
TIME (hours)
3
4
5
6
7
0
20
40
60
80
100
120

The frequency modulated signal output from the wavestaff was stored on standard magnetic cassette tape using a Realistic SCT-12 stereo cassette tape deck. The specifications for the tape deck are given in Appendix II. Selection of this recorder was made after testing sixteen other cassette tape units. The model quality ranged from the least expensive Realistic model to the more expensive Sony model. It was found that all stereo cassette tape decks tested were able to record the full range of frequency signals (0-10 kHz) output by the wavestaff system. Portable single channel cassette recorders could only record up to about 7 kHz and were not capable of recording the full range of frequency signals. Little difference, if any, was observed in the performance between brands. The brand of cassette tape used in all recorder tests was Maxell UDXL/I. This is a standard tape with normal bias and 120 microsecond equalization.

The Realistic SCT-12 recorder was selected over other stereo cassette tape decks because of its small size, plastic construction, and economical price. The dimensions of the recorder are 8.3 cm X 14.7 cm X 24.7 cm. Plastic construction was preferred because it would not corrode in the marine environment.

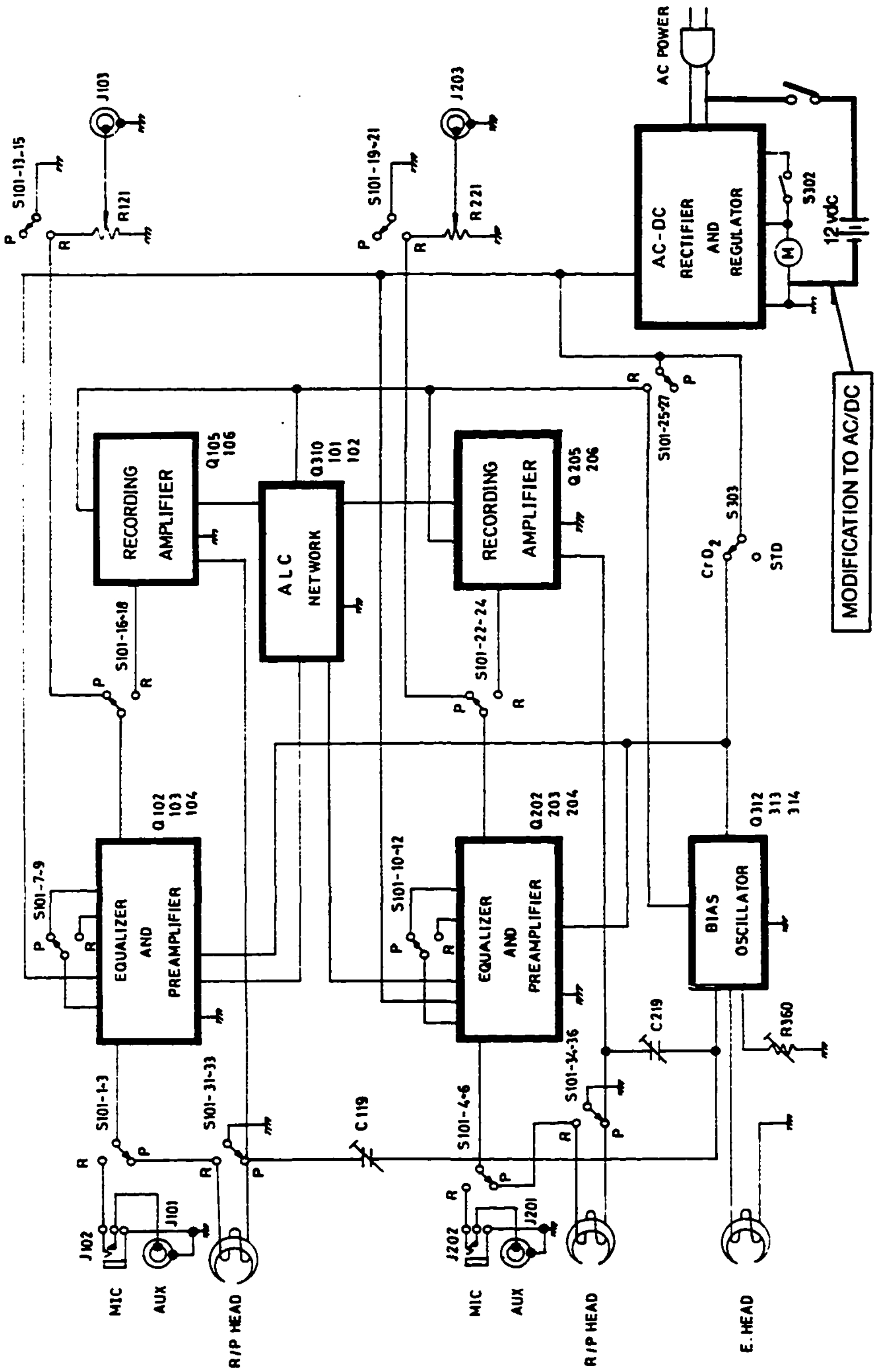
The recorder was originally designed to use ac power only. Since the wavestaff system was to function as

a fully contained instrument, modification of the recorder to ac/dc power was required. Figure 5 shows the way in which this was done. An external switch was added to the cassette recorder to provide the choice of ac or dc supply power.

After the cassette deck was modified, two types of cassette tapes were tested for optimum performance. The tests were conducted by connecting the voltage output directly to a strip chart recorder and at the same time recording the output frequency signal on a cassette tape. Standard and chromium dioxide cassette tapes were the two types tested. A significant difference in the amplitude of the output frequency signal from the recorder was found to exist between the two tapes. The desired information is contained in the frequency of the signal and not in the amplitude. Test data recorded directly on the strip chart recorder were essentially identical to the data output from the cassette recorder using both types of cassette tapes. Standard TDK cassette tape was used for all field and calibration experiments. This tape has normal bias and 70 microsecond equalization.

The major disadvantage with this type of data storage system is the length of tape which can be used. Duration of the longest cassette tape available is 120 minutes (60 minutes per side). At a sampling rate of a

Figure 5. Modification of Circuit Schematic for Realistic SCT-12 Stereo Cassette Deck Enabling AC or DC Power Use



AC POWER
J103
J203
S101-13-15
S101-19-21
R121
R221
AC-DC
RECTIFIER
AND
REGULATOR
S302
12 vdc
MODIFICATION TO AC/DC
RECORDING
AMPLIFIER
Q105
106
A L C
NETWORK
Q310
101
102
Q205
206
S101-25-27
S303
CrO_2
STD
S101-16-18
S101-22-24
EQUALIZER
AND
PREAMPLIFIER
Q102
103
104
Q202
203
204
S101-7-9
S101-10-12
BIAS
OSCILLATOR
Q312
313
314
C219
R360
C119
S101-1-3
S101-31-33
S101-4-6
S101-34-36
J102
J101
J202
J201
MIC
AUX
R/P HEAD
E. HEAD

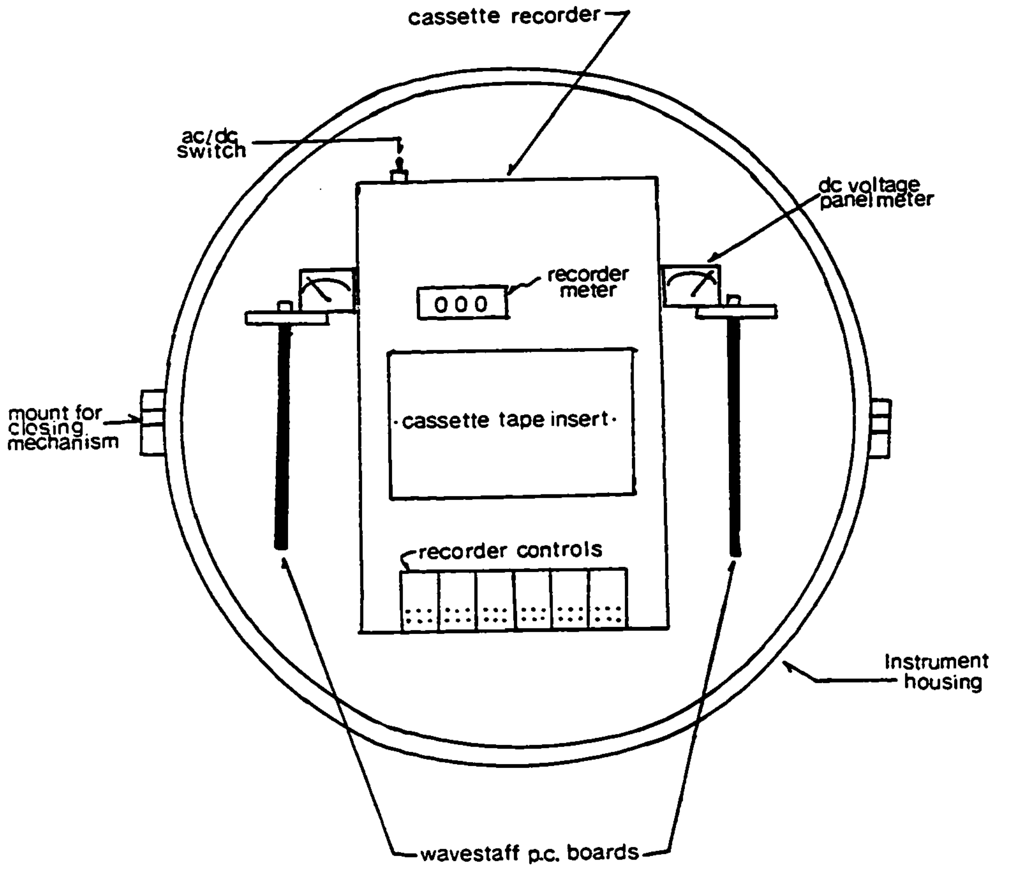
quarter second, this represents 28,800 words of data. For comparison, standard digital cassette tape has a packing density of 242 bits per centimeter (615 bits per inch) and is usually 98.4 m in length. This converts to 138,375 words of data or about ten hours of continuous sampling time.

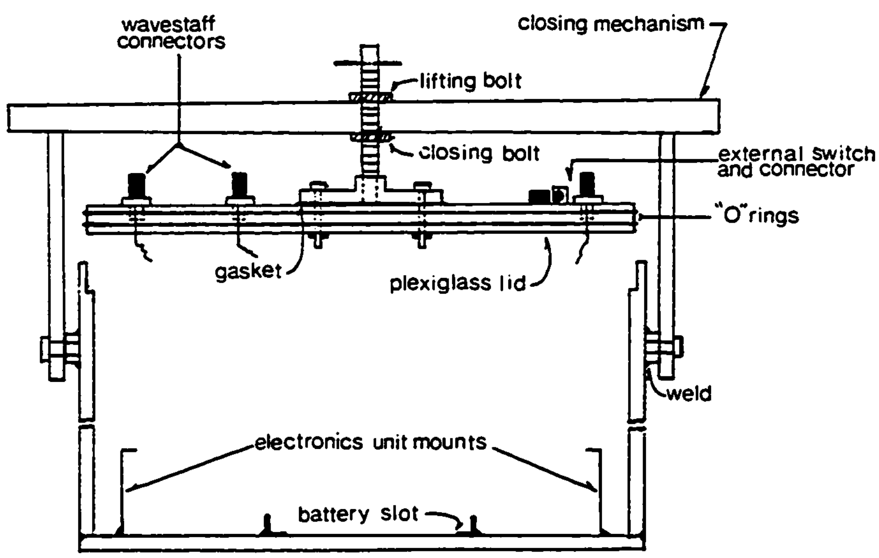
The instrument housing was fabricated from steel pipe 30.48 cm in length and diameter (figure 6). The wall thickness was 7.94 mm. The housing contained two printed circuit boards, one for each wavestaff, the cassette tape deck, and batteries. All these were attached to a plexiglass frame which bolted to the bottom of the housing (which was welded to the steel pipe). The plexiglass frame, with items attached could be removed from the housing as a unit. This allowed both for easy troubleshooting and for battery checks. The weight of the housing with all items in place was approximately 187 kg.

The housing was sealed using a lid 2.54 cm in thickness fitted with double "o" rings on its outside edge (see figure 6). It was necessary to construct an opening/closing mechanism and to attach it to the outside of the housing. Without this, the lid could not be removed from the housing.

An eight hour water leakage test was conducted from the Oceanography Department's research vessel, the R/V Linwood Holton. The housing was tested at a depth

Figure 6. Instrument Housing. Top View Shown in Upper Portion. Side View Shown in Lower Portion.


cassette recorder
ac/dc switch
dc voltage panel meter
recorder meter
000
mount for closing mechanism
cassette tape insert
recorder controls
Instrument housing
wavestaff p.c. boards


wavestaff connectors
closing mechanism
lifting bolt
closing bolt
external switch and connector
"O"rings
gasket
plexiglass lid
weld
electronics unit mounts
battery slot

of 11.5-13.1 meters. No leaks developed and the housing was opened and closed with ease.

The sensor wires from the wavestaffs were connected to the electronics inside the housing via Electro Oceanics underwater connectors. Each wavestaff used a separate connector, each of which contained two conductors. An external switch, manufactured by Electro Oceanics, was used to turn the cassette recorder on and off for each data set during the field experiments. Turning the recorder on and off could be seen in the data as zero voltages and was very useful in the identification of individual data sets. All the connectors and the switch were mounted on the plexiglass housing lid.

The ability to see through the plexiglass lid proved to be advantageous during the field experiments. The digital tape counter could be seen and the count could be recorded before and after each data set. In addition, a voltmeter for each wavestaff circuit was mounted on the plexiglass frame inside the instrument housing. This allowed the operation of each wavestaff to be checked before and after each data set.

Occasionally, a cassette tape had to be changed during a field experiment. This was due to the limited

recording time of a cassette tape. In this event, it was required to remove the instrument housing from the surf zone, open the lid, change the cassette tape (or just turn it over), close the lid, then return the instrument back to the surf zone. This normally took a total time of 15 minutes, but has been achieved in as little as seven minutes.

Initially, a problem of sand infiltrating between the outer edge of the plexiglass lid and the inner wall of the instrument housing was encountered. The sand penetrated as far as the first "o" ring. This made it difficult to remove the lid from the housing. The problem was solved by applying Mortite weatherstrip and caulking cord over the space between the plexiglass lid and instrument housing.

Five different sensor wires were evaluated before the first successful dynamic response test was achieved. Increasingly better results were obtained by successively decreasing the diameter of the sensor wire. The reduction has the effect of minimizing the amount of water available for rundown. In Table 3 are listed the types of sensor wires and their diameters that were evaluated for dynamic response. Thin magnet wire was the sensor wire chosen for this study. The wire has a single copper conductor coated with enamel and a diameter of 0.35 mm. The major disadvantage of this sensor wire was the limited abuse it could withstand. New sensor wires had to be used for each

Table 3. Tested Sensor Wires

Wire type	Diameter (mm)	Coating Material	Conductor
Self-fabricated	12.7	polypropolene	Al rod
Stripped RG-59U coaxial cable	7.2	polyethylene	solid Cu
Hook-up 18 AWG	2.0	thermoplastic	stranded Cu
Audio speaker	1.6	vinyl	stranded Cu
Hook-up	1.3	teflon	stranded Ag
Kynar computer wrap	0.51	plastic vinyl	solid Cu
Magnet	0.35	enamel	solid Cu

experiment even though great care of the wires was taken during each experiment. Future sensor wire designs should incorporate a more durable conductor with a flexible coating.

The sensor wire was connected to the instrument housing via a coaxial cable (RG-59U) 6.6 meters in length. An inexpensive underwater connector for joining the two wires was fabricated with two rubber stoppers, a polyvinyl-chloride (PVC) coupling and a coupling nut. The connector never failed while being used in the surf zone.

The sensor wire was mounted to the lower end of the wavestaff support frame by sewing the wire through a rubber

stopper and attaching the rubber stopper to the wavestaff frame. Attempts to fasten the sensor wire directly to the support frame were unsuccessful because the copper conductor was too easily broken. The rubber stopper was attached to the support frame by sewing a loop of monofilament through the stopper and attaching this loop to the support frame.

The wavestaff support frames were constructed from PVC pipe, 3.8 cm in diameter. Baseplates were attached to the bottom of each support frame. The dimensions of each baseplate were 45.7 cm X 45.7 cm X 0.32 cm. The design of the baseplate limited the water depth at which the wavestaff could be deployed. This depth was approximately 15 cm.

The process here termed rundown is associated with the film of water which remains on a sensor wire during receding water levels. The only known solution to the problem is the use of a sensor wire of very small diameter. The problem, as related to capacitance wave sensors, was first reported by Tucker and Charnock (1954). Rundown has been referred to as "flowback phenomenon" by Wilner (1960) and "capillary effect" by Krizek and Monsonyi (1974). McGoldrick (1970) considered rundown as the "meniscus" formed around the sensing probe. He studied the effects of static and dynamic surface tension on the meniscus. Similar treatment was also used by Sturm (1973) in a study

of capillary waves on currents. Kinsman (1965) suggests that the rundown problem does not have a significant effect on wave measurements.

The rundown problem was discovered in this study after many unsuccessful attempts to obtain satisfactory dynamic response with sensor wires of large diameter (see Table 3). It must be noted that excellent static response of the wavestaff was obtained in every experiment with larger diameter wires.

The effects of rundown on the output amplitude of a wavestaff under dynamic conditions can be quite severe. The unwanted effects of rundown found in this study agree with those described in previous reports. These are summarized as follows: (1) wave crests are spuriously broadened; (2) wave troughs appear spuriously pointed; (3) amplitude reduction increases with increasing frequency; and (4) amplitude reduction is less with decreasing sensor wire diameter.

A large majority of field studies using wavestaffs have presented only static response characteristics of the wavestaffs used, apparently indicating that the dynamic response of the wavestaffs was not tested. The importance of measuring the dynamic response of a wavestaff could not be over-stressed. All studies which utilize wavestaffs should report static and dynamic response characteristics. Moreover, the dynamic response of the combined electronics-probe system should be tested.

Calibration Procedures and Results

All calibration data used in the reduction of actual records was obtained under field conditions. The field calibration experiments were performed to determine wavestaff response characteristics and were done in a manner that simulates actual field experiments. Both static and dynamic tests were performed. Static calibration tests were frequently carried out in the laboratory to check the wavestaff electronics and cassette recorder operation. All calibration tests were conducted in sea water.

A calibration test site was required having a water depth of three to four meters and some type of pier structure on which to place the calibration devices. Two sites were used. The initial site was located on the pier maintained and used by Virginia Pilot Association at the end of Bousch Street in Norfolk, Virginia. Use of the final site required permission of the Norfolk Redevelopment and Housing Authority, and was located in the south end of the Freemason Harbor complex, Norfolk, Virginia.

Static calibration tests were carried out by raising and lowering the wavestaff in 15 cm increments along the entire length of the staff. The wavestaffs were held at each increment for a period of 30 seconds. The

static response characteristics of the seaward wavestaff are shown in figure 7 and the shoreward wavestaff in figure 8. Data for the shoreward staff was not obtained during field experiments two and three because of a failure in the Electro Oceanics underwater connector. The gain constant of both wavestaffs was consistently near 33 mv/cm. The offset constant of the seaward wavestaff ranged from approximately 5.1 to 6.4 volts while that of the shoreward wavestaff ranged from approximately 4.4 to 4.8 volts. An explanation for this variation in the offset constant is the use of different sensor wires between tests.

Dynamic calibration tests were conducted by oscillating the wavestaffs, vertically, relative to the water surface, at known amplitudes and frequencies. To do this, a hand crank and pulley system was constructed. A "clacker" was attached to the hand crank to aid in aehieving smooth wavestaff oscillation. Simulated sinusoidal motion for various wave periods were obtained by maintaining a designated time interval between "clacks". Each simulation lasted for about three minutes. Wave amplitudes of 15 cm and 30 cm and wave periods ranging from two to 16 seconds were used in dynamic response tests. The dynamic response characteristics of both wavestaffs show a flat response down to about four seconds (figures 9 and 10). The

Figure 7. Static Response of Seaward Wavestaff for Each Field Experiment

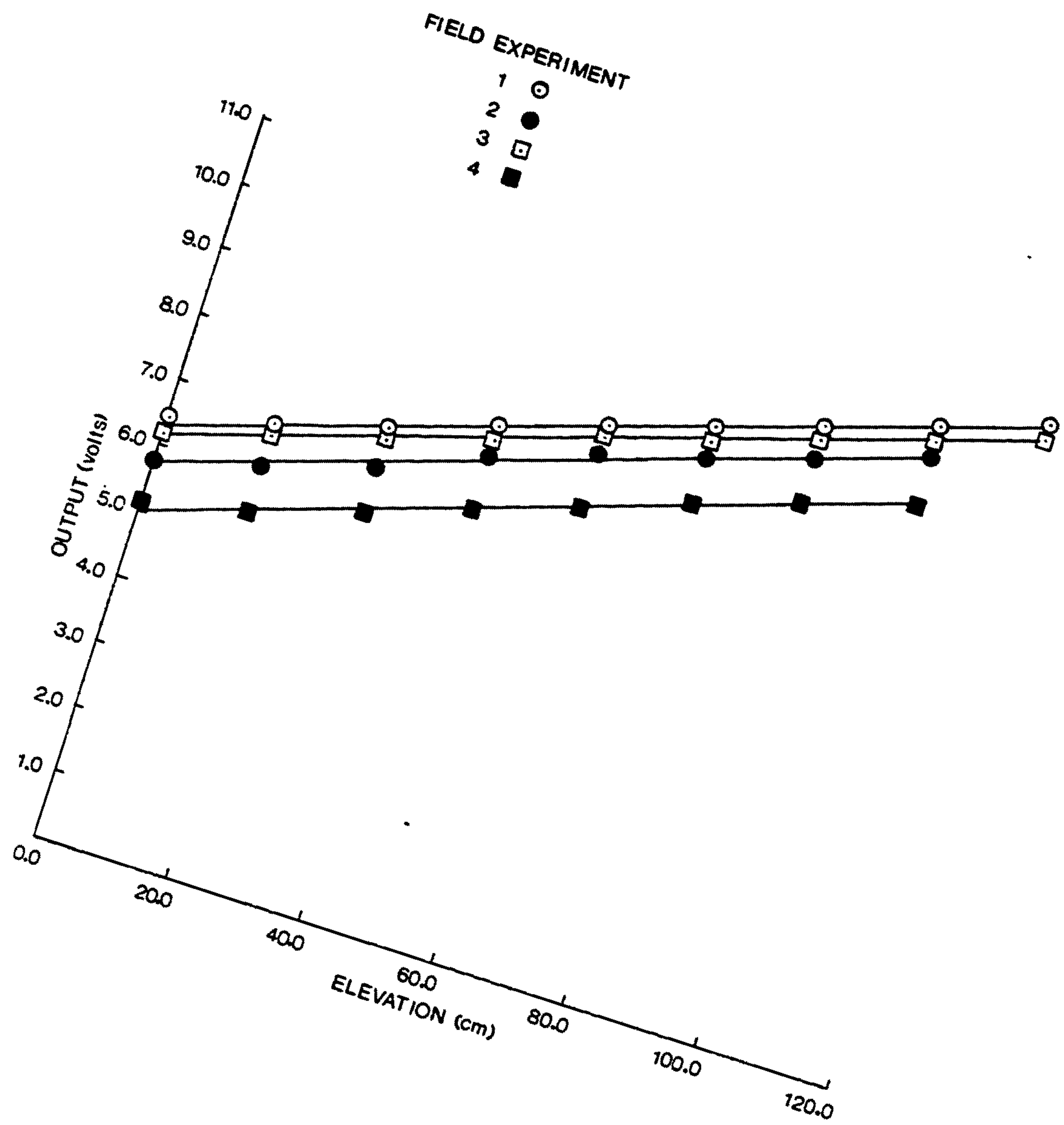

FIELD EXPERIMENT
1
2
3
4
OUTPUT (volts)
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
ELEVATION (cm)

Figure 8. Static Response of Shoreward Wavestaff for Each Field Experiment

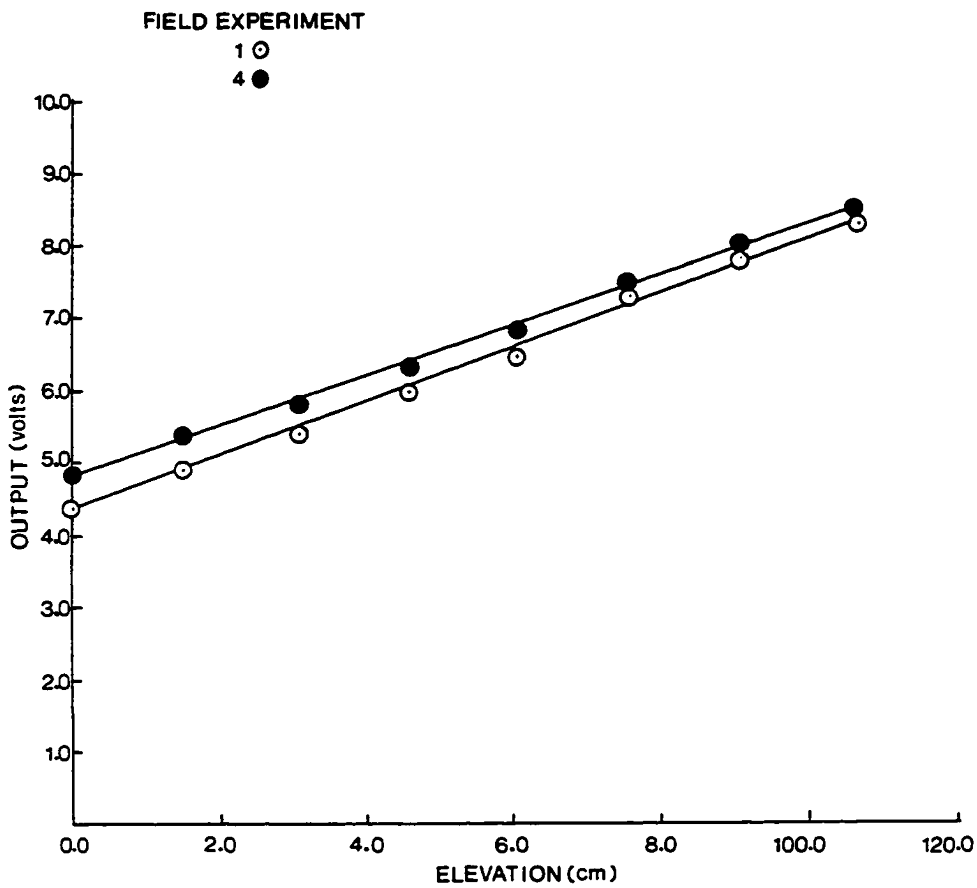
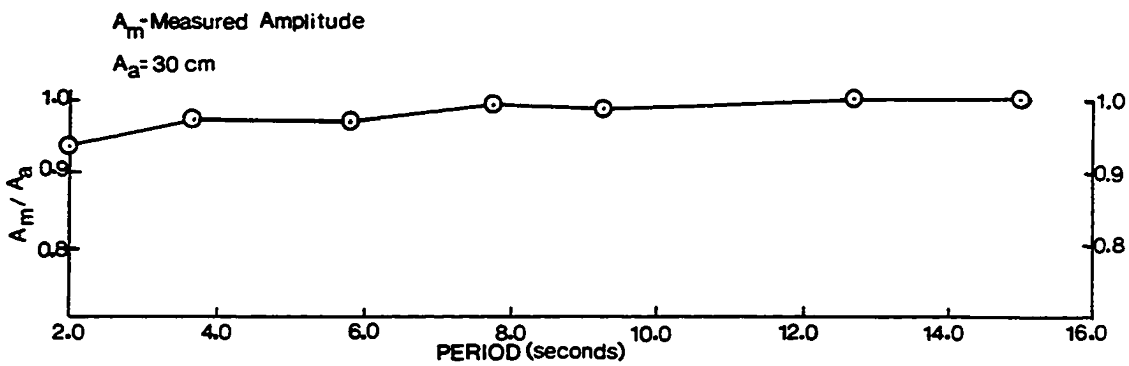

FIELD EXPERIMENT
1
4
OUTPUT (volts)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2.0
4.0
6.0
8.0
100.0
120.0
ELEVATION (cm)

Figure 9. Frequency Response of Seaward Wavestaff for Amplitudes of 15 and 30 Centimeters


A_m-Measured Amplitude
A_a= 30 cm
A_m/A_a
1.0
0.9
0.8
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
PERIOD (seconds)

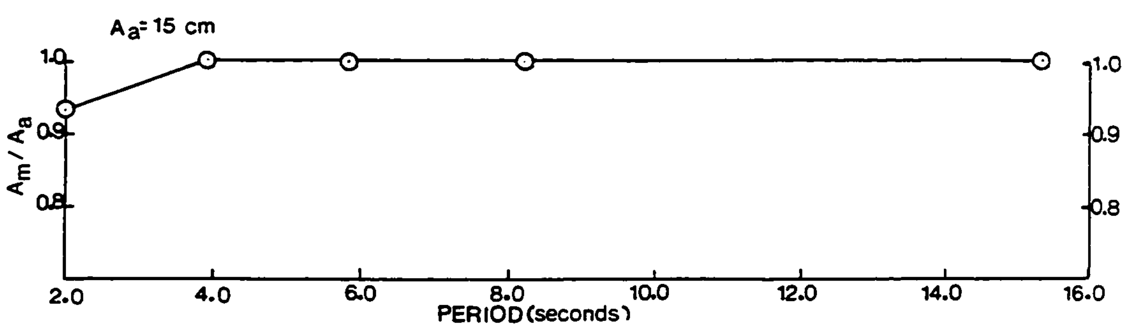
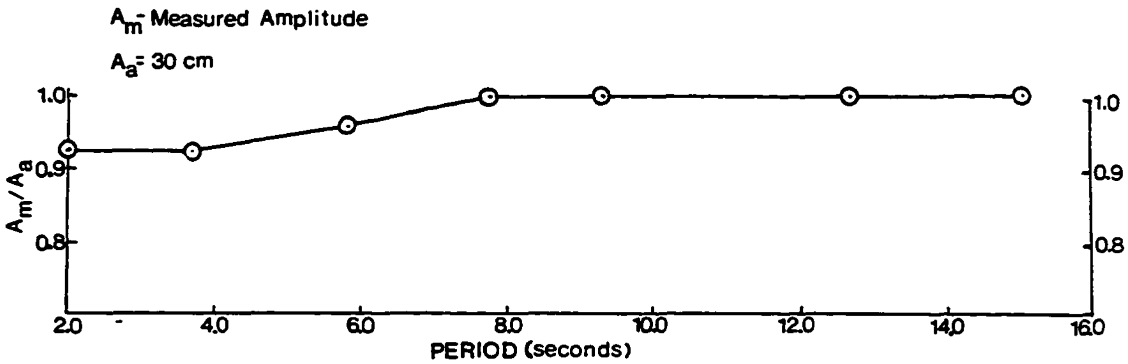
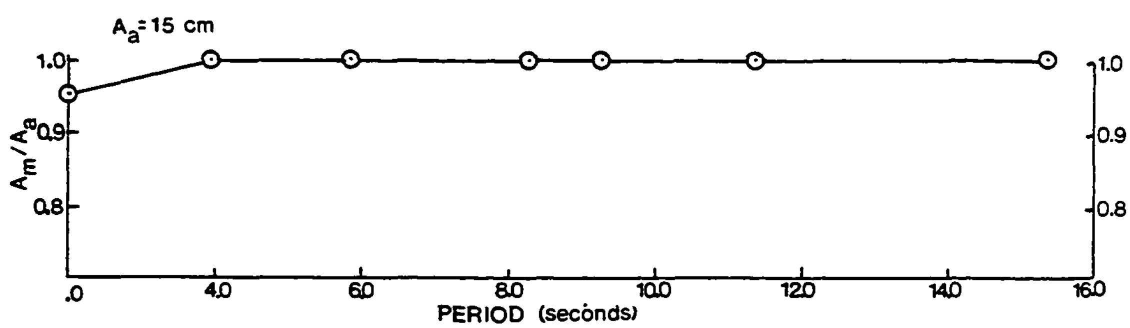

A_a= 15 cm
A_m/A_a
1.0
0.9
0.8
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
PERIOD (seconds)

Figure 10. Frequency Response of Shoreward Wavestaff for Amplitudes of 15 and 30 Centimeters


A_m = Measured Amplitude
A_a = 30 cm
1.0
0.9
0.8
A_m/A_a
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
PERIOD (seconds)


A_a = 15 cm
1.0
0.9
0.8
A_m/A_a
.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
PERIOD (seconds)

slight amplitude reduction below this value is due to water remaining on the wire (rundown). Better frequency response may be obtained by using smaller diameter wire. The diameter of the sensor wire used in all experiments was 0.35 mm.

Experimental Site

The ideal field experiment site could be described as having a gentle slope with no longshore bars, a wide surf zone, a well-defined breaker region, a small tidal variation, easy vehicle access, small waves, weak longshore currents, and a maximum water depth in the surf zone of 1.5 meters (wading depth). It was also essential that the site be located in the Tidewater, Virginia area.

The experimental site selected was located at the end of 17th Street, Virginia Beach, Virginia, immediately north of the local fishing pier (see figure 1). The nearshore profiles measured before each field experiment are shown in figures 11-14. Breaker heights at the study site are usually a meter or less. Longshore current speeds are generally 30 cm per second. The tides are semidiurnal with an average range of approximately 0.9 m. The beach has been nourished artificially at locations several blocks north of the site. In addition, sediment is periodically pumped onto the beach from a sand-bypassing system at Rudee Inlet which is less than 2 km south of the experiment site.

Figure 11. Beach Profiles and Measurement Locations for Field Experiment No. 1. Symbols for Data Sets are: (1) ○ , (2) ● , (3) □ , (4) ■ , (5) △ , (6) ▲ .

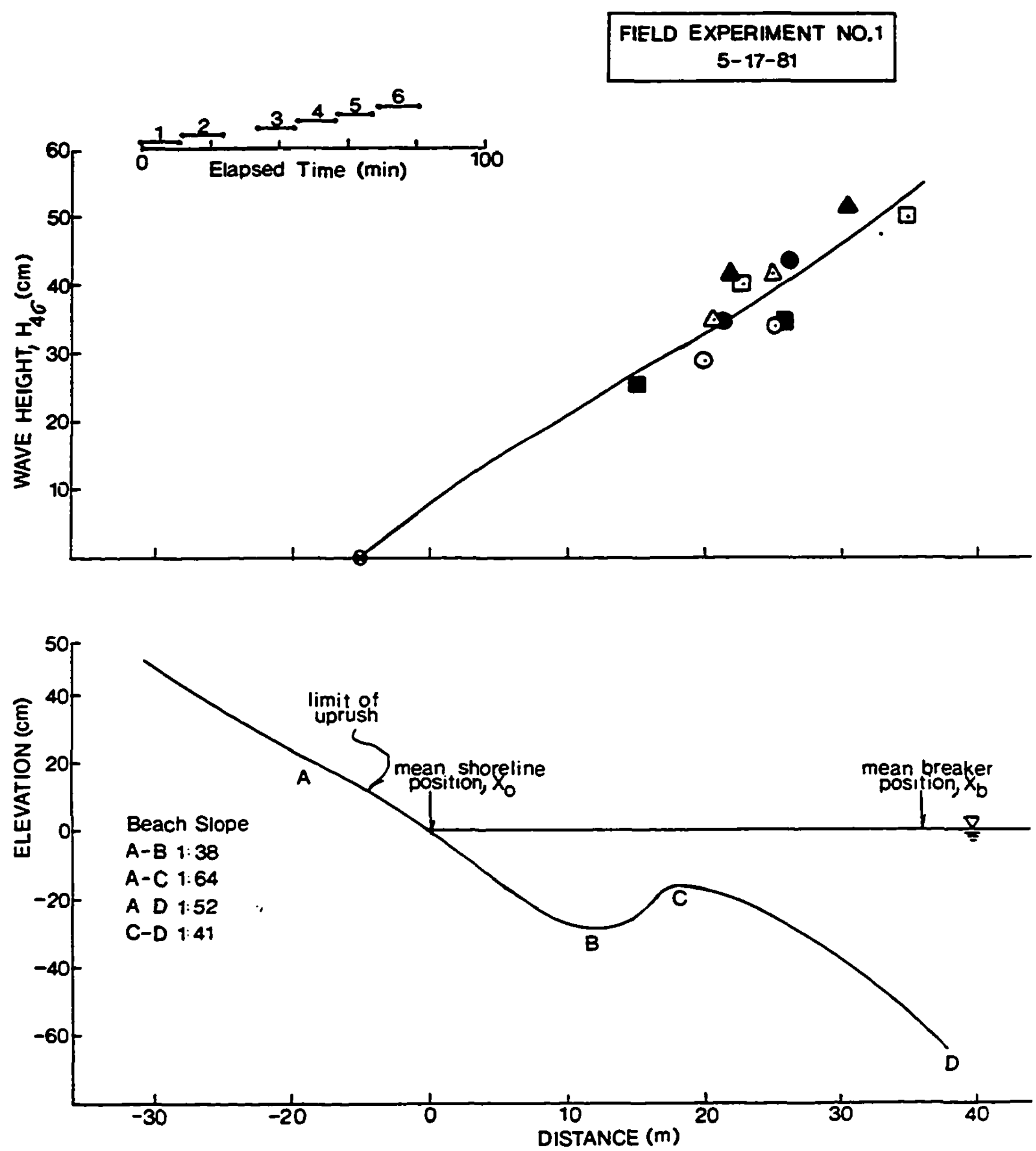
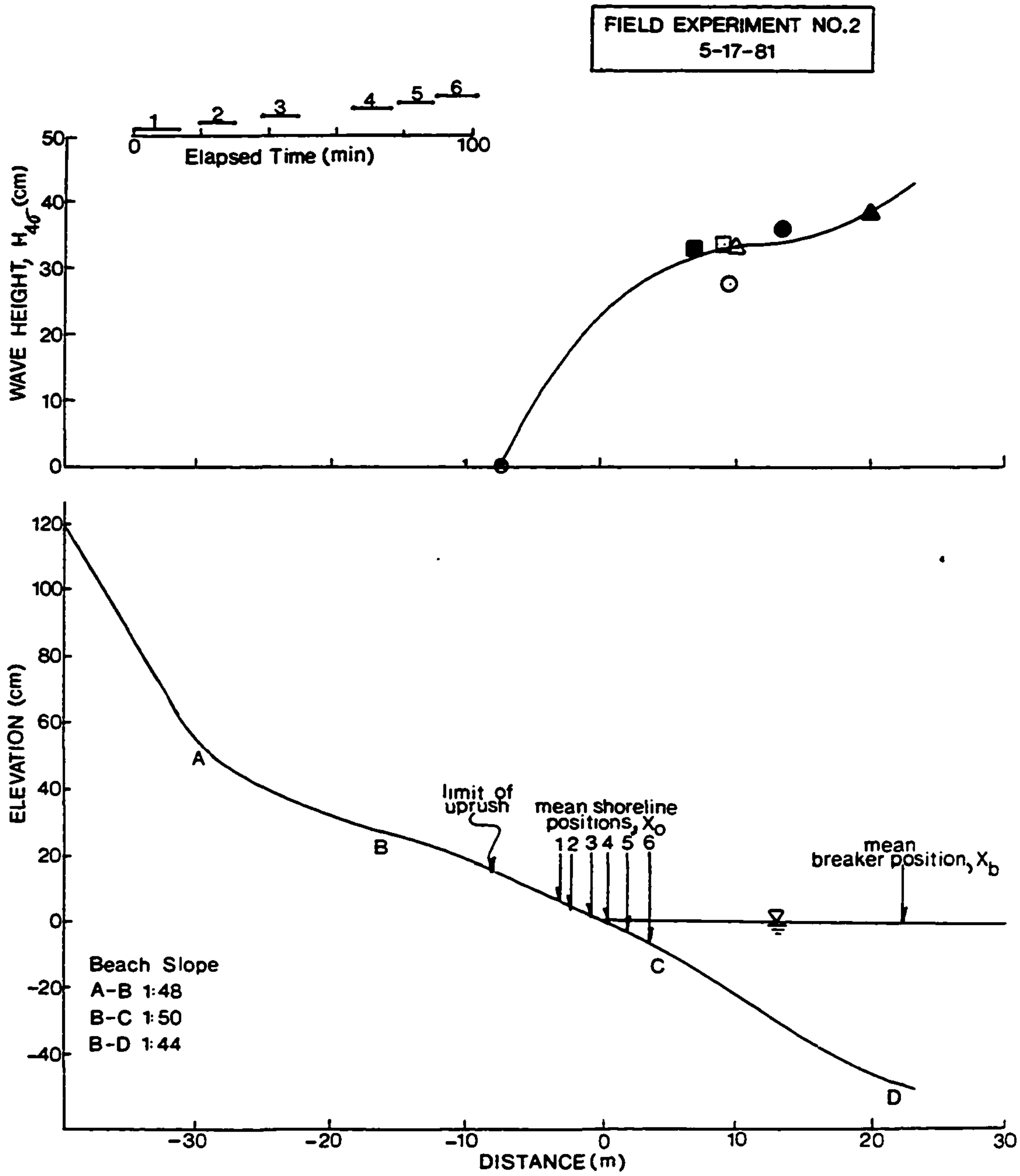

FIELD EXPERIMENT NO.1
5-17-81
Elapsed Time (min)
0
100
1
2
3
4
5
6
WAVE HEIGHT, H_{46} (cm)
60
50
40
30
20
10
ELEVATION (cm)
50
40
20
0
-20
-40
-60
limit of uprush
mean shoreline position, X_o
mean breaker position, X_b
A
B
C
D
Beach Slope
A-B 1:38
A-C 1:64
A D 1:52
C-D 1:41
-30
-20
0
10
20
30
40
DISTANCE (m)

Figure 12. Beach Profiles and Measurement Locations for Field Experiment No. 2. Symbols for the Data Sets are: (1) ○ , (2) ● , (3) □ , (4) ■ , (5) △ , (6) ▲ .



FIELD EXPERIMENT NO.2
5-17-81
1
2
3
4
5
6
0
100
Elapsed Time (min)
WAVE HEIGHT, H_{46} (cm)
50
40
30
20
10
0
ELEVATION (cm)
120
100
80
60
40
20
0
-20
-40
A
B
C
D
limit of uprush
mean shoreline positions, X_o
1 2 3 4 5 6
mean breaker position, X_b
Beach Slope
A-B 1:48
B-C 1:50
B-D 1:44
-30
-20
-10
0
10
20
30
DISTANCE (m)

Figure 13. Beach Profiles and Measurement Locations for Field Experiment No. 3. Symbols for the Data Sets are: (1) o , (2) ● , (3) □ , (4) ■ , (5) ▲ .

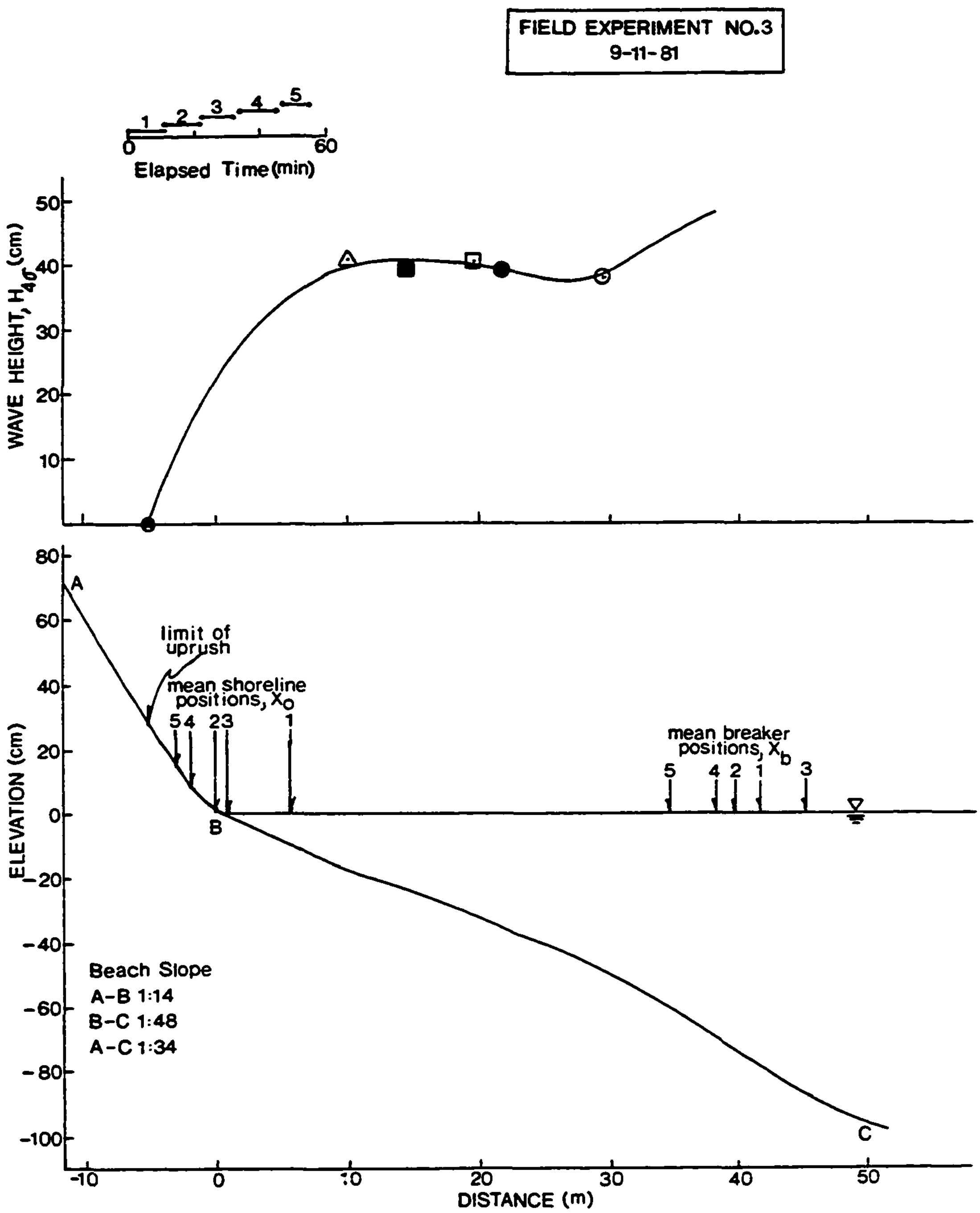
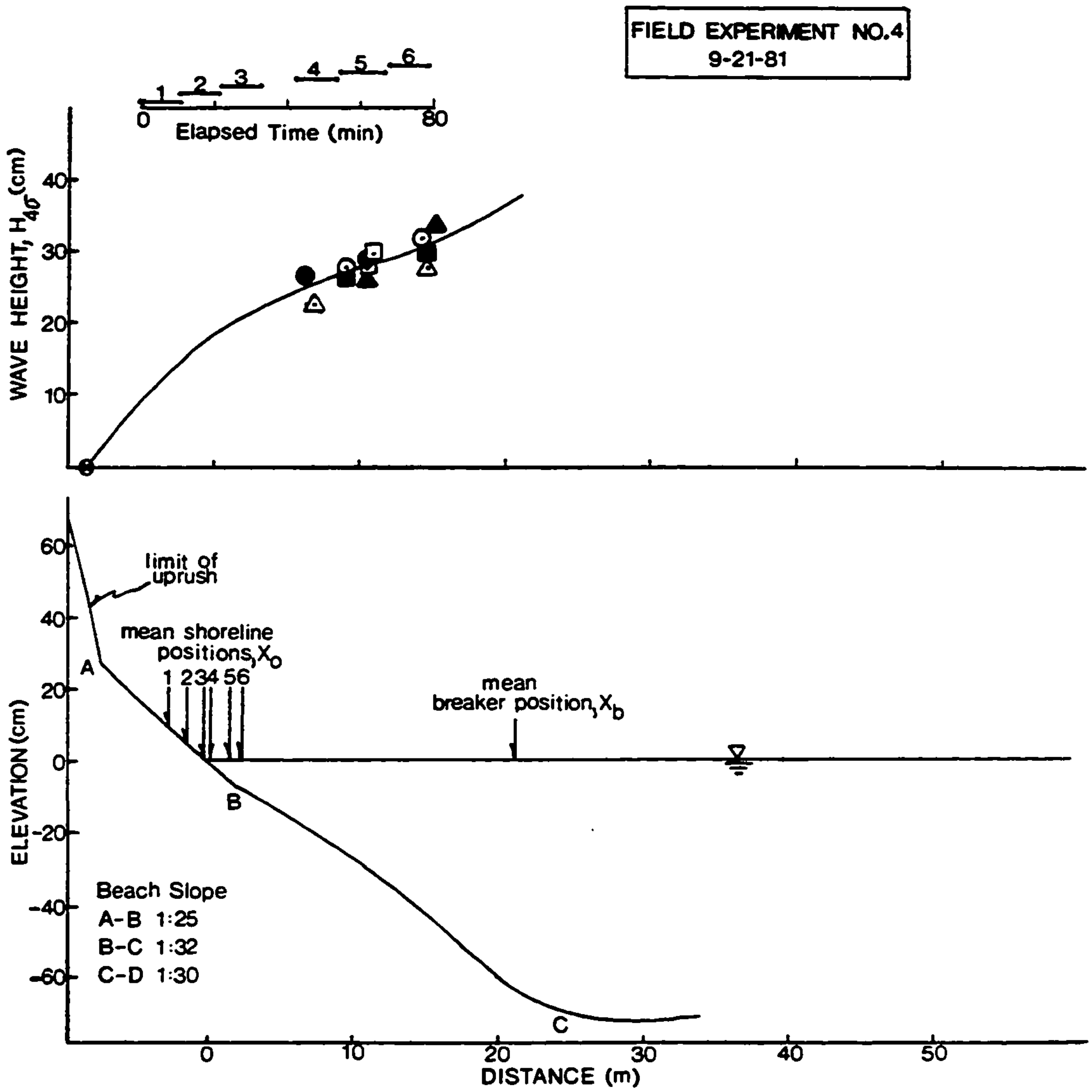

FIELD EXPERIMENT NO.3
9-11-81
1
2
3
4
5
0
60
Elapsed Time (min)
WAVE HEIGHT, H_{46} (cm)
50
40
30
20
10
80
60
40
20
0
-20
-40
-60
-80
-100
ELEVATION (cm)
A
B
C
limit of uprush
mean shoreline positions, X_o
5 4 2 3 1
mean breaker positions, X_b
5 4 2 1 3
Beach Slope
A-B 1:14
B-C 1:48
A-C 1:34
-10
0
10
20
30
40
50
DISTANCE (m)

Figure 14. Beach Profiles and Measurement Locations for Field Experiment No. 4. Symbols for the Data Sets are: (1) ○ , (2) ● , (3) □ , (4) ■ , (5) △ , (6) ▲ .


FIELD EXPERIMENT NO.4
9-21-81
1 2 3 4 5 6
0
80
Elapsed Time (min)
WAVE HEIGHT, H_{40} (cm)
40
30
20
10
limit of uprush
mean shoreline positions, X_o
1 2 3 4 5 6
mean breaker position, X_b
A
B
C
ELEVATION (cm)
60
40
20
0
-20
-40
-60
Beach Slope
A-B 1:25
B-C 1:32
C-D 1:30
0
10
20
30
40
50
DISTANCE (m)

Field Procedures

As in most field experiments, weather played a major part in the selection of days for field experiments. Days were chosen only if there were small waves, calm winds and no precipitation. The weather conditions for each field experiment are listed in Table 4.

Table 4. Physical Conditions During Field Experiments

Field Experiment	Wind Direction/Speed (knots)	Longshore Current Direction/Speed (ft/sec)
1	W/5-15	N/1
2	SW/5	N/1.2
3	E/5	N/1.2
4	SSE/8-15	variable

Each field experiment required a minimum of four people to carry out the procedures. These procedures are illustrated in figure 15. The wavestaffs were deployed and held in place manually during the taking of each data set using PVC extensions attached to each wavestaff support frame (see figure 16). This method worked well and allowed repositioning of the wavestaffs quickly (see elapsed times, figures 11-14). The time to complete an entire data set, including the time to reposition the

Figure 15. Sequence of Field Procedures for Each Field Experiment

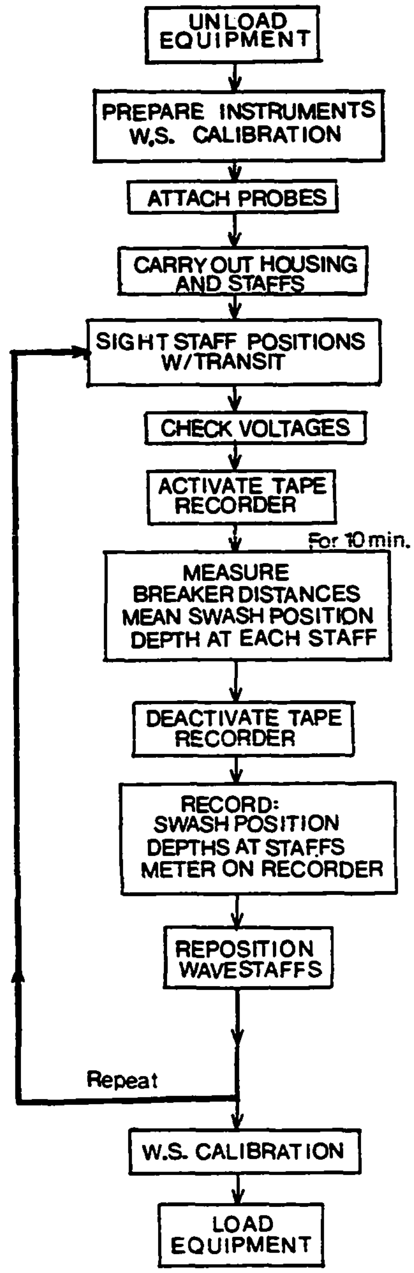
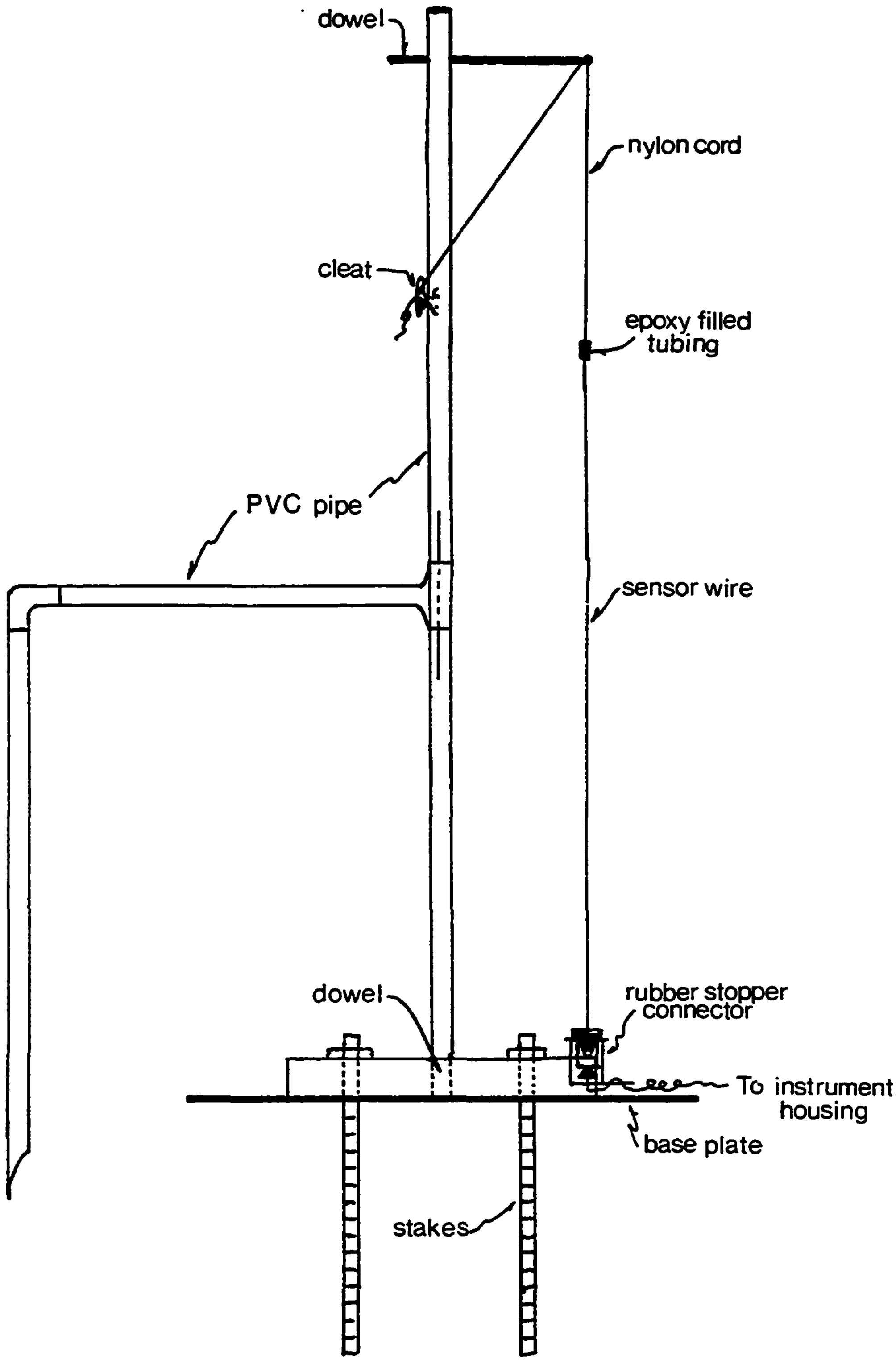

UNLOAD EQUIPMENT
PREPARE INSTRUMENTS W.S. CALIBRATION
ATTACH PROBES
CARRY OUT HOUSING AND STAFFS
SIGHT STAFF POSITIONS W/TRANSIT
CHECK VOLTAGES
ACTIVATE TAPE RECORDER
For 10 min.
MEASURE
BREAKER DISTANCES
MEAN SWASH POSITION
DEPTH AT EACH STAFF
DEACTIVATE TAPE RECORDER
RECORD:
SWASH POSITION
DEPTHS AT STAFFS
METER ON RECORDER
REPOSITION WAVESTAFFS
Repeat
W.S. CALIBRATION
LOAD EQUIPMENT

Figure 16. Sensor Wire Support Frame and Extension for Manual Deployment in the Surf Zone


dowel
nylon cord
cleat
epoxy filled tubing
PVC pipe
sensor wire
dowel
rubber stopper connector
To instrument housing
base plate
stakes

wavestaffs was usually 12-13 minutes. It generally required about four hours to complete an entire experiment.

The duration of each data set was approximately 10 minutes (see figures 11-14). Measurements of breaker distances, mean swash positions, and the mean water depth at each staff were taken during each data set. The breaker point was taken to be the place where the wave crest curled over completing the breaking process. Bowen et al. (1968) refer to this point as the plunge point.

After each data set the cassette recorder was turned off and the meter count recorded. The wavestaff electronics, for each staff, remained on throughout the experiment.

The instrument housing was left virtually unmanned during data sets. It was held in place with two steel stakes attached to each side. These were 0.5 meters long and constructed of 0.32 cm angle iron. The housing had a tendency to shift position, requiring frequent visual inspections during the taking of the data sets. This shifting was due to scour at the base of the housing.

Static calibrations of each wavestaff were carried out before and after each experiment. Field calibrations were conducted in a 14-gallon plastic container filled with sea water taken from the site.

The positions of each wavestaff, breaker points, and mean swash locations were sighted using a level transit.

Each transit reading would give the position in the form of a distance and azimuth both relative to the transit position on the beach. The position measurements were later converted to x-y components indicating the offshore and alongshore directions, respectively. The x-component was used for calculating offshore wavestaff positions, nearshore bottom profiles, and breaker point estimates.

III. DATA ANALYSIS

Wave Data Preparation

After the acquisition of the field data which were stored on magnetic cassette tape, a second phase of operations was needed to transfer the data into the university computer system (see figure 2). The wave data in analog form, stored on cassette tape, are contained in the varying frequency portion of the recorder output signal. Doubling the amplitude of the signal enables the signal to be received by the frequency-to-voltage unit. The output of this unit is the original analog voltage which was output by the wavestaff detector circuit. This procedure was verified with calibration data and the cassette tape tests (page 20). The data at this point were recorded on both a strip chart recorder and a digital data logger so that a further check of the data could be made at a later stage. The data were digitally recorded onto digital cassettes using an Interocean model 680 digital data logger. The digitization interval was a quarter-second. The allowable input analog voltage range of the digital data logger is $\pm$ 7.999 volts. To prevent any possible damage to the data logger the input voltage was attenuated using an instrumentation amplifier based on a Burr-Brown 3662 low offset voltage amplifier.

The digitized data were then transferred into the university Dec-10 disk storage system using an Interocean digital cassette reader. The time necessary to transfer the data into the computer and data editing was considerable. It generally required 9-13 seconds to read in one group of data. Each group contained eight seconds of data or 64 words (data values).

Editing of data became necessary as a result of transmission errors between the digital cassette reader and the university Dec-10 computer. The errors consistently were in the form of spurious spikes and interchanged data between the two channels. The latter error would only affect one group of data at a time and was easily edited.

Conversion of the data back to the original analog voltage values was accomplished using the actual attenuation constants of the instrumentation amplifier. These constants were determined for each channel by simultaneously recording on the data logger, known input and the corresponding output voltages of the instrumentation amplifier. A least squares equation was fit to the data. The equations for channels one and two of the amplifier are:

$$\text{Channel 1:} \quad y = 0.5193x + 0.0103 \tag{3}$$

$$\text{Channel 2:} \quad y = 0.5181x + 0.0327 \tag{4}$$

where x is the input voltage value and y is the attenuated output voltage value.

Calculations and Plotting

All wave data read into the university Dec-10 disk storage system were in digital voltage form. The computer programs used for data editing, calculations, and plot routines are listed in Appendix III. Text editor commands for interfacing the digital cassette reader and a rearranging data format structure are also listed. The conversion from voltage to actual measures of surface elevation were computed with the following relation:

$$\eta(t) = \frac{\text{voltage-offset constant}}{\text{gain constant}} , \qquad (5)$$

where $\eta(t)$ is the measured water surface elevation over time. The gain and offset constants are those determined from the static calibration tests before and after each field experiment.

Equation (5) works in the following way: Subtracting out the offset constants corrects for zero offset, which in effect reduces the signal voltages such that zero dc volts will correspond with the zero level on the wave-staff. In the same step, division by the gain constant converts the signal voltage values to actual measures of water surface elevation. Ideally, if the gain and offset constants have been accurately determined, the varying dc voltage signal can be converted to actual measures of water surface elevation above the sea bed. The mean value computed from the wave record could then be used to approximate

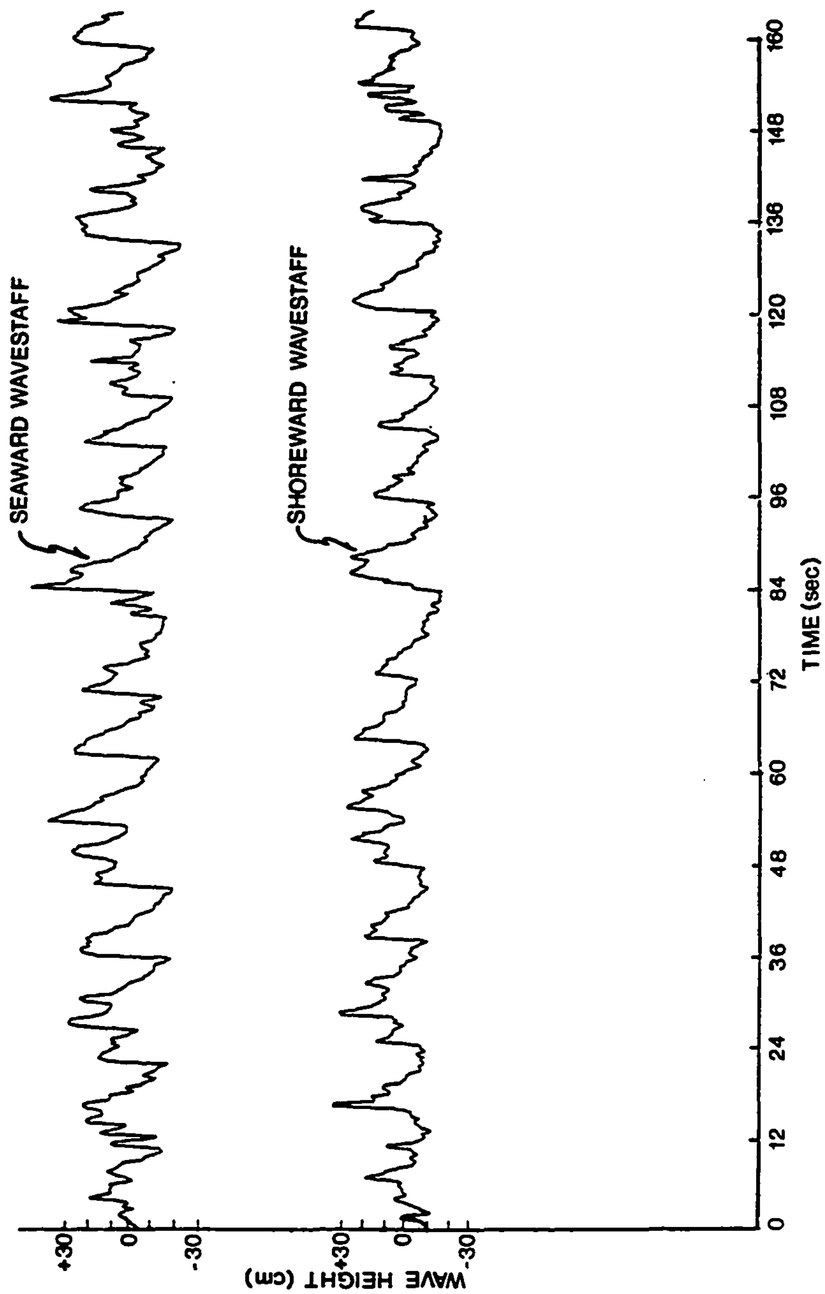
the mean water depth at the wavestaff location, providing the offset constant remained stable.

The offset constants did vary considerably (explained earlier) so were not used to determine the mean water depth at each wavestaff location. They were used, however, in plotting the two wave records (simultaneously) so that they would be offset from one another and eliminate any intersections.

Each wave record was detrended using a linear least squares criterion. This was done by fitting a linear function to the data and then subtracting this function from the data. The wave data were then usually inspected for errors by simultaneously plotting the data from each wavestaff. A sample plot of a wave record is shown in figure 17. The wave heights shown are not relative to the sea bed and have been offset from one another as described above. The records are not exactly simultaneous, but, rather, are a quarter-second out of phase. This is due to the sampling design of the digital data logger.

A final check of the data was made by comparing wave records output by the computer with the strip chart records of the analog data before it was recorded on digital cassette and read into the computer (see figure 2). Occasionally the wave data at this stage was not error-free and required further editing. In the end, wave records

Figure 17. Sample Computer Plot of a Wave Record


SEAWARD WAVESTAFF
SHOREWARD WAVESTAFF
WAVE HEIGHT (cm)
+30
0
-30
TIME (sec)
0
12
24
36
48
60
72
84
96
108
120
136
148
160

output from the computer compared identically to the wave records output onto the strip-chart recorder.

Relative position in the surf zone was taken as the ratio of the distance from the mean breaker position to the surf zone width. The width of the surf zone is the distance from the mean breaker position to the shoreline of mean water level. Use of relative surf zone position takes into consideration spatial changes which may have occurred in the surf zone geometry between data sets, thereby making separate data sets comparable.

Mean breaker position was approximated by averaging all measured breaker distances taken during a data set. The number of breaker positions measured during a data set varied; the maximum number measured during a data set was twelve. When the mean breaker position was found to be relatively stationary throughout an experiment, a mean of all measured breaker positions was calculated and used for the mean of each individual data set.

The shoreline of mean water level was assumed to be the point at which the mean water level intersected the foreshore. This position was estimated graphically using figures 11-14. The height of mean water level above the sea bed was estimated using the mean water depths at each wavestaff. These depths were visually estimated during the data sets in each field experiment. The mean water level for each data set is not shown in figures 11-14 but can be

obtained by extending a horizontal line from the indicated mean water shoreline to the mean breaker position.

Wave height was estimated from the digitized records by computing the standard deviation of the elevation of the water surface as a function of time, then multiplying this value by four,

$$H_{4\sigma} = 4\left[\frac{\Sigma[\eta(t) - \overline{\eta(t)}]^2}{n-1}\right]^{\frac{1}{2}} = 4\sigma \qquad (6)$$

where $H_{4\sigma}$ is wave height and σ is the standard deviation (i.e. root mean square amplitude). Wave height, when calculated this way, is sometimes referred to as the significant wave height, $H_{1/3}$.

Silvester (1974) showed that one way to obtain equation (6) is to substitute the relationship between a statistical wave parameter, E, and the variance of the record, σ^2, found by Longuet-Higgins (1952),

$$E = 2\sigma^2 \qquad (7)$$

into the relationship between the significant wave height, $H_{1/3}$, and $\sqrt{E}$ found by Longuet-Higgins and Cartwright (1956),

$$H_{1/3} = 2.83\sqrt{E} \qquad (8)$$

yielding,

$$H_{1/3} = 2.83\sqrt{E} = 2.83\sqrt{2}\sigma \sim 4\sigma \qquad (9)$$

The statistical wave parameter, E, has dimensions of $(\text{length})^2$ and is proportional to the energy of the waves at the measuring point. To eliminate any confusion, the use of $H_{4\sigma}$ instead of $H_{1/3}$ for wave height has been chosen for this study.

The calculated wave heights, as a function of offshore distance for all field experiments, together with the bottom profile for the time of the experiment, are shown in figures 11-14 along with the locations of the mean water shorelines and breaker positions used to calculate the relative surf zone positions for each wavestaff. The mean water level shown represents an average of the data sets in the experiment.

A least squares cubic polynomial was fitted to the wave data collected during each field experiment (figures 11-14). These curves were computed on Hewlett Packard model 41C hand calculator using the POLYC program available in the HP STAT-PAC. The program reference is HP-67/97 MATH PACI, Program MA1-07.

At present, there is no established criterion for classifying breaker type on a natural beach. Previous field studies have given qualitative descriptions of the observed breaker type. Studies by Galvin (1968) and Gaughan (1976) produced different criteria for breaker type classification for laboratory studies. An attempt was made in the present study to classify the observed breaker type quantitatively for each field experiment utilizing both laboratory criteria. The agreement between the observed and the laboratory breaker type classification is fair (Table 5). This may be expected since the laboratory studies have neglected certain physical factors such as

Table 5. Comparison of Breaker Type Classification Using Laboratory Criterion to the Observed Breaker Type

Field Experiment	Galvin (1968)	Gaughan (1976)	Observed
1	plunging	spilling-plunging	plunging
2	plunging	spilling-plunging	spilling
3	plunging	spilling-plunging	mixed
4	spilling	spilling	spilling

wind. Different breaker types were present during each field experiment. A qualitative classification has been chosen for use in the analysis.

The first field experiment took place at slack before flood. The breaker point position and mean water shoreline variation between data sets were small, and hence surf zone width was taken to be constant throughout the experiment (see figure 11). The breaker line was moderately well-defined and was characterized by plunging breakers. Six data sets were collected in this field experiment in a total elapsed time of 81 minutes. Winds were northwest (offshore) at five to fifteen knots.

The second field experiment was conducted just prior to slack before flood. The breaker point position appeared to remain constant but the mean water shoreline retreated offshore, resulting in a narrowing of the surf

zone width of about six meters (see figure 12). The breaker zone was well-defined, and the breakers were of the spilling type. Six data sets were collected in a total elapsed time of 101 minutes. Winds were west-northwest (offshore) at five knots.

The third field experiment was conducted on the same day as the second experiment, but during a flood tide about two hours prior to slack before ebb. This was the only experiment where both the breaker point position and the mean water shoreline were not constant (figure 13). Both appeared to move onshore at about the same rate, resulting in a fairly constant surf zone width. The breaker zone was moderately defined, with the larger waves occasionally breaking farther out, in the vicinity of the breaker zone of the second experiment. It should be noted that these breakers were well beyond wading depth so that their positions could not be measured. Mixed spilling-plunging breakers were present during this experiment. Seven data sets were collected in a total elapsed time of 72 minutes. Winds were east (onshore) at five knots.

The fourth field experiment was conducted about one hour after slack before ebb. South-southeast (onshore) winds at 8-15 knots produced small wind waves and spilling breakers. The breaker zone was not well-defined so that a mean breaker position for all data sets was used. The shoreline of mean water level moved offshore resulting in

a decreasing surf zone width during the experiment. Six data sets were collected in a total elapsed time of 78 minutes (figure 14).

Wave heights, as a function of relative surf zone position measured during each field experiment, are shown in figures 18-21. For comparison, two estimates, derived from traditional methodologies, of wave heights across the surf zone are illustrated with the dotted and dashed lines. The mean breaker position, X_b, is located at the right of each graph and the shoreline of mean water level is located at the left of each graph.

The calculation of estimated wave heights across the surf zone was based on the assumption that the height of the broken wave is a constant proportion of the mean water depth, locally,

$$H(x) = \gamma_b \, h(x), \qquad (10)$$

where $H(x)$ is the wave height estimate as a function of offshore distance, x; γ_b is the ratio of breaker height to breaker depth; and $h(x)$ is the mean water depth as a function of offshore distance. The mean water depth across the surf zone was determined graphically from figures 11-14. The wave height estimates indicated with dotted lines in figures 18-21 were calculated by using McCowan's ratio, $\gamma_b = 0.78$. The wave height estimates indicated with the dashed lines were calculated using a value for γ_b determined using a method outlined in the Shore Protection Manual

Figure 18. Comparison of Observed Wave Heights with Calculated Wave Heights Versus Relative Surf Zone Position for Field Experiment No. 1.

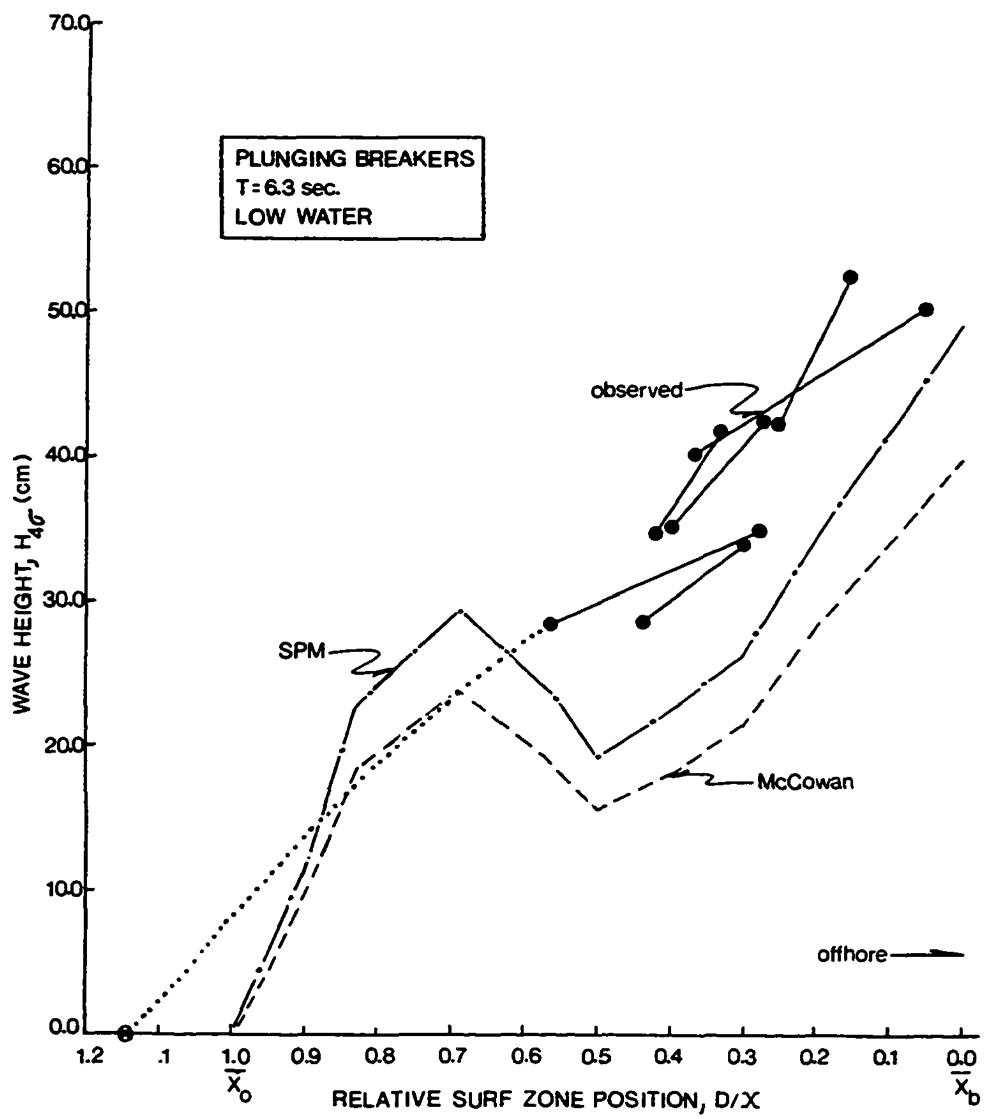

PLUNGING BREAKERS
T=6.3 sec.
LOW WATER
observed
SPM
McCowan
offhore
WAVE HEIGHT, $H_{4\sigma}$ (cm)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1.2
.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
$\overline{X}_o$
$\overline{X}_b$
RELATIVE SURF ZONE POSITION, D/X

Figure 19. Comparison of Observed Wave Heights With Calculated Wave Heights Versus Relative Surf Zone Position for Field Experiment No. 2.

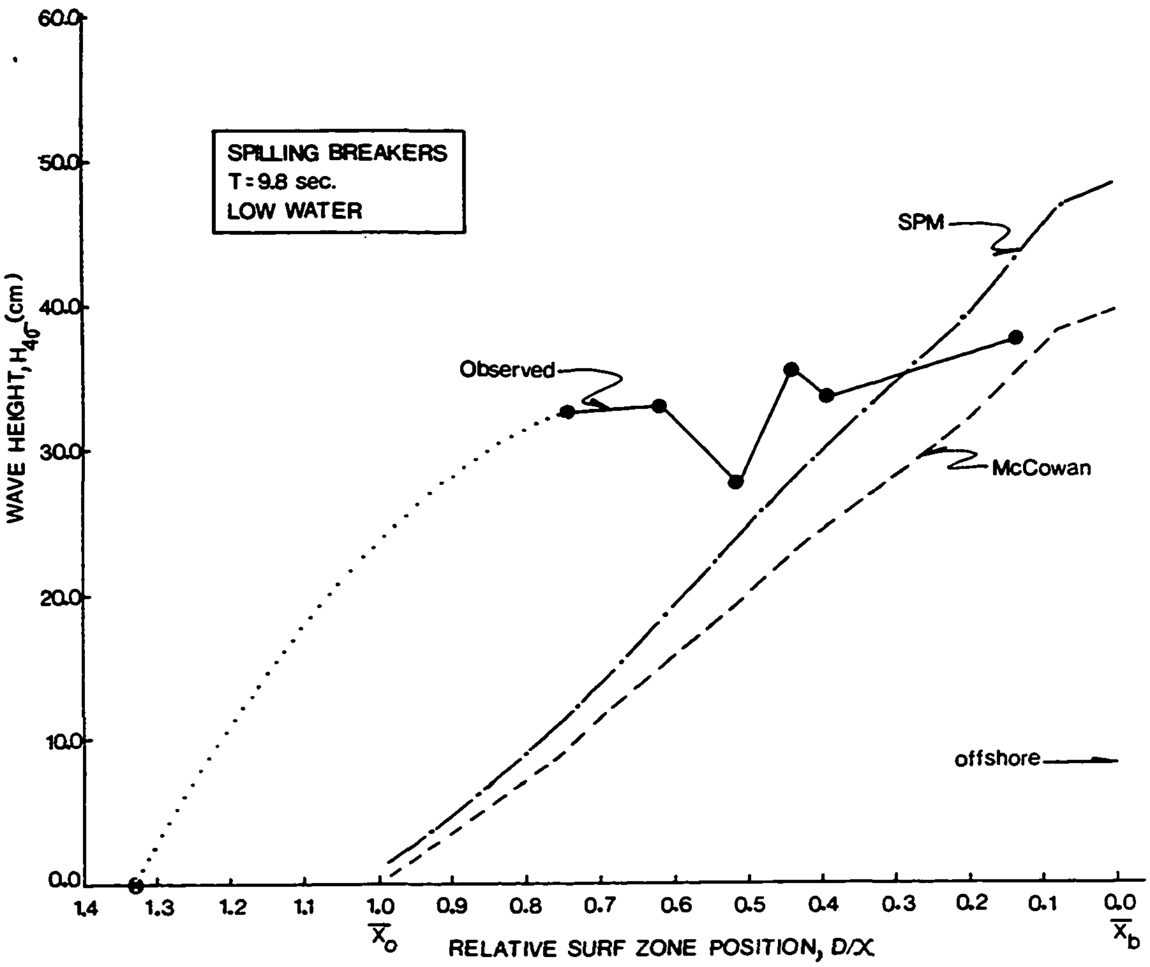

SPILLING BREAKERS
T = 9.8 sec.
LOW WATER
WAVE HEIGHT, $H_{4\sigma}$ (cm)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Observed
SPM
McCowan
offshore
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
$\overline{X}_o$
$\overline{X}_b$
RELATIVE SURF ZONE POSITION, D/X

Figure 20. Comparison of Observed Wave Heights With Calculated Wave Heights Versus Relative Surf Zone Position for Field Experiment No. 3.

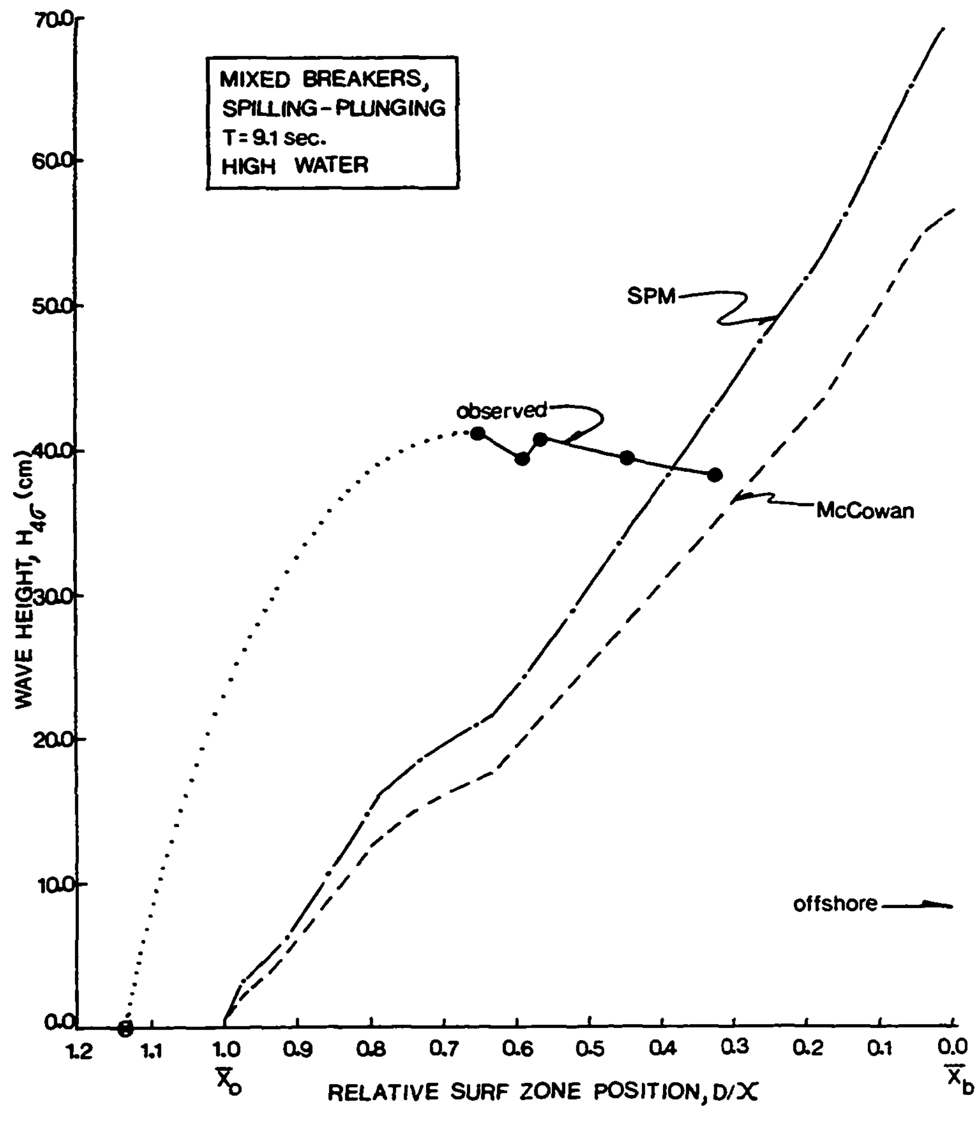
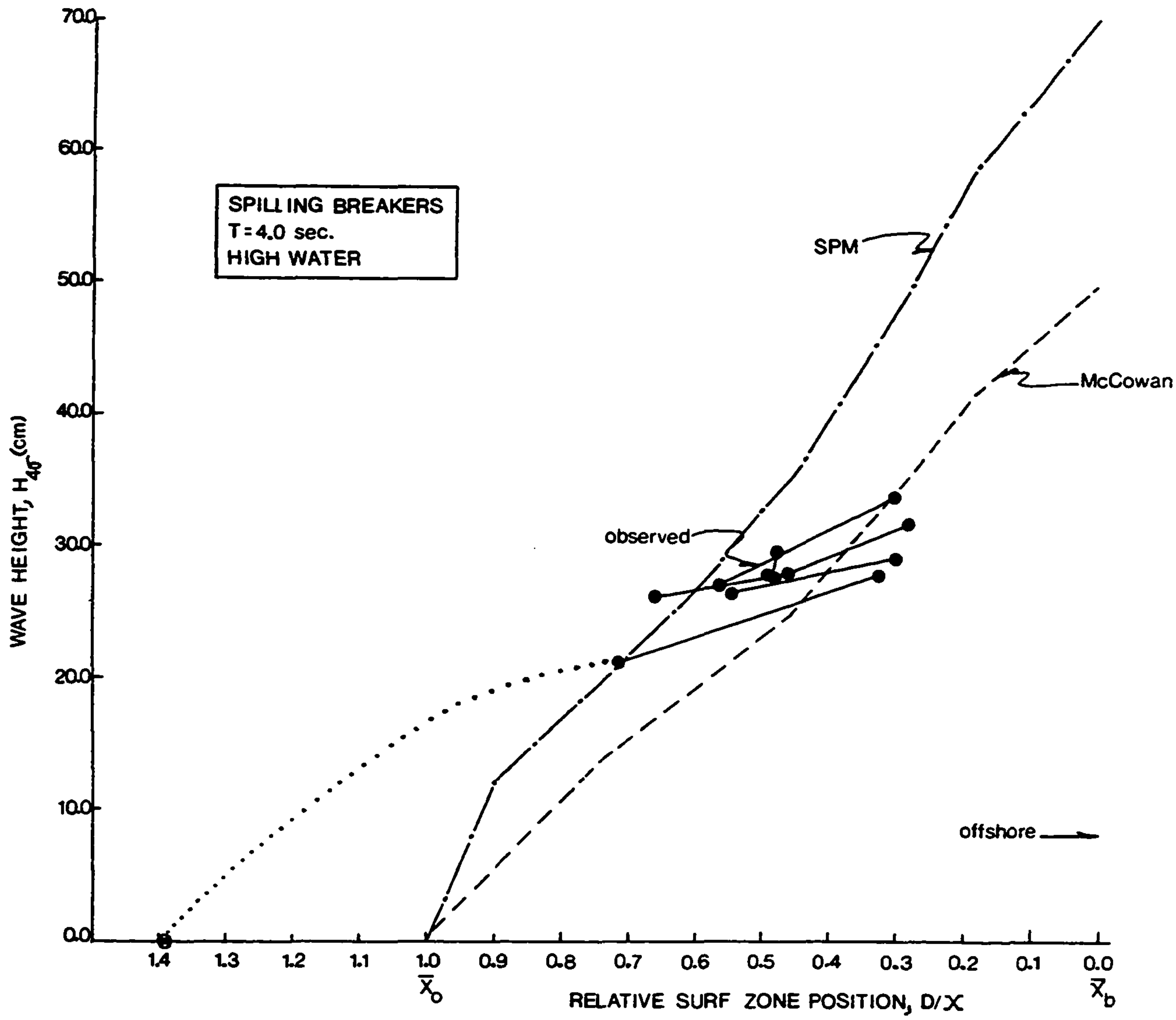

MIXED BREAKERS, SPILLING-PLUNGING
T=9.1 sec.
HIGH WATER
SPM
observed
McCowan
offshore
WAVE HEIGHT, H_{46} (cm)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
$\overline{X}_b$
RELATIVE SURF ZONE POSITION, D/X
$\overline{X}_b$

Figure 21. Comparison of Observed Wave Heights With Calculated Wave Heights Versus Relative Surf Zone Position for Field Experiment No. 4.


SPILLING BREAKERS
T=4.0 sec.
HIGH WATER
SPM
McCowan
observed
offshore
WAVE HEIGHT, H_{40} (cm)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
$\bar{X}_o$
$\bar{X}_b$
RELATIVE SURF ZONE POSITION, D/X

(1975, p. 7-3 to 7-12). This method takes into account beach slope, water depth and wave period. The values of γ_b for each field experiment were determined from graphs in the Shore Protection Manual (1975, see figures 7-2 and 7-4).

IV. INTERPRETATION OF RESULTS

The field experiments were designed to test the generalization that wave height is approximately a constant proportion of the mean water depth as a wave travels across a surf zone. The decay of wave height predicted using this assumption was found to differ from that observed in the field experiments of this study (figures 18-21). This result indicates that wave height decay in the surf zone is non-linear and that the implication of equation 10 that bottom friction is the sole or dominant factor in the wave height decay process cannot be assumed. Many factors act together to control wave height decay across the surf zone. The factors considered in this study include breaker height, breaker type, wave celerity, nearshore beach slope, foreshore slope, surf zone width, tidal elevation and local weather conditions. The factor or factors that controls the rate of decay in wave height may very well be dependent upon the relative surf zone position.

The change in wave height across the surf zone occurs in three phases; each phase is characterized by different factors as controls over the rate of change in wave height. This scheme is best illustrated when applied to spilling breakers (see figures 19, 20, 21). The first phase is characterized by a rapid decay in wave height just shoreward of the breaker point. Wave heights at

breaking for each field experiment was assumed to be approximately equal to those predicted with the breaker criterion of McCowan and the Shore Protection Manual. The first phase occurs at a relative surf zone position up to about 0.1 in field experiments two through four and 0.6 in the first field experiment. It begins after an incident wave approaches the beach and breaks, disrupting the momentum of the wave and causing it to transform into a surf bore. This is a dramatic event resulting in a high rate of energy loss due to turbulence. At this point a plunging breaker loses more energy than a spilling breaker of the same height. The part of the surf zone in which this first phase occurs was wider with plunging breakers than with spilling (figures 18-21). It is not known how much energy is lost in breaker types of different heights during the first phase of wave height decay. The question is important because its answer would determine the amount of wave energy available after breaking for the surf zone processes that govern sediment transport across the shore zone.

The second phase in the change of wave height is characterized by a less rapid, constant or even increasing wave height in a region centered at approximately the mid-surf position in all field experiments except for the first. The first experiment was the only one in which plunging breakers were present. These breakers broke seaward of the inner bar and rapidly dissipated their energy on the bar.

The inner bar and trough had the effect of shifting the second phase toward shore. No wave measurements were taken in the trough, but if it is assumed that the rate of wave height decay is relatively low across the trough, then the second phase would approximately be centered at a relative surf zone position of approximately 0.8.

The observed change in wave height during the second phase is believed to result from a continuous competition between energy loss through turbulent dissipation and the affects of wave shoaling. The turbulence in the broken wave will act to dissipate the wave energy and decrease wave height. At the same time, wave shoaling decreases wave celerity and wave length and acts to increase wave height. If turbulent dissipation dominates over wave shoaling, then a decrease in wave height results. If the effects of wave shoaling dominate, then an increase in wave height occurs. The decrease in wave height observed in field experiments one, two and four (figures 18, 19 and 21 respectively) can be explained with the former mechanism. The increase in wave height observed in the third field experiment can be explained by the latter mechanism.

The third phase of wave height decay is where the remainder of the wave energy is finally dissipated and bottom friction becomes the dominant factor as the wave travels up the foreshore in the form of swash. This phase began at a relative surf zone position between 0.7 and 0.8

in field experiments two through four and 0.9 in the first field experiment. No wave measurements were obtained on the foreshore. The zero wave heights shown in figures 11-14 and figures 18-21 were taken to represent the upper limit of swash which was visually estimated during the field experiments. It is evident from figures 18-21 that spilling breakers, which dissipate energy less rapidly than plunging breakers, contain more remaining energy at the shoreline of mean water level. Hence, runup height (vertical distance) associated with spilling breakers is greater than that of plunging breakers. This was the case in field experiments one and four where the runup for the spilling breakers was about 30 cm higher than plunging breakers.

Results from the field experiments, when generalized, lead to the following description: After a wave breaks there is a rapid decay in wave height due to turbulence induced by the breaking process. As the wave or bore propagates towards shore, wave height remains nearly constant because of a balance between turbulence and wave shoaling affects. As the wave or bore approaches the foreshore, the beach slope increases and bottom friction becomes a dominant factor. The wave dissipates remaining energy as it travels to the upper limit of swash.

The affect of reflected waves on the height of shoreward propagating waves is not known. It is certain

that wave reflection does have an influence on waves in the surf zone. No significant reflected waves were observed during the first two field experiments. These were conducted at the time of low water; foreshore slopes were relatively low (figures 13-14). Reflected waves were noted during the last two field experiments but only infrequently. These experiments were conducted at the time of high water; foreshore slopes were steeper. The affect of reflected waves is assumed to be minor in the foregoing analysis.

V. SUMMARY AND CONCLUSIONS

A capacitance wavestaff has proved to be a useful tool for the field study of beaches. The wavestaff system used in this investigation is limited to use with breaker heights of about one meter or less. This limitation is due to the method of wavestaff deployment. The wavestaffs could be used in larger waves with an alternative deployment method. Flick et al. (1979) describe a method in which a wavestaff (resistance type) is clamped to a disc-shaped, steel base plate which is buried in a temporarily fluidized sand bed. This method of mounting probably could withstand waves three to four meters in height.

The frequency response of the capacitive wavestaff is strongly dependent on diameter of the sensor wire. Suitable dynamic response for waves of period greater than two seconds cannot be achieved with sensor wires of diameter greater than 0.35 mm. Coating material of the wire, such as teflon, does not have as much affect on dynamic response as does wire diameter.

The fully self-contained instrument housing was easily and quickly deployed. This method is preferred over a method using data and power cables that are strung to shore. The capability of viewing the voltage outputs of both wavestaffs and the meter count on the cassette recorder through the plexiglass lid was highly advantageous.

The use of a stereo cassette deck for storing analog data was satisfactory and economical. The main disadvantage of this method was the limited amount of data storage space. Two solutions would be to use longer cassettes or a digital cassette recorder. Data could also be stored using microprocessors. This latter method would be the best solution because it eliminates mechanical parts and would use low power digital electronics.

An operational definition and methodology for classifying breaker type on a natural beach is needed. Such a classification should contain additional physical factors not considered in existing laboratory classifications. One such factor which should be considered is wind.

Changes in bore height across a surf zone cannot be adequately described by a linear relationship. Water depth is not the most significant factor in wave height decay across a surf zone.

Wave height decay in the surf zone appears to take place in three phases. In the first phase, a rapid decay in wave height occurs because of turbulence induced by the breaking process. Turbulence is less important in the second phase as the affects of wave shoaling become more significant. Wave height remains nearly constant because of the balance between turbulence and wave shoaling. Wave height is decreased by turbulence and increased by wave shoaling. The last or third phase in wave height decay

occurs where frictional forces at the sea bed become dominant. Remaining wave energy is rapidly dissipated as a wave propagates up the beach slope against the force of gravity.

Spilling breakers dissipate energy less rapidly than plunging breakers. More energy is available at the shoreline with spilling breakers and consequently runup heights are greater than for plunging waves of the same breaking height.

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APPENDIX I

Cost Breakdown For Capacitance Wavestaff System

Cost Breakdown For Capacitance Wavestaff System

Item		Cost
Electronics		
Printed circuit boards with components (2)		$ 28.22
Frequency/voltage converter, Datel Model VFV-10K (2)		124.00
Six volt lantern battery; Eveready Model 1209 (8)		20.00
Stereo cassette recorder Realistic Model SCT-12		79.95
	Subtotal	$ 252.17[1]
Instrument Housing		
Steel container; 50 lbs. @ 13¢/lb.		$ 13.00
Open/close mechanism		4.00
Plexiglass lid		donated
Steel bottom		donated
"O" rings (2)		2.00
	Subtotal	$ 19.00
Electro Oceanics Underwater Connectors		
B53F2-F1 4 @ $24.15		$ 96.60
B51F2-M1 3 @ $11.55		34.65
[2]Splicing kit		32.50
External switch SPST		36.75
Silicone grease, Dow Corning DC4		5.05
	Subtotal	$ 205.55

Cost Breakdown For Capacitance Wavestaff System (continued)

Item		Cost
Sensor wire support frame		
PVC pipe, 1½" O.D. X 10 ft. (2)		$ 8.84
[3]Closet rod		.50
Wire fasteners		donated
Aluminum base plate (2) 1/8" X 18" X 18"		donated
	Subtotal	$ 9.34
Miscellaneous		
Epoxy paint		$ 5.67
Screws and bolts		5.00
Solder		5.00
Plexiglass for instrument electronics		donated
Printed circuit board connectors		4.75
	Subtotal	$ 20.42

System Grand Total $506.48

[1]Quoted price in Table 1 was calculated as follows:

Electronics	$28.22	
Housing	19.00	
Frame	9.34	
Total	$56.56	(two wavestaffs)

[2]Not recommended

[3]Used inside PVC pipe to strengthen the support

APPENDIX II

Specifications For Realistic SCT-12 Stereo Cassette Deck

SPECIFICATIONS

PLAYBACK				
ITEM	UNIT	NOMINAL	LIMIT	TEST TAPE & CONDITION
Output Level	mV	775	775±3 dB	MTT-112 B
S/N Ratio	dB	50	45	MTT-112 B & Blank Cassette
Channel Crosstalk	dB	45	40	MTT-141 Use B.P.F.
Track Crosstalk	dB	55	50	MTT-121 Use B.P.F.
Tape Speed Deviation	%	±1.5	+3/-2	MTT-111
Wow & Flutter	% RMS	0.18	0.35	MTT-111
REW & F. F. Time	Sec	85	100	C-60
Output Noise Level	mV	2.0	5.0	Blank Cassette
Distortion (THD)	%	2.0	3.0	MTT-112 B
Frequency Response	dB			MTT-117 L
125 Hz		0	-6, +6	
333 kHz		0	0	
10 kHz		0	-6, +6	
Minimum Output Level	mV	85	85±3dB	MTT-112 B

RECORD/PLAYBACK				
Output Level	mV	775 550	775±3 dB 550±3 dB	SRL, 1 kHz MTT-502 (Fe) BASF CrO2 C-60 (CrO2)
S/N Ratio	dB	45	35	MTT-502, SRL, 1 kHz Input Open
Input Sensitivity	dBm			
MIC INPUT		-70	-70+0/-6dB	MTT-502, 1 kHz, SRL
AUX INPUT		-20	-20+0/-6dB	
Input Impedance	ohm			
MIC		500-5K		
AUX		150 K		
Channel Crosstalk	dB	40	30	MTT-502, 1 kHz, SRL Input Open, Use B.P.F.
Track Crosstalk	dB	55	50	MTT-502, 1 kHz, SRL Input Open, Use B.P.F.
Erase Ratio	dB	55	50	MTT-502, 1 kHz, SRL Use B.P.F.
Record/Erase Bias Frequency	kHz	85	±5	
Distortion (THD)	%	2.0	3.0	MTT-502, 1 kHz, SRL
Frequency Response	dB			MTT-502, SRL-20 dB (Fe) BASF CrO2 C-60 (CrO2)
100 Hz		±3	±6	
1 kHz		0	0	
10 kHz		±3	±6	
12 kHz (CrO2 Tape Only)		±3	±6	

Power Requirements: 120 volts, 60 Hz 8 watts (220/240 volts, 50 Hz 8 watts for European and Australian models)

NOTE: Nominal Specs represent the design specs, all units should be able to approximate these-some will exceed and some may drop slightly below these specs. Limit Specs represent the absolute worst condition which still might be considered acceptable; in no case should a unit perform to less than within any Limit Spec.

APPENDIX III

Fortran Programs Used For Data Editing and Analysis

```
      PROGRAM XLATE
C     THIS PROGRAM WAS PROVIDED BY DICK PHILLIPS.
C*****************************************************
C
C     PROGRAM TO TRANSLATE GROUPED DATA INTO
C     DATA IN COLUMN FORM  I.E. ONE CHANNEL'S
C     WORTH OF DATA IN EACH COLUMN
C
C     THE LAST LINE IN THE DATA SET CONTAINS THE
C     NUMBER OF SAMPLES PER CHANNEL
C
C*****************************************************
C
      DIMENSION DAT(16),IDAT(8)
      DOUBLE PRECISION ANAME1,ANAME2
C
      WRITE(5,100)
100   FORMAT(1H ,5X'ENTER INPUT FILE NAME')
      READ(5,101)ANAME1
101   FORMAT(A10)
      WRITE(5,102)
102   FORMAT(1H ,5X'ENTER OUTPUT FILE NAME')
      READ(5,101)ANAME2
C
      OPEN(UNIT=22,FILE=ANAME1)
      OPEN(UNIT=23,FILE=ANAME2)
C
      NCHAN=2
C
C
C
      NCOUNT=0
C
C     NCOUNT IS THE TOTAL NUMBER OF SAMPLES IN EACH CHANNEL
C
      IS=1
      IR=0
C
1000  CONTINUE
C
      READ(22,1,END=999)GROUP
1     FORMAT(A5,1X)
      IF(GROUP.EQ.5HGROUP) GO TO 2
      BACKSPACE 22
      READ(22,*)(IDAT(I1),I1=1,8)
      IE=IS+7
      I1=1
      DO 30 I=IS,IE
            DAT(I)=FLOAT(IDAT(I1))/1000.
            I1=I1+1
30    CONTINUE
C
      IPRNT=(8+IR)/NCHAN
      IR=8-NCHAN*IPRNT+IR
      IS=1
      IE=NCHAN
C
      DO 10 I=1,IPRNT
            WRITE(23,5)(DAT(I1),I1=IS,IE)
5     FORMAT(2X,8(F6.3,1H,,1X))

            IS=IS+NCHAN
            IE=IE+NCHAN
10    CONTINUE
C
      DO 20 I=1,IR
            DAT(I)=DAT(NCHAN*IPRNT+I)
20    CONTINUE
C
      IS=IR+1
      NCOUNT=NCOUNT+IPRNT
C
2     CONTINUE
C
      GO TO 1000
C
999   WRITE(5,4)NCOUNT,NCHAN
4     FORMAT(1H ,5X'THERE ARE'I6' SAMPLES IN EACH OF'I3' CHANNELS')
C
      WRITE(23,4)NCOUNT,NCHAN
      STOP
      END
```

```
C          PROGRAM DETRND.FOR
C        THIS ROUTINE TAKES A TWO COLUMN DATA FILE
C        ,ONE AT A TIME, FITS A FIRST DEGREE FOR AND
C        COMPUTES A T-STATISTIC TO TES HO:SLOPE=0.. THIS IS
C        A TWO TAILED TEST WHICH WAS TAKEN FROM "STATISTICS
C        AND DATA ANALYSIS IN GEOLOGY" BY JOHN C. DAVIS(1973).P229
C        IF MORE COLUMNS OF DATA EXIST IN DATA FILE THEN
C        JUST ADD A CALL STMT FOR EACH ADDITIONAL COL..
C        FURTHER INFO EXIST IN "APPLIED REGRESSION ANALYSIS" BY
C        DRAPER(1973)
C*********************************************************************
C
         DIMENSION X(6000),Y(6000)
         DOUBLE PRECISION ANAMEI
         COMMON /S1/T(6000)
C
         WRITE (5,11)
11       FORMAT(2X,"ENTER INPUT FILENAME")
         READ (5,5)ANAMEI
5        FORMAT(A10)
         WRITE(5,1[illegible])
1[illegible]       FORMAT(2X,"ENTER NUMBER OF DATA POINTS")
         READ(5,*)N
C
         OPEN(UNIT=2[illegible],FILE=ANAMEI)
C
         T(I)=0.0[illegible]
         AN=0.0[illegible]
         DO 1[illegible] I=1,N
                 READ (2[illegible],*) X(I),Y(I)
                 T(I)=AN/4.0[illegible]
                 AN=AN+1
C                T(I)=1.0[illegible]*FLOAT(I-1)
C        TYPE*,X(I),Y(I),T(I)
1[illegible]       CONTINUE
C
         WRITE(5,13)
13       FORMAT(1X,"PARAMETERS FOR COL OF ACC")
C
         CALL LINE (X,N,AX,BX)
C
         WRITE(5,14)
14       FORMAT(2X,"PARAMETERS FOR COL OF WSI")
C
         CALL LINE (Y,N,AY,BY)
C
         DO 70 I=1,N
                 X(I)=X(I)-(BX*T(I))
                 Y(I)=Y(I)-(BY*T(I))
70       CONTINUE
         OPEN(UNIT=21,FILE="DFT.DAT")
         DO 80 I=1,N
                 WRITE(21,*)X(I),Y(I)
80       CONTINUE
         CLOSE(UNIT=2[illegible])
         CLOSE(UNIT=21)
         STOP
         END
         SUBROUTINE LINE (Y,N,AO,BO)
C
```

```
      DIMENSION Y(6000)
      COMMON/S1/ X(6000)
C
C
C
C
C     INITIALIZING EQUATIONS
      SUMX=0.
      SUMY=0.
      SXY=0.00
      SXX=0.00
      SSD=0.00
      SSR=0.00
      SST=0.00
      SUMT=0.00
      SXSQ=0.00
C
      DO 10 I=1,N1
            SUMX=SUMX+X(I)
            SUMY=SUMY+Y(I)
10    CONTINUE
C
C
      XMEAN=SUMX/FLOAT(N1)
      YMEAN=SUMY/FLOAT(N1)
C
      DO 20 J=1,N1
            DXX=X(J)-XMEAN
            DYY=Y(J)-YMEAN
            SXY=SXY+(DXX*DYY)
            SXX=SXX+(DXX*DXX)

20    CONTINUE
C
C
C
      BQ=SXY/SXX
      AQ=YMEAN-BQ*XMEAN
C
      WRITE(5,13)BQ
13    FORMAT(2X,'SLOPE = ',1X,F13.8)
      WRITE(5,14)AQ
14    FORMAT(2X,'Y-INTERCEPT=',1X,F13.8,/)
C
C
C
C
C
      DO 30 I=1,N1
            YE=AQ+BQ*X(I)
            YED=YE-YMEAN
            YDD=Y(I)-YMEAN
            RES=YE-Y(I)
      if (res.eq.0.0)res=.1e-05
      SSD=SSD+RES*RES
      SSR=SSR+YED*YED
      SST=SST+YDD*YDD
      SUMT=SUMT+X(I)
      SXSQ=SXSQ+X(I)*X(I)
30    CONTINUE
      RSQ=SSR/SST
      RR=SQRT(RSQ)
      AN2=N1-2
      TSMD=SSD/AN2
C
C
      SUMT2=SUMT*SUMT
      COR=SUMT2/FLOAT(N1)
      SSX=SXSQ-COR
C
      DIV=TSMD/SSX
      TDUM=SQRT(DIV)
      TA=BQ/TDUM
C
C
      WRITE(5,50)TA
50    FORMAT(2X,'T-ALPHA=',F12.4)
      TYPE*,SSX
      TYPE*,RR
C
C
      RETURN
      END
```

```
C              PRONG2.FOR
C        THIS PROGRAM USRES TRANSLATED DATA FROM THE XLATE
C        PROGRAM,IN "TWO CHANNEL" FORM. ONE CHANNEL FORM
C        CAN BE HANDLED BY THE PRONG.FOR PROGRAM.
C
C
C
C        THE TRANSLATED DATA FROM XLATE, IS USED TO
C        CALC. ELEVATIONS OF WAVE HT. AND PUT THESE IN A ELEV.OUT
C        FILE. THE DATA IN THIS FILE SHOULD BE IDENTICAL
C        TO WHAT WAS OUTPUT BY THE STRIP-CHART RECORDER.
C        THIS CAN BE CHECKED BY USING THE 2WAVES.FOR ROUTINE.
C
C
         DIMENSION VOLT(7000),AMAX(2),AMIN(2)
         DIMENSION SUM(2),SUMSQ(2),AMEAN(2),[illegible](2),[illegible](2)
         DIMENSION VAR(2),SDEV(2),ELEV(2)
         COMMON /S1/ H1(7000),H2(7000)
         COMMON /S2/ SIG2(2),SIG4(2)
         COMMON /S3/HEIGHT(2),PINCH(2)
         DOUBLE PRECISION ANAME
C        THE NUMBER OF POINTS IS GIVEN BY XLATE.FOR PROG.
C
         WRITE(5,11)
11       FORMAT(1X,'ENTER INPUT FILENAME ')
         READ(5,12)ANAME
12       FORMAT(A10)
C
         WRITE(5,100)
100      FORMAT(2X,'ENTER THE NUMBER OF DATA POINTS')
         READ(5,*)NUM
C
C        GAIN CONSTANTS ARE DETERMINED FROM STATIC
C        CALIBRATION TESTS.
C
         WRITE(5,200)
200      FORMAT(2X,'ENTER [illegible] GAIN CONSTANTS-[illegible]')
         READ(5,*)[illegible]
C
C        OFFSET CONSTANTS ARE DETERMINED FROM [illegible]
C        CONVENIENT NUMBERS CAN BE CHOSEN FOR THIS OFFSET.
C
         WRITE(5,300)
300      FORMAT(2X,'ENTER AS OFFSET CONSTANTS-[illegible]')
         READ(5,*)[illegible]
C
C        THE FOLLOWING CONSTANTS ARE CORRECTIONS FOR [illegible]
C        YELLOW AMPLIFIER BOX,4 CHANNELS.
C
         GP1=0.[illegible]327
         GM1=0.51[illegible]
         GP3=0.51[illegible]3
         GM3=0.51[illegible]3
C
C        THE CONSTANTS FOR [illegible](.IE. GP1,GM1) ARE [illegible]
C        CORRECTIONS FOR OUTPUT FOR VARIOUS [illegible].
C
         WRITE(5,400)
400      FORMAT(2X,'GAIN USED,[illegible]=.51[illegible],[illegible]=.51[illegible]')
         WRITE(5,[illegible])
```

```
410     FORMAT(2X,'OFFSET USED,WS1=.0327,WS3=0.01..')
C
        DO 101 I=1,2
                SUM(I)=0.
                SUMSQ(I)=0.
                AMAX(I)=0.
                AMIN(I)=1.E+30
101     CONTINUE
C
C       THE NEXT READ STMTS TAKES TWO VALUES AT A TIME,
C       ONE FROM EACH COLUMN
C
        OPEN(UNIT=20,FILE=ANAME)
        OPEN(UNIT=21,FILE='WVHT.OUT')
C       OPEN(UNIT=22,FILE='VOLT.OUT')
        DO 201 I1=1,NUMP
                READ(20,*) (VOLT(I),I=1,2)
                        DO 202 J=1,2
                        IF(J.EQ.1) VOLT(1)=(VOLT(J)-G..)/...
                        IF(J.EQ.2) VOLT(2)=(VOLT(J)-GS1)/...
                        IF(J.EQ.1) ELEV(1)=(VOLT(1)-...)/...
                        IF(J.EQ.2) ELEV(2)=(VOLT(2)-...)/...
                        SUM(J)=SUM(J)+ELEV(J)
                        SUMSQ(J)=SUMSQ(J)+ELEV(J)*ELEV(J)
                        AMAX(J)=AMAX1(AMAX(J),ELEV(J))
                        AMIN(J)=AMIN1(AMIN(J),ELEV(J))
202                     CONTINUE
        H1(I1)=ELEV(1)
        H2(I1)= ELEV(2)
        WRITE(21,*,ERR=999) (ELEV(I), I=1,2)
444     FORMAT(2F..3)
C       WRITE(22,555,ERR=999) (VOLT(I), I=1,2)
555     FORMAT(2F..3)
201     CONTINUE
C
        N=NUMP
        CALL STAT (N,SUM,SUMSQ,AMEAN,VAR,SDEV,...)
C
C
C
        CLOSE(UNIT=20)
        CLOSE(UNIT=21)
        CLOSE(UNIT=22)
        WRITE(5,1)ANAME
1       FORMAT(1.X,'FILE',2X,A1.)
        WRITE(5,2)
2       FORMAT(1.X,'WAVESTAFF',11X,'1',9X,'2')
        WRITE(5,3)
3       FORMAT(1.X,'N POINTS',4X,I6)
        WRITE(5,4)AMEAN(1),AMEAN(2)
4       FORMAT(1.X,'MEAN',11X,F8.3,5X,F8.3)
        WRITE(5,7)VAR(1),VAR(2)
7       FORMAT(1.X,'VARIANCE',7X,F8.3,5X,F8.3)
        WRITE(5,8)SDEV(1),SDEV(2)
8       FORMAT(1.X,'ARMS',10X,F1..4,5X,F1..4)
        WRITE(5,9)AMAX(1),AMAX(2)
9       FORMAT(1.X,'MAX',12X,F8.3,5X,F8.3)
        WRITE(5,10)AMIN(1),AMIN(2)
10      FORMAT(1.X,'MIN',12X,F8.3,5X,F8.3)
        WRITE(5,111)SIG2(1),SIG2(2)
```

```
111     FORMAT(10X,'2 SIGMA=',7X,F8.3,5X,F8.3)
        WRITE(5,122)SIG4(1),SIG4(2)
122     FORMAT(10X,'4 SIGMA=',7X,F8.3,5X,F8.3)
c       WRITE(5,112) HEIGHT(1),HEIGHT(2)
c12     FORMAT(10X,'HGHT-IN. =',4X,F10.4,5X,F10.4)
        STOP
999     CONTINUE
        END
        SUBROUTINE STAT(N,SUM,SUMSQ,AMEAN,VAR,SDEV,ELEV)
        DIMENSION SUM(2),SUMSQ(2),AMEAN(2),AMSQ(2),ARMS(2)
        DIMENSION VAR(2),SDEV(2),ELEV(2)
        COMMON /S1/ H1(7000),H2(7000)
        DIMENSION XB(2),XB2(2),SUMD(2)
        COMMON /S2/ SIG2(2),SIG4(2)
        COMMON /S3/HEIGHT(2),PINCH(2)
        DO 301 I2=1,2
                AMEAN(I2)=SUM(I2)/FLOAT(N)
C               AMSQ(I2)=SUMSQ(I2)/FLOAT(N)
C               ARMS(I2)=SQRT(AMSQ(I2))
                SUMD(I2)=0.
301     CONTINUE
C
        DO 399 J1=1,N
        ELEV(1)=H1(J1)
        ELEV(2)=H2(J1)
                DO 401 I3=1,2
                XB(I3)=ELEV(I3)-AMEAN(I3)
                XB2(I3)=XB(I3)*XB(I3)
                SUMD(I3)=SUMD(I3)+XB2(I3)
401     CONTINUE
399     CONTINUE
        NN=N-1
        DO 501 I4=1,2
                VAR(I4)=SUMD(I4)/FLOAT(NN)
                SDEV(I4)=SQRT(VAR(I4))
                SIG2(I4)=2.0*SDEV(I4)
                SIG4(I4)=4.0*SDEV(I4)
501     CONTINUE
        RETURN
        END
```

```
C                 PROGRAM 2WAVES.PLT
C
C
C          ROUTINE WHICH PLOTS WAVE DATA
C          FORMAT OF DATA FILE IS 2 COLUMN,NO LINE NUMBERS
C          THE NUMBER OF POINTS PLOTTED,NX, IS SELECTABLE
C
           DOUBLE PRECISION DATE
C
           DIMENSION X(6000),Y1(6000),Y2(6000)
           WRITE (5,106)
106        FORMAT(2X,'ENTER  FILE NUMBER ')
           ACCEPT 107,DATE
107        FORMAT(A10)
C          OBTAIN NUMBER OF DATA POINTS FROM xlate [illegible]
C
           WRITE(5,104)
104        FORMAT(2X,'ENTER NUMBER OF DATA POINTS')
           ACCEPT*,NX
           OPEN(UNIT=20,FILE=DATE)
C
C          THIS DO LOOP READS Y VALUES FROM INPUT DATA FILE
           DO 30 I=1,NX
                   READ(20,*,END=999) Y1(I),Y2(I)
30         CONTINUE
           GO TO 70
           I=I-1
999        WRITE(5,98)I
98         FORMAT(1X,2X,'READ',/X,I5,2X,'POINTS')
70         CONTINUE
C
C          THIS DO LOOP SETS DX=45 POINTS PER 1.0
C          DELTA-T=[illegible]/3.0
           DX=0.0208333333
           DO 40 K=1,NX
                   J=K-1
                   X(K)=J*DX
40         CONTINUE
C
           AMX=DX*NX
           CALL PLOTS(10)
           CALL PLOT(0.,-11.,-3)
           CALL PLOT(0.,.80,-3)
           CALL AXIS(0.,0.,10HTIME (SEC),-10,AMX,0.,0.,10.)
           CALL AXIS(0.,0.,12HWAVE HT (FT),12,9.,[illegible])
           CALL SYMBOL(2.0,[illegible],.25,DATE,0.,10)
C
           CALL PLOT(X(1),Y1(1),3)
           DO 20 I=2,NX
           CALL PLOT(X(I),Y1(I),2)
20         CONTINUE
C
           CALL PLOT(X(1),Y2(1),3)
           DO 25 J=2,NX
                   CALL PLOT (X(J),Y2(J),2)
25         CONTINUE
           CALL PLOT (X(NX),Y2(NX),999)
           CLOSE(UNIT=20)
C
C
```